Chapter 3 – Construction Technologies and Procedures

Advanced Materials and Technology Manual
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3.0 INTRODUCTION

This chapter provides details related to project selection (i.e., project selection criteria used to determine whether a project will require use of a given technology), MnCORS, creation of design and alignment files for use with intelligent compaction, paver mounted thermal profiling and automated machine guidance milling technologies, data lot establishments and best practices related to technologies such as intelligent compaction, paver mounted thermal profiling and automated machine guidance milling.
3.1 PROJECT SELECTION

3.1.1 Intelligent Compaction (IC) and Paver Mounted Thermal Profile (PMTP) Methods

Chapter 8, of the Pavement Design Manual, outlines the recommended site conditions used to assist with determination as to whether (2016SP) Quality Management – Paver Mounted Thermal Profile Method and/or (2016SP) Quality Management Special – Intelligent Compaction Method should be included on a given project. The link to this chapter is available on the MnDOT Pavement Design Manual website at:

http://www.dot.state.mn.us/materials/pvmtdesign/manual.html

3.1.2 (2011SP) Construction Surveying & (2105SP/2106SP) Excavation and Embankment – Digital Surface Model Method Using the AMG-Excavation System

Automated Machine Guidance – Excavation is recommended for use when muck excavation quantities are greater than or equal to 50,000 cy, when muck excavation activities are anticipated to be under water (consider the size and/or depth of excavation activities), or if conditions make it difficult to use conventional survey methods for creation of the as-built surface and calculation of volumes.


The use of these provisions is recommended for use when placing concrete pavement on top of a milled asphalt pavement (i.e., whitetopping and unbounded concrete overlays), or on projects where there is variable depth milling and limited area for a stringline.
3.2 MNCORS / RTRN GNSS NETWORK

The Continuously Operating Reference Station Network is a cooperative effort between MnDOT, other state agencies and institutions, counties, cities and private enterprises with the goal of providing Global Navigation Satellite System (GNSS) corrections state-wide. Using signals from all available GNSS satellites, and receivers at over 146 known positions, MnCORS is able to continuously provide survey grade positioning corrections. See Figure 3.1 for the network map / station locations. More detailed information regarding each station and an update on the network status can be found at:

http://www.dot.state.mn.us/surveying/cors/mncors_contacts.html.

FIGURE 3.1 – Image of the CORS/VRS Network Map.
Access the MnCORS GNSS Network website at the link below to receive a free account to access this network.

http://www.dot.state.mn.us/surveying/cors/index.html

This system is stable and has been successfully used by many individuals. Figure 3.2 illustrates the number of users of the MnCORS network since fiscal year 2002 through 2018. There were nearly 4,500 users connecting to the network in FY2017.

**FIGURE 3.2 – The number and type of MnCORS users over time.**
3.3 DESIGN AND ALIGNMENT FILES

3.3.1 Intelligent Compaction Method

A design and alignment file(s) are required for projects requiring the use of intelligent compaction method.

These files are imported into Veta to allow for more detailed analyses with respect to given locations within the project limits and to allow for removal of miscellaneous data that is not associated with the given compaction efforts (see figure 3.3). Additionally, these background or alignment files are loaded onto the on-board display of each intelligent compaction roller to allow the roller operator to visually see the line-work of the production area(s) with respect to compaction efforts. This real-time view helps ensure that adequate and uniform compaction efforts occur across the production area.

FIGURE 3.3 – Use of complex shapes within alignment file to trim intelligent compaction data.
The intelligent compaction system currently requires a GNSS accuracy of ± 2 in (50 mm) in the horizontal direction. This level of accuracy is required to help ensure that adequate compaction is achieved across the entire data lot. Pavement performance issues are often associated with improper compaction near longitudinal joints and the outer limits of the road core (shoulder PIs). Consequently, a horizontal accuracy of at least ± 2 in is required for the line work within the alignment files.

The intelligent compaction method requires the creation of design file containing only the following levels: lane lines, in-place centerline, station text, tick marks and labeling for exceptions.

Save a copy of the design file in the following formats:

1. DGN, DWG and KMZ design File and
2. LandXML Alignment File

Creation of complex shapes are no longer required unless the following conditions exist:

1. Boiler plate inserted into the contract has a modification date prior to June 27, 2018, or
2. Lanes have a significant amount of variable offsets (tapers) from the alignment.

See the following subsections for the specified instructions:

• Saving Microstation Seed File
• Creating a LandXML alignment file using Microstation/GEOPAK
• Saving as a Google Earth File (KMZ)
• Creation a Design File with a Complex Shape and Alignment

SAVING MICROSTATION SEED FILE

The following provides the steps for creation of the Microstation file associated with the IC method.

1. Copy a New Seed File
Copy the seed file to the project folder and rename to Functional Area **SP_IC.dgn** (e.g. d3408023_IC.dgn).

(2) **Assign the County Coordinate System**

This will only need to be completed once per file, as it is saved in the File Settings.

(2.1) **Select** Tools > Geographic > Select Geographic Coordinate System from the Microstation main menu.

(2.2) If the County has already been defined it will be listed in the dialog. The dialog will be blank if it has not been defined.

(2.3) Click **Select from Library** (second icon from the left). While one can navigate through the Library tab to find the county, it is easier to use the Search tab.

(2.4) Enter the county into the **Search Text** and select **Find Now**. At least 3 lines for each county will appear. Select the **US Foot option.** Click **Add to Favorites** if it is a county that is often used.

(2.5) Select **OK** to add the County to the Geographic Coordinate System dialog and to close the Select dialog.

(2.6) Review the Coordinate System and if everything is correct, close the dialog.
(2.7) Save these changes in Microstation (File > Save Settings from the Microstation menu to save the County Coordinate System), otherwise, exiting and opening the file again will lose the county coordinate system. Additionally, update the server copy to save in ProjectWise.

**CREATING A LANDXML ALIGNMENT FILE USING MICROSTATION/GEOPAK**

The following provides the steps for creation of the LandXML file associated with the IC method.

(1) **Open Coordinate Geometry**

Select GEOPAK > ROAD > Geometry > Coordinate Geometry from the main Microstation menu.

(2) **Select Job**

Under job, browse and select the *.GPK file containing alignment chains and select OK.
(3) **Export LandXML File**

(3.1) **Select File > Export > LandXML 1.2 Geometry** from the Coordinate Geometry window.

(3.2) **File Location**

Select the path for the XML file to be stored and name the XML file.
(3.3) Output Mode and Element Type

Select **Output Mode > Create** (**select > Append** if adding alignments to an existing LandXML file).

(3.4) Verify that the **Element Type** is set to **Chains**.

(3.5) **Select** the **Chain** to be exported from the chain dropdown menu.
SAVING AS A GOOGLE EARTH FILE (KMZ)

The *kmz file will be used with MnDOT’s intelligent construction data management tool “Veta”. There is an instruction video on creation of a *KMZ file on the Advanced Materials and technology Website (http://www.dot.state.mn.us/materials/amt/manualsguides&videos.html).

(1) In the Design DGN, turn off everything except “Text” this will allow for a clean Google Earth export.
(2) Set the view to the area of interest. Please note that the larger the area, the fuzzier Google Earth is when using the zoom feature.

(3) **Select Tools > Geographic > Export Google Earth (KML) File** from the main Microstation menu. Or **File > Export > Google Earth**.

(4) A dialog will open where one can name the Google Earth file.

Please note that it is creating a KMZ file, not KML as seen in the tool tip. Use the default name if a KMZ file has not already been created from this Microstation file. Otherwise, change the name in order to save. Click Save.

(5) The following are some miscellaneous details related to the use of Google Earth.

(5.1) Google Earth opens and moves to the location of the file. One will see the Google Earth background, with the Microstation drawing on top.
(5.2) If the Microstation Elements appear dis-jointed or incomplete, toggle OFF then ON the location in the Places area of the side bar. This will “refresh” the elements to allow them to display properly.

(5.3) Zoom in and out using the wheel on the mouse.

(5.4) Pan by holding down the data point button on the mouse.

(5.5) If the view is “drifting”, click a data point on the screen.

(5.6) If the sidebar menu is not displayed, select View > Sidebar. Here one can turn off/on the levels in the Microstation File (e.g., Street Names, etc).

(5.7) To see the “videolog” tool, toggle on Street View” in the lower left section of the sidebar (Layers section). Small cameras appear in the drawing. Click on one to open to Street view. To get back to the Top view, click the design file in the Places section in the Sidebar menu.

**CREATING A DESIGN FILE WITH A COMPLEX SHAPE AND ALIGNMENT**

As previously discussed, the creation of complex shapes are no longer required unless the following conditions exist:

(1) Boiler plate inserted into the contract has a modification date prior to June 27, 2018, or

(2) Lanes have a significant amount of variable offsets (tapers) from the alignment.

The following provides the steps for creation of complex shapes for those projects meeting the above conditions.

Create a design file with closed complex shapes where the edges of each Traffic and Auxiliary (only continuous left turn lanes and passing lanes) Lane are closed at each end.

The following instructional videos are available on the Advanced Materials and technology Website (http://www.dot.state.mn.us/materials/amt/manualsguides&videos.html): Creating Closed complex Shape and Converting Complex Shape to a B-Spline Curve.

(1) Load/import the roadway alignment in the SP_IC.DGN. Do not reference in alignment file.

  Only include Alignment Levels, Lane Line Levels and User Defined Levels in this file.
(2) **Replace the Spirals with Arcs** as Veta cannot read the Spirals correctly. The horizontal position should be within 3 in (76 mm) when replacing Spirals with an Arc. Verify that the Spirals are removed during the creation of the Arcs.

(3) **Creation of Complex Shape**

(3.1) Use the Microstation drafting tool (e.g., Copy Parallel, Place Line, Create Complex Shape) to create elements to make a closed complex shape, for each **Traffic and Auxiliary Lane**, where the edges of the lanes are closed at each end.

(3.2) Exclude all taper areas by ending the complex shape at beginning of the taper where lane width begins to change.

(3.2) Differentiate each Lane by using the user defined levels (UDEF [A, B, C, D, etc.]) for associated shape(s).
(3.3) Automatic Method – Maximum Gap Value

Increase the maximum gap value from the default value of 0.0100 ft to 0.1 ft when using the Automatic Method. Overlaps and gaps on the outside edges of the shape elements occur when the complex shape does not include all of the elements (e.g., for instances with curve less PIs).

(3.4) Projects with Exceptions
Creation of separate complex shapes for each Traffic and Auxiliary Lane on each side of the exception are no longer required for projects containing exceptions. The complex shape can now run through the exception(s).

**3.5 Variations in required Complex Shape Boundaries**

Slight variations of the required boundaries for the closed complex shapes may occur at the request of the Contractor. For instance, construction staging may be setup for grading work to be completed across the entire embankment width, in lieu of constructing one lane at a time. This would require the creation of one closed complex shape to include (enclose) all adjacent Traffic and Auxiliary Lanes (see first example image below). Additionally, there may be instances for paving applications where there is a continuous left turn lane and the Contractor paves 1.5 lanes (18-ft passes) instead of each lane separately. This case would require the complex shapes to be created for 1.5 lanes, in lieu of 3, separate 12-ft lanes (see second example below).

**3.6 Converting Complex Shapes to B-Spline Curve**

Convert all complex shapes to a B-spline curve as follows: Select Tools > Curves > Curve Utilities > Convert to b-spline curve.
3.3.2 Paver Mounted Thermal Profile Method

A design file(s) is required for projects requiring the use of the paver mounted thermal profile method. These files are used to assist with determination of the monetary price adjustment for thermal coverage and to assist construction personnel with locating areas with medium to high levels of thermal segregation during the asphalt paving operation.

Follow the same procedures outlined in section 3.3.1 Intelligent Compaction Method when generating background and alignment files for the paver mounted thermal profile method. Please note that the same design file is used for both the intelligent compaction and paver mounted thermal profile method.

3.3.3 Automated Machine Guidance – Milling Method

Ensure typical sections indicate where the AMG-Milling Method is required.

If the surface models cannot be included with the contract and are instead provided as a RID document, add a note to the SEQ to the Mill Bituminous Surface Special pay item stating to assist with more accurate bidding: “X percent < A inches, A inches ≤ Y percent ≤ B inches; Z percent > B inches”
Contract Model Packages to be provided to the bidders should include a combination of digital data in the exchange format (i.e., LandXML [.xml]), in the proprietary design format for those who have the software (i.e., *.dgn, *.dwg), and as Infrastructure construction Models (*.icm) (when available) to provide a means of checking the exchanged data.

When producing the LandXML outputs of surfaces, it is important to include both triangles and features in the surface definition. Without the features, the software will re-triangulate the surface, which may not match the design intent.

Provide a Provision for RID with a link to the location of the digital data. It is recommended to provide a list of the files and the associated metadata and can also include a list of expectations and authorized uses (e.g., the digital data was developed only for use with the automated machine guidance – milling method).

Ensure that the following digital data is provided to the bidders:

1. GPK file with centerline and final profile.

2. The following surface model files from shoulder PI to shoulder PI using a maximum node spacing of 5-ft vertices or less:
   (2a) Surface Models and 3D Breaklines for:
       (i) Existing Pavement
       (ii) Milled Surface
       (iii) Proposed Pavement
   (2b) 2D Line-Work

3. The existing pavement surface and milled surface (within ± 0.01 ft) at 500 ft linear-intervals (exported in *.csv or *.xlsm format) for the following nodes (this will assist with bidding a unit price for the variable depth milling):
   (3a) Edges of pavement and centerlines.
   (3b) Edge of shoulder (when AMG-Milling is required on shoulders)
3.4 DATA LOT ESTABLISHMENTS

3.4.1 Examples of Data Lot Establishments for the IC and PMTP Methods

An immense amount of data is collected from the instrumented rollers and thermal profiling systems during daily compaction and paving efforts, respectively. Consequently, appropriate establishment of standardized naming of data lots are needed to properly filter the data and to reduce the number of filter operations required in Veta during data analyses and summaries. Improper data lot designations may result in incorrect grouping of data, which can adversely affect monetary price adjustments. It is important that operators use the correct data lot designations during all compaction and paving efforts. The naming convention of each data lot is standardized per the following special provision tables:

Paver Mounted Thermal Profile Method: Tables 2016-5 (PMTP) and 2016-6 (PMTP)

Intelligent Compaction: Tables 2016-7 (IC) and 2016-8 (IC)

The following subsections outline examples of the standardized data lot naming convention for a few different construction operations.

Reminders:

The centerline offsets must be labeled from left to right in the direction of increasing stationing for the automation within Veta to work correctly.

If the centerline offsets vary throughout the data lot, use the predominate centerline offset throughout the operation.

EXAMPLE 1 – DIVIDED HIGHWAY, ASPHALT PAVING

The following outlines general information about the example 1 project (4-lane divided highway with asphalt paving). Figure 3.4 presents a map illustrating the divided highway and data lot locations. Table 3.1 lists the standardized naming convention for each data lot. For this case, the paving width is 12-ft in each traffic lane.

• Divided Highway (2 Westbound and 2 Eastbound Traffic Lanes)
• Hot Mix Asphalt Paving Operation
• 12-ft Paving Operation
• Two (2) Lifts of Hot Mix Asphalt

FIGURE 3.4 – Example 1: Map of a divided highway for data lot standardized naming convention.
### TABLE 3.1 – Example 1: Standardized names of data lots for divided highway.

<table>
<thead>
<tr>
<th>Data Lot Location (Note 1)</th>
<th>Lift</th>
<th>Lot Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>TH12-HMA-L1-12L-CL-WB</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>TH12-HMA-L2-12L-CL-WB</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>TH12-HMA-L1-CL-12R-WB</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>TH12-HMA-L2-CL-12R-WB</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>TH12-HMA-L1-12L-CL-EB</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>TH12-HMA-L2-12L-CL-EB</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>TH12-HMA-L1-CL-12R-EB</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>TH12-HMA-L2-CL-12R-EB</td>
</tr>
</tbody>
</table>

Note 1: The referenced data lot location is the letter in bold and parenthesis presented in Figure 3.1.

### EXAMPLE 2 – 4-LANE UNDIVIDED HIGHWAY, ASPHALT PAVING

The following outlines general information about the example 2 project (4-lane undivided highway with asphalt paving). Figure 3.5 presents a map illustrating the undivided highway and data lot locations. Table 3.2 lists the standardized naming convention for each data lot. For this case, the paving width is 12-ft in each traffic lane.

- Undivided Highway
- 2 West Bound Traffic Lanes; 2 East Bound Traffic Lanes
- Hot Mix Asphalt Paving Operation
- 12-ft Paving Operation
- Two (2) Lifts of Hot Mix Asphalt

**FIGURE 3.5 – Example 2: Map of an undivided highway for data lot standardized naming convention.**
TABLE 3.2 – Example 2: Standardized names of data lots for undivided highway.

<table>
<thead>
<tr>
<th>Data Lot Location (Note 1)</th>
<th>Lift</th>
<th>Lot Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>TH12-HMA-L1-24L-12L</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>TH12-HMA-L2-24L-12L</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>TH12-HMA-L1-12L-CL</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>TH12-HMA-L2-12L-CL</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>TH12-HMA-L1-CL-12R</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>TH12-HMA-L2-CL-12R</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>TH12-HMA-L1-12R-24R</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>TH12-HMA-L2-12R-24R</td>
</tr>
</tbody>
</table>

Note 1: The referenced data lot location is the letter in bold and parenthesis presented in Figure 3.2.

EXAMPLE 3 – UNDIVIDED HIGHWAY, ASPHALT PAVING WITH AUXILIARY LANE

The following outlines general information about the example 3 project (3-lane undivided highway and asphalt paving). Figure 3.6 presents a map illustrating the undivided highway and centerline offsets. Table 3.3 lists the standardized naming convention for each data lot. For this case, the paving width is 1.5 lanes (18-ft).

- Undivided Highway
- (3, 12-ft lanes) 1 West Bound Traffic Lane; 1 East Bound Traffic Lane; 1 Auxiliary Lane
- Hot Mix Asphalt Paving Operation
- 18-ft Paving Operation
- Two (2) Lifts of Hot Mix Asphalt
FIGURE 3.6 – Example 3: Map of an undivided highway (with auxiliary lane) for data lot standardized naming convention.

TABLE 3.3 – Example 3: Standardized names of data lots for undivided highway with auxiliary lane.

<table>
<thead>
<tr>
<th>Data Lot Location (Note 1)</th>
<th>Lift</th>
<th>Lot Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>TH12-HMA-L1-18L-CL</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>TH12-HMA-L2-18L-CL</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>TH12-HMA-L1-CL-18R</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>TH12-HMA-L2-CL-18R</td>
</tr>
</tbody>
</table>

Note 1: The referenced data lot location is the letter in bold and parenthesis presented in Figure 3.3.
3.5 INTELLIGENT COMPACTION (IC) METHOD

This method consists of using the intelligent compaction systems to continually monitor compaction efforts during grading and/or asphalt paving operations.

3.5.1 Typical Process for Data Transfer

Figure 3.7 presents an illustration showing the transfer of intelligent compaction and paver mounted thermal profile data from the instrumented systems to Veta. Details pertaining to each figure within this illustration are outlined below using the corresponding numeric number.

FIGURE 3.7 – Illustration of intelligent compaction and thermal profiling data flow.

(1) The intelligent compaction and paver mounted thermal profiling technology must store the data internally at least every 5 minutes and transfer the data directly from the device to the cloud storage within 15-minute intervals, or at least once per day when there is limited cellular coverage.

(3) Cloud Mapping:
Moba | eRoutes
Topcon | SiteLink3D
Trimble | VisionLink
Wirtgen | Witos – HCQ – Roadscan
…cloud mapping for other vendors will be added as MnDOT is notified of these platforms.

(4) VETA (Non-proprietary software)

(2) Cloud Storage
(Data in Binary Format [Machine Code]):
Leica | ConX
Moba | eRoutes
Topcon | SiteLink3D
Trimble | TCC
Wirtgen | Witos – HCQ – Roadscan
…cloud storage for other vendors will be added as MnDOT is notified of these platforms.

(1) The intelligent compaction and paver mounted thermal profiling technology must store the data internally at least every 5 minutes and transfer the data directly from the device to the cloud storage within 15-minute intervals, or at least once per day when there is limited cellular coverage.
The Department requires direct transfer to cloud storage, in lieu of use of a removable device to transfer data, in order to mitigate potential data loss. Data loss was typically between 40 to 60 percent on all projects when the Department originally allowed the use of removable storage devices. Data loss was often associated with over-writing files, forgetting to copy all files off of data acquisition systems, loss of removable storage devices, corrupt devices, etc.

(2) The data is transferred from the Instrumented Roller/Thermal Profiling System and stored in Cloud Storage (remote server). The Cloud Storage and associated user names and passwords are provided to the Contractor by the vendor/distributor of the system. Both the Contractor and Agency can gain access to the real-time data using the provided login information. It is recommended that the Contractor provides the Engineer with a different user name and password that are associated with limited user privileges.

(3) The data is then transferred from the cloud storage to the cloud computing mapping/analysis software, or directly into Veta (see [4]). The cloud computing mapping/analysis software allows the users view the near, real-time data through the internet and/or a portable electronic device application (e.g., iPAD, iPhone, Android, etc.). The cloud computing and associated user names and passwords are provided to the Contractor by the vendor/distributor of the system. Both the Contractor and Engineer can gain access to the real-time mapping/analysis using the provided login information. It is recommended that the Contractor provides the Engineer with a different user name and password that are associated with limited user privileges.

The data is then transferred from the cloud computing platform into Veta. This method of data transfer is not recommended, as possible tampering of data may occur using filtering features present with the cloud computing platform and/or modification of data contained within the exported, dbase files.

(4) The data is transferred directly from cloud storage into Veta. This is the preferred method as the vendor data contained within the cloud storage is in Binary Format (Machine Code) which is extremely difficult to tamper.

Final analyses and reporting of intelligent compaction and paver mounted thermal profiling data, to meet contract requirements, will be completed using Veta.

### 3.5.2 Training of Contractor’s Personnel

It is recommended that the Contractor’s personnel obtain training per Table 3.4, at least one time per calendar year, prior to use of instrumented rollers. Table 3.5 provides a check list for content that is recommended for inclusion in training of both the IC Supervisors and Onsite IC Support. Table 3.6 provides a check list for content that is recommended for inclusion in the training of the Operators of the instrumented rollers.

<table>
<thead>
<tr>
<th>Personnel</th>
<th>Training By</th>
<th>Training Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intelligent Compaction Supervisors</td>
<td>See Table 3.5</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 3.4 – Training of contractor personnel.

<table>
<thead>
<tr>
<th>Personnel</th>
<th>Training By</th>
<th>Training Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onsite IC Support</td>
<td>• Vendor or Manufacturer</td>
<td></td>
</tr>
<tr>
<td>Operator(s) of the Instrumented Rollers</td>
<td>• Vendor or Manufacturer, or Intelligent Compaction Supervisor, or Onsite IC Support</td>
<td>See Table 3.6</td>
</tr>
</tbody>
</table>

### TABLE 3.5 – Recommended training content for IC supervisors and onsite IC support.

<table>
<thead>
<tr>
<th>Training Completed</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>Provided Administrator/Manager rights for system troubleshooting and training on how to use complete troubleshooting.</td>
</tr>
<tr>
<td>☐</td>
<td>Process to contact Vendor / Sales Representative with further issues after troubleshooting.</td>
</tr>
<tr>
<td>☐</td>
<td>Educated on the training necessary for new or returning operators of instrumented rollers.</td>
</tr>
<tr>
<td>☐</td>
<td>Setup and operation of the IC system.</td>
</tr>
<tr>
<td>☐</td>
<td>Setup and operation of Rover. Including coordinate export.</td>
</tr>
<tr>
<td>☐</td>
<td>Site Setup and Calibration (includes setup of local, ground-based base station, Rovers, MnDOT’s MnCORS/RTRN)</td>
</tr>
<tr>
<td>☐</td>
<td>Verification of complete radio coverage for site.</td>
</tr>
<tr>
<td>☐</td>
<td>Verification of cellular coverage for site (needed when accessing MnDOT’s MnCORS/RTRN).</td>
</tr>
<tr>
<td>☐</td>
<td>Uploading alignment and site calibration files to instrumented rollers.</td>
</tr>
<tr>
<td>☐</td>
<td>Verification of accuracy of instrumented roller (includes: accelerometer range, GNSS Accuracy, pavement surface temperature, digital data recording correctly)</td>
</tr>
<tr>
<td>☐</td>
<td>Daily checks to ensure that the IC system is mapping (working) correctly.</td>
</tr>
<tr>
<td>☐</td>
<td>Daily verification of GNSS Coordinates or temperature, or both.</td>
</tr>
<tr>
<td>☐</td>
<td>Manual and wireless transfer of Data Files.</td>
</tr>
<tr>
<td>☐</td>
<td>Creation and setup of folders for different projects in cloud storage.</td>
</tr>
<tr>
<td>☐</td>
<td>Creation and use of standardized lot naming convention.</td>
</tr>
<tr>
<td>☐</td>
<td>Use of Manufacturers cloud storage and cloud computing.</td>
</tr>
<tr>
<td>☐</td>
<td>Certification of Veta Software Operator.</td>
</tr>
</tbody>
</table>
### TABLE 3.6 – Recommended training content for the operators of the instrumented rollers.

<table>
<thead>
<tr>
<th>Training Completed</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>Daily setup and operation of instrumented roller.</td>
</tr>
<tr>
<td>☐</td>
<td>Basic troubleshooting of instrumented roller system.</td>
</tr>
<tr>
<td>☐</td>
<td>When to contact onsite IC support (e.g., screen not painting, intermittent GNSS signal).</td>
</tr>
<tr>
<td>☐</td>
<td>Manual and wireless transfer of data files.</td>
</tr>
<tr>
<td>☐</td>
<td>Creation and use of lot names. Understanding of importance of lot names for data management, correct map visualization by other staff and calculations of monetary price adjustments.</td>
</tr>
<tr>
<td>☐</td>
<td>Reading of X and Y Coordinates or temperature, or both (on the Onboard Documentation System) for verification of GNSS and Temperature Measurements</td>
</tr>
</tbody>
</table>

### 3.5.3 Recommended Intelligent Compaction System Checks

It is recommended that the Contractor perform an independent equipment demonstration to ensure that the IC system is working correctly before the start of compaction efforts on each project. The parameters outlined in Table 3.7 provide general guidance for items to be reviewed during the system check. Form IC-103 “Approval of Instrumented Roller for Use” provides a check list for items that are recommended for verification during the system demonstration. This form is available on the Advanced Materials and Technology website under the Forms & Worksheets tab:


### TABLE 3.7 – Recommended intelligent compaction system checks.

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Demonstration</th>
<th>Testing Location</th>
<th>No. of Passes</th>
<th>Measurement Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Width</td>
</tr>
<tr>
<td>Verification of Adequate Sensor Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Soft Material (Note 1)</td>
<td>Project Site</td>
<td>1</td>
<td>≥ 7 ft (2 m)</td>
</tr>
<tr>
<td>2</td>
<td>Stiff Material (Note 1)</td>
<td>or Offsite Location</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verification of Data Contained within Measurement pass files</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Data Quality (Note 2)</td>
<td>Project Site</td>
<td>2</td>
<td>≥ 7 ft (2 m)</td>
</tr>
</tbody>
</table>

Note 1: Verify that the ICMVs can identify differences between weak and strong materials.

Note 2: Verify that all measurements are recorded and meet the requirements of 2016 Quality Management Special – Intelligent Compaction Method.

As part of the checks, it is recommended that the GNSS and temperature measurements are calibrated. The following subsections outline these procedures.
CALIBRATION OF GNSS ACCURACY

Step 1. Verify that the rover(s) are calibrated to the correct coordinate system, using control points, within the project limits. Complete this verification prior to checking the intelligent compaction system’s GNSS.

Step 2. Mark a spot on the ground next to the drum location being recorded and displayed by the onboard documentation system (e.g., center [or left or right edge] of a steel roller drum or the outside edge of a pneumatic roller tire). See Figure 3.8.

NOTE—For pneumatic rollers, ensure that the outside edge of a pneumatic roller tire is used, as not all pneumatic rollers have a wide-track width.

FIGURE 3.8 – Photo of marking spot on the ground next to the roller drum.

Step 3. Collect and compare the coordinates from the rover and the instrumented roller (see figure 3.9). The coordinates should compare within 0.5 ft (150 mm) of each other in the horizontal direction (X and Y direction). It is recommended that a digital photo (or snapshot using the on-board display) is used to capture the coordinates of the instrumented roller on the onboard display (see figure 3.10). This helps mitigate translation errors when recording the measurements on the form.

FIGURE 3.9 – Photo of collection of coordinate using rover.
CALIBRATION OF THE INSTRUMENTED ROLLER TEMPERATURE ACCURACY

Step 1: Power on the IC temperature sensors, a minimum of 10 minutes, before verifying measurements.

Step 2: Collect and compare the temperature measurements from an independent device and the temperature sensor(s) of the instrumented roller (see figure 3.11). The temperatures should compare within 5°F (2.8°C).

FIGURE 3.10 – Photo of digital picture of the instrumented roller coordinates displayed on the onboard display.

FIGURE 3.11 – Photo of the infrared sensor mounted on an instrumented roller.
3.6 PAVER MOUNTED THERMAL PROFILE (PMTP) METHOD

This method consists in using a paver mounted thermal profiling system to continually monitor the surface temperature of the mat immediately behind the paver screed during placement operations.

3.6.1 Typical Process for Data Transfer

See section 3.5.1 for details related to the transfer of paver mounted thermal profile data from the system into Veta.

3.6.2 Recommended PMTP System Checks

It is recommended that the Contractor perform an independent equipment check to ensure that the PMTP system is working correctly before the start of paving efforts on each project.

CALIBRATION OF GNSS ACCURACY

Collect and compare the coordinates from the PMTP system with an independent measuring device such as a rover.

Verify that the rover(s) are setup to the correct coordinate system. Complete this verification prior to checking the PMTP system’s GNSS.

Collect and compare the coordinates from the rover and the PMTP system. The coordinates should compare within 4 ft (1.2 m) of each other in the horizontal direction (XY direction).

CALIBRATION OF TEMPERATURE ACCURACY

Collect and compare the temperature measurements from an independent device and the temperature sensor(s) of the paver mounted thermal profile system. The temperatures should compare within 5°F (2.8°C).

CALIBRATION OF DMI ACCURACY

If a distance measuring instrument (DMI) is utilized with the PMTP system, verify that the correct correction factor is set for accurate stationing per the manufacturer’s procedures.

3.6.3 Field Review of Surface Temperature Measurements

It is recommended that the Engineer views the surface temperature readings and/or thermal summary on the PMTP system display within the first 100 tons of production and at about 1,000 ton intervals thereafter, for each day of production. This periodic review is intended to assist with ensuring that there are no problems with the system and/or with workmanship.
3.7 AUTOMATED MACHINE GUIDANCE – MILLING METHOD

This method consists in using automated machine guidance when removing the existing pavement by cold milling. The milling machine is still operated by a contractor personnel, however, the milling operation is controlled by an onboard data acquisition system which automatically follows a Milling Surface Model to control variable depth milling based on inputs from robotic total stations. The operator has control to make manual adjustments for teeth ware should the as-built milling depths start to deviate from the pre-set elevations.

3.7.1 Best Practices

The following lists some best practices when using automated machine guidance during the milling operation:

**CONTROL POINTS / LINE OF SIGHT**

- Know the project site. Ensure that there are no obstructions between the ground control and the prisms on the milling machine during the operation. For instance, know the traffic movement – will the RAP truck placement or live traffic on adjacent lane(s), cause obstructions, etc.
- Alternate control on each side of the roadway. Typically, control is needed every 500 ft alternating on each side of the roadway to ensure that there is no loss in control. Cases have occurred where contractors have elected to place double monuments (one on each side of roadway) to assist with control needs / site conditions.
- Check existing control points for accuracy to ensure points have not been bumped or shifted since placement.
- It is recommended that the Contractor and Engineer check in on the same control point prior to the start of the milling operation each day to ensure that no discrepancies exist between robotic total stations that could affect tolerance acceptance measurements.
- Ensure that common control points are utilized during the milling operation and for tolerance verifications. Use common back-sights when possible.

**ROBOTIC TOTAL STATIONS**

- Ensure robotic total stations are calibrated and working correctly.
- Setup robotic total stations at least an hour before milling starts to ensure working properly.
- Note that certain radio channels can sometimes affect signal range.

**AMG SYSTEM**

- Work with mechanics to determine whether any adjustments were made to the milling machine that could potentially affect the profile. For instance, adjustments made by mechanics to the hydraulics of the milling machine will affect the offsets/prism locations. This will require re-calibration of the AMG equipment.
- Mount all 3D equipment one day or more in advance of milling operation.
• Ensure wireless connections are working effectively within project limits.
• Ensure the milling machine is calibrated within tolerance before milling begins by using an independent robotic total station.
• Complete a 3D component check on the milling machine to ensure prisms, slope sensors, robotic total stations, etc. are showing up in diagnostics, harness are attached correctly, there are no pinch points on cabling or locations where the cables can get caught by another object, etc.
• Ensure prisms are not affected by vibrations on mast. Use anti-vibration rod.
• It is recommended that practice runs are completed with milling crew to ensure individuals are familiar with setup of robotic total stations and the AMG-system.
• The milling operator should make only incrementally small adjustments, not abrupt adjustments, if milling head adjustments are deemed necessary to adjust for out of tolerance milling depths due to tooth wear, etc. For most cases, the AMG system will already be making corrections for these offsets that can compound the milling depth change if the operator is making abrupt adjustments.
• Ensure that the milling machine is recording the milled surface by logging into the cloud mapping service, if available, within the first 1,000ft of milling production.

QUALITY CONTROL

• Verify that quality control measurements are taken immediately behind the milling machine and that the specified tolerances are being met.