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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.

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

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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.

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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.

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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

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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.

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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 5.9.4 for applying load

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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

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