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Standard Test Methods for Evaluating Performance of Highway Traffic Monitoring Devices[1]

This standard is issued under the fixed designation E2532; 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 *Purpose*—The two test methods contained in this standard define acceptance tests for evaluating the performance of a Traffic Monitoring Device (TMD) according to the functions it performs, the data it provides, the required accuracy of the data, and the conditions under which the device operates. Acceptance tests are recommended whenever a TMD is purchased, installed, or performance validation is desired. The tests are performed in a field environment and result in an accept or a reject decision for the TMD under test.

1.2 *Exceptions*—Exceptions and options to the test methods may be included in any derivative test method presented by a user as part of the procurement process for TMDs. Sellers may offer exceptions and options in responding to an invitation to bid.

1.3 *Units*—The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units,[2] which are provided for information only and are not considered standard.

1.4 The following safety procedures apply to Sections 6 and 7, which describe the details of the acceptance test methods. When a test site accessible by the public (for example, a street or highway) is used for the acceptance test of the TMD, obtain approval from the public authority having jurisdiction over the site for the traffic control procedures to be used during the test. *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]

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E867 Terminology Relating to Vehicle-Pavement Systems

E1318 Specification for Highway Weigh-In-Motion (WIM) Systems with User Requirements and Test Methods

E2300 Specification for Highway Traffic Monitoring Devices

3. Terminology

3.1 Definitions of terms and definitions of terms specific to these test methods are given below.

3.2 *Definitions:*

3.2.1 *accepted reference value, n*—value attributed to a particular quantity (for example, vehicle class by number of axles and interaxle spacings, vehicle count, lane occupancy, or vehicle speed) and agreed upon by the user and seller in advance of testing of a TMD, which has an uncertainty appropriate for the given purpose. **E2300**

3.2.2 *accuracy, n*—closeness of agreement between a value indicated by a TMD and an accepted reference value. **E2300**

3.2.3 *axle, n*—axis oriented transversely to the nominal direction of vehicle motion, and extending the full width of the vehicle, about which the wheels at both ends rotate. **E867, E1318**

3.2.4 *axle count, n*—number of vehicle axles enumerated at a point on a lane or roadway during a specified time interval. **E867**

3.2.5 *bias, n*—a generic concept related to a consistent or systematic difference between a set of test results from the process and an accepted reference value of the property being measured. **E177**

3.2.6 *correct detection, n*—an indication by a TMD that a vehicle actually passing over the detection area of the TMD is detected by the TMD. **E2300**

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[1] These test methods are under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and are the direct responsibility of Subcommittee E17.52 on Traffic Monitoring.

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[2] *Standard Practice for Use of the International System of Units (SI): The Modern Metric System*, IEEE/ASTM SI 10™-2002, The Institute of Electrical and Electronics Engineers (IEEE), Inc., 3 Park Avenue, New York, NY, 10016-5997, USA and American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA, ISBN 0-7381-3317-5.

[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.

3.2.7 *data item, n*—characteristic associated with individual vehicles (for example, count, class, and speed) or the continuum of vehicles at a location (for example, density, flow rate, and queue length). **E2300**

3.2.8 *detection area, n*—road surface area above which a sensor detects a vehicle or vehicle component. **E2300**

3.2.9 *electronics unit, n*—device that provides power to one or more sensors, filters and amplifies the signals produced by the sensors, and may perform other functions such as sensitivity adjustment, failure indication, and delayed actuation of traffic control signals.[4] **E2300**

3.2.10 *false detection, n*—an indication by a TMD that a vehicle not actually passing over the detection area of the TMD is detected by the TMD. **E2300**

3.2.11 *flow rate, n*—number of vehicles passing a given point or section of a lane or roadway during a designated time interval, usually 15 min, but expressed as an equivalent hourly rate in vehicles/h. **E2300**

3.2.12 *lane occupancy, n*—percent of selected time interval that vehicles are detected in the detection area of a sensor; the time interval during which the lane occupancy is measured is usually 20 to 30 s.[5] **E2300**

3.2.13 *missed detection, n*—an indication by a TMD that a vehicle actually passing over the detection area of the TMD is not detected by the TMD. **E2300**

3.2.14 *precision, n*—a generic concept related to the closeness of agreement between test results obtained under prescribed like conditions from the measurement process being evaluated. **E177**

3.2.15 *sensor, n*—device for acquiring a signal that provides data to indicate the presence or passage of a vehicle or of a vehicle component over the detection area with respect to time (for example, flow rate or number of axles and their spacing), or one or more distinctive features of the vehicle such as height or mass. **E2300**

3.2.16 *speed, n*—rate of vehicle motion expressed as distance per unit of time. **E2300**

3.2.17 *time stamp, n*—recorded date and time at which a measurement was made; information and format may be tailored to the application, but usually consists of month, day, year, hour, minute, second, and subsecond. **E2300**

3.2.18 *tolerance, n*—allowable deviation of a value indicated by the device under test or a device in service from an accepted reference value. **E2300**

3.2.19 *traffic monitoring device, n*—equipment that counts and classifies vehicles and measures vehicle flow characteristics such as vehicle speed, lane occupancy, turning movements, and other parameters typically used to portray traffic movement. **E2300**

3.2.20 *vehicle class by axle, n*—characterization of a vehicle by its number of axles and interaxle spacings. **E2300**

3.2.21 *vehicle class by length, n*—characterization of vehicles by their total length. **E2300**

3.2.22 *vehicle count (volume), n*—total number of vehicles observed or predicted to pass a point on a lane or roadway during a specified time interval. **E2300**

3.2.23 *vehicle, n*—one or more mobile units coupled together for travel on a highway; a vehicle contains one powered unit and may include one or more non-powered full-trailer or semi-trailer units. **E867**

3.2.24 *vehicle passage, n*—sensor output pulse signal produced when an initial vehicle detection is made in the detection area of the sensor. **E2300**

3.2.25 *vehicle presence, n*—sensor output signal produced the entire time a vehicle is detected in the detection area of the sensor. **E2300**

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *aliasing, n*—phenomenon that occurs when a signal containing frequencies greater than one-half the sampling frequency is digitized, causing those frequencies in excess of one-half the sampling frequency to be folded back into the digitized signal spectrum.

3.3.2 *straddling vehicle, n*—a vehicle that has one or more tires in an adjacent lane or shoulder.

3.3.3 *vehicle density, n*—number of vehicles occupying a given length of a lane or roadway at a particular instant, usually expressed in units of vehicles/lane-mile (lane-km).

4. Summary of Acceptance Test Methods

4.1 Two categories of acceptance tests are described. The first, the Type-approval Test, is intended for TMDs that have never been type-approved. The second, the On-site Verification Test, is applicable to production versions of TMDs that have previously passed a Type-approval Test, but are now being installed at a new location or have been repaired. Fig. 1 illustrates the procedure for determining which of the tests is applicable. The rigorous Type-approval Test verifies the functionality of all features of the TMD and provides information for evaluating the accuracy of the data item outputs when monitoring vehicle flows consisting of a mix of all anticipated vehicle classes under a specified range of operating conditions. The On-site Verification Test provides the TMD user and seller with a means for determining whether the production version of a TMD installed at a particular site meets the performance and user requirements identified in Specification E2300. Both categories of acceptance tests compare the outputs of the TMD under test with those of equipment that produce acceptable reference values. If all features of the TMD function properly and the output data are within the agreed upon tolerances, then the TMD is reported to have passed the acceptance test. If not, the TMD is reported to have failed the test.

[4] Klein, L. A., Gibson, D., and Mills, M. K., *Traffic Detector Handbook: Third Edition*, FHWA-HRT-06-108 (Vol. I) and FHWA-HRT-06-139 (Vol. II), U.S. Department of Transportation, Federal Highway Administration, Washington, DC, Oct. 2006. Also available at: http://www.tfhrc.gov/its/pubs/06108/ and http://www.tfhrc.gov/its/pubs/06139/.

[5] Different sensor models or technologies used to measure lane occupancy may have different detection area sizes and, hence, produce different occupancy values, although all devices are operating properly.

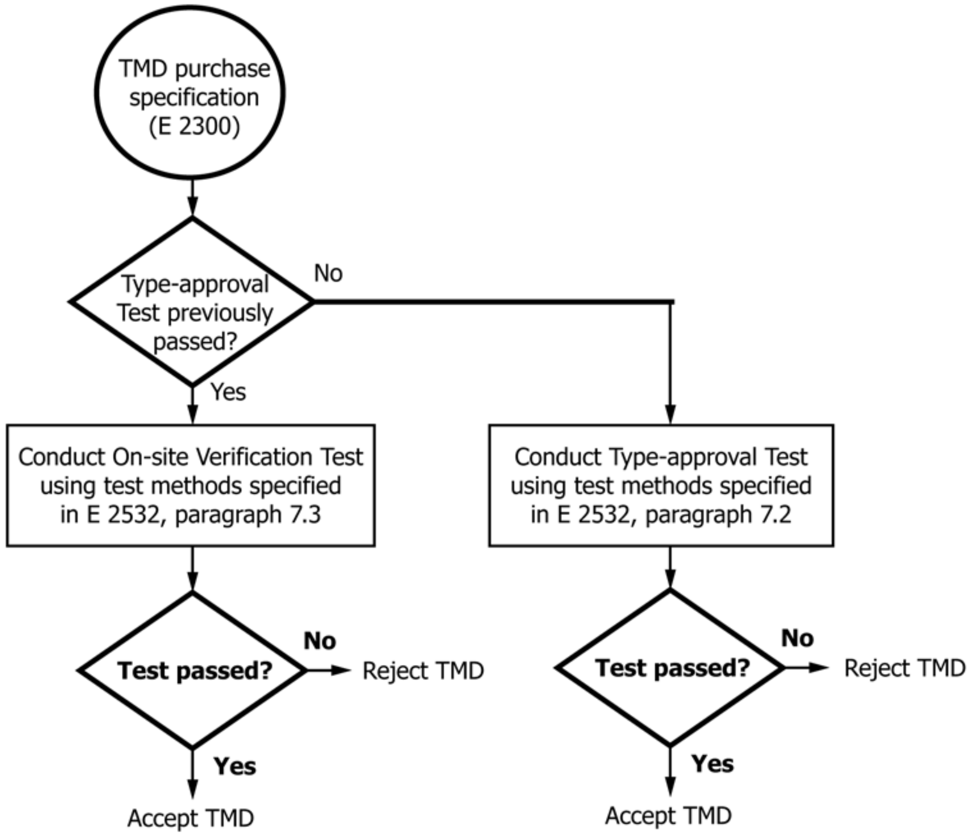

FIG. 1 Process for Determining Applicable TMD Acceptance Test

5. Device Classification

5.1 *Type, Tolerance, and Operating Conditions*—The type, tolerance, and operating conditions of the TMD to be tested shall be specified according to Specification E2300.

5.2 *Use of Measured Data in Support of Other Applications*—Additional vehicle flow parameters may be calculated from the recorded data. Among these parameters are vehicle flow rate, density, headway, intersection delay, vehicle gap in time or distance, queue length, and turning movements. Other highway system performance measures, such as volume-to-capacity ratio, total vehicle hours traveled, total vehicle miles traveled, average travel speed, number and categories of accidents, pollutant emissions, and fuel consumption may also be calculated from data recorded by appropriate sensors. These test methods do not address the ability of the TMD to calculate or provide data for these additional vehicle flow parameters or highway system performance measures.

6. Standardization of Acceptance Test Conditions

6.1 *Installation Requirements*—It shall be the responsibility of the user to install the TMD under test in accordance with the manufacturer's requirements. Conditions that are typically specified when installing and evaluating TMDs are described in 6.2 through 6.9.

6.2 *Vehicle Flow Rates and Vehicle Classes*—The TMD shall be tested under flow rates that include vehicle-to-vehicle gaps both less than and greater than 1 s and a mix of vehicle classes characteristic of the operating conditions in which the device will be used. The vehicle classes shall be specified by the user.

6.3 *Lighting*—The TMD shall be tested under lighting characteristic of the operating conditions in which the device will be used. Lighting conditions may include day, night, dawn, dusk, and other hours where artifacts or unusual conditions such as shadows and sun glint occur. The lighting conditions and times of day for the test will depend on the technology used in the TMD under test. The user shall specify the specific lighting conditions, if any, required for the tests. Table 1 contains lighting and environmental factors that shall be considered when evaluating TMDs.

6.4 *Temperature*—The user shall specify the maximum and minimum ambient air temperatures in which the TMD under

TABLE 1 Lighting and Weather Factors That May be Included as Part of TMD Testing

Lighting and Weather Factors[A]
1. Dawn ambient lighting
2. Dusk ambient lighting
3. Nighttime ambient lighting
4. Sun glint
5. Rain characterized by rain rate
6. Fog or dust characterized by human visual range
7. Snow characterized by snow fall rate and snow flake size

[A] Data gathered to verify TMD operation under these conditions may be gathered simultaneously with data used to verify operation at the vehicle flow rates and mix of vehicle classes specified in 6.2.

test (including sensor components installed on, under, or above the roadway and components installed in roadside cabinets) is expected to operate properly and under which it will be tested.

6.5 *Other Environmental Conditions*—The user shall specify other environmental conditions under which the TMD shall be tested. These include rain and rain rates, fog and visibility range, snow and snowfall rate, wind-borne dust, movement caused by wind and vibration, and any other conditions that are perceived by the user to affect the performance of the TMD.

6.6 *Evidence that TMD Can Operate Under Specified Environmental Conditions*—If applicable, the seller shall supply evidence that the device offered has been tested and found capable of operating under the specified environmental conditions.

6.7 *Power*—The user shall provide and maintain electrical power at each test site or specify an optional power source that can supply the power required by the TMD and the data recording equipment.

6.8 *Data and Video Communication*—If specified, the user shall provide and maintain an adequate data and video communication link between the test site and the data recording equipment. This link may also transmit information to monitor the performance of the TMD under test and adjust its settings, if applicable. Such a communications link may be wireless. TMD output data and video shall be recorded in a synchronized manner as specified by the user to support TMD evaluation.

6.9 *Options, Exceptions, and Added Features*—Any desired options, exceptions, or added data display or data recording features needed to evaluate the performance requirements of the TMD shall be specified by the user. If applicable, 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 display of selected records must occur without interference with the continuous acquisition of data.

6.10 *Acceptance Test Requirement*—The user shall specify the acceptance test category, Type-approval or On-site Verification using the process illustrated in Fig. 1, and the testing schedule that will be utilized prior to final acceptance by the user and final payment to the seller before the beginning of the test. The acceptance test procedure may require the user to provide traffic control as part of TMD installation. The user or the user's authorized representative, in cooperation with the seller, shall conduct the required acceptance test on site after the TMD has been installed and calibrated. A written report containing the test result shall be prepared by the user or their representative when testing has been completed, and a copy of the report shall be furnished to both the user and the seller.

6.10.1 *Type-approval Test Requirement*—The TMD specification developed in accordance with Specification E2300 requires that the TMD pass a rigorous Type-approval Test if it has not previously passed such a test. The Type-approval Test, described in 7.2, provides information for verifying the accuracy and functionality of all features of the TMD while it monitors a flow consisting of a mix of anticipated vehicle classes. If the seller does not provide evidence that the brand and model of TMD offered has previously passed a type-approval test, the user will not be assured of the capability of the TMD and shall either *(1)* require a Type-approval Test be performed at a site conforming to the conditions defined in 6.1 through 6.9 (the test site may be one supplied by the user or a third party), or *(2)* reach an agreement with the seller before the acceptance test begins as to the tolerance values that will be acceptable if the test site conditions provided by the user do not incorporate those specified in 6.1 through 6.9. In the latter case, the responsibility for inadequate TMD performance can lie with the seller, the user, or both.

6.10.2 *On-site Verification Test Requirement*—The On-site Verification Test described in 7.3 may be used after the specified brand and model of TMD has passed a suitable Type-approval Test and the production version of such a TMD is offered by the seller. If the seller provides satisfactory evidence that such a TMD has already passed the applicable Type-approval Test and the user provides site conditions that incorporate those given in 6.1 through 6.9, the TMD will be expected to perform at the site within the tolerances specified for the TMD output data. If the TMD fails to perform within these tolerances in such an On-site Verification Test, the installed TMD will be declared faulty and the seller shall be responsible for corrective action.

7. Procedure

7.1 *Scope*—The procedures for conducting a Type-approval Test and an On-site Verification Test for each type of TMD specified according to Specification E2300 are described in this section.

7.1.1 *Accuracy Required of Accepted Reference Value Measuring Equipment*—The data-measuring accuracy requirements for all equipment used to obtain accepted reference value data, that is, the data with which the performance of the TMD under test are compared, shall be agreed upon before testing begins by the user and the seller, or their designated representatives. Where possible, it is recommended that the equipment used to obtain reference value data have an accuracy at least an order of magnitude greater than the accuracy specified for the TMD under test.

7.2 *Type-approval Test for Traffic Monitoring Devices:*

7.2.1 *Scope of Type-approval Test*—The Type-approval Test provides information to evaluate the performance of a brand and model of TMD under a variety of field site conditions that include traffic volume and vehicle classes representative of operating environments in which the device is expected to operate. Performance requirements for each type of TMD shall be identified according to Specification E2300 and any supplemental test requirements as defined in Section 6 of this test method.

7.2.2 *Significance and Use*—The Type-approval Test allows the user to determine whether the previously untested brand and model of TMD meets the data measuring requirements listed in the TMD specification.

7.2.3 *Approval of Site and Test Conditions*—Both the user and the seller or their appointed representatives shall approve the type-approval test site and the TMD installation prior to conducting the Type-approval Test. The TMD settings and other test conditions shall be documented to verify compliance with the test conditions described in Section 6. If traffic control is required for TMD installation and setup, the traffic control procedures shall be in accordance with those of the public authority having jurisdiction over the test site.

7.2.4 *Duration of Type-approval Test*—The Type-approval Test shall be conducted until the required data are recorded for a minimum of three hours. Additional time and tests may be required to verify proper operation of the TMD under all of the environmental and other operating conditions specified by the user.

7.2.5 *Calibration*—The TMD under test shall be calibrated by the seller and approved by the user. The calibration procedures shall be documented and made available for inspection by the user.

7.2.6 *Type-Approval Test Method*—The following steps shall be performed when conducting a Type-approval Test.

7.2.6.1 Install the TMD according to the seller's instructions or according to another procedure mutually agreed upon by the user and seller or their designated representatives. The user shall satisfy any site-specific installation requirements, such as lightning protection. The installation procedures shall be recorded and made part of the report specified in 7.2.9.

7.2.6.2 Adjust variable TMD operating parameters to values agreed upon by the user and seller or their designated representatives and enter these values in the report specified in 7.2.9. Ensure that the TMD under test is calibrated.

7.2.6.3 Record all data output by the TMD under test using a device capable of time stamping the data. Similarly record the output from the equipment used to gather accepted reference value data. Each vehicle detection event shall be output by the TMD in a format that can be directly correlated with the video. Acceptable data formats are roadway-based events and vehicle-based events. Roadway-based events consist of: *(1)* sensor ID corresponding to a specific detection area in a particular lane, *(2)* start time of the detection event (synchronized with the time recorded on the video), *(3)* at least one of the following items—*(3a)* duration of the detection event or *(3b)* end time of the detection event, and *(4)* contact closures synchronized with the start and end of the detection event when those contact closures refer to a specific detection area in a particular lane. Vehicle-based detection events consist of: *(1)* lane number, *(2)* start time of the detection event, and *(3)* at least two of the following three items— *(3a)* detection event duration, *(3b)* vehicle speed, and *(3c)* vehicle length. All detection events must have a time resolution equal to or greater than one video frame resolution, which is equal to $1/30$ s for National Television System Committee (NTSC) video. The digitizing of data from the TMD and the reference value equipment shall occur at a sampling frequency sufficient to prevent compromising of data quality by aliasing.

7.2.6.4 Document the test and test conditions with the time of day, TMD identifier, vehicle class, ambient lighting, weather, and other items specified in Section 6.

7.2.6.5 TMD performance shall be evaluated for the vehicle flow rates and mix of vehicle classes described in 6.2.

7.2.6.6 TMD testing shall also be conducted under various lighting, temperature, weather, and other local environmental conditions in accordance with the requirements of 6.3 through 6.5 when the performance of the TMD is deemed by the user to possibly vary under these conditions. Table 1 lists environmental factors that should be considered when evaluating TMDs. Not all TMD technologies will be affected by these factors, and some, if not all of the factors, may be eliminated from the test procedure as mutually agreed upon by the user and seller or their designated representatives. The test data required by the conditions specified in Table 1 may be obtained simultaneously with data used to verify TMD operation at the vehicle flow rates and mix of vehicle classes described in 6.2.

7.2.6.7 For the purposes of verifying TMD performance, straddling vehicles are to be eliminated from consideration by identifying them from the video recordings made in conjunction with obtaining accepted reference value data.

7.2.7 *Methods for Obtaining Accepted Reference Value Data*—The seller shall have primary responsibility for supplying the equipment and personnel for obtaining the accepted reference value data needed for interpreting the results of the Type-approval Test. The user or a third party (such as a city, county, or state agency or a university facility) may conduct the test or provide other assistance.

7.2.7.1 The detection area of the TMD under test shall be marked with tape, paint, or other means so that it is visible in the recorded imagery, and yet appear as inconspicuous as feasible to drivers. If it is not possible or safe to physically mark the detection area of the TMD as described above, the detection area may be distinguished by a digital overlay on the digitized video. The effective detection area boundaries of the TMD under test shall be established by driving one or more vehicles, representative of those in the vehicle classes to be detected, over the detection area of the TMD. The effective detection area of the TMD under test is found by noting the vehicle location with respect to the TMD's marked detection area when the TMD indicates an output signal and when the output signal is dropped.

7.2.7.2 Axle count reference values shall be determined by analysis of imagery recorded by a video camera[6] installed in a manner that gives it an unimpeded view of the vehicle axles as they pass over the effective detection area of the TMD under test. Time shall be indicated on the video recording to the same precision as the TMD time stamp data. The video recording time stamp shall be synchronized with the TMD time stamp. It is recommended that the other data items output by the TMD under test also be indicated on the video recording. If the video is digitized, a time reference shall be provided and synchronized with the TMD data. Two or more human observers shall each record the number of axles and the corresponding time of each detection event by viewing the video imagery. These observations may be recorded as manual entries in a data notebook or manually entered into a separate computer data screen that is synchronized with the TMD data and video. Each observer shall view the imagery for no longer than a 15-min interval before taking a rest of at least 5 min to help assure accurate determination of the reference value for the number of

[6] Suggested items to be included in a specification for a video camera utilized to gather accepted reference value data are listed in Appendix X1.

axles. If the difference in axle counts reported by any observers exceeds the largest observer-reported value by an amount equal to 10 % of the specified device tolerance (calculated as a percent of the largest observer-reported value and rounded up to the nearest whole integer), then repeat the reference value observations. For example, if the tolerance is 10 %, the values obtained by two observers shall not differ by more than 1 % (10 % of 10 %). When satisfactory agreement among observer-reported axle counts has been achieved, use the average of the observer-reported counts as the reference value against which to compare the performance of the device under test.

7.2.7.3 Vehicle count reference values for the number of correct detections shall be determined on a vehicle-by-vehicle basis by analyzing images of the vehicles recorded by one or more video cameras installed in a manner that give them an unimpeded view of the vehicles as they pass over the effective detection area of the TMD under test. Time shall be indicated on the video recording to the same precision as the TMD time stamp data. The video recording time stamp shall be synchronized with the TMD time stamp. It is recommended that the other data items output by the TMD under test also be indicated on the video recording. If the video is digitized, a time reference shall be provided and synchronized with the TMD data. Two or more human observers shall each record the number of correct detections and the corresponding time of each detection event by viewing the video imagery. These observations may be recorded as manual entries in a data notebook or manually entered into a separate computer data screen that is synchronized with the TMD data and video. Each observer shall view the imagery for no longer than a 15-min interval before taking a rest of at least 5 min to help assure accurate determination of the reference value for the number of vehicles. If the difference in the number of correct detections reported by the observers exceeds the largest observer-reported value by an amount equal to 10 % of the specified device tolerance (calculated as a percent of the largest observer-reported value and rounded up to the nearest whole integer), then repeat the reference value observations. When satisfactory agreement among the number of observer-reported correct detections has been achieved, use the average of the observer-reported quantities as the reference value against which to compare the performance of the device under test. The observers shall also calculate the numbers of missed detections and false detections by comparing their recorded observations with the output of the TMD under test when the TMD reports detections on an individual vehicle basis. When the TMD reports detections aggregated over a known time interval, the observers shall calculate the numbers of missed detections and false detections by aggregating their recorded observations over the same interval and then comparing that value with the output of the TMD under test. An example of an automated method for determining the number of correct detections, missed detections, and false detections is described in Appendix X2.

7.2.7.4 Vehicle speed reference values shall be obtained using two or more matched axle-detecting sensors at known distances from each other, which are affixed to or installed in the pavement as near as feasible to midway within the detection area of the TMD under test. The vehicle speed reference value shall be calculated as the distance between any two axle sensors divided by the time difference between actuation of the second and first axle sensors. This time difference may be calculated or recorded by the axle-detecting equipment. Imagery recorded by a video camera with an unimpeded view of vehicles as they pass over the effective detection areas of the TMD under test and the axle-detecting sensors shall be used to assist in correlating reference speed measurements with a particular vehicle and the data output by the TMD under test. The test personnel shall record color and other descriptive vehicle information to assist with the correlation of reference speed data to a particular vehicle. It is recommended that the reference speed data recorded by the axle-detecting sensors be time stamped. It is also recommended that time and other data items output by the TMD under test be indicated on the video recording. If the video is digitized, a time reference shall be provided and synchronized with the TMD data. Any additional procedures needed to correlate reference and TMD speed measurements shall be developed and approved by the user and the seller, or their designated representatives, prior to starting the Type-approval Test. An example of an automated method for determining vehicle speed reference values is described in Appendix X2.

7.2.7.5 Vehicle classification reference values shall consist of the number of vehicles of a particular class as displayed on imagery recorded by one or more video cameras installed in a manner that give them an unimpeded view of the vehicles as they pass over the effective detection area of the TMD under test. Time shall be indicated on the video recording to the same precision as the TMD time stamp data. The video recording time stamp shall be synchronized with the TMD time stamp. It is recommended that the other data items output by the TMD under test also be indicated on the video recording. If the video is digitized, a time reference shall be provided and synchronized with the TMD data. Two or more human observers shall each record the number and class of vehicles and the corresponding time of each detection event by viewing the video imagery. These observations may be recorded as manual entries in a data notebook or manually entered into a separate computer data screen that is synchronized with the TMD data and video. Each observer shall view the imagery for no longer than a 15-min interval before taking a rest of at least 5 min to help assure accurate determination of the reference values for the number and class of vehicles. If the difference in the number for any class of vehicles reported by the observers exceeds the largest observer-reported value by an amount equal to 10 % of the specified device tolerance (calculated as a percent of the largest observer-reported value and rounded up to the nearest whole integer), then repeat the reference value observations. When satisfactory agreement among observer-reported numbers and classes of vehicles have been achieved, use the average of the observer-reported number of vehicles in a class as the reference value against which to compare the performance of the device under test. Vehicle classes shall be identified according to the 13-class FHWA schedule shown in Table 2 when the TMD under test supports this classification scheme. When the TMD does not support this classification

TABLE 2 U.S. FHWA 13 Vehicle Classification System[A]

2-Digit Code[B]	Category
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

[A] *Traffic Monitoring Guide*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC, May 2001.
[B] Some applications require two additional classes, Classes 14 and 15. Class 14 is a user-defined class and Class 15 is a class into which unclassified vehicles are placed.

scheme, the user and the TMD seller or their designated representatives shall mutually agree upon the classification taxonomy. An example of an alternative classification taxonomy is two or more vehicle classes differentiated by vehicle length.

7.2.7.6 Vehicle presence reference values shall consist of the appearance of a vehicle as displayed on imagery recorded by one or more video cameras installed in a manner that give them an unimpeded view of the vehicles as they pass over the effective detection area of the TMD under test. The presence of a vehicle in the effective detection area of the TMD shall be noted from the recorded imagery. Time shall be indicated on the video recording to the same precision as the TMD time stamp data. The video recording time stamp shall be synchronized with the TMD time stamp. It is recommended that the other data items output by the TMD under test also be indicated on the video recording. If the video is digitized, a time reference shall be provided and synchronized with the TMD data. Two or more human observers shall each view the video imagery to establish and record the reference time that corresponds to the presence of a vehicle. These observations may be recorded as manual entries in a data notebook or manually entered into a separate computer data screen that is synchronized with the TMD data and video. Each observer shall view the imagery for no longer than a 15-min interval before taking a rest of at least 5 min to help ensure accurate recording of the presence of a vehicle and its reference time. If the difference in vehicle presence indications reported by any observers exceeds the largest observer-reported value by an amount equal to 10 % of the specified device tolerance (calculated as a percent of the largest observer-reported value and rounded up to the nearest whole integer), then repeat the reference value observations. When satisfactory agreement among observer-reported vehicle presence indications has been achieved, use the average of the observer-reported quantities as the reference value against which to compare the performance of the device under test. An example of an automated method for determining vehicle presence reference values is described in Appendix X2.

7.2.7.7 Lane occupancy reference values for a vehicle shall consist of the percent of a selected time interval the vehicle is in the effective detection area of a video camera installed in a manner that provides an unimpeded view of the vehicle as it passes over the effective detection area of the TMD under test. The effective detection area of the video camera shall be determined using the procedure described in 7.2.7.1 with the "video camera" substituted for the "TMD under test." Note that different sensor models or technologies that provide lane occupancy output data may have different detection area sizes and, hence, produce different occupancy values, although all devices are operating properly. Time shall be indicated on the video recording to the same precision as the TMD time stamp data. The video recording time stamp shall be synchronized with the TMD time stamp. It is recommended that the other data items output by the TMD under test also be indicated on the video recording. If the video is digitized, a time reference shall be provided and synchronized with the TMD data. Two or more human observers shall each view the video imagery to establish and record the start frame or start time and the end frame or end time that correspond to the appearance of a vehicle in the effective TMD detection area. These observations may be recorded as manual entries in a data notebook or manually entered into a separate computer data screen that is synchronized with the TMD data and video. The observers shall view the imagery for no longer than 15-min intervals before taking a rest of at least 5 min to help assure accurate recording of the reference value for lane occupancy. If the difference in the number of frames or time intervals that correspond to the appearance of a vehicle in the effective TMD detection area as reported by any observers exceeds the largest observer-reported value by an amount equal to 10 % of the specified device tolerance (calculated as a percent of the largest reported observer-value and rounded up to the nearest whole integer), then repeat the reference value observations. When satisfactory agreement among the observer-reported number of frames or time intervals has been achieved, use the average of the observer-reported numbers as the reference value against which to compare the performance of the device under test. An example of a lane occupancy calculation method using video recordings of vehicle flow made at 30 frames/s is to note the number of frames in which the vehicle is in the TMD detection area over a 1-s interval and divide by 30. An example of an automated method for determining lane occupancy reference values is described in Appendix X2.

7.2.8 *Tolerance Compliance Calculation*—Calculate the difference between the accepted reference value and the TMD output for each data item using the percent difference, single-interval absolute value difference, or multiple-interval absolute value difference defined in Specification E2300. Compare with the tolerance specified by the user in the purchase specification.

7.2.9 *Interpretation of Test Results and Report*—All specified data collection features, data processing features, and options for the TMD under test shall be demonstrated to function properly before the TMD is accepted. If any specified TMD data item is not output or its difference as calculated in 7.2.8 (*for all values of the data item measured*) exceeds the specified tolerance, declare the TMD nonfunctional or inaccurate and record that it failed the Type-approval Test. Regardless of whether the TMD fails or passes the Type-approval Test, the user or his representative shall prepare a written report when testing is complete which documents the test result, all device settings, test conditions and duration, drawings and photographs that illustrate the location of the TMD under test with respect to the traffic flow direction and devices used to acquire accepted reference value data, detection areas of the TMD and the devices used to acquire accepted reference value data overlaid on the road surface, accepted reference value data, and TMD output data used in making the test result determination.

7.2.10 *Precision and Bias*—The Type-approval Test results in an accept or a reject decision for the TMD under test. Therefore, no information is presented about either the precision or bias of the test method for measuring the performance of a TMD since the test result is nonquantitative.

7.3 *On-site Verification Test for Traffic Monitoring Devices:*

7.3.1 *Scope of On-site Verification Test*—This test provides the TMD user and seller with a means for determining whether a production version of a TMD installed at a particular site meets the performance and user requirements identified according to Specification E2300 after the TMD has passed a type-approval test. It requires the user to specify and document the test conditions that exist when the test is conducted. The conditions under which the On-site Verification Test is performed are different than those used in the Type-approval Test.

7.3.2 *Significance and Use*—The On-site Verification Test may be used after the brand and model of TMD offered by the seller has passed a Type-approval Test and the production version of such a TMD is offered by the seller. The On-site Verification Test indicates the in situ performance of the TMD offered.

7.3.3 *Approval of Site and Test Conditions*—Both the user and the seller or their appointed representatives shall approve the on-site verification test site and the TMD installation prior to conducting the On-site Verification Test. If traffic control is required for TMD installation and setup, the traffic control procedures shall be in accordance with those of the public authority having jurisdiction over the test site.

7.3.4 *Duration of On-site Verification Test*—The On-site Verification Test shall be conducted until the required number of measurements defined in Table 3 are obtained.

7.3.5 *On-site Verification Test Method*—The On-site Verification Test shall be conducted by the user in cooperation with the seller or their designated representatives. The following steps are required for each instrumented lane.

7.3.5.1 The seller or his designated representative shall calibrate the TMD under test using the procedure referenced in 7.2.5.

7.3.5.2 Install the TMD according to the procedures listed in 7.2.6.1.

7.3.5.3 Initialize the TMD in accordance with the manufacturer's requirements. Adjust any variable device settings to values previously agreed upon.

7.3.5.4 Gather TMD output data for the vehicle flow rates, mix of vehicle classes, and applicable environmental factors that apply at the selected test site.

7.3.5.5 While acquiring the TMD output data referred to in 7.3.5.4, simultaneously acquire reference value data according to the procedures described in Table 3.

7.3.6 *Tolerance Compliance Calculation*—Calculate the difference between the accepted reference value and the TMD output for each data item using the percent difference, single-interval absolute value difference, or multiple-interval absolute value difference defined in Specification E2300. Compare with the tolerance specified by the user in the purchase specification.

7.3.7 *Interpretation of Test Results and Report*—All specified data collection features, data processing features, and options for the TMD under test shall be demonstrated to function properly before the TMD is accepted. If any specified TMD data item is not output or its difference as calculated in 7.3.6 (*for all values of the data item measured*) exceeds the specified tolerance, declare the TMD nonfunctional or inaccurate and record that it failed the On-site Verification Test. Regardless of whether the TMD fails or passes the On-site

TABLE 3 Procedures for Obtaining Accepted Reference Value Data During an On-site Verification Test

Data Item	Procedure[A]
Axle count	Two or more human observers shall count and record the number of axles on a data sheet prepared by the user for this purpose while they observe the mix of vehicles passing through the effective detection area of the TMD under test.[B] A minimum of 50 axles shall be counted.
Vehicle count	Two or more human observers shall count and record the number of vehicles on a data sheet prepared by the user for this purpose while they observe the mix of vehicles passing through the effective detection area of the TMD under test.[B] A minimum of 50 vehicles shall be counted.
Vehicle speed	A radar or laser speed gun shall be used to measure the speed of a vehicle as it passes through the effective detection area of the TMD under test. The accuracy of the speed gun shall be in accordance with the requirements of 7.1.1. The speed gun values shall be entered on a data sheet prepared by the user for this purpose. The operator of the speed gun shall be trained in its use to help ensure that the measurements are valid. A minimum of 50 vehicles shall have their speeds measured.
Vehicle classification	Two or more human observers shall note and record the class of vehicles on a data sheet prepared by the user for this purpose while they observe the mix of vehicles passing through the effective detection area of the TMD under test.[B] A minimum of 50 vehicles among all observed classes shall be included in the test.
Vehicle presence	Two or more human observers shall note and record the presence of vehicles on a data sheet prepared by the user for this purpose while they observe the mix of vehicles passing through the effective detection area of the TMD under test.[B] A minimum of 50 vehicles shall be included in the test.
Lane occupancy	Use same procedures as in 7.2.7.7. A minimum of 50 vehicles shall be included in the test.

[A] The detection area of the TMD under test shall be marked as in 7.2.7.1 when acquiring accepted reference value data. Data sheets used to record reference value data shall contain, but not be limited to, the following test condition information: TMD identifier; type of data acquired; test date; test start and end times; weather; road description (for example, number of lanes and their widths, road surface type and condition, grades); location of TMD under test and its detection area with respect to the roadway; pertinent TMD installation criteria; columns for accepted reference value data; names, affiliation, and contact information for data recorders; signature of data recorders at conclusion of test.

[B] When axles or vehicles are counted or when vehicles are classified or their presence noted, the observers shall acquire data in no more than 15-min intervals before taking a rest of at least 5 min to help assure accurate recording of the reference values. See 7.2.7.2 for the method that shall be used to account for differences among the data recorded by the observers and for determining which observer's data set shall be compared with the corresponding value from the device under test.

Verification Test, the user or his representative shall prepare a written report when testing is complete, which documents the test result, all device settings, test conditions and duration, drawings and photographs that illustrate the location of the TMD under test with respect to the traffic flow direction and devices used to acquire accepted reference value data, detection areas of the TMD and the devices used to acquire accepted reference value data overlaid on the road surface, accepted reference value data, and TMD output data used in making the test result determination.

7.3.8 *Precision and Bias*—The On-site Verification Test results in an accept or a reject decision for the TMD under test. Therefore, no information is presented about either the precision or bias of the test method for measuring the performance of a TMD since the test result is nonquantitative.

8. Keywords

8.1 correct detection; data item; false detection; incident detection; interaxle spacing; lane occupancy; missed detection; test methods; traffic monitoring device; vehicle classification; vehicle counter; vehicle critical dimension; vehicle detector; vehicle flow parameter measurement; vehicle flow rates; vehicle passage; vehicle presence; vehicle sensor; vehicle speed; vehicle-to-vehicle gap

APPENDIXES

(Nonmandatory Information)

X1. ITEMS TO BE CONSIDERED FOR INCLUSION IN A VIDEO CAMERA SPECIFICATION

TABLE X1.1

Resistance to nonlinear artifacts such as vertical smear for CCD cameras or flare, bloom, and comet-tail for older vidicon or inexpensive CMOS cameras.
Manual shutter control to accommodate fast moving vehicles. One rule-of-thumb is: Maximum allowable shutter speed (s) = (1×10^{-5}) (distance to center of detection area expressed in feet).
Dynamic range affecting the ability to quantitatively detect very dim and very bright regions in a single image. Dynamic range for CCD cameras is defined as the ratio of the useful full well capacity to the noise floor. The higher the full well capacity and the lower the noise, the larger the dynamic range of the camera. Since full well capacity is approximately proportional to pixel size, increasing pixel size to increase dynamic range may reduce spatial resolution. Minimum of 25 dB; ≥48 dB desirable.
Sensitivity defined as minimum detectable light intensity above the camera noise floor.
Camera noise floor defined as minimum achievable noise level that cannot be reduced by camera design or operating factors.
Auto-iris time constant control. (Standard CCTV auto-iris lenses can be inadequate for computer vision applications because the time constant is too small. Technically, the auto-iris specification is a lens rather than a camera specification, but nevertheless, is inseparable from defining the camera requirements.)
Environmental factors affecting camera operation such as temperature, wind, vibration, and shock.

X2. VIDEO VEHICLE DETECTOR VERIFICATION SYSTEM[7]

X2.1 Scope

X2.1.1 Sensor testing and evaluation methods requiring comparison against human-verified accepted reference values are not practical when many sensors of different types are concurrently tested on as many as six lanes, or when large data-recording intervals generate thousands of records. In these cases, an automated test process becomes an important adjunct to the testing protocol. This appendix describes the features of an automated system that validates the detection output quantities from individual sensors. The design is based on the fusion of data from each of the sensors under test with data from a reference image processing system to create a reliable composite accepted reference value record. This system reduces the human labor required for sensor validation by replacing the current practice of using either a single reference sensor or a human observer to generate the accepted reference value with an automatic technique that generates the accepted reference value and compares it with the output of the sensors under test. Details concerning the data fusion architecture, data fusion algorithms, computer vision detection methods, and automated data reduction and reporting methods not found in this appendix are described in Footnote 7.

X2.1.2 This case study is not meant to represent the only embodiment of the automated procedures that are possible. Rather it is provided as an example of how the methods described in these test methods can be partially or fully automated through applications of modern technology when the simultaneous testing of multiple sensors is required and large amounts of data must be analyzed.

X2.2 Physical Components

X2.2.1 The Video Vehicle Detector Verification System (V^2DVS) was developed and deployed for the California Department of Transportation (Caltrans) by the California Polytechnic State University at San Luis Obispo, CA. It is physically composed of a cluster of data acquisition computers (field machines), one per lane, at each test site and a central server for archiving and automated processing of data. A PC-based client program facilitates remote monitoring and control of all field machines, manual verification of accepted reference values, and generation of test results through the central server. All field machines are 2-U industrial rack-mount Linux/PC platforms, each interfaced to a video camera located on an overcrossing above an assigned lane. The collected raw data consist of JPEG-compressed images and a database containing the time of arrival, speed, other metrics of every detected vehicle in each lane, and a reference record created by the V^2DVS system based on real-time image analysis. The system supports multiple test sites, with a maximum of eight hardwired sensors with contact closure pairs and an unlimited number of network or serial-communicating sensors for each lane at each site. At maximum traffic capacity, as many as 96 000 records per hour per site are generated.

X2.3 Physical Layout

X2.3.1 Fig. X2.1 shows the placement of the reference video cameras above each lane and one of two poles on which side-viewing, multilane sensors and other devices are mounted. Each of the six traffic lanes is equipped with duplex inductive loops and provision for other interchangeable roadway sensors. The V^2DVS field machines are housed in a roadside Caltrans Type 334C cabinet illustrated in Fig. X2.2.

X2.4 Vehicle Imaging Sensor

X2.4.1 The V^2DVS video detection capabilities serve only to aid in automated data reduction as the placement of individual cameras above each lane is ideal for imaging purposes, but is not considered practical as a solo device for generating automated, high reliability accepted reference values. Each lane's downward-looking camera is canted out approximately 10 degrees from the vertical to view departing traffic. Camera height is 10.7 m above the roadway for every lane. The field of view for each camera extends from immediately below the overcrossing deck to approximately 25 m down-road to encompass most of the detection areas used by different sensors (exceptions are video-based detection systems which use far-field approaching or departing traffic views). The field of view for the downward-looking cameras can be adjusted remotely, but should be standardized for all lanes. Wider fields of view produce relatively smaller vehicles within the images, which in turn reduce the measurement accuracy for the vehicle position at the time of detection. Images are color, with a configurable JPEG compression ratio. Default compression settings yield images of size 640 × 240 pixels and between 15 and 30 kbytes.

X2.5 Communication Between Sensors Under Test and V^2DVS

X2.5.1 Each sensor under test must communicate with the V^2DVS system for each vehicle. Communication may be real-time, in which a record is acquired immediately, or delay-time, in which a record is acquired prior to the time of the communication, to accommodate some sensors that do not produce real-time detection records. The V^2DVS computers maintain a circular buffer of the most recent video 300 images, acquired at 60 video fields (images) per second, to facilitate communication delays of up to 5 s.

X2.5.2 V^2DVS accepts two communication methods: *(1)* hardwired (contact closure or active-low signal), and *(2)* network that allows a sensor to report an exact time for detection to V^2DVS. For real-time communication, the most

[7] MacCarley, C. A., *Video Vehicle Detector Verification System (V^2DVS) Operators Manual*, California Polytechnic State University, San Luis Obispo, CA, Rev. 4, Jan. 2007.

FIG. X2.1 Over-Lane Video Cameras and One of Two Roadside Sensor-Mounting Poles

FIG. X2.2 V^2DVS Data Acquisition Computers in Type 334C Cabinet

recently acquired complete image is recorded along with the time the record is received, accurate to 0.001 s. For delay-time communication, the image acquired at the time closest to the time of detection is recorded as the detection image. V^2DVS incorporates an NTP (Network Time Protocol) local time server, which must be referenced by any sensor that uses delay-time communication to ensure exact time synchronization.

X2.6 Record Storage

X2.6.1 All records (image and data) are stored locally on each field machine and automatically pushed via SFTP (Secure File Transfer Protocol) on a bandwidth-available basis to the central server, which stores data objects in a MySQL database and compressed images in indexed directories. Local storage capacity allows tests up to twenty days in duration prior to the need to off-load data to the server. Since the field sites are connected to the server via multiple networks, including a slow 802.11b wireless link, periods exceeding 24 h may be required to push a few hours of traffic data. The server can also be temporarily set up on site to avoid these bandwidth limitations.

X2.7 Post Processing of Data

X2.7.1 In post-processing, V^2DVS automatically compares all detection times reported for each vehicle by the various sensors. This comparison provides a composite accepted reference value dataset based upon user-selectable degrees of confidence requirements. V^2DVS also estimates vehicle speeds, assuming that the vehicle travels at constant speed through the detection area, to compensate for different detection times due to different detection areas. The duplex loop detector time-of-flight measurements function as secondary vehicle speed measurement references. Video vehicle speed measurement algorithms were developed to ensure high accuracy even under adverse ambient illumination conditions; specifically, to accurately measure speed during morning and evening rush hours when the most interesting traffic conditions occur, and when long shadows propagating from vehicles in adjacent lanes would otherwise lead to false vehicle detections. Algorithmic methods were developed and iteratively refined to reliably reject these artifacts, based on both the texture and continuity of a shadow propagating from an adjacent lane. To facilitate the latter mechanism, V^2DVS detection zones extend into adjacent lanes on either side of the lane containing the sensor under test.

X2.8 Vehicle Detection Categories

X2.8.1 The system pre-assigns all detections into three categories: verified/grouped, unverified, and false. Each category has its own color code to simplify human verification. A human operator can view all detections and reclassify any into either verified/grouped or false; both reclassification categories also have their own color code for later reverification.

X2.9 Adaptive Consensus-Based Accepted Reference Value Generation

X2.9.1 The most significant labor-saving feature of V^2DVS is its ability to automatically generate an accurate accepted reference value record, against which all individual detection events are compared to determine and report the accuracy of the individual sensors under test. A biased voting process is used for each detection event, in which the conclusion of the weighted majority of the sensors for each lane is believed to be the truth (that is, if the majority of the sensors saw it, it must have been there). An adaptive learning algorithm continuously optimizes the weighting coefficients to maximize the accuracy of the synthesized accepted reference value dataset.

X2.9.2 A type of recursive filter gradually adapts the weighting coefficient $a_i(k)$ for the i^{th} sensor based upon its agreement or disagreement with the consensus for each detection event k.

X2.9.3 If every detection is correct (that is, agrees with the consensus), $a_i(k)$ asymptotically approaches unity. If the sensor consistently fails to detect or falsely detects, $a_i(k)$ asymptotically approaches zero. Therefore, sensors that are frequently incorrect (that is, in disagreement with the weighted majority) are devalued in the consensus voting, while accurate (that is, in agreement with the weighted majority) sensors are more and more strongly weighted.

X2.10 Manual Verification of Indeterminate Cases

X2.10.1 V^2DVS provides graphical tools for rapid human resolution of reported detections for which a clear consensus does not exist. The V^2DVS workstation window for final verification is shown in Fig. X2.3. Automatically correlated detections are indicated by blue dots. Green dots are those in a selected group, which represent the same vehicle detected by each of the sensors under test in that lane. False detections are indicated by red dots. Yellow dots represent vehicles for which the system defers to human confirmation of the final verification decision. An example of V^2VDS numerical and statistical results from a brief data collection interval is shown in Table X2.1.

X2.11 System Error and Accuracy

X2.11.1 Automated data reduction greatly reduces the workload associated with accepted reference value generation, since it requires human verification only for detection records that cannot be automatically correlated. In the final analysis, vehicle detections are classified as either correct, false, or failure to detect by this automated approach. Errors are most commonly due to ambiguous vehicle lane position. Accuracy is dependent upon the size of the admissible time/distance aperture, with more conservative settings tending to reject valid detections and less conservative settings admitting incorrect matches that sometimes cause alignment errors that propagate to other proximate vehicles in the accepted reference value data set.

X2.12 Future Capabilities

X2.12.1 A similar approach for consensus-based speed and length measurement is currently in development through a contract with Caltrans.

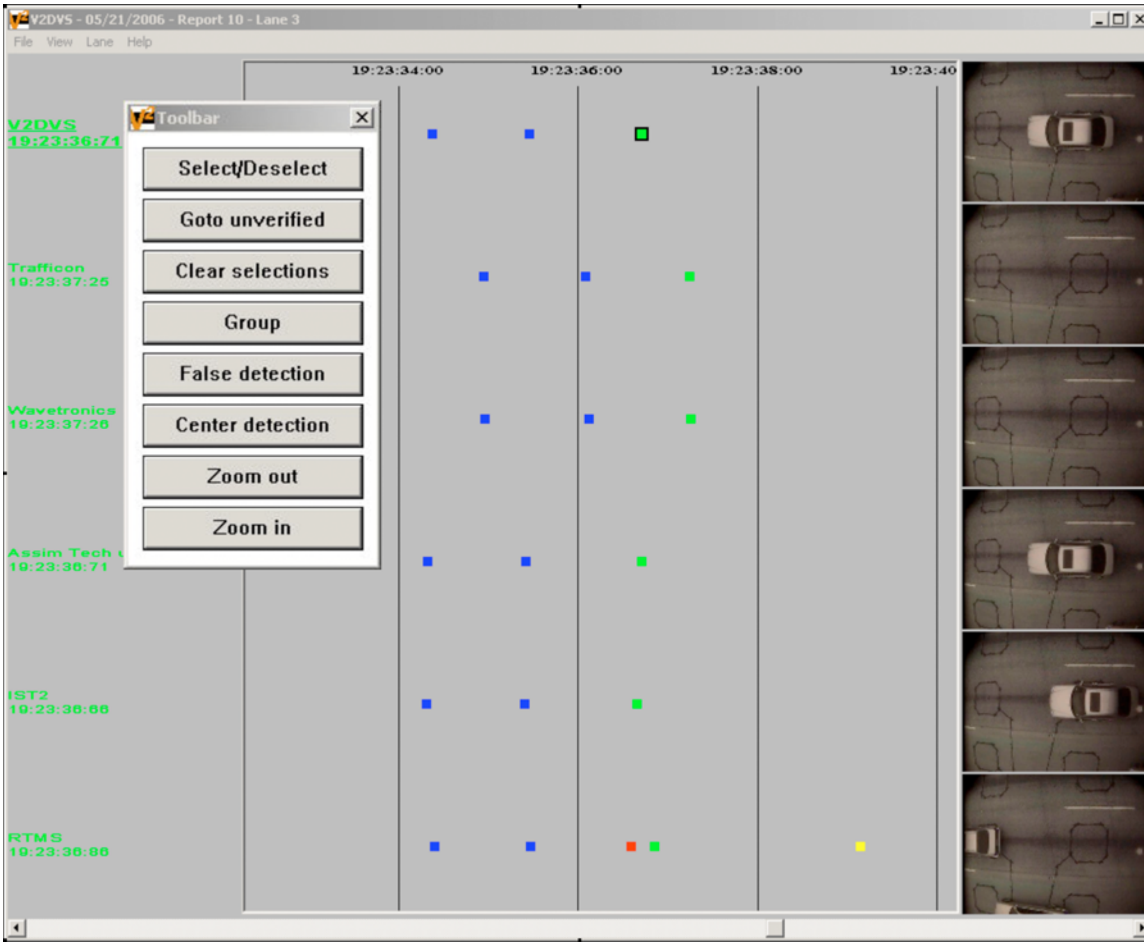

FIG. X2.3 V^{2}DVS WorkStation Window

TABLE X2.1 V^{2}VDS Statistical Report

Report Name

Accepted Reference Value Dataset: 104
Site: Sand Canyon OC, I 405
Data Collection Start: Sunday, May 21, 2006, 12:49:00 p.m.
Data Collection End: Sunday, May 21, 2006, 3:16:00 p.m.

Sensor		Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6	Total	Percent of Accepted Reference Value
SUT[A] 1	Correct	925	371	878	871	769	2	3816	99.97 %
	Fail	0	0	0	0	0	1	1	0.03%
	False	0	0	0	0	0	0	0	0.00%
SUT 2	Correct	766	358	700	627	630	3	3084	80.80%
	Fail	159	13	178	244	139	0	733	19.20%
	False	0	3	0	2	0	2	7	0.18%
SUT 3	Correct	824	3	575	661	619	1	2683	70.29%
	Fail	101	368	303	210	150	2	1134	29.71%
	False	132	0	216	363	425	1	1137	29.79%
SUT 4	Correct	905	353	823	0	0	0	2081	54.52%
	Fail	20	18	55	0	0	0	93	2.44%
	False	1426	3	839	0	0	0	2268	59.42%
SUT 5	Correct	767	245	800	774	653	3	3242	84.94%
	Fail	158	126	78	97	116	0	575	15.06%
	False	107	2	58	25	7	2	201	5.27%
Accepted Reference Value	Correct	925	371	878	871	769	3	3817	100.00%

[A] Sensor under test.