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

This standard is issued under the fixed designation E1318; 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 *Weigh-In-Motion*—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 of a highway vehicle is due only to the local force of gravity acting upon the composite mass of all connected 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, called load in this specification, that is carried by the tires of each wheel assembly, axle, and axle group on the vehicle.

1.2 *Other Traffic Data*—Ancillary traffic data 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 to aid enforcement. In addition to tire-load information, a WIM system is capable of producing all, or specified portions of, these traffic data.

1.3 *Standard Specification*—Highway WIM systems generally have three applications: collecting statistical traffic data, aiding enforcement, and enforcement. This specification classifies four types of WIM systems according to their application and details their respective functional, performance, and user requirements. It is a performance-type (end product-type) specification. Exceptions and options to the specification may be included in any specification prepared by the user as part of the procurement process for WIM equipment or services, and vendors may offer exceptions and options in responding to an invitation to bid.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.[2]

1.5 The following precautionary 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:*[3]
E867 Terminology Relating to Vehicle-Pavement Systems
2.2 *AASHTO Standards:*[4]
Interim Guide for Design of Pavement Structures—1972, 1981
Guide for Design of Pavement Structures—1986, 1993

3. Terminology

3.1 *Definitions:*

3.1.1 *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. (See Terminology E867)

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *accuracy, n*—the closeness or degree of agreement (satisfies a stated tolerance and percent compliance) between a value measured or estimated by a WIM system and an accepted reference value.

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[2] ASTM SI10 - 02 IEEE/ASTM SI 10 American National Standard for Use of the International System of Units (SI): The Modern Metric System, The Institute of Electrical and Electronics Engineers, Inc., 1828 L. St. NW, Suite 1202, Washington, DC 20036–5101,USA, and ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA, www.astm.org.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, http://www.transportation.org.

3.2.2 *axle, n*—the axis oriented transversely to the nominal direction of vehicle motion, and extending the full width of the vehicle, about which the wheel(s) at both ends rotate.

3.2.3 *axle-group load, [lb (kg)], n*—the sum of all tire loads of the wheels on a defined group of adjacent axles; a portion of the gross-vehicle weight.

3.2.3.1 *Discussion*—An axle group can be defined in terms of the number of axles included in the group and their respective interspaces.

3.2.4 *axle load [lb (kg)], n*—the sum of all tire loads of the wheels on an axle; a portion of the gross-vehicle weight.

3.2.5 *dynamic vehicle tire force, [lb (kg)], n*—the component of the time-varying force applied perpendicularly to the road surface by the tire of a moving vehicle.

3.2.5.1 *Discussion*—In addition to the force of gravity, this force can include the dynamic effects of influences such as road surface roughness, vehicle acceleration, out-of-round tires, dynamically-unbalanced wheels, tire inflation pressure, vehicle suspension and aerodynamic features, and wind. For purposes of this specification, the WIM System shall be adjusted or calibrated to indicate the magnitude of the measured dynamic vehicle tire force in units of mass, lb (kg). (See 3.2.13.1).

3.2.6 *gross-vehicle weight, [lb (kg)], n*—the total weight of the vehicle or the vehicle combination including all connected components; also, the sum of the tire loads of all wheels on the vehicle. (See 3.2.13.1).

3.2.7 *single-axle load, [lb (kg)], n*—the load transmitted to the road surface by the tires of all wheels lying between two parallel transverse vertical planes 3.3 ft (1 m) apart, extending across the full width of the vehicle; a portion of the gross-vehicle weight.

3.2.8 *tandem-axle load, [lb (kg)], n*—the total load transmitted to the road surface by the tires on all wheels of two consecutive vehicle axles that are more than 3.3 ft (1 m) and not more than 8 ft (2.4 m) apart; a portion of the gross-vehicle weight.

3.2.9 *tire load, [lb (kg)], n*—the portion of the gross-vehicle weight imposed upon the static tire at the time of weighing, expressed in units of mass, due only to the vertically-downward force of gravity acting on the total mass of the static vehicle.

3.2.10 *tolerance, n*—the defined limit of allowable departure of a value measured or estimated by a WIM system from an accepted reference value.

3.2.11 *triple-axle load, [lb (kg)], n*—the total load transmitted to the road surface by the tires on all wheels of three consecutive vehicle axles, with not more than 12 ft (3.7 m) between the two axles furthest apart; a portion of the gross-vehicle weight; also called tridem-axle load.

3.2.12 *weigh, v tr*—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.

3.2.12.1 *Discussion*—Refer to Sec. 2.20, of *National Institute of Standards and Technology (NIST) Handbook 44* (**1**)[5] for a definition of each type of weighing device. These devices are usually subjected to field standard test weights at each locality of use and are adjusted to indicate units of mass (See Sec. 3.2, Appendix B, *NIST Handbook 44*).

3.2.13 *weight, [lb (kg)], n*—the external force of gravity acting vertically downwards upon a body with a magnitude equal to the body's mass multiplied by the local acceleration of free fall.[2]

3.2.13.1 *Discussion*—The force of gravity—thus, the acceleration of free fall—is different at various locations on or near the surface of Earth; therefore, weighing devices in commercial use or in official use by government agencies for enforcement of traffic and highway laws or collecting statistical information are usually used in one locality and are adjusted or calibrated to indicate mass at that locality (**1**). The indicated mass can be converted to weight (in units of force) by multiplying by the local value of the acceleration of free fall, if it is known. The conventional value adopted by ISO is 32.174 049 ft/s^2 (9.806 65 m/s^2). Weight is a special case of force, as weight is due only to the local force of gravity, which is always directed vertically downwards. For purposes of this specification, and in accordance with common weighing practice, the WIM system shall be adjusted or calibrated to indicate the magnitude of estimated weight and load in units of mass, pounds [avoirdupois] (kilograms), and the direction of the associated force vector will always be downwards toward the approximate center of Earth.

3.2.14 *wheelbase, ft (m), n*—the distance between the front-most and the rear-most axles on a vehicle or combination that has the tires on these axles in contact with the road surface at the time of weighing.

3.2.15 *wheel load, [lb (kg)], n*—the sum of the tire loads on all tires included in the wheel assembly on one end of an axle; a wheel assembly may have a single tire or dual tires.

3.2.16 *WIM system, n*—a set of sensors and supporting instruments that measure the presence of a moving vehicle and the related dynamic tire forces at specified locations with respect to time; estimate tire loads; calculate speed, axle spacing, wheelbase, vehicle class according to axle arrangement, and other parameters concerning the vehicle; and process, display, store, and transmit this information. This standard applies only to highway vehicles.

4. Classification

4.1 *Types*—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 (See 1.3). All systems shall be designed to operate with the local electrical power of the country (that is, 110V, ac, 60-Hz power in North America). Lightning protection for affected system components shall be provided by the vendor. The user may specify as options a completely battery-powered system or

[5] The boldface numbers given in parentheses refer to a list of references at the end of the text.

battery-backup power in case of failure of normal power. All systems shall allow the user to select at the beginning of each data-taking session the units of measurement: either U.S. customary units or SI units.[2] The units setting shall remain where last assigned unless changed by the user at the beginning of a data-taking session. Load and weight values shall be expressed in units of mass: pounds [avoirdupois] in U.S. customary units, or kilograms in SI units. The SI recommends expressing large values of mass in megagrams, Mg. In commercial usage, which includes most applications and interpretations of WIM data, 1 Mg = 1000 kg = 1 metric ton = 1 tonne.

4.1.1 *Type I*—This type of WIM system shall be designed for installation in one or more lanes at a traffic data-collection site and shall be capable of accommodating highway vehicles moving at speeds from 10 to 80 mph (16 to 130 km/h), inclusive. For each vehicle processed, the system shall produce all data items shown in Table 1. Provisions shall be made for entering selected limits and tolerances for wheel, axle, axle-group (including bridge-formula grouping (**2**)) loads, gross-vehicle weight, and 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, except Item 13, can be displayed in alphanumeric form for immediate review. This may be accomplished by connecting a portable (for example, laptop) computer, furnished and supported by the vendor as a part of the WIM-system equipment, directly to the on-site instruments. Software on the host computer that supports the WIM system shall calculate ESALs (Item 13 in Table 1) as described at 5.9. Means shall be provided for temporary, on-site storage of Data Items 1, 5, 6, 8, 9, 10, and 11 for each vehicle processed by the WIM system, or for only those vehicles with a front-axle or a front-wheel load that equals or exceeds a threshold value set into the on-site system by the user at the beginning of a data-taking session, for example, 2000 lb (900 kg) wheel load. To any vehicle record for which Data Items 1, 5, 6, 8, 9, 10, and 11 are to be stored, an invalid-measurement code shall be assigned when (1) the left-side and right-side wheel loads for an axle have a difference of 40 % or more; and (2) either of the wheel loads for such axle equals or exceeds 2000 lb (900 kg). Both the 40 % and the 2000 lb (900 kg) values shall be programmable by the user. Also, means shall be provided for rapid, efficient transfer of these data to files made available on a compatible host computer (furnished by either the user or the vendor, as specified for the specific site by the user) at a remote location according to an appropriate time schedule and data format specified by the user. The vendor shall furnish, document, and support software for use on the host computer for processing the transferred data items in such a way that all data items shown in Table 1 can be displayed in alphanumeric form for immediate review and subsequent use by the host computer user. This same software shall be provided on the portable computer for use when it is processing data during calibration and testing. 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 lane-wise count of all vehicles traveling in each lane, 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 (according to axle arrangement) and by lane of travel.

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 (front-most to rear-most axle)
13.	Equivalent Single-Axle Loads (ESALs)
14.	Violation Code

4.1.2 *Type II*—This type of WIM system shall be designed for installation in one or more lanes at traffic data-collection sites and should be capable of accommodating highway vehicles moving at speeds from 15 to 80 mph (24 to 130 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 with sensors installed in one or more lanes off the main highway lanes at weight-enforcement stations, or in one or more main highway lanes, to identify vehicles operating at speeds from 10 to 80 mph (16 to 130 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 (see 7.3.6.1). However, when the sensors are installed in the main highway lane(s), the Type III system will not be required to measure vehicle acceleration. Provisions shall be made for entering selected limits for wheel, axle, axle-group (including bridge-formula grouping (**2**)) 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 that 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 included as a feature 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 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 III WIM system from producing wheel-load information (Item 1 in Table 1) if this data item is not of interest for enforcement. Option 3 for this type of WIM system 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 2 is specified), 5, 6, 8, 9, 10, and 11. These basic-data items allow subsequent computation of statistical traffic data.

4.1.4 *Type IV*—This type of WIM system has not yet been approved for use in the United States, but for conceptual development purposes, it shall be designed for use at weight-enforcement stations to detect weight-limit or load-limit violations. Speeds from 2 to 10 mph (3 to 16 km/h), inclusive, shall be accommodated. A Type IV system that uses tire-force sensors (see 5.13) that support the entire tire-contact area(s) of all tires on a wheel assembly simultaneously shall also be capable of indicating the wheel load(s), if applicable, and individual axle loads for a stationary vehicle. 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 (**2**)) 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 *Accuracy*—Each type of WIM system shall be capable of performing the indicated functions within the accuracy (3.2.1) shown in Table 2. A test method for determining compliance with these requirements under prevailing site conditions is given in Section 7. The stated accuracy should be maintained for ambient air temperatures at the WIM site from –20 to 120 °F (–28 to 50 °C); however, the user shall specify at the time of system procurement the range of temperatures within which the WIM system must operate properly. The vendor shall supply evidence that the system offered is capable of compliance. After computation of the data items shown in Table 2, no digit shall be retained that indicates less than 100 lb (50 kg) for load and weight, 1 mph (2 km/h) for speed, or 0.1 ft (0.03 m) for axle spacing and wheelbase.

5.2 *Vehicle Class*—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* (**2**) for the complete description of FHWA Vehicle Types. The axle-spacing values used for this process shall be associated with each vehicle classified via the software. The values shall be made readily accessible to the user, and a means shall be provided for the user to modify the values easily. The FHWA Vehicle Type shall be indicated by the 2-Digit Code shown in Table 3. A user-defined Vehicle Type Code 14 shall be provided for application by the user. A Vehicle Type Code 15 shall be applied to any vehicle that the software fails to assign to one of the types described.

5.3 *Site Identification Code*—Provisions shall be made in Type I, Type II, Type III, and Type IV WIM systems for entering, displaying, and recording a ten-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 (**2**).

5.4 *Lane and Direction Code*—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 (**2**).

5.5 *Date*—Date of passage shall be indicated numerically in each vehicle record processed by Type I, Type II, Type III, and Type IV WIM systems. The date format(s) used by the WIM system to produce the vehicle record shall be clearly documented and defaulted to the generally accepted format in the country of use. In the United States, the MM/DD/YYYY format, where MM is the month, DD is the day, and YYYY is the year, is generally accepted.

TABLE 2 Functional Performance Requirements for WIM Systems

Function	Tolerance for 95 % Compliance[A]				
	Type I	Type II	Type III	Type IV	
				Value ≥lb (kg)[B]	±lb (kg)
Wheel Load	±25 %		±20 %	5000 (2300)	300 (100)
Axle Load	±20 %	±30 %	±15 %	12 000 (5400)	500 (200)
Axle-Group Load	±15 %	±20 %	±10 %	25 000 (11 300)	1200 (500)
Gross-Vehicle Weight	±10 %	±15 %	±6 %	60 000 (27 200)	2500 (1100)
Speed	±1 mph (2 km/h)				
Axle-Spacing and Wheelbase	±0.5 ft (0.15 m)				

[A] 95 % of the respective data items produced by the WIM system must be within the tolerance.
[B] Lower values are not usually a concern in enforcement.

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

5.6 *Time*—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: hh:mm:ss, where hh is the hour beginning with 00 at midnight and continuing through 23, mm is the minute, and ss is the second.

5.7 *Vehicle Record Number*—Type I, Type II, Type III, and Type IV WIM systems shall provide sequential-numbering (user-adjustable) for each recorded vehicular data set.

5.8 *Wheelbase*—Type I and Type II WIM systems shall compute wheelbase as the distance between the front-most and the rear-most axles on the vehicle or combination that has the tires on these axles in contact with the road surface at the time of weighing. This value shall be rounded to the nearest 0.1 ft (0.03 m) before display or recording.

5.9 *ESALs*—Type I and Type II WIM systems shall compute Equivalent Single-Axle Loads (ESALs) using American Association of State Highway and Transportation Officials (AASHTO) axle load equivalence factors (see 2.2, Annex A1, and (**3**, **4**, **5**, **6**)) for single, tandem, and triple axles for flexible or for rigid pavements. Provision shall be made for the user to select one of these pavement types for application at the beginning of any given data-processing session. The computations must be made using only U.S. customary units. Software on the host computer that supports the WIM 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 rounded to two significant 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 $\overline{SN}$ used for computing flexible pavement equivalence factors shall be user adjustable, but shall be defaulted to 5.0 (see 2.2). The value for thickness of rigid pavement slab, D, used in computing rigid pavement equivalence factors shall be user adjustable, and shall be defaulted to 9.0 in. (see 2.2) 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-processing session. The user shall specify the method(s) (see 5.9.2 and 5.9.3) that will be provided by the vendor in the WIM-system software on the host computer for applying LEFs to compute ESALs. Every Type I and Type II WIM system shall include software on the host computer for performing the computation of ESALs by the method described in 5.9.3.

5.9.1 *Computation of LEFs*—Equations for calculating the AASHTO axle load equivalence factor (LEF) for each axle type (single, tandem, triple) and load are presented in Annex A1. These equations may be used to calculate directly the LEF for an individual axle load and type, terminal serviceability, and pavement strength characteristic ($\overline{SN}$ for flexible or D for rigid) in lieu of using the tabular (previously calculated from the equations for selected increments of the variables) values presented in the AASHTO pavement design guides (see 2.2). The equations were derived from statistical analysis of data taken during the AASHO (now AASHTO) Road Test (**3**, **4**); therefore, the applicability of the equations to model the relationship among the included variables is limited to the nature and range of each variable that was observed at the AASHO Road Test. The axle load that was included as a variable in the derivation of the regression equations was only the load on axles of the test trucks that were called load axles. The observed change in pavement serviceability that resulted from the steering axle on each test truck, except pickup-type trucks, that was run at the AASHO Road Test was not assessed separately, but was incorporated into that which was attributed in the regression equations to the loads on the other axles (single or tandem) on each test truck. The steering axle and the rear axle on pickup-type test trucks were both called load axles and provided data points for direct inclusion of the effects of 2000-lb single-tire, single-axle loads in developing the regression equations.

5.9.2 *Applying LEFs to Compute ESALs: Method Using AASHO Road Test Concepts*—By AASHTO's concept, Equivalent Single Axle Loads (ESALs) are the cumulative number of applications of an 18 000-lb single-axle load (a common denominator) that will have an equivalent effect on pavement serviceability of a specified pavement structure as all applications of the axle loads on single, tandem, and triple axles on all vehicles in a defined mixed-traffic stream. AASHTO ESALs are determined by calculating the LEF for each axle set on all vehicles in a measured or assumed mixed-traffic stream according to its axle type (single, tandem, or triple) and magnitude of load for a defined pavement structure and terminal serviceability, and summing the LEFs. Except for axle loads of 2000 lb or less on the axles of two-axle vehicles, the LEF calculated for a single axle is not applicable to the steering axle in calculating ESALs. The nominal values of steering axle loads at the AASHO Road Test ranged from 2000 to 12 000 lb. Thus, no steering axle load exceeded 12 000 lb, nominal. So, for steering axles loaded to less than 12 000 lb (as at the AASHO Road Test) no LEF should be applied to the steering-axle load; its effect has already been accounted for. But, for steering axles loaded to 12 000 lb or more (not used at the AASHO Road Test), an appropriate, single-tire LEF should be applied, and these ESALs should be accumulated along with those from the other (non-steering) axle(s) on the vehicle (**6**).

5.9.3 *Applying LEFs to Compute ESALs: Method Used for the Examples in AASHTO Guides*—The method that is illustrated by numerical examples shown in 2.2 for applying load equivalence factors in calculating ESALs have been followed by state agencies and FHWA since 1972. So that ESALs values comparable to those already on file will be produced by future WIM systems that comply with this specification, the illustrated methodology shall, as a minimum, be implemented in every such system. In the numerical examples in the guides, the steering axle is considered to be a "single" axle along with other single axles on a vehicle. In calculating the total ESALs for all vehicles in an observed or assumed mixed-traffic stream, for each vehicle class, the number of axles, according to axle type, in various load classes is listed, and then a tabular value (calculated from the regression equations by using the middle value in the load range) for the "Traffic Equivalency Factor" (called herein a Load Equivalence Factor, LEF) is multiplied by the number of observed axles, according to axle type, in each load class to yield the "A 18 Kip EAL's" (Average 18-Kip Equivalent Axle Loads) attributable to each axle type for all observed axles. The sum of the EALs for all observed axles is divided by the number of observed vehicles in the class to yield an average number of equivalent axle loads, EALs, per vehicle of that class.

5.10 *Violations*—Violations of all user-set parameters shall be determined by Type I, Type II, Type III, and Type IV WIM systems. A 2-character violation code, such as shown in Table 4, 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 that are in violation of user-set limits may be specified by the user, for example, flashing, underlining, bold-facing, or audio tones.

5.11 *Acceleration*—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 *User-Assignable Code*—For Type I, Type II, Type III, and Type IV WIM systems, provision shall be made to allow manual entry of a user-assignable three-digit code into any vehicular data set prior to recording.

TABLE 4 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

5.13 *Tire-Force Sensor*—As the tires of a vehicle being weighed in motion might travel anywhere between the instrumented traffic lane edges, it is necessary for the magnitude of the signal from the tire-force sensor(s) in the lane to be the same (within tolerance) for a given applied tire force(s), regardless of the lateral position of the tire(s) within the lane, if consistent load and weight estimates are to be made by a WIM system.

5.13.1 Therefore, the user shall specify that every tire-force sensor installed for use with a Type I, Type III, or Type IV WIM system shall be certified by the vendor to have been tested prior to installation and found to produce signals that were linearly proportional, within 2 % of the applied load, to a simulated tire load. The simulated tire load shall be applied at three levels: 10, 50, and 90 % of rated sensor capacity. Each level of applied load shall be measured such that its magnitude is known to be within 0.25 % of its true value, for example, via a NIST-certified load cell. Loads shall be applied at the approximate longitudinal center (in the direction of traffic movement) of the sensor and at three equally spaced intervals laterally between the ends of each half-lane-width portion (nominally, 6 ft (1.8 m)) of the sensor. The maximum allowable difference (tolerance) between the highest and the lowest of the three signal values recorded at any load level shall be 2 % of the highest value.

5.13.2 The user shall specify that every sensor, usually a piezo-type axle-load sensor, nominally 12 ft (3.6 m) long to cover a full lane width, installed for use with a Type II WIM system shall be certified by the vendor to have been tested under known impact loads applied at multiple, evenly-spaced intervals of 1 ft (0.3 m) or less along the length of the sensor prior to installation and found to meet Class I signal-uniformity tolerances (better than seven percent) (**7**).

6. User Requirements

6.1 *Site Conditions*—In order for any WIM system to perform properly, the user must provide and maintain an adequate operating environment for the system's sensors and instruments. System performance is degraded by less-than-ideal site conditions, even though the WIM-system sensors, instruments, and algorithms are capable of high-quality performance. Thus, construction or selection of each WIM site as well as monitoring and appropriate maintenance of the site and the sensors, are vital to WIM system performance, testing, and evaluation. The following site conditions, or better, shall be provided by the user if the performance criteria given in this specification are to be consistently realized. The user can require quality of performance only in proportion to the quality of the site conditions provided.

6.1.1 *Horizontal Alignment*—The horizontal curvature of the roadway lane for 200 ft (60 m) in advance of and 100 ft (30 m) 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 *Longitudinal Alignment (Profile)*—The longitudinal gradient of the road surface for 200 ft (60 m) in advance of and

100 ft (30 m) 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 *Cross Slope*—The cross-slope (lateral slope) of the road surface for 200 ft (60 m) in advance of and 100 ft (30 m) beyond the WIM-system sensors shall not exceed 3 % for Type I, Type II, and Type III WIM system installations, and shall not exceed 1 % for Type IV installations.

6.1.4 *Lane Width and Markings*—The width of the paved roadway lane for 200 ft (60 m) in advance of and 100 ft (30 m) beyond the WIM-system sensors shall be between 12 and 14 ft (3.6 and 4.3 m), inclusive. For Type III, except those with sensors in the main highway lanes, 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. 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 *Surface Smoothness*—To allow reliable WIM-system performance within the tolerances shown in Table 2, the surface of the paved roadway 200 ft (60 m) in advance of and 100 ft (30 m) beyond the WIM-system sensors shall be smooth before sensor installation and 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 16-ft (5-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, or sensor array, place the straightedge along each respective lane edge with the end furthest from the sensors at the distances from the longitudinal center of the sensors as indicated below. Then pivot the straightedge about this end, and sweep the end nearest the sensors between the lane edges while checking clearance beneath the straightedge with the circular plate. Apply the procedure to the road surfaces both in advance of and beyond the sensors.

Lane Edge	Longitudinal distance from Center of Sensors, ft (m)
Right	16, 25, 38, 51, 64, 77, 90, 103, 116, 129, 142, 155, 168, 181, 194, 207 (5, 8, 12, 16, 20, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63)
Left	16, 30, 43, 56, 69, 82, 95, 108, 121, 134, 147, 160, 173, 186, 199, 212 (5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65)

6.1.6 *Pavement Structure*—The user shall provide and maintain an adequate pavement structure and surface smoothness to accommodate the WIM-system sensors throughout their service life and shall install and maintain the sensors in accordance with the recommendations of the system vendor. Experience has indicated that a Portland cement concrete (also called rigid) pavement structure generally retains its surface smoothness over a longer period of time than a bituminous (also called flexible) pavement structure under heavy traffic at a WIM site. Consideration should be given to providing a 300-ft (90-m) long continuously reinforced concrete pavement (CRCP) or a jointed concrete pavement (JCP), with transverse joints spaced 16 ft (5 m) or less apart, at permanent WIM sites on freeways and principal arterial highways. (See Terminology E867 for definitions of pavement types.) The surface of every such rigid pavement should be ground smooth after curing and before the WIM sensors are installed approximately 200 ft (60 m) beyond the beginning of the ground-smooth pavement section. The user should assure that the skid resistance (See Terminology E867) of the surface after grinding is at least as good as that of the adjacent surfaces. At a site with flexible pavement, a 50-ft (15-m) long section comprising full-depth-asphalt, or black-base, design should be considered for installation at each end of the Portland cement concrete pavement structure to effect a stiffness transition between the two pavement structural types.

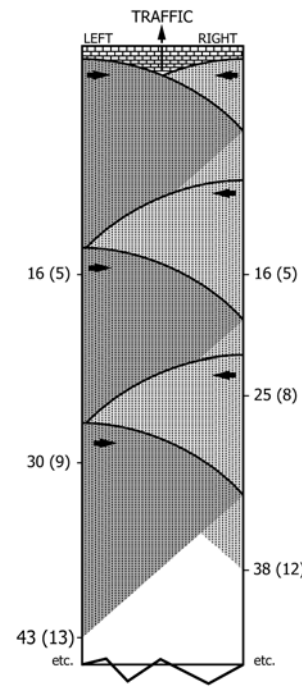

FIG. 1 Straightedge Positions

6.1.7 *Instrument Environment*—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 *Power*—The user shall provide and maintain an adequate electrical power supply at each WIM site, or specify an optional battery-powered system as described in 4.1, or both.

6.1.9 *Data Communication*—The user shall provide and maintain an adequate data communication link between the WIM site and the remote host computer where data will be processed. This link can also serve to monitor the performance of the WIM system and adjust its settings from a remote location.

6.1.10 *Temperature Range*—The user shall specify the reasonable maximum and minimum ambient air temperatures in which the WIM system being procured will be operated, and the vendor shall supply evidence that the system offered is capable of performing properly within this temperature range.

6.2 *Options, Exceptions, and Additional Features*—Any desired optional features described in Sections 4 and 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 *Recalibration*—The user shall recalibrate every WIM system following any significant maintenance or relocation. Recalibration shall be performed no less frequently than annually. Abrupt or unusual changes in data patterns can also indicate the need for recalibration. 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 to ensure consistent performance.

6.4 *Acceptance Test*—As part of every new WIM system procurement contract, or any major modification contract on an existing system, the user shall specify the test method and the schedule for testing that will be accomplished prior to final acceptance by the user and final payment to the vendor. This test shall be conducted on-site by the user or the user's authorized representative in cooperation with the vendor, after the system has been installed or modified and calibrated (see 7.5). The specification shall state clearly the proportions of initial-calibration and acceptance-test expenses to be borne by the user and by the vendor, including the expenses for providing and operating test vehicles and for traffic control. The On-site Acceptance/Verification Test described in 7.6 may be referenced for this purpose.

6.4.1 *Implications of a Type-Approval Test*—The acceptance-test specification should require that the WIM system being offered by the vendor pass a rigorous Type-Approval Test, conducted under excellent site conditions (see 6.1), to demonstrate that the system is capable of performing adequately under such conditions. This test verifies the functionality of all features of the system, as well as its highest potential accuracy when the sensors are subjected to loads from a wide range of vehicle types. If the vendor provides credible evidence that the type and model of system being offered has already successfully passed the applicable Type-Approval Test described in Section 7 and the user provides site conditions that meet or exceed those given in 6.1, the system will be expected to perform at the site within the tolerances stated in Section 5. If it fails to perform within these tolerances in an on-site acceptance test where the site conditions meet or exceed those given in 6.1, the indication is that the installed system is faulty and the vendor shall be responsible for corrective action. However, if the vendor does not provide evidence of previous Type-Approval testing, the user will not be assured of the capability of the system and shall either require conduct of a Type-Approval Test (expenses to be negotiated) wherein the user shall provide appropriate site conditions (see 6.1), or reach an agreement with the vendor before the on-site acceptance test begins as to the specific, quantified tolerance values that will be acceptable if the site conditions provided by the user do not meet or exceed those given in 6.1. In the latter case, the responsibility for inadequate WIM-system performance can lie with the vendor, the user, or both.

6.4.2 *On-Site Acceptance/Verification Test*—The On-Site Acceptance/Verification Test described in 7.6 may be used in lieu of a full Type-Approval Test under the circumstances outlined in 6.4.1. It is an abbreviated form of the Type-Approval Test that indicates primarily the effects of the prevailing site conditions upon the performance of a capable WIM system.

7. Test Methods for WIM System Performance

7.1 *Scope*—Test methods for evaluating the performance of each type of WIM systems are presented in this section. Procedures are given for conducting a Type-Approval Test (see 7.2, 7.3, 7.4) for any new or modified type or model WIM system, and an On-Site Acceptance/Verification Test (see 7.6) for newly-installed or recently-modified equipment at a site or for verifying the performance of an in-service system at the site. Also included in this section is a Calibration Procedure for on-site calibration (see 7.5)—to remove as much bias as practicable from the weight, load, speed, axle-spacing, and wheelbase estimates—to be used at the time of system installation or whenever site conditions or equipment have changed. Both test methods and the calibration procedure require weighing and measuring static vehicles to determine reference values against which WIM-system-estimated values will be compared. The recommended procedure for weighing static vehicles is outlined next.

7.1.1 *Apparatus for Weighing Static Vehicles*—All apparatus used for weighing static vehicles shall be certified as meeting the applicable maintenance tolerance specified in *NIST Handbook 44* (**1**) within 30 days prior to use. 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 that meet the respective tolerance specification of *NIST Handbook 44* (**1**). The minimum number of wheel-load weighers required is two and the preferred minimum number is six. Alternatively, an axle-load scale or a multi-platform vehicle scale that has approaches and aprons adjacent to the load-receiving platform(s) that can support the tire-pavement contact surfaces of all tires on the vehicle being weighed as described in 7.1.2 may be used to weigh wheel loads on one end of an axle by positioning the wheel(s) on the other end of the axle on the adjacent apron. When this alternative technique is used, the wheel loads on both ends of the axle shall be determined, and then used only to apportion the measured axle load between the wheels on each end of the axle. 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 that meet the respective tolerance specification of *NIST Handbook 44* (**1**), 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 oscillations induced by inertial forces (for example, via a load of undulant liquid) of the vehicle have subsided to a point that indicated tire load is changing less than three scale divisions in 3 s. If more than 6 s are required to reach this stable condition when making any tire-load measurement after the brakes on the vehicle being weighed are fully released, the vehicle shall be eliminated from the Test Unit for Type-Approval Test Loading. (see 7.2.4, 7.3.4, and 7.4.4.)

7.1.3 *Procedure for Weighing and Measuring Test Vehicles to Obtain Reference Values*—Two test vehicles (see 7.5.3) are used for the Calibration Procedure, the Type-Approval Test, and the On-Site Acceptance/Verification Test. The following procedure shall be applied for obtaining reference load, weight, axle-spacing, and wheelbase values for each of the two static test vehicles.

7.1.3.1 Measure the distance between adjacent axles on each test vehicle and record these data to the nearest 0.1 ft (0.03 m) as axle-spacing reference values. Also, measure directly the distance between the front-most and the rear-most axles on each test vehicle and record these data to the nearest 0.1 ft (0.03 m) as wheelbase reference values.

7.1.3.2 Weigh each test vehicle a minimum of three times, with brakes released, as described in 7.1.1 and 7.1.2 to measure tire loads for the wheel(s) on each end of every axle on the static vehicle. Move the vehicle completely away from the scale or weigher before beginning a new set of tire-load measurements, and always approach the weighing devices from the same direction for weighing. Sum the applicable tire loads to determine wheel, axle, and tandem-axle loads as well as gross-vehicle weight each time the vehicle is weighed. After summation, round each calculated value to the nearest 100 lb (50 kg) before recording it.

7.1.3.3 Calculate the arithmetic mean and round it to the nearest 100 lb (50 Kg) for all wheel load, axle-load, tandem-axle-load, and gross-vehicle-weight values that resulted from weighing each test vehicle three or more times; also calculate the difference in percent (truncate to an integer value) from this mean of each individual value used in calculating the respective mean.

7.1.3.4 Compare these percent differences from the mean to the following specified limits for each applicable load or weight value for each test vehicle: gross-vehicle weight = ±2 %, tandem-axle 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 weighing process for the static vehicle is producing results that are suitable for use as reference-value loads and weights against which WIM-system estimates will be evaluated.

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

7.1.3.6 Repeat 7.1.3.5 until the weighing process yields reference-value loads and weights that are within the specified range.

7.1.3.7 For reference-value loads and weights against which to compare WIM-system estimates, use the calculated arithmetic mean value (rounded to the nearest 100 lb (50 kg)) for the respective wheel load, axle-load, tandem-axle-load, and gross-vehicle-weight values that resulted from successfully weighing each test vehicle three or more times. Record these mean values for future reference.

7.2 *Type-Approval Test for Type I and Type II WIM Systems:*

7.2.1 *Scope*—The Type-Approval Test described here is for evaluating the performance capabilities of a new type or model WIM system under excellent site conditions and under traffic loading that is representative of that which will be of interest where Type I and Type II WIM systems will usually be applied. Performance requirements for each type of WIM system are given in Section 5 of this specification, and associated user requirements are given in Section 6. The WIM system being evaluated in the Type-Approval Test shall be subjected to a loading test unit comprising two test vehicles (see 7.5.3) plus approximately 51 additional vehicles selected from the traffic stream at the Type-Approval Test site. Other types of vehicles may be added to the loading test unit by the user who is conducting the test at any Type-Approval Test site where large numbers of vehicles in classes not already included are operating. Likewise, the user conducting the test may eliminate vehicles of a particular class(s) from the loading test unit if none appears at the site within a practicable duration of the test. For each vehicle eliminated, one of another class prevalent at the site shall be added to maintain a total of 51 additional vehicles in the loading test unit. Vehicles determined to be carrying a shifting or undulating load at the time of reference-value weighing (see 7.1.2) may also be eliminated. Another vehicle of the same class shall be substituted for the one eliminated. The two test vehicles, that will make multiple passes over the WIM-system sensors at the minimum and at the maximum speed specified by the user between 10 and 80 mph (16 and 130 km/h), and at intermediate speeds, provide a basis for evaluating the performance of the WIM system over a range of speeds. 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 (see 7.2.4) shall be weighed statically on certified weighing devices as described in 7.1.1, 7.1.2, and 7.1.3 at a suitable site within reasonable proximity to the Type-Approval Test site.

7.2.2 *Significance and Use*—Interpretation of the results from the Type-Approval 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 that can be achieved by the particular type and model of system, as the road surface conditions that potentially affect the location and magnitude of dynamic tire forces significantly, shall be the best available for conducting the Type-Approval Test and shall, as a minimum, satisfy the user requirements given in Section 6.

7.2.3 *Site for Type-Approval Test*—Both the user (or a recognized representative of user's interests) and the vendor shall approve the Type-Approval Test site as well as the WIM-system installation prior to conducting the test. The actual road-surface and WIM-system sensor conditions that prevail in each lane during type-approval testing shall be documented in terms that verify compliance with the user requirements given in 6.1.

7.2.4 *Test Unit for Type-Approval Test Loading*—The test unit for loading the WIM system being evaluated in the Type-Approval Test shall comprise two test vehicles (see 7.5.3) that will make multiple runs over the WIM-system sensors at prescribed speeds along with 51 additional vehicles selected in random order from the traffic stream at the Type-Approval Test site. Each of the additional vehicles will be weighed once statically as described in 7.1.1 and 7.1.2 and will have the center-to-center spacing between adjacent axles and wheelbase measured and recorded (see 7.1.3.1). Wheel-load data are not required for the 51 additional vehicles. The number of additional 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 5. See 7.2.1 concerning modification of the loading test unit.

7.2.5 *Calibration*—Within 48 h prior to beginning the Type-Approval Test, the WIM system shall be calibrated in accordance with the calibration procedure presented in 7.5.

7.2.6 *Procedure*—The user shall be in responsible charge and shall include the following steps in conducting the Type-Approval Test.

TABLE 5 Composition of Test Unit for Type-Approval Test Loading of WIM Systems

Vehicle Class	Number of Selected Vehicles (Total = 51)
05	5
06	5
08 (2S1)[A]	4
08 (2S2)	4
08 (3S1)	4
09 (3S2)	20
11 (2S1-2)	3
12 (3S1-2)[B]	3
13	3

[A] Two-axle tractor, single-axle semi trailer.
[B] Three-axle tractor, single-axle semi trailer, two-axle full trailer.

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 that, as a minimum, meets the applicable requirements stated in 6.1.

7.2.6.2 Ensure that a site for weighing vehicles statically and measuring the center-to-center spacing between adjacent axles and wheelbase (see 7.1.3.1) is available within a reasonable distance of the WIM site, where traffic can be controlled safely and the two test vehicles can turn around safely and conveniently for making multiple passes. Obtain approval from the public authority having jurisdiction over the site for the traffic control procedures, including permission to exceed the legal speed limit if applicable (see 7.5.5.3), that will be used during testing. Provide facilities at this site for weighing all vehicles in the loading test unit (see 7.1.1). Document the location of the static weighing site and describe the facilities that were actually utilized at this site in the test report, including certification requirements per 7.1.1.

7.2.6.3 Install the WIM system in accordance with the vendor's recommendations and execute the calibration procedure that is presented in 7.5.

7.2.6.4 After agreement by both the user and the vendor, install the settings defined in 7.5.5.6 on the WIM-system.

7.2.6.5 Using traffic control procedures approved by the appropriate public authority and other reasonable safety precautions, have each test vehicle make five or more runs over the sensors in each lane at an attempted speed approximately 5 mph (8 km/h) less than the maximum speed, and then five or more additional runs at an attempted speed approximately 5 mph (8 km/h) greater than the minimum speed, used during calibration (see 7.5.5.3). At each speed, one or more runs shall be made with the test vehicle tires near the left-hand lane edge, and one or more runs with the test vehicle tires near the right-hand lane edge. The other runs shall be made with the test vehicle approximately centered in the lane. Weigh each test vehicle statically after or before every run over the WIM sensors (see 7.1.2). Do not determine wheel loads, axle-spacing, or wheelbase for every run. Record all data, and correlate the WIM-system vehicle record number for every run of each test vehicle with the corresponding static weighing record.

7.2.6.6 The reference-value vehicle speed for each run of each test vehicle over the WIM-system sensors shall be determined by either: (*1*) dividing wheelbase (measured on the static test vehicle to the nearest 0.1 ft (0.03 m) (see 7.1.3.1) by the time interval (measured to the nearest ms) between when the tires on the front-most axle and when those on the rear-most axle of the moving test vehicle actuated a designated tire-force sensor, or (*2*) calculating an adjusted speed for the vehicle that made the test run, that is, [multiply WIM speed by (reference-value wheelbase / WIM wheelbase)].

7.2.6.7 Make the calculations shown in 7.2.7 for the 20 or more runs (five or more runs at two speeds by two vehicles) of the test vehicles and compare the functions and performance of the WIM system with all specification requirements, including speed, axle spacing, and wheelbase. Use reference values for speed (7.2.6.6) and axle spacing and wheelbase (7.1.3.1) that were determined separately for these calculations. See Section 4 for functions and Section 5 for performance tolerances.

7.2.6.8 If any WIM-system function fails or more than 5 % of the load, weight, axle-spacing, or wheelbase values resulting from all test-vehicle runs fail to satisfy the specification, the user who is responsible for conducting the Type-Approval Test shall decide whether to continue the test. In making this decision, the user shall consider that at least 95 % of all WIM-system-estimated values from the runs already made by the two test vehicles plus values from the runs that will be made by the 51 additional vehicles must meet the specified tolerances for the system to be type approved.

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

7.2.6.10 Allow each of the selected vehicles to pass over the WIM-system sensors at normal speed and require each vehicle to stop for weighing (see 7.1.1 and 7.1.2) and for measurement of axle spacing and wheelbase (see 7.1.3.1). Wheel-load measurements for the 51 additional vehicles are not required.

7.2.6.11 Make the calculations shown in 7.2.7 and compare the performance of the WIM system with the specification requirements stated in Section 5 for the two test vehicles and the remainder of the vehicles in the Type-Approval Test loading unit (see 7.2.4).

7.2.6.12 Interpret and report the results as described in 7.2.8.

7.2.7 *Calculation*—Calculation is needed for defining the reference-value loads, weight of the static vehicle, and speed of the moving vehicle as it crossed over the WIM-system sensors. Additional calculation is required for determining whether data items produced by the WIM-system satisfy specification requirements.

7.2.7.1 *Procedure for Calculating Reference-Value Loads, Weight, and Speed*—Only certified weighing devices (see 7.1.1) shall be utilized for determining reference-value tire loads. Reference-value loads and weight are calculated by summing tire loads. For WIM systems that produce estimates of wheel loads, calculate reference-value axle load by summing two wheel loads, axle-group load by summing the wheel loads for all wheels in each defined axle group, and gross-vehicle weight by summing the wheel loads for all wheels on the vehicle. For WIM systems that 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. Reference-value speed shall be calculated as described in 7.2.6.6. Reference-value axle -spacing and wheelbase are determined as described in 7.1.3.1.

7.2.7.2 *Procedure for Calculating Percent of Non-Complying Data Items*—For each data item produced by the WIM system and shown in Table 2, calculate the difference or the percent difference in the WIM-system value and the corresponding reference value by using the following relationships. Difference, *D*, in speed (mph (km/h)), axle-spacing (ft (m)), and wheelbase (ft (m)):

$$D = (C - R) \tag{1}$$

Difference, *d*, in loads and weight (%):

$$d = 100[(C - R)/R] \tag{2}$$

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.

7.2.7.3 Determine the number of calculated differences that exceeded the tolerance value 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:

$$P_{de} = 100[n/N] \tag{3}$$

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.

Truncate P_{de} to an integer value.

7.2.8 *Interpretation of Test Results and Report*—If any specified WIM-system function failed, or if more than 5 % of the calculated differences for any applicable data item (specified in Section 4) resulting from all passes of the two test vehicles (each vehicle made five or more passes at two 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 dysfunctional or inaccurate and report that it failed the Type-Approval Test. Regardless of whether the system fails or passes the Type-Approval Test, the user who was in charge of conducting the test shall record all data used in making the determination, including the existing surface conditions, and prepare a Type-Approval Test Report. Copies of the dated and signed report shall be retained by the user and furnished to the vendor for future reference. A courtesy copy of the report sent to ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959 (Attention: Chair, Subcommittee E17.52) will be appreciated and will be used to improve the future quality and usefulness of this standard. Potential users of this standard may contact ASTM at the above address for information about Type-Approval Test reports.

7.2.9 *Precision and Bias*—No information is presented about either the precision or bias of this *Type-Approval Test for Type I and Type II WIM Systems* as the test result is not quantitative; it is either pass or fail.

7.3 *Type-Approval Test for Type III WIM Systems:*

7.3.1 *Scope*—A procedure is given for conducting a Type-Approval Test of a Type III WIM system. This system is designed for installation at weight-enforcement stations with sensors off the main highway lanes, or in one or more main highway lanes, to identify vehicles operating within a user-specified range of speeds between 10 and 80 mph (16 and 130 km⁄h), inclusive, that are suspected of weight-limit or load-limit violation. The system must also control official traffic-control devices that direct suspect vehicles to a scale for confirmation weighing and measurement and direct non-suspect vehicles past the scales without stopping. The Type-Approval Test shall be conducted under the site conditions described in 6.1 and under traffic that includes vehicles that are representative of the vehicle classes of interest where Type III WIM systems will usually 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, as the required reference-value weighing devices are continually available for on-site calibration at any chosen time. Test loading for the Type-Approval 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 negative longitudinal acceleration of a vehicle while it is over the off-main-lane 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 Type-Approval Test is conducted. When the sensors of the Type III WIM system are installed in the main highway lanes, the Type-Approval Test procedure shall be the same as described herein except that the deceleration testing described in 7.3.6.1 will not be conducted. The Type III system shall accommodate the same speed criteria as a Type I system, and the tolerances for 95 % compliance shown in Table 2 for load and weight values, speed, axle-spacing, and wheelbase for a Type III system shall be satisfied.

7.3.2 *Significance and Use*—Interpretation of the results from the Type-Approval Test will allow the user to determine whether the tested 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 that potentially affect the location and magnitude of dynamic tire forces significantly shall be the best available for conducting the Type-Approval Test and shall, as a minimum, satisfy the user requirements shown in Section 6.

7.3.3 *Site for Type-Approval Test*—See 7.2.3.

7.3.4 *Test Unit for Type-Approval Test Loading*—The test unit for loading the WIM system being evaluated in the Type-Approval 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 at least 80 % of the applicable legal limit: gross-vehicle weight, axle-group load, axle load, or wheel load.

7.3.5 *Calibration*—See 7.2.5.

7.3.6 *Procedure*—The procedure for conducting the Type-Approval Test for Type III WIM systems shall be the same as described in 7.2.6 with the following exception:

7.3.6.1 After 7.2.6.8, if continuation is approved, verify the ability of the WIM system with sensors installed off the main highway lanes 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), inclusive, and apply heavy braking for approximately 1 s while the vehicle is passing over the sensor array. Excessive negative longitudinal acceleration (deceleration) should be indicated by the Violation Code DE (see Table 4). Compare the WIM-system estimates of loads and weight for these runs with those for steady-speed runs and include these comparisons in the Type-Approval Test Report for this Type III WIM system. Proceed with 7.2.6.9.

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*—No information is presented about either the precision or bias of this *Type-Approval Test for Type III WIM Systems* as the test result is not quantitative; it is either pass or fail.

7.4 *Type-Approval 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. Even though this type WIM system has not yet been approved for use in the United States, a procedure for type-approval testing to determine compliance 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, exempting the Type IV WIM system from producing wheel-load information (see 4.1.4), has been specified for the Type IV WIM system under test. When this option has not been specified, wheel-load values are required, and 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 indicated by the scale between the wheels on the axle. Alternatively, an axle-load scale or a multi-platform vehicle scale that has approaches and aprons adjacent to the load-receiving platform(s) that can support the tire-pavement contact surfaces of all tires on the vehicle being weighed as described in 7.1.2 may be used to weigh wheel loads on one end of an axle by positioning the wheel(s) on the other end of the axle on the adjacent apron. When this alternative technique is used, the wheel loads on both ends of the axle shall be determined, and then used only to apportion the measured axle load between the wheels on each end of the axle.

7.4.2 *Significance and Use*—Interpretation of the results from the Type-Approval 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 that 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 Type-Approval Test and shall, as a minimum, satisfy the user requirements shown in Section 6.

7.4.3 *Site for Type-Approval 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. Neither the longitudinal profile nor the cross slope shall exceed 1 %.

7.4.4 *Test Unit for Type-Approval Test Loading*—See 7.3.4.

7.4.5 *Calibration*—Within seven days prior to beginning the Type-Approval Test, every Type IV system that uses tire-force sensors (see 5.13) that support the entire tire-contact area(s) of all tires on a wheel assembly simultaneously shall, when subjected to field standard test weights (see 5.13.1), be adjusted to meet the acceptance tolerance for wheel-load weighers or for portable axle-load weighers as stated in *NIST Handbook 44* (**1**), depending upon whether wheel-load data or only axle-load data (4.1.4, Option 2) are of interest. Type IV systems that use tire-force sensors that support only part of the tire-contact area(s) at one time during dynamic tire-force measurements shall be calibrated within this same time period as described in 7.5, except the speeds (see 7.5.5.3) shall be 2 and 10 mph (3 and 16 km/h) (see 4.1.4). All weighing apparatus used in the Type-Approval Test for determining reference-value tire loads shall be certified as meeting the applicable maintenance tolerance specified in *NIST Handbook 44* (**1**) within 30 days prior to beginning the Type-Approval Test.

7.4.6 *Procedure*—The procedure for conducting the Type-Approval 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 7.5.5.3, 7.2.6.5 and 7.2.6.10, the respective minimum, intermediate, and maximum speeds of the test vehicles shall be 2, 6, 8, and 10 mph (3, 10, 13, and 16 km/h),

7.4.6.3 In 7.2.6.9, calculate the difference in each load or weight from the arithmetic mean and compare the difference to one-half the applicable tolerance for a Type IV WIM system shown in Table 2.

7.4.6.4 After 7.2.6.8, 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 4). 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 E17 on Vehicle-Pavement Systems. Proceed with 7.2.6.9.

7.4.6.5 In 7.2.7.2, calculate the differences in WIM-estimated load and weight values from their respective reference values and express the differences in pounds (kilograms), rather than percent.

7.4.7 *Calculation*—See 7.2.7 except as described in 7.4.6.5.

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

7.4.9 *Precision and Bias*—No information is presented about either the precision or bias of this *Type-Approval Test for Type IV WIM Systems* as the test result is not quantitative; it is either pass or fail.

7.5 *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 shall be conducted by the user with cooperation of the vendor, or by their authorized representatives as a fundamental part of every Type-Approval Test and is recommended for inclusion in every On-site Acceptance/Verification Test (see 7.6). It requires that two loaded, pre-weighed and measured (see 7.1.3) test vehicles each make multiple runs over the WIM-system sensors in each lane at specified speeds.

7.5.2 *Significance and Use of Calibration*—The tire-force sensors of a WIM system are typically designed to produce a signal, with respect to time, that is linearly proportional to the magnitude of the component of dynamic tire force applied perpendicularly to the road surface by the tires of a moving vehicle. The function of calibration is to define factors that will be subsequently applied within WIM-system calculations to correlate the observed vehicle speed and tire-force signals with the corresponding tire-load, axle-spacing, and wheelbase values for the static vehicle. The dynamic tire force results from a complex interaction among the vehicle components, the WIM-system sensors, the road surface surrounding the sensors, and other factors (see 3.2.5). Road-surface profiles and sensor installation are different at every WIM site, and every individual vehicle has unique tire, suspension, mass, and speed characteristics. Therefore, it is necessary to recognize the effects of these site-specific, speed-specific, and vehicle-specific influences on WIM-system performance and attempt to compensate for their adverse effects as much as is practicable via on-site calibration. The calibration procedure shall be applied immediately after the initial installation of a Type I or

Type II, or Type III WIM system at every site. It shall be applied again when a system is reinstalled or whenever site conditions or WIM-system components (including software and settings) have changed significantly. Recalibration shall be performed no less frequently than annually.

7.5.3 *Test Unit for Calibration Loading*—The test unit for calibration loading shall comprise two loaded, pre-weighed, and measured test vehicles that will each make multiple runs over the WIM-system sensors in each lane at prescribed speeds. Both test vehicles shall be Class 09 (see Table 3). The two axles on the semi-trailer of one of the test vehicles shall have an axle spacing of 5.0 ft (1.5 m) or less (conventional tandem), and the two axles on the semi-trailer of the other test vehicle shall be separated by at least 9.0 ft (2.7 m), but not more than 12 ft (3.7 m) (spread tandem). For purposes of calibration and testing, each of the axles on the semi-trailer of the latter test vehicle (spread tandem) shall be considered to produce a single-axle load (3.2.7) on the road surface. To avoid characteristically adverse dynamic loading effects on the tires of the steering axle, the spacing between the first (steering axle) and second (front axle of drive tandem axle) axles on the tractor of each test vehicle shall be equal to or less than 14 ft (4.3 m) or equal to or greater than 18 ft (5.5 m). The fifth-wheel location on the tractor shall be forward of the longitudinal center of the tandem drive axle, and its actual location shall be documented in the calibration and test reports. These test vehicles shall have air-type suspension on all dual-tired axles; however, another suspension type that is deemed by the user who is conducting the test to be representative of most vehicles of their type operating at the site may be approved by the user. The suspension type of every test vehicle used for calibration loading shall be carefully documented in the test report (preferably including video images). Each test vehicle shall be loaded to at least 90 % of its respective registered gross-vehicle weight with a non-shifting, approximately-symmetric (side-to-side) 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. Reference-value weighing and measuring of the two test vehicles shall be in accordance with 7.1.3.7 and 7.1.3.1.

7.5.4 *Site Conditions*—Before initial calibration begins, the existing site conditions (see 6.1) in each lane where WIM-system sensors are installed shall be described quantitatively and made a matter of permanent record for future reference (see 6.1.5 for surface smoothness measurement). Estimates of the location and magnitude of each observed pavement surface deviation greater than the 0.125 in. (3 mm) measured beneath the straightedge with the circular plate should be documented. Record the time and the approximate ambient air temperature at the beginning, during, and at the end of the calibration process. After initial calibration, alternative means of measuring the surface smoothness of the paved roadway 200 ft (60 m) in advance of and 100 ft (30 m) beyond the WIM-system sensors may be used to avoid closing the traffic lane. Data from inertial profiling instruments analyzed via computer simulation of the 16-ft (5-m) straightedge and circular plate is suggested as a possible alternative measurement technique.

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

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 Provide means for calculating the reference-value vehicle speed for each run of each test vehicle over the WIM-system sensors by either: (*1*) dividing reference-value wheelbase (measured on the static test vehicle to the nearest 0.1 ft (0.03 m) (see 7.1.3.1) by the time interval (measured to the nearest ms) between when the tires on the front-most axle and when those on the rear-most axle of the moving test vehicle actuated a designated tire-force sensor, or (*2*) calculating an adjusted speed for the vehicle that made the test run, that is, [multiply WIM speed by (reference-value wheelbase / WIM wheelbase)].

7.5.5.3 Using traffic control procedures approved by the appropriate public authority and other reasonable safety precautions, have each test vehicle (see 7.5.3) make a series of three or more runs over the WIM-system sensors at the minimum and at the maximum speed specified by the user, who is conducting the test, between 10 and 80 mph (16 and 130 km/h) for Type I, Type II, and Type III systems. The maximum specified speed shall be less than the legal speed limit at the site unless the user for an unusual and justifiable reason obtains prior approval from the appropriate public authority for the test trucks to exceed the legal speed limit at the site during WIM-system calibration and subsequent testing. Such approval shall be documented in the Type-Approval Test report. These two speeds should differ by at least 20 mph (30 km/h) and should be above and below the average speed of vehicles operating at the site. Then, have each test truck pass over the sensors three or more times at an intermediate speed that is representative of the prevailing speed of truck traffic at the site. At each speed, the runs shall be made with the test vehicle approximately centered in the lane. Record all data, and note the vehicle record number for every run of each test vehicle.

7.5.5.4 Calculate the difference in the WIM-system estimate and the respective reference value for the two test vehicles for each wheel-load, axle-load, tandem-axle load, gross-vehicle-weight, speed, axle-spacing, and wheelbase value. Express the difference in load and weight values in percent (see 7.2.7), and find a mean value for the differences for each set of values.

7.5.5.5 Determine the necessary changes, according to the vendor's recommendations, to the WIM-system settings that will adjust the calculated mean value of the respective differences for each of these values to equal approximately zero. For WIM systems that estimate wheel load (Type I and perhaps other types), the adjustment will be to settings that affect the wheel-load estimates on each side of the vehicles, separately. Reference-value wheel loads for each test truck are determined as described in 7.1.1 and 7.1.2. For systems that estimate axle loads and not wheel loads, the adjustment will be to the settings that affect axle loads. WIM-system estimates for axle-spacing and wheelbase are usually calculated as the product of speed [distance between two different sensors (an input value to software for the site) / travel time of the vehicle (or an axle) between the two different sensors] and the measured time between successive axles on the moving vehicle actuating one chosen sensor. Therefore, assuming that vehicle speed is constant while the vehicle crosses over the sensors, proportional adjustments to the distance between the two sensors used to measure speed (an input value to software for the site) will result in proportional changes in the WIM-system estimates for axle-spacing and wheelbase. When the WIM-system estimates for axle-spacing and wheelbase equal the respective reference values, the indicated WIM-system speed value can also be taken as correct. Reference-value axle-spacing and wheelbase measurements for each test truck are determined manually as described in 7.1.3.1. Each individual vehicle interacts with the road surface differently at different speeds, but about the same at the same speed. It is, therefore, essential for every WIM system to include a feature that invokes the proper set of calibration factors for use in estimating load and weight values when the observed vehicle is running at a particular, measured speed. These factors can be derived from analysis of errors in the measurements recorded after the two test vehicles each made three or more runs at three different speeds. In determining appropriate calibration factors for subsequent application, spread sheet and graphical presentation of the raw and calculated data can aid greatly in interpreting the sense and magnitude of errors and their trend with respect to vehicle speed. The vendor should advise about adjusting calibration-factor settings for selected, available speed set points and how their software interpolates between these points in applying a particular calibration factor for each observed vehicle speed.

7.5.5.6 Install the settings determined in 7.5.5.5 and have each test vehicle make two more runs over the WIM-system sensors in each lane, approximately centered in the lane, at two different speeds to verify the effectiveness of the changed settings. The first run shall be at an attempted speed about 5 mph (8 km/h) below the maximum speed specified by the user for calibration, and the second run should be about 5 mph (8 km/h) above the minimum specified speed (7.5.5.3). Make the calculations shown in 7.2.7 after the four runs of the test vehicles are completed and compare the functions and performance of the WIM system with all specification requirements, including loads, weight, speed, axle spacing, and wheelbase. Use the reference values for speed (7.2.6.6) and axle spacing and wheelbase (7.1.3.1) that were determined separately for these calculations. If any specified WIM-system function failed, or if any WIM-system indicated value was outside the specified tolerance shown in Table 2, make further, appropriate changes to the settings and make four more test vehicle runs. Continue making corrections to the system settings and test truck runs until specified performance requirements are satisfied or until the user declares that the system is unsatisfactory for further testing.

7.6 *On-Site Acceptance/Verification Test for Type I, Type II, and Type III WIM Systems:*

7.6.1 *Scope*—This test method provides the WIM-system user with a practicable means for determining whether or not a new, modified, or in-service Type I, Type II, or Type III system that has been installed at a particular site meets or exceeds specified functional and performance requirements (see Sections 4 and 5) and defines for the user and the vendor the test method that will be applied for evaluating the installed WIM system. It also requires the user to quantify and document the site conditions that exist at the site (see 6.1 and 7.5.4) when the test is conducted. It uses two test vehicles for the test loading unit and is an abbreviated form of the more-rigorous Type-Approval Test (see 7.2 and 7.3) for these WIM-system types that may be used in lieu of a full Type-Approval Test under the circumstances outlined in 6.4.1.

7.6.2 *Significance and Use*—In procuring a new WIM system or in contracting for a major modification to an existing system for use at a particular site, the user shall specify (see 6.4) an acceptance test method and the schedule of testing that will be accomplished prior to final acceptance of the product or service by the user and final payment to the vendor. The On-site Acceptance/Verification Test described here may be referenced for this purpose in the specification or for verifying the performance of an in-service WIM system.

7.6.3 *Procedure*—The test shall be conducted on-site by the user or the user's authorized representative, in cooperation with the vendor, immediately after a Type I, Type II, or Type III WIM System has been installed or modified or whenever an evaluation of the in-service performance of one of these WIM-system types is desired over a specified range of speeds. The following steps are required for each instrumented lane.

7.6.3.1 Execute the Calibration Procedure as presented in 7.5, including quantification of surface smoothness, and install the settings defined in 7.5.5.6 on the WIM system. If agreed upon in advance by both the user and the vendor, another calibration procedure may be used in lieu of the one presented in 7.5 for conducting the On-site Acceptance/Verification Test. Do not recalibrate the WIM system prior to conducting an in-service verification test.

7.6.3.2 With the settings agreed upon by both the user and the vendor installed on the WIM system, have each of the two test vehicles (see 7.5.3) make five or more runs over the sensors in each lane at an attempted speed approximately 5 mph (8 km/h) less than the maximum speed, and then make five or more additional runs at an attempted speed approximately 5 mph (8 km/h) greater than the minimum speed used during calibration (see 7.5.5.3). At each speed, one or more runs shall be made with the test vehicle tires near the left-hand lane edge, and one or more runs with the test vehicle tires near the right-hand lane edge. The other runs shall be made with the test vehicle approximately centered in the lane. Record all data, and note the vehicle record number for every run of each test vehicle. Determine reference-value loads and weight as described in 7.1.3.7, axle-spacing and wheelbase as described in 7.1.3.1, and speed as described at (*2*) in 7.2.6.6.

7.6.4 *Calculation*—Make the calculations shown in 7.2.7 for the 20 or more runs (five or more runs at two speeds by two vehicles) of the test vehicles and compare the functions and performance of the WIM system with all specification requirements, including loads, weight, speed, axle-spacing, and wheelbase. See Section 4 for functions of the various WIM-system types. Performance tolerances are described in Table 2.

7.6.5 *Interpretation of Test Results and Report*—All specified data-collection features, data-processing features, and options of the system type described in Section 4 shall be demonstrated to function properly before the system is accepted. If any of these failed to function properly, the system failed the test. If more than 5 % of the calculated differences for any applicable data item resulting from all passes of the two test vehicles exceeded the tolerance specified in Table 2 for that item and WIM-system type and the road surface smoothness equaled or exceeded that described in 6.1.5, declare that the WIM system was inaccurate and record the fact that it failed the On-Site Acceptance/Verification Test. If the road surface smoothness at the site did not equal or exceed that described in 6.1.5, failure might be due to fault in the installed WIM system, fault in the user-provided site conditions, or to a combination of both (see 6.4.1). Regardless of whether the system fails or passes the *On-Site Acceptance/Verification Test for Type I, Type II, and Type III WIM Systems*, the user who was in charge of conducting the test shall record all data used in making the determination, including the existing surface conditions, and prepare an On-Site Acceptance/Verification Test Report. Copies of the dated and signed On-Site Acceptance/Verification Test Report shall be retained by the user and furnished to the vendor for future reference.

7.6.6 *Precision and Bias*—No information is presented about either the precision or bias of this *On-Site Acceptance/Verification Test for Type I, Type II, and Type III WIM Systems* as the test result is not quantitative; it is either pass or fail.

8. Keywords

8.1 axle load; pavement and bridge; traffic; type-approval test; vehicle; weighing vehicles; weigh-in-motion; weight enforcement; WIM

ANNEX

(Mandatory Information)

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

A1.1 Load Equivalence Factors and ESALs

A1.1.1 A numerical factor that defines the number of applications of a chosen standard axle load and type that is expected to cause damage to a specified pavement structure equivalent to the damage that will be caused by one pass of an axle load and type under consideration is called a Load Equivalence Factor (LEF). The vehicle records produced by Type I and Type II WIM systems (see 4.1.1 and 4.1.2) include data for defining axle load (see 3.2.4) and type (front, single, tandem, triple) for each individual axle or axle set (see 3.2.7, 3.2.8, 3.2.11).

A1.1.2 Equivalent Single Axle Loads (ESALs) are the cumulative number of applications of the chosen standard single-axle load that will have an equivalent effect on pavement serviceability as all applications of various axle loads and types by vehicles in a mixed-traffic stream. ESALs are determined by summing the calculated LEF for each individual axle or axle set according to axle load and type on all vehicles in the measured or assumed mixed-traffic stream for the defined pavement structure.

A1.1.3 *AASHTO Load Equivalence Factors*—The load equivalence factors, LEFs, that were derived from statistical analysis of data taken during the AASHO (now AASHTO) Road Test (**3, 4**) are frequently used for pavement design and analysis. For use in the *AASHO Interim Guides for Design of Pavement Structures, 1972 and 1981*, and in subsequent *AASHTO Guides for Design of Pavement Structures, 1986 and 1993*, (see 2.2), an 18 000-lb single axle was chosen as the standard axle load and type for calculating LEFs for flexible and rigid pavements. In addition to axle load and axle type, each LEF depends on the structural capacity (structural number, $\bar{SN}$) of a flexible pavement or on the thickness, D, of a rigid pavement, plus the terminal condition that is chosen to define failure of the pavement structure (terminal serviceability, p_t). The AASHTO equations for calculating LEFs for both flexible and rigid pavements are presented in the following sections.

A1.2 AASHTO Axle Load Equivalence Factors and ESALs for Flexible Pavements

A1.2.1 *AASHTO Design Equations*—The design equations for flexible pavements presented in the *AASHO Interim Guide for Design of Pavement Structures, 1972, Appendix C* (see 2.2), are:

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

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

$$G_t = \log\left[\frac{4.2 - p_t}{4.2 - 1.5}\right] \quad \text{(A1.3)}$$

where:

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

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

L_1 = load on one single axle, or on one tandem-axle set, lb/1000,

L_2 = axle-type code: 1 for a single axle, 2 for a tandem-axle set,
β = a function of design and load variables that influences the shape of the P versus W serviceability curve,
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 $p_t = 1.5$, and
p_t = serviceability at the end of time *t*; terminal serviceability. (Serviceability is the ability of a pavement at the time of observation to serve high-speed, high-volume automobile and truck traffic.)

A1.2.2 *Calculation of AASHTO LEFs*—The design equation (Eq A1.1) for flexible pavements can be arranged into a ratio format and solved to calculate a load equivalence factor. The number of applications of an 18 000-lb single-axle load $W_{t_{18,1}}$ that is expected to cause an equivalent change in serviceability to a flexible pavement with the same structural number $\bar{SN}$ and terminal serviceability p_t as one application $W_{t_{Li,n}} = 1$ of an axle load under consideration L_i and axle type *n* is called the Load Equivalence Factor, $LEF_{L_i n}$. This load equivalence factor can be calculated by solving the following equations **(5)**.

$$LEF_{L_i n} = \frac{W_{t_{18,1}}}{W_{t_{L_i n}}} = \left[\frac{(L_i+n)^{4.79}}{(18+1)^{4.79}}\right]\left[\frac{10^{G_t/\beta_{18,\ 1}}}{(10^{G_t/\beta_{L_i,\ n}})\,(n^{4.331})}\right] \quad (A1.4)$$

$$\beta_{L_i,\ n} = 0.40 + \frac{0.081(L_i+n)^{3.23}}{(\bar{SN}+1)^{5.19}\,(n^{3.23})} \quad (A1.5)$$

$$\beta_{18,\ 1} = 0.40 + \frac{1094}{(\bar{SN}+1)^{5.19}} \quad (A1.6)$$

where:

$LEF_{L_i n}$ = Load Equivalence Factor; the number of 18 000-lb single-axle load applications that will have an equivalent effect upon pavement serviceability as one application of a load L_i on a type *n* axle for the given flexible pavement structural number $\bar{SN}$ and terminal serviceability p_t,
L_i = load *i* on the axle set (type) under consideration, lb/1000,
n = axle-type code: 1 for a single axle, 2 for a tandem-axle set, or 3 for a triple-axle set, (Support for using $n = 3$ to calculate LEFs for triple-axle sets is presented in *AASHTO 1986, Vol 2, Appendix MM*, see 2.2.),
G_t = see (Eq A1.3).

A1.2.3 *Calculation of AASHTO ESALs*—Equivalent Single Axle Loads (ESALs), by AASHTO's concept, are the cumulative number of applications of an 18 000-lb single-axle load (a common denominator) that will have an equivalent effect on pavement serviceability of a specified pavement structure as all applications of various axle loads and types by vehicles in a mixed-traffic stream. AASHTO ESALs are determined by calculating the LEF for each axle set on all vehicles in a measured or assumed mixed-traffic stream according to its axle type (single, tandem, or triple) and magnitude of load for a defined pavement structure and terminal serviceability, and summing the LEFs. The LEF calculated for a single axle is applicable only to non-steering axles and to single-tire single axles on two-axle vehicles loaded to 2000 lb or less, as the regression equations developed from analysis of the AASHO Road Test data are based only on such axles. The damaging effect of the steering (front) axles, with single tires, on the test trucks was not evaluated separately, but instead was incorporated into the effects resulting from the other axles on the test trucks, called load axles. The regression coefficients in the AASHTO design equations are sensitive to the units of measurement for load; therefore, AASHTO ESALs must be calculated only in U.S. customary units.

A1.3 AASHTO Axle Load Equivalence Factors and ESALs for Rigid Pavements

A1.3.1 *AASHTO Design Equations*—The design equations for rigid pavements presented in the *AASHO Interim Guide for Design of Pavement Structures, 1972, Appendix D, Revised 1981* (see 2.2), are:

$$\log W_t = 5.85 + 7.35\log(D+1) - 4.62\log(L_1+L_2) + 3.28\log L_2 + \frac{G_t}{\beta} \quad (A1.7)$$

$$\beta = 1.0 + \frac{3.63(L_1+L_2)^{5.20}}{(D+1)^{8.46}\,L_2^{3.52}} \quad (A1.8)$$

$$G_t = \log\left[\frac{4.5-p_t}{4.5-1.5}\right] \quad (A1.9)$$

where:

D = thickness of rigid pavement slab, in.

All other terms in these equations are as defined in A1.2.1.

A1.3.2 *Calculation of AASHTO LEFs*—The design equation (Eq A1.7) for rigid pavements can be arranged into a ratio format and solved to calculate a load equivalence factor. The number of applications of an 18 000-lb single-axle load $W_{t_{18,1}}$ that is expected to cause an equivalent change in serviceability to a rigid pavement with the same slab thickness *D* and terminal serviceability p_t as one application $W_{t_{Li,n}} = 1$ of an axle load under consideration L_i and axle type *n* is called the Load Equivalence Factor, $LEF_{L_i n}$. This load equivalence factor can be calculated by solving the following equations **(5)**.

$$LEF_{L_i,\ n} = \frac{W_{t_{18,1}}}{W_{t_{L_i n}}} = \left[\frac{(Li+n)^{4.62}}{(18+1)^{4.62}}\right]\left[\frac{10^{G_t/\beta_{18,\ 1}}}{(10^{G_t/\beta_{L_i,\ n}})\,(n^{3.28})}\right] \quad (A1.10)$$

$$\beta_{L_i,\ n} = 1.0 + \frac{3.63(L_i+n)^{5.20}}{(D+1)^{8.46}\,(n^{3.52})} \quad (A1.11)$$

$$\beta_{18,\ 1} = 1.0 + \frac{1.620\times 10^7}{(D+1)^{8.46}} \quad (A1.12)$$

where:

$LEF_{L_i n}$ = Load Equivalence Factor; the number of 18 000-lb single-axle load applications that will have an equivalent effect upon pavement serviceability as one application of a load L_i on a type *n* axle for the given rigid pavement slab thickness *D* and terminal serviceability p_t,
D = thickness of rigid pavement slab, in.,
L_i = load *i* on the axle set (type) under consideration, lb/1000,

n = axle-type code: 1 for a single axle, 2 for a tandem-axle set, or 3 for a triple-axle set (support for using $n = 3$ to calculate LEFs for triple-axle sets is presented in *AASHTO 1986, Vol 2, Appendix MM*, see 2.2.), and

G_t = see (Eq A1.9).

A1.3.3 *Calculation of AASHTO ESALs*—See A1.2.3.

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