
Standard Practice for Intelligent Compaction Technology for Embankment and Asphalt Pavement Applications

AASHTO Designation: PP 81-18 (2020)¹

**Tech Subcommittee: 5c, Quality Assurance
and Environmental**

Release: Group 1 (April)



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1. SCOPE

- 1.1. This work shall consist of compaction of roadway embankment, or asphalt pavement, or both, using Intelligent Compaction (IC) rollers within the limits of the work described in the plans or provisions.
- 1.2. IC is defined as a process that uses rollers equipped with a measurement-documentation system that automatically records compaction parameters (e.g., spatial location, stiffness, temperature, pass count, vibration amplitude, and frequency) in real-time during the compaction process. IC rollers equipped with accelerometers use roller vibration measurements to assess mechanistic material properties and to ensure that optimum compaction and uniformity is achieved through continuous monitoring of operations.
- 1.3. The contractor shall supply sufficient numbers of rollers, and other associated equipment, necessary to complete the compaction requirements for the specific materials.
- 1.4. This specification is to be applied during the contractor's quality control.
- 1.5. All tasks are the contractor's responsibility, unless designated otherwise within this provision.

2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standard:*
 - [M 146](#), Terms Relating to Subgrade, Soil–Aggregate, and Fill Materials
- 2.2. *Other Documents:*
 - Christopher, B. R., C. Schwartz, and R. Boudreau. *Geotechnical Aspects of Pavements: Reference Manual/Participant Workbook*. FHWA-NHI Course Number 132040, FHWA NHI-05-037. U.S. Agency of Transportation, Federal Highway Administration, U.S. Department of Transportation, May 2006.
 - www.intelligentcompaction.com
 - Mooney, M. A., R. V. Rinehart, N. W. Facas, O. M. Musimbi, D. J. White, and Pavana K. R. Vennapusa. *National Cooperative Highway Research Report 676: Intelligent Soil Compaction Systems*. Transportation Research Board, Washington, DC, 2010.

3. TERMINOLOGY

3.1. Definitions:

3.1.1. *cloud*—a Web-based user interface.

3.1.1.1. *cloud storage*—network storage (typically the Internet) where the IC data are stored in virtualized pools of storage.

3.1.1.2. *cloud computing*—the use of computing resources (hardware and software) that are delivered as a service over a network to enable near-real-time visualization (maps) and manipulation of IC data.

3.1.2. *control points* (sometimes referred to as “survey marks,” “survey markers,” “monuments,” “hubs,” or “control points”)—objects placed to mark key survey points on the earth’s surface. These markers are used to indicate elevation and horizontal position.

3.1.3. *coordinate system*—a system that uses one or more numbers or coordinates to uniquely determine the position of a point or other geometric element on a manifold such as Euclidean space.

3.1.3.1. *geodetic coordinates*—a non-earth-centric coordinate system used to describe a position in longitude, latitude, and altitude above the imaginary ellipsoid surface based on a specific geodetic datum. WGS84 and NAD83 datum are required for use with Universal Transverse Mercator (UTM) and State Plane, respectively.

3.1.3.2. *state plane coordinates*—a set of 126 geographic zones or coordinate systems designed for specific regions of the United States. Each state contains one or more state plane zones, the boundaries of which usually follow county lines. There are 110 zones in the continental United States, with 10 more in Alaska, 5 in Hawaii, and 1 for Puerto Rico and the U.S. Virgin Islands. The system is widely used for geographic data by state and local governments because it uses a Cartesian coordinate system to specify locations rather than a spherical coordinate system. By ignoring the curvature of the earth, “plane surveying” methods can be used, speeding up and simplifying calculations. Additionally, the system is highly accurate within each zone (error less than 1:10,000). Outside a specific state plane zone, accuracy rapidly declines, thus the system is not useful for regional or national mapping. The current state plane coordinates are based on NAD83. Issues may arise when a project crosses state plane boundaries.

3.1.3.3. *Universal Transverse Mercator (UTM)*—a metric-based, geographic coordinate system that uses a 2-dimensional (2D) Cartesian coordinate system to give locations on the surface of the earth. This system divides the earth between 80°S and 84°N latitude into 60 zones, each a six-degree band of longitude width, and uses a secant Transverse Mercator projection in each zone (the scale is reduced so that the cylinder slices through the model globe). Zone 1 covers longitude 180° to 174°W; zone numbering increases eastward to zone 60° that covers longitude 174° to 180°E.

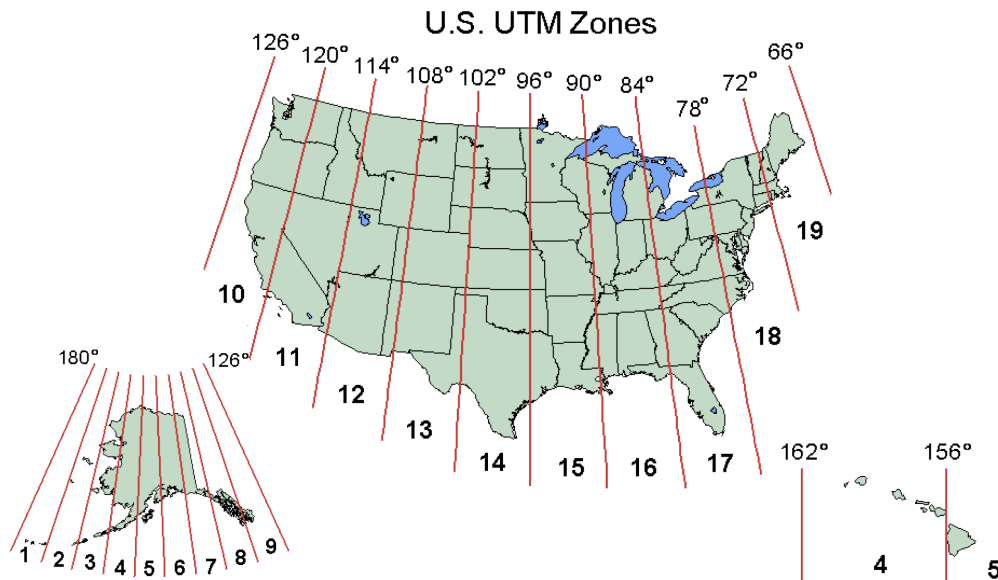


Figure 1—Image of UTM Zones in the United States

- 3.1.4. *Coordinated Universal Time (UTC)*—the primary time standard by which the world regulates time. It is one of several closely related successors to Greenwich Mean Time (GMT). For most purposes, UTC is synonymous with GMT. It is based on a 24-hr time scale from the mean solar time at the earth's prime meridian (0° longitude) located near Greenwich, England.
- 3.1.5. *data*—measurements recorded by the instrumented roller, or information generated/processed from these measurements (e.g., GNSS coordinates, stiffness, temperature, pass count, speed, frequency, amplitude).
- 3.1.5.1. *gridded all passes data*—includes all measurement passes recorded for a given grid (see Figure 2). This data is generally used to build compaction curves for establishment of rolling patterns.

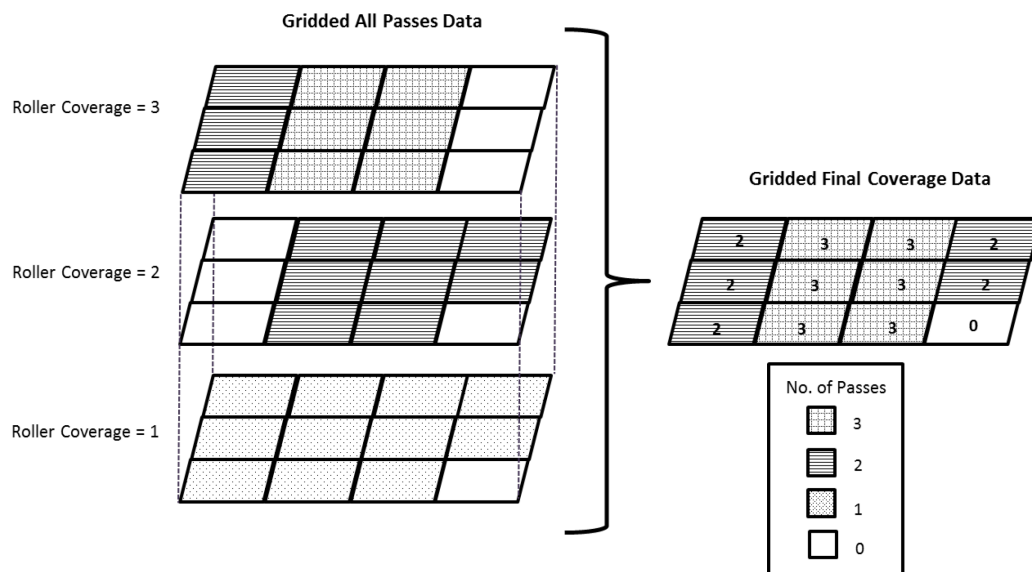


Figure 2—Schematic of Coverage, Gridded All Passes Data, and Gridded Final Coverage Data

- 3.1.5.2. *gridded data*—data processed from the raw data using meshes. The raw data is duplicated over the meshes for the entire roller drum width, resulting in multiple data points covering the drum width (see Figure 3). This process is used to track partial drum overlaps among passes.

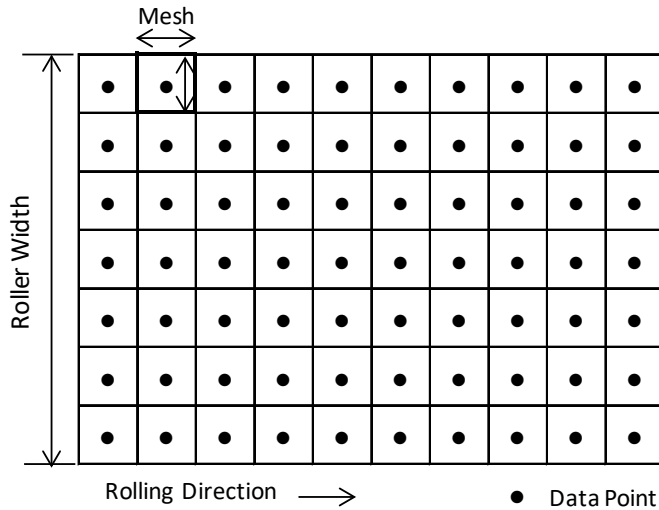


Figure 3—Schematic of Gridded IC Data

- 3.1.5.3. *gridded final coverage data*—summarizes the final (last) measurement passes recorded for a given grid (e.g., total pass count, last stiffness, last temperature [see Figure 2]). Grid sizes are typically at a mesh size of 1 ft (0.3 m) in the X and Y direction for post-processed data.
- 3.1.5.4. *mesh*—a collection of vertices connected to other vertices that defines the shape of the roller drum in 2D polygons (typically multiple squares). The defined data mesh size is generally 0.3 m by 0.3 m (1 ft by 1 ft) in horizontal directions (see Figure 3).
- 3.1.5.5. *raw data*—data recorded during compaction operations prior to the gridding process. It consists of one data point for a roller drum width, recorded at approximately 10 Hz or 0.3 m (1 ft) intervals. Therefore, the data mesh (data footprint) is about one drum width by 0.3 m (1 ft) (see Figure 4).

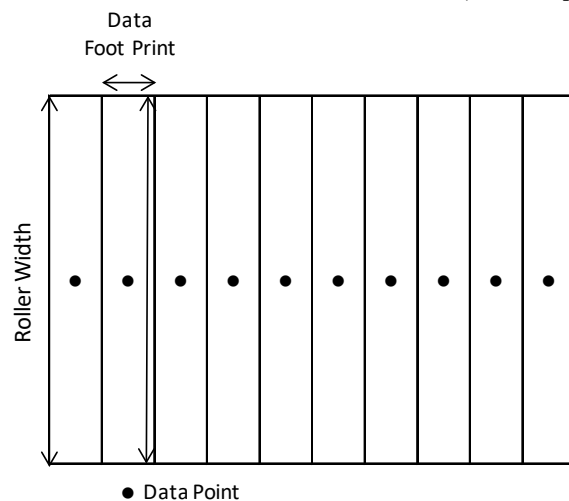


Figure 4—Schematic of Raw Data

- 3.1.5.6. *Veta*—a standardized intelligent construction data management (ICDM) software that stores, maps, and analyzes IC and associated geospatial data (e.g., thermal profiled data, spot test data).

This software can perform standardized data processing, analysis, and reporting to provide project summary results quickly in the field from various IC manufacturers. In particular, the software can provide statistics, histograms, and correlations for the IC measurements (e.g., speed, temperature, pass count, intelligent compaction measurement value (ICMV)); document coverage area; and evaluate the uniformity of compaction as part of the project quality control operations. (Software can be downloaded from www.intelligentcompaction.com.)

- 3.1.6. *design files*—databases containing the vector image data of the roadway alignment. Design files can be exported from software programs in various formats (e.g., DWG, KMZ, XML).
- 3.1.6.1. *DGN files*—are MicroStation Design Files. These files contain a database of 2D or 3D drawings containing vector image data of the alignment created with MicroStation.
- 3.1.6.2. *DWG files*—are AutoCAD Drawing Database files. These files contain a database of 2D or 3D drawings containing vector image data of the alignment created with AutoCAD.
- 3.1.6.3. *KML files*—are Keyhole Markup Language files that store geographic modeling information in XML format. These files contain points, lines, polygons, and images; they are used to identify and label locations, overlay textures, and add HyperText Markup Language (HTML) content.
- 3.1.6.4. *KMZ files*—store the alignment in a format viewable in Google Earth (a global mapping program that provides a bird’s eye view of locations throughout the United States and other areas of the world). KMZ files are zipped KML files which make them easier to distribute and share with multiple users.
- 3.1.6.5. *XML files*—extensible markup language data files that use tags to define objects and object attributes; they are formatted much like an HTML document, but use custom tags to define objects and the data within each object. These files are formatted as a text-based database and, therefore, can be edited by a basic text editor.
- 3.1.7. *Global Navigation Satellite System (GNSS)*—a satellite system that is used to pinpoint the geographic location of a user’s receiver anywhere in the world. Three GNSS systems are currently in operation: the United States’ Global Positioning System (GPS), the Russian Federation’s Global Orbiting Navigation Satellite System (GLONASS), and Europe’s Galileo. Each of the GNSS systems employs a constellation of orbiting satellites working in conjunction with a network of ground stations.
- 3.1.7.1. *Global Positioning System (GPS)*—a space-based satellite navigation system that provides location and time information anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. This system also provides the time stamp needed for IC.
- 3.1.7.2. *GPS base station*—a GPS receiver at an accurately known fixed location that is used to derive correction information for nearby portable GPS receivers. This correction data allows propagation and other effects to be corrected out of the position data obtained by the portable GPS receivers, which provides increased location precision and accuracy over the results obtained by uncorrected GPS receivers. This system consists of an antenna, radio, radio antenna, and power source. The radio and environment/physical conditions control the distance that the correction signal travels. The typical range of the correction signal is about 3.2 km (2 mi) in radius without repeaters. A repeater may extend the distance an additional 3.2 km (2 mi).
- 3.1.7.3. *Real Time Kinematic (RTK)*—RTK satellite navigation is a technique used to enhance the precision of the ground-based data derived from satellite-based positioning systems (e.g., GPS, GLONASS, Galileo). It uses measurements of the signal’s carrier wave and relies on a single reference station to provide real-time corrections that that can be within centimeter-level accuracy.

- 3.1.7.4. *RTK network*—a system that uses multiple base stations to provide high-accuracy GPS positioning within a coverage area that is generally larger than that covered by a ground-based GPS Base Station.
- 3.1.7.5. *Remotely Operated Video Enhanced Receiver (Rover)*—a portable radio/receiver used to determine GPS coordinates for given point locations.
- 3.1.7.6. *Virtual Reference Station (VRS)*—networks that use RTK networks to provide high-accuracy, RTK Global Navigation Satellite Systems typically through the use of cellular wireless services (e.g., OmniSTAR™, Trimble VRS™, Trimble VRS NOW™).
- 3.1.8. *instrumented roller*—a self-propelled roller integrated with a navigation satellite system and onboard documentation system that can display real-time, color-coded maps of roller location, number of passes, roller speeds, and amplitude and vibration frequencies of the roller drum. Some systems are also equipped with drum vibration instrumentation, infrared temperature sensors, and/or automatic feedback control. The onboard documentation system on these rollers would also display real-time, color-coded maps of stiffness response or pavement surface temperatures, or both.
- 3.1.8.1. *automatic feedback control*—automatically adjusts roller operating settings, such as vibration frequency and amplitude, based on real-time feedback from the drum vibration measurement system.
- 3.1.8.2. *finishing roller*—the final roller used in the compaction process for the given layer.
- 3.1.8.3. *instrumented roller failure*—occurs when the instrumented roller system does not collect and/or store data in accordance with Section 4.3, and/or the roller becomes inoperable.
- 3.1.8.4. *Intelligent Compaction (IC) roller*—used synonymously with “instrumented roller.”
- 3.1.8.5. *operating settings*—roller settings (e.g., speed, direction, frequency, peak vertical force amplitude).
- 3.1.8.6. *Intelligent Compaction Measurement Value (ICMV)*—the stiffness of the materials based on the response of the roller drum vibrations and underlying material responses.
- 3.1.9. *layer*—the total thickness of each material type. It may be comprised of single or multiple lifts.
- 3.1.9.1. *base*—see [M 146](#).
- 3.1.9.2. *embankment*—see [M 146](#).
- 3.1.9.3. *grading grade*—the surface of material immediately beneath the base.
- 3.1.9.4. *lift*—a unit of material within a layer that is placed for compaction.
- 3.1.9.5. *subbase*—see [M 146](#).
- 3.1.9.6. *subgrade*—see [M 146](#).
- 3.1.9.7. *top of subgrade*—the surface of material immediately beneath the subbase material. If there is no subbase layer, then the top of subgrade is the grading grade.
- 3.1.10. *measurement pass*—a roller pass performed by an instrumented roller, where all required information (per Section 4.3.5) is recorded in a data file.

- 3.1.10.1. *coverage*—the total area resulting from roller passes on a given location (see Figure 2).
- 3.1.10.2. *cumulative measurement pass count*—the gridded final coverage data for pass count (the number of passes). The pass count reflects the number of roller passes in one area of the mat (e.g., 0.3 m by 0.3 m [1 ft by 1 ft area]), not the total number of passes across the width of the mat for a given roller.
- 3.1.10.3. *lot roller coverage*—the percent of roller coverage (RC) for the given lot.
- 3.1.10.4. *roller coverage (RC)*— the percent of required compaction area where the minimum required cumulative measurement pass count is achieved.
- 3.1.10.5. *roller pass*—the area covered by one width of the roller in a single direction.
- 3.1.11. *proof roll*—the testing of embankments with a heavy roller to evaluate the adequacy of the roadbed construction relative to subgrade strength, stiffness, and moisture content. The proof roller will detect weak-unstable embankment areas to depths typically up to 1.5 m (5 ft). This equipment is typically loaded to masses of about 14 metric tons (15 tons) on each tire. “Proof roll” is used synonymously with “test roll.”
- 3.1.12. *quality control personnel*—the individuals employed by the contractor to execute this work.
- 3.1.12.1. *Intelligent Compaction supervisor*—the contractor’s employee responsible for performance and compliance with Intelligent Compaction requirements.
- 3.1.12.2. *on-site IC support*—the contractor’s personnel responsible for the on-site execution of the Intelligent Compaction requirements. The on-site IC support must also understand and perform the responsibilities per Appendix X1.
- 3.1.12.3. *operator(s) of instrumented roller(s)*—the contractor’s personnel operating instrumented roller(s). The operator must comply with the requirements of this specification and understand and perform the responsibilities per Appendix X2.
- 3.1.13. *site*—the project where the instrumented rollers are required.
- 3.1.13.1. *site analysis*—the process where the contractor determines the number of GPS repeaters needed to cover the entire working length of the project and to address project staging of GPS repeaters and base station(s) when used. This process should be completed before or during site setup/calibration.
- 3.1.13.2. *site setup/calibration*—the process of comparing GNSS measurements on known coordinates and creating a “best fit” (least squares adjustment) for the coordinate grid by scaling and rotating the grid to fit the measurements. This allows future GNSS work to be more accurate as a result of the site being adjusted to a “local” coordinate system.
- 3.1.14. *traffic lane*—the portion of a traveled way for the movement of a single line of vehicles.
- 3.1.14.1. *auxiliary lane*—a portion of the roadway adjoining the traveled way for parking, speed change, or other purposes supplementary to through traffic movement.
- 3.1.14.2. *centerline offsets*—the location of the left and right edge of the production/compaction area with respect to the centerline, facing in the direction of increasing stationing. Stationing typically increases from West to East and South to North.

- 3.1.14.3. *direction of travel*—the direction that traffic moves during non-construction conditions (e.g., northbound, southbound, eastbound, westbound).
- 3.1.14.4. *roadway*—general terms denoting a public way for purposes of vehicular travel, including the entire area within the right of way.
- 3.1.14.5. *traveled way*—the portion of the roadway for the movement of vehicles, exclusive of shoulders and auxiliary lanes.

4. EQUIPMENT REQUIREMENTS

- 4.1. The plan documents, originally provided with the contract, remain the basis of the contract. The contractor is responsible for any necessary conversions of the provided electronic data.
- 4.2. *Rover:*
- 4.2.1. Use a survey grade GNSS rover receiver during site calibration and coordinate checks for the IC system(s).
- Note 1**—It is recommended that the agency requires the contractor to provide an additional rover, meeting the requirements of Section 4.2 (for agency use), if the agency does not currently have one available for use on the project. If a rover is provided to the agency through the contract, it is recommended that a time frame for return of the equipment by the agency is included (e.g., “The agency shall return the survey equipment no later than 90 days after final acceptance of all work”). Additionally, ensure that the contractor loads the alignment file onto the rover (if the alignment file is available by the agency, as this often requires special software), and provides training on the operation of the rover prior to the start of compaction efforts requiring the technology. Ensure that the rover provided to the agency includes cabling, antenna, charger, accessories, and three sets of rechargeable batteries.
- 4.2.2. Setup to reference the local, ground-based base station or the VRS Network used on the project.
- 4.2.3. Display and store the date, time, and coordinates as required by Table 1. Coordinates shall be projected to meet the state-required coordinate system (e.g., UTM, State Plane, and County Coordinates).

Table 1—Required Format of Rover Data

Description	Data Format Examples
Date Stamp, MDDYY	3/19/13
Time Stamp, HHMMSS.SS (military format)	21:46:22.96 (21 hr 46 min 22.96 s)
Latitude (decimal degrees) or Northing (m or ft)	45.22777335 or 524195.65
Longitude (decimal degrees) or Easting (m or ft)	94.85920403 or 153328.47
Longitude (decimal degrees)	94.85920403
Latitude (decimal degrees)	45.22777335
Height (Z)	909.85

- 4.2.4. Maintain this equipment for the duration of the contract (this includes necessary hardware and software upgrades).
- 4.3. *Instrumented Roller System Requirements:*

- 4.3.1. Use instrumented rollers calibrated according to Manufacturer’s recommendations and meeting the requirements of Tables 2 and 3. Refer to Appendix X3 for recommended system checks of each instrumented roller prior to compaction efforts.
- 4.3.2. Intelligent compaction systems from multiple manufacturers are allowed; however, use systems from the same manufacturer on rollers working in tandem.
Note 2—Veta cannot currently combine data from multiple manufacturers into one project. This feature will be added in future enhancements.
- 4.3.3. Use intelligent compaction software, and cloud computing, capable of mapping and exporting gridded all passes and gridded final coverage data meeting the requirements of this provision and supporting the following features/abilities:
- 4.3.3.1. *Filtering by:*
- 4.3.3.1.1. Instrumented roller,
- 4.3.3.1.2. Date and time stamp, and
- 4.3.3.1.3. Lot designation.
- 4.3.3.2. Creating boundaries.
- 4.3.3.3. Calculation of gridded final coverage data using filtered data (e.g., gridded final coverage for a given roller and lot; gridded final coverage within the entire project limits).
- 4.3.4. Provide the agency with access to the cloud storage and cloud computing prior to the start of compaction efforts requiring the IC method until 90 days after final acceptance of all work.
Note 3—It is recommended that cloud storage and computing be included in the requirements due to the large data losses often associated with manual transfer methods of IC data.

Table 2—Required Instrumented Roller Equipment

Specification	Description	Instrumented Rollers	Instrumented Roller Components				
			GNSS	Accelerometer	Temperature Sensor	Modem or Wi-Fi	Onboard Documentation System
Embankment and Reclamation	Self-Propelled, Vibratory: Smooth, Single-Drum Steel Smooth, Double-Drum Steel Pad (Sheep's) Foot	Required _{a,b}	Required _c	Required _d	None	Required _e	Required _{c,f}
Embankment and Reclamation	Self-Propelled, Pneumatic Roller			None	None		
Asphalt Pavement	Self-Propelled, Vibratory: Smooth Double-Drum Steel			Required _d	Required _g		
Asphalt Pavement	Self-Propelled, Pneumatic Roller			None			

Notes:

^a Instrument all rollers used in locations requiring the intelligent compaction method with the technology.

^b Use the intelligent compaction method during the duration of compaction efforts in areas requiring this method.

^c Capability to use the agency specified Coordinate System file for site calibration and the ability to connect to a RTK-GPS using either a local, ground-based station(s) or VRS network (use the VRS network only when coverage is available throughout the project limits).

^d Mount accelerometer in or about the drum, per the manufacturer's recommendations, to measure the interactions between the rollers and compacted materials.

^e The modem or Wi-Fi is used for transferring data to cloud storage.

^f Use an onboard document system with a minimum of the following capabilities:

- (1) Displays real-time, color-coded maps of: line work (alignment file), roller drum location, number of roller passes, intelligent compaction measurement value (ICMV) for systems with an accelerometer, and pavement surface temperature for systems with temperature sensors.
- (2) Displays and store current value for: roller speed, vibration frequency, vibration amplitude, GNSS coordinates, and pass count.
- (3) Ability to internally store data until data transfer, to automatically transfer data to cloud storage, and to manually transfer data using a removable media device.
- (4) Allows operator to define, label, and/or select the standardized name of each lot.

^g Instrument rollers with one non-contact, temperature sensor, mounted on or near, the front of the roller for measuring pavement surface temperatures. A second temperature sensor may be mounted on, or near, the rear.