Consultant Support for Intelligent Compaction and Paver-Mounted Thermal Profiling Projects in 2020-2021


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16. Abstract Due to the success of the MoDOT 2017-2019 Intelligent Compaction and Paver-Mounted Thermal Profiling (IC-PMTP) projects that demonstrate the paving quality improvements on numerous field projects, MoDOT has established a plan that includes additional IC-PMTP projects in 2020 and using IC-PMTP data for acceptance in 2021. To ensure the continued success of the MoDOT IC-PMTP projects in 2020 and beyond, MoDOT has procured Consulting Support for the selected IC-PMTP projects in 2020-2021 and implemented many initiatives such as data quality assurance (QA), performance tracking, and future acceptance with IC-PMTP data. This report is Part 2 of the Task 7 deliverable – Final Report for the 2021 work.		

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EXECUTIVE SUMMARY

The MoDOT 2017-2019 Intelligent Compaction and Paver-Mounted Thermal Profiling (IC-PMTP) projects demonstrated paving quality improvements on numerous field projects. Therefore, MoDOT established a plan to include additional IC-PMTP projects in 2020 and 2021. The primary goal of this project was to ensure the continued success of the MoDOT IC-PMTP projects in 2020 and beyond. MoDOT procured consulting support (this project) for selected IC-PMTP projects in 2020-2021 and implemented many initiatives such as data quality assurance (QA), performance tracking, and future acceptance with IC-PMTP data.

This project's Scope of Work (SOW) included seven (7) main tasks from 3/16/2020 to 4/29/2022, spanning approximately 25 months.

This report is a summary of the completed work in 2021. The work completed during 2020 is summarized in a previous report. The primary findings from 2021 are as follows:

- In-person training was disrupted by COVID-19. However, remote training was generally successful. There were many learning curves because of the new software analysis features and data QA analysis procedures. Most of the common issues from 2020 were resolved before the 2021 season. The most common issues noted during 2021 quality checks were data management. It is recommended that AASHTO PP 114 Data Lot Names for use with Intelligent Construction Technologies" is piloted in 2022 and 2023 to standardize and improve data management. AASHTO PP 114 uses "data lot names" included in the header block of data. Implementing the data lot naming is compatible with the automated Veta filter group generation. It is recommended to be adopted in future MODOT IC-PMTP specifications after piloting it in 2022 and 2023.
- There was a restructuring of MoDOT personnel related to IC-PMTP projects in 2021. Therefore, there was a learning curve while new personnel were trained on IC-PMTP protocols. The learning curve was particularly challenging for the data QA pilot projects, and therefore, there was limited QA data collected in 2021.
- The implementation of IC-PMTP is successful based on the data trends observed. For the first time since implementation, 100 percent of projects in 2021 achieved the 70 percent IC coverage thresholds, and 2021 showed more low thermal segregation classifications and less severe thermal segregation classifications than previous years. These trends may indicate acceptance of technology by contractors, increased understanding, and successful implementation of IC.
- MoDOT is one of the leading State DOTs focused on implementing data QA procedures for intelligent construction. The data QA procedures developed and piloted in 2020 and 2021 are complex and require a basic understanding of Veta software and engineering judgment for a successful implementation. Long-term goals include adding a feature in Veta to automate the data QA process. Until then, the Excel macro tools that were developed are the best solution. Due to the MoDOT restructuring of personnel, fewer data were collected for data QA in 2021. These state-of-the-art procedures will continue to have a steep learning curve, and training

and technical support are recommended through workshops, project support, train-the-trainers training (TTT), and just-in-time training (JITT).

- The temperature segregation index (TSI) and the cyclic fatigue index parameter S_{app} were calculated for different sublots, and a comparison between laboratory test results and in-situ parameters was conducted. This analysis is summarized in the 2020 annual report. Data is being collected to compare IC data and density. Approximately 75% of the data has been received to date. Performance tracking will be continued under future contracts.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CCV:	Compaction Control Value (Sakai, TOPCON)
CMV:	Compaction Meter Value (Caterpillar, Trimble, Dynapac, and Volvo)
DGPS:	Differential Global Positioning System
DMI:	Distance Measurement Instrument
DPS:	Dielectric constant Profiles Systems
EDV:	Estimated Density Value (Volvo)
FOV:	Field of View
GNSS:	Global Navigation Satellite System
GPR:	Ground Penetrating RADAR
GPS:	Global Positioning System
HCQ:	HAMM Compaction Quality system
HMA:	Hot Mix Asphalt
IC:	Intelligent Compaction
ICMV:	Intelligent Compaction Measurement Values
IMU:	Inertial Measurement Unit
IR:	Infrared Scanning
ISIC:	International Society for Intelligent Construction
MATC:	Mobil Asphalt Technology Center
MTOP:	Mean Temperature at Optimum Pass
MTV:	Material Transfer Vehicle
NDG:	Nuclear Density Gauge
NRRA:	National Road Research Alliance
OEM:	Original Engineering/Equipment Manufacturer
PDH:	Professional Development Hour

PMTPS: Paver-Mounted Thermal Profile Systems

PPK: Post-Processed Kinematic

PPM: PaveProj Program (MOBA)

QA: Quality Assurance

QC: Quality Control

RAP: Recycled Asphalt Pavements

RAS: Recycled Asphalt Shingles

RDM: Rolling Density Meter

RE: Resident Engineer

RTK: Real-time kinematic positioning system

S_{app}: Cyclic fatigue index parameter

SOW: Scope of Work

TPF: Transportation Pooled Fund

TSI: Thermal Segregation Index

UTM: Universal Transverse Mercator

CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

The MoDOT 2017-2019 Intelligent Compaction and Paver-Mounted Thermal Profiling (IC-PMTP) projects demonstrated paving quality improvements on numerous field projects. Therefore, MoDOT established a plan to include additional IC-PMTP projects in 2020 and 2021. The primary goal of this project was to ensure the continued success of the MoDOT IC-PMTP projects in 2020 and beyond. MoDOT procured consulting support (this project) for selected IC-PMTP projects in 2020-2021 and implemented many initiatives such as data quality assurance (QA), performance tracking, and future acceptance with IC-PMTP data.

1.2 PROJECT SCOPE AND SUMMARY OF WORK PLAN

This project's Scope of Work (SOW) included seven (7) main tasks from 3/16/2020 to 4/29/2022, spanning approximately 25 months. The tasks of this project are listed as follows:

- Task 1 – IC-PMTP Training Program
- Task 2 – IC-PMTP Data Quality Assurance (QA)
- Task 3 – Pilot Innovative Technologies
- Task 4 – IC-PMTP Project Supports
- Task 5 – Pavement Performance Tracking
- Task 6 – Feedback Meeting and Executive Briefing
- Task 7 – Final Report (this report includes a summary of 2021 activities)

1.3 STRUCTURE OF REPORT

This report is the 2021 deliverable for Task 7. The 2020 activities were summarized in a previous report, and Table 1 outlines the content of this report.

Table 1. Summary of the report.

Chapter	Description of Tasks
Chapter 1	Introduction
Chapter 2	Summary of Task 1 – IC-PMTP Training Program
Chapter 3	Summary of Task 2 – IC-PMTP Data QA
Chapter 4	Summary of Task 3 – Pilot Innovative Technologies
Chapter 5	Summary of Task 4 – IC-PMTP Project Supports
Chapter 6	(No associated task) Summary of Project Results.
Chapter 7	Summary of Task 5 – Pavement Performance Tracking
Chapter 8	Summary of Task 6 – Feedback Meeting and Executive Briefing

Chapter	Description of Tasks
Chapter 9	Recommendations and Conclusions

CHAPTER 2 TASK 1-IC-PMTP TRAINING PROGRAM

2.1 INTRODUCTION

Training materials were upgraded to reflect the technological advancements of IC and PMTP and updated MoDOT specifications. Updates were also made to reflect the new features of Veta analysis software. The upgrades included changes to the IC-PMTP protocols to reflect the new analysis procedures and specification changes. A summary of the training program updates is presented in Table 2. Details regarding the training material upgrades were summarized in the 2020 report. No significant changes were made between 2020 and 2021.

Table 2. Summary of IC-PMTP training program updates.

Update	Description of Update
Training agenda	Updated the agenda to reflect Veta 6.0 features.
Presentation materials	Updated the presentation materials to reflect the Veta 6.0 features. Created a quick reference guide for Veta 6.0
Protocols	Simplified naming convention and file management recommendations. Updated the summary sheet to reflect changes in specifications. Created instructions and video tutorials for data QA procedures and GPS obstructions.
Training workshops	Due to COVID-19, all training was performed remotely. The 2021 workshop was held on April 14 via GoToWebinar. There were 41 registered participants and 31 attendees. All attendees received certificates of completion with six Professional Development Hours (PDH) units.
IC-PMTP data QA training for Resident Engineers	Training workshops were held for data QA training in 2020, and recorded tutorials were published on the IC-PMTP SharePoint site. Due to COVID-19, training could not be held onsite. There were also challenges associated with reduced work hours by MoDOT personnel in 2020. Therefore, in 2021 data QA training was limited.

2.2 SUMMARY

Due to the impact of COVID-19, all training workshops were conducted online in 2021. All online workshops were recorded and posted on the MoDOT IC_PMTP SharePoint Site. The IC-PMTP training materials and protocols were updated to reflect the technological advancements in IC and PMTP data collection and analysis.

The data QA procedures are complex and require engineering judgment and a basic understanding of Veta and IC-PMTP project analysis. There was limited QA data collected in 2021 due to COVID-19 illness and staff turnover. Therefore, it is recommended that more training workshops for data QA be held before the 2022 construction season.

CHAPTER 3 TASK 2-IC-PMTP DATA QA

3.1 INTRODUCTION

MoDOT is one of the leading State DOTs focused on implementing data QA procedures for intelligent construction. The U.S. Code of Federal Regulations (CFR) includes requirements for quality assurance (QA) procedures (FHWA, 2020A). 23 CFR 637 Subpart B includes requirements for construction QA programs. 23 CFR 637.207 states that:

- Quality control sampling and testing results may be used as part of the acceptance decision provided that:
  - The sampling and testing have been performed by qualified laboratories and qualified sampling and testing personnel.
  - The quality of the material has been validated by verification testing and sampling. The verification sampling shall be performed on samples that are taken independently of the quality control samples.
  - The quality control sampling and testing are evaluated by an independent assurance (IA) program.

In summary, there are three requirements for using contractor quality control testing for acceptance. It is important to consider that these requirements were initially written for traditional spot testing. Traditional spot tests involve physical sampling and testing of materials. The physical sampling of material (e.g., coring) is different from the data collection and analysis methods used in intelligent construction. Intelligent construction data is also unique because data is collected for the entire project rather than a specified frequency. Therefore, the conventional validation and verification methods of sampling and testing (e.g., witnessing 10 percent of coring operations and bulk specific gravity testing procedures and sampling a companion core) do not apply. Therefore, new procedures need to be developed to meet the 23 CFR 637 requirements for intelligent compaction data.

The first requirement is that *qualified laboratories and personnel perform QC*. A qualified laboratory does not apply to intelligent compaction data. Qualified personnel may include intelligent compaction technicians who complete the MoDOT training program. MoDOT has offered contractor and agency personnel training programs each year since intelligent construction implementation, and these programs may be used to qualify contractor personnel.

The second requirement is *validation by verification testing*. Traditionally, the two validation considerations by verification testing include the physical sampling of material (e.g., coring) and then testing the material (e.g., bulk specific gravity of core). For intelligent construction data, validation considerations include data collection and data analysis. Validating the *data analysis* requires checks of the contractor reports, including data transfer to the summary sheet. Validation is critical to ensure the pay adjustments being calculated are valid. These checks can be performed by REs on a percentage of the production for each project. The objective of Task 2 was to develop verification methods for *data collection*. Two procedures were developed, one for verifying IC pass count data collection and the other for verifying PMTP temperature data collection. Each procedure is described in the remainder of this chapter.

The third requirement is *IA evaluation of all acceptance sampling and testing*. IA is traditionally performed by observing technicians, using split samples or proficiency samples, and equipment calibration checks. The IA requirements have not been considered at this time.

Parallel efforts are being made with the Transportation Pooled Fund (TPF)-5(466) National Road Research Alliance (NRRA). MoDOT is a member of TPF-5(466) and one of the leading DOTs working on the challenges associated with data QA for intelligent construction technologies (ICT). MoDOT is funding another research project, "Implementation of Data Quality Assurance (QA) for Innovative Technologies at MoDOT." This ongoing project began in 2021 and aimed to advance MoDOT's efforts to find data QA solutions for ICT.

3.2 TASK 2-1: DATA QA PLAN AND TOOLS

The data QA plan and analysis tools were developed in 2020 and are described in detail in the 2020 report. These efforts are briefly summarized in the following sections.

3.2.1 IC Pass Count Data QA

To perform data QA on the pass count reported by IC equipment, a machine tracking system called DirtMate manufactured by Propeller was used. The DirtMate device is a GPS rover mounted onto active IC machines using magnets and brackets (Propeller, 2020). DirtMates are solar-powered. The built-in real-time kinematic and post-processed kinematic (RTK/PPK) GPS receiver collects elevation data from the ground underneath the machine. At the same time, an inertial measurement unit (IMU) is used to determine utilization metrics (idle, working, off). IMUs measure acceleration, angular velocity, and magnetic fields. When combined with sensor fusion software, IMUs can determine motion, orientation, and heading. The data is transferred to a supplied network gateway by a wireless transmitter, and a separate hotspot device is used to connect the DirtMate to the network.

The Consultant developed an Excel spreadsheet macro tool to evaluate IC pass count data by comparing IC data with DirtMate data. The spreadsheet, instructions, and examples were uploaded to the MoDOT SharePoint site. Despite advertising these materials via email, few MoDOT personnel knew of the materials. It is recommended that the IC-PMTP site be reorganized in 2022 to make it easier to navigate and find the training materials.

3.2.2 PMTP Temperature Data QA

PMTP temperature data QA was performed using FLIR infrared cameras. Two models, E5 and E85, were piloted for temperature data QA in 2020. The technical details of the two camera models can be found on FLIR's webpage (FLIR 2020). The FLIR E5 has a larger field of view (FOV), meaning that its images cover a larger pavement area per image. Therefore, The FLIR E5 was recommended for the 2021 season.

The Consultant developed an Excel spreadsheet macro tool to evaluate PMTP temperature data by comparing PMTP data with FLIR data. The spreadsheet, instructions, and examples were uploaded to the MoDOT SharePoint site. Despite advertising these materials via email, few MoDOT personnel knew of the materials. It is recommended that the IC-PMTP site be reorganized in 2022 to make it easier to navigate and find the training materials.

3.3 TASK 2-2: PILOT DATA QA PROJECTS

Data QA for IC pass count and PMTP temperature profile was conducted on several pilot projects. The purpose of the pilot projects was to demonstrate the feasibility and gather enough data to establish reasonable acceptance tolerances. A summary of the pilot project efforts in 2020 can be found in the 2020 final report. One of the key lessons learned in 2020 was that more training was needed to implement the new data QA protocols successfully. However, in 2021 the IC-PMTP management at MoDOT was restructured, and new Field Office support staff were assigned to IC-PMTP support. In addition to the changes in key IC-PMTP personnel, COVID-19 illnesses affected project staffing and travel allowance for onsite support. Therefore, piloting data QA was particularly challenging in 2021.

The challenges of piloting data QA were discussed in depth during the 2021 feedback meeting (Task 6). The feedback and recommendations for future data QA efforts are summarized in Chapter 8.

3.4 SUMMARY

The Consultant developed detailed instructions and software tools for the IC pass count data QA and PMTP temperature data QA. Several examples were created to demonstrate the instructions. Online training workshops were conducted for the targeted MoDOT staff and contractors.

The analysis procedures are complex, and the Consultant produced training videos and step-by-step instructions for implementation. The long-term goal of data QA is to implement a tool in Veta to automate the process. The Consultant is working with the FHWA, the Transportation Pooled Fund (TPF) Veta study, the National Road Research Alliance (NRRA), and the International Society for Intelligent Construction (ISIC) to study the feasibility of simplifying data QA.

Training opportunities were limited in 2021 due to COVID-19 related travel restrictions. Several challenges were discussed during the 2021 feedback meeting, and recommendations to overcome these challenges are summarized in Chapter 8.

CHAPTER 4 TASK 3-PILOT INNOVATION TECHNOLOGIES

4.1 INTRODUCTION

Dielectric Profiling Systems (DPS) are ground penetrating RADAR (GPR)-based systems that measure the dielectric constant of asphalt pavements to evaluate the uniformity and density. DPS was piloted on selected 2021 projects to measure dielectric constant profiles, which were used to predict asphalt in-place density or void ratio. The results of the pilot projects are included in the following sections.

4.2 DPS PILOT PROJECTS

The FHWA Equipment Loan Program at the Mobile Asphalt Technology Center (MATC) (FHWA, 2020B) agreed to loan MoDOT a unit of the GSSI PaveScan Rolling Density Meter (RDM) 2.0 (GSSI, 2020) for field testing and evaluation during the 2021 construction season. The RDM 2.0 uses three GPR antennas mounted to a pushcart, as illustrated in Figure 1.

Source: MoDOT (2021)

Figure 1. Photo. RDM 2.0 DPS equipment

4.2.1 Calibration of Equipment

MoDOT Field Office personnel and the Consultant attended training from the MATC on operating the equipment. The training and RDM 2.0 literature recommend a multi-part calibration process described as follows.

4.2.1.1 Airwave Calibration

The airwave calibration is performed by tilting the sensors at least 45 degrees off the ground and taking a reading (GSSI 2020). Airwave calibrations should be performed daily or any time after the system has been powered down. The RDM 2.0 will automatically direct the user to the calibration window when airwave calibration is needed (GSSI 2020).

4.2.1.2 Plate Calibration

A metal plate calibration must be performed with an airwave calibration (GSSI 2020). The metal plate calibration involves activating the sensors one at a time over a metal plate, as shown in Figure 2. The display will notify the user when the metal plate calibration is completed.

Source: MoDOT (2021)

Figure 2. Photo. RDM 2.0 metal plate calibration.

4.2.1.3 Line Calibration

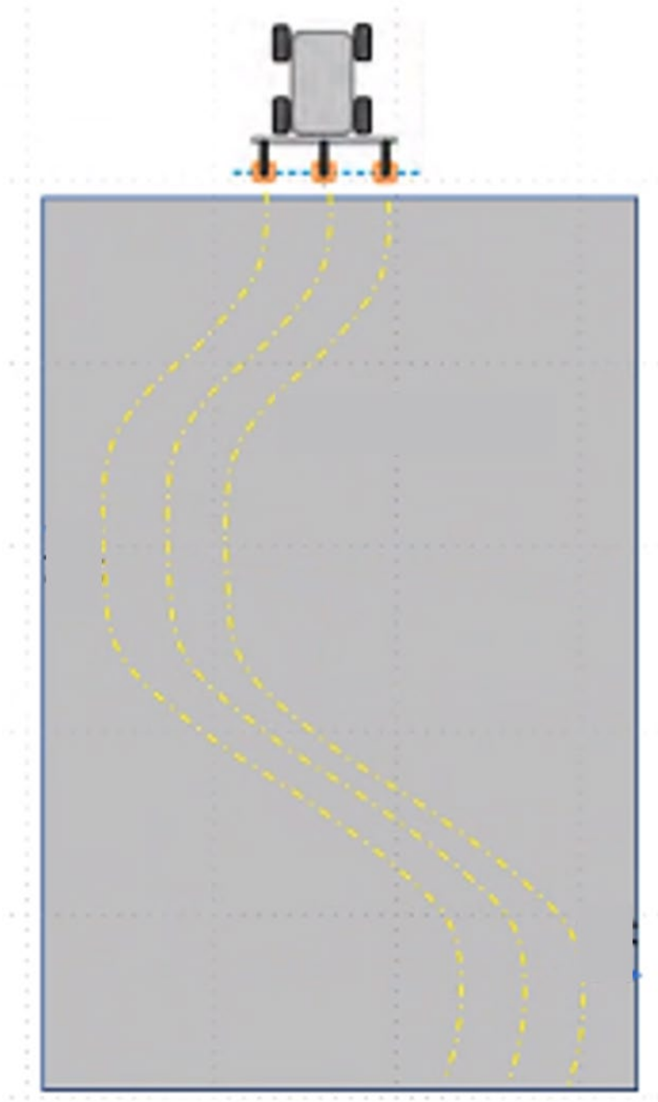
Line calibrations are performed using a string line to mark a 10-foot straight line transversely across the calibration site. Each sensor collects data along the 10-foot line, and a laser line is mounted on each sensor to help keep the sensor on the line. The median dielectric value is compared for each sensor, and the dielectric values should be within 0.08 of each other (MATC 2021). An example of line calibration performance is shown in Figure 3.


Source: MoDOT (2021)

Figure 3. Photo. RDM 2.0 line calibration.

4.2.1.4 Swerve Calibration

Swerve calibrations collect a random sample of data along a 250-foot length of the pavement. Data is collected along the designated length as the operator “swerves” from side to side of the pavement. An illustration of the swerve pattern is shown in Figure 4. At the end of the 250-foot length, the cart is turned 180 degrees, and the RDM 2.0 travels back the same distance in another similar swerve pattern. Training materials state that although the path back is not exact, it is a random sample of the overall population. Although the sensors take different paths, enough data has been collected that the three different sensor median readings should be similar. The training materials recommend that the median dielectric values of each sensor should be within 0.08 of each other (MATC 2021). Note that the swerve test calibration recommended median values were never met during the pilot studies.



Source: FHWA MATC (2021)

Figure 4. Illustration. Example of swerving pattern for swerve calibration.

4.2.2 Data Collection

Table 3 summarizes all DPS data collected during the pilot studies. The Consultant was onsite to perform assistance on Project Code 4. Therefore, Project Code 4 will be highlighted in this report.

Table 3. Summary of DPS data collected to date with current data issues.

Project Code, Contractor Code	Date of Collection
5, 5	08/05/2021
3, 12	05/26/2021
4, 5	10/05/2021
8, 8	06/22/2021
6, 1	08/19/2021

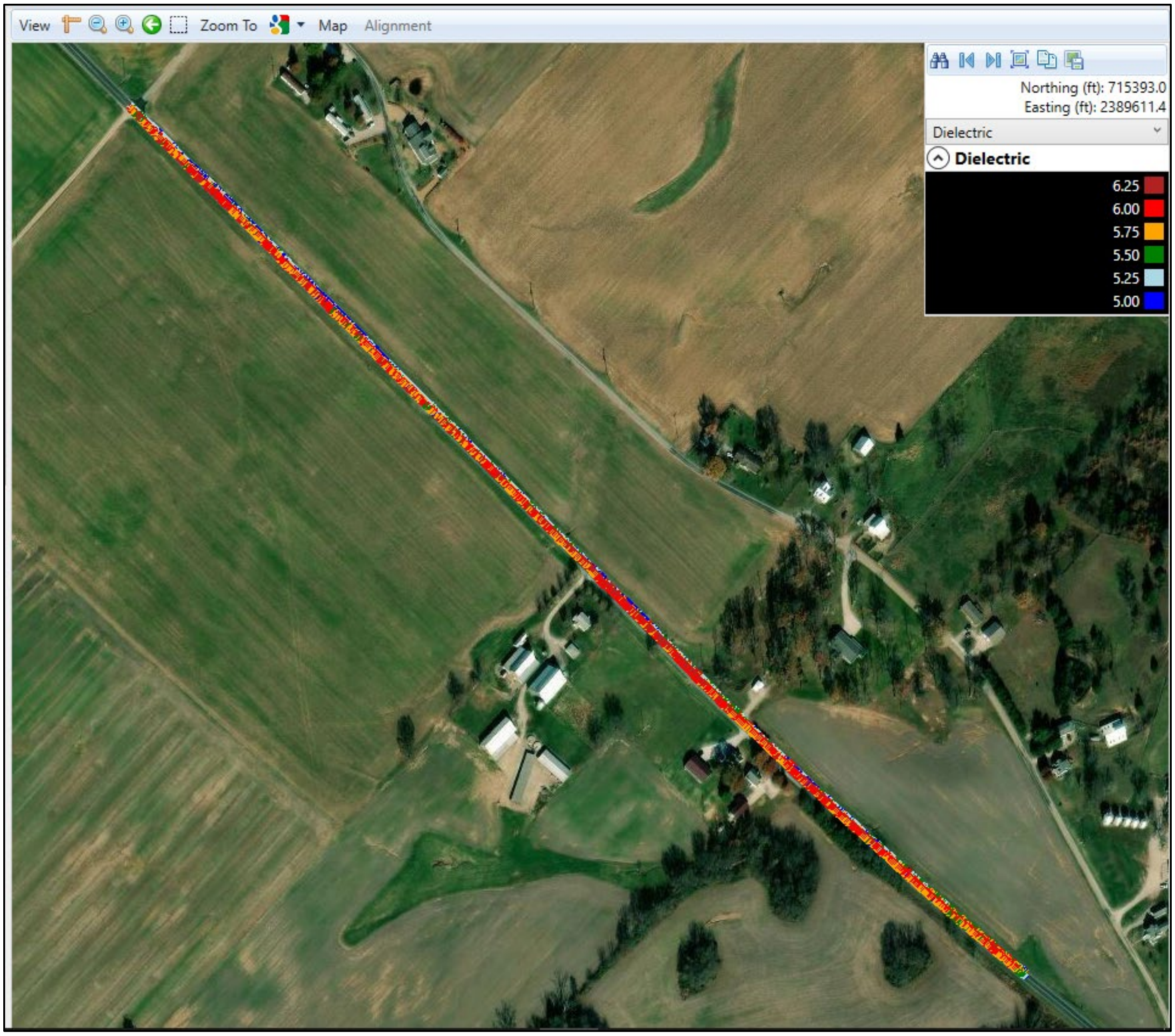
The export TDS files, compatible with Veta, did not include coordinate data during the pilot studies. The equipment vendor was notified that there was no coordinate data, and therefore, the data could not be viewed in Veta. The vendor provided a software patch to fix this issue, and a permanent fix should occur in a future software update.

4.2.3 Results of Project Code 4

The Consultant provided onsite support for Project Code 4. Therefore, the details are highlighted in this report in the following sections.

4.2.3.1 Data Collection

Approximately 3,200 feet of data were collected on Project Code 4. The extent of collected data is shown in Figure 5.



Source: Project Team (2021)

Figure 5. Screenshot. The extent of dielectric data collected using the RDM 2.0 on Project Code 4

Data collection was limited due to the following reasons:

- Limitations with the timing of the contractor's lane closures. Contractors must meet closure length and time requirements or are subject to penalties. Therefore, MoDOT does not control traffic closures.
- Data collection issues. The data was not exporting GPS coordinates (as described previously in section 4.2.3.1). At the time, it was believed to be an issue with the GPS connection, and therefore, data were collected in the same location three times. However, it was later discovered that it was a vendor export issue.
- Limited working hours for MoDOT personnel in 2020.

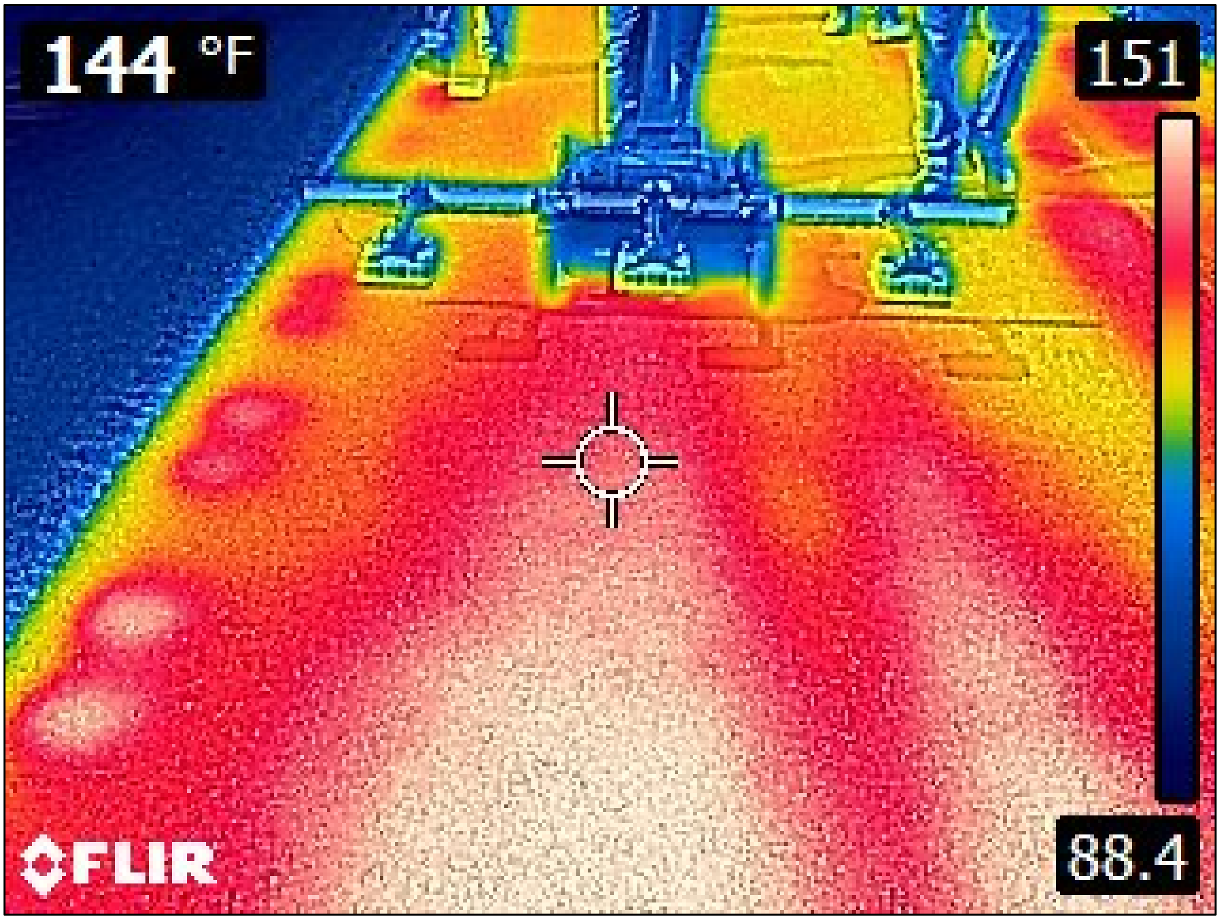
MoDOT contacted the contractor and asked them to collect loose mix samples and perform the gyratory compaction correlation, and they agreed to perform the work. The compaction correlation is further described in section 4.2.3.2.

The DPS equipment was set up with a 2-foot sensor offset for a total collection width of 4 feet. The 2-foot offset was the preferred setup because the contractor's temporary lane markings were placed inside the lane, as shown in Figure 24. The temporary lane markings caused erroneous readings, and therefore, only 8 feet of the total width of the mat was collected. Veta has filtering capabilities to remove such obstructions after data collection. Therefore, it is recommended that full-width data be collected in the future. There is some error in GPS and human-induced wander, and therefore, each 4-foot width varies by location. The data wander is further illustrated under section 4.2.3.2.

Source: MoDOT (2021)

Figure 6. Photo. Temporary lane markings on either side of the pavement interfere with RDM readings (false low density, out of range density).

A total of four rollers were used for compaction. The DPS data were collected behind the finish (final) roller. FLIR images were taken during DPS testing showing that data was collected at temperatures generally ranging from 120˚F to 150˚F. An example FLIR image is shown in Figure 7.



Source: Project Team (2021)

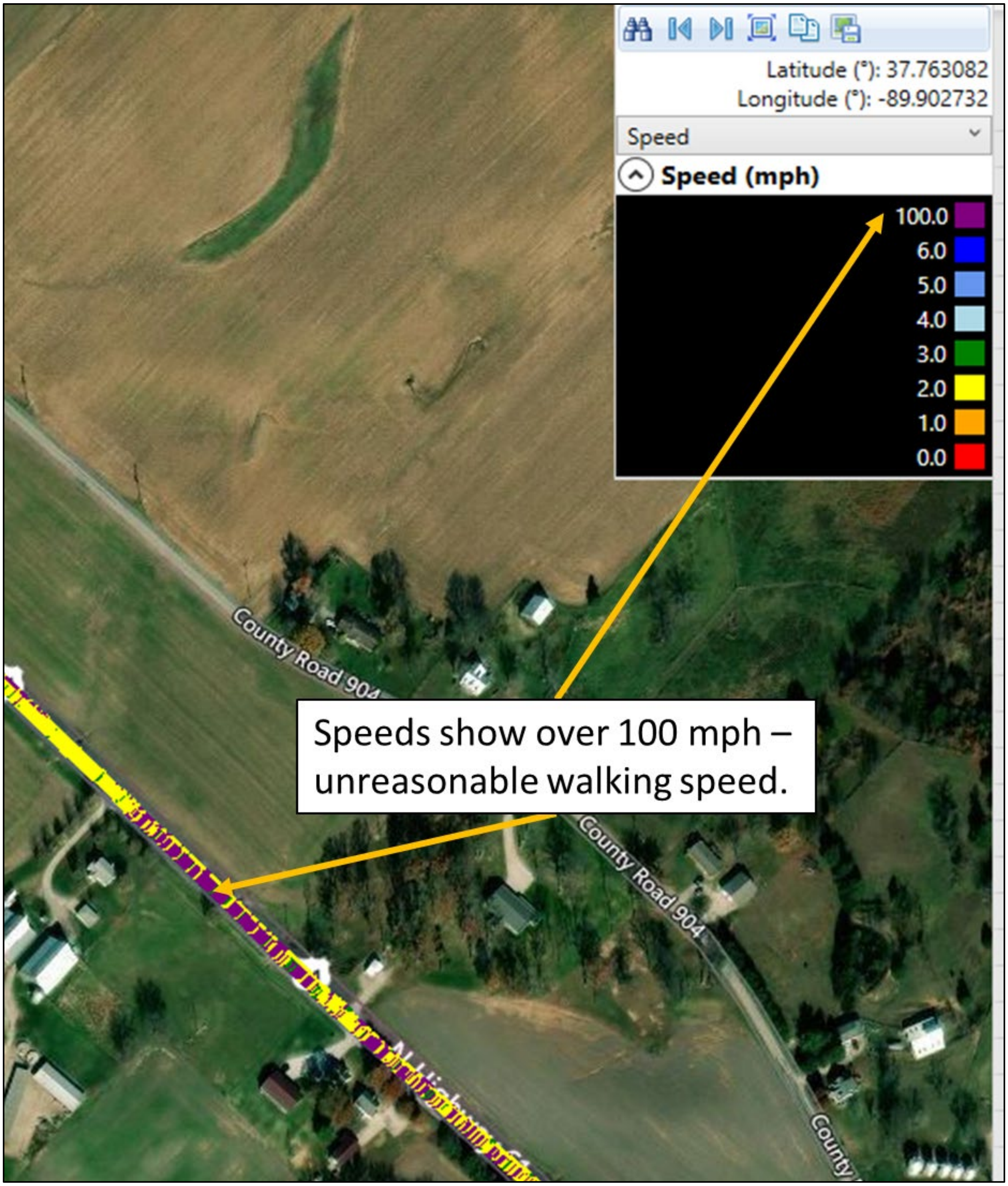
Figure 7. Photo. Example FLIR image capturing data collection temperatures

4.2.3.2 Data Analysis

Data was imported to Veta for analysis. The following describes some of the lessons learned from data analysis.

(a) Time Stamps and Coordinates

When viewing the data in Veta, unreasonably high speeds were seen, as illustrated in Figure 8. The DPS data showed that each of the three sensors had a unique timestamp and coordinate, causing issues with the speed calculation. There should only be one timestamp and one coordinate for each row of data. The vendor was notified to resolve this issue.



Source: Project Team (2021)

Figure 8. Screenshot. DPS data shows areas with unreasonable speeds

(b) Failure to Export Coordinates

Despite the vendor's efforts to export the TDS and CSV files with coordinates, some files still had missing coordinate data. The vendor was notified to resolve this issue.

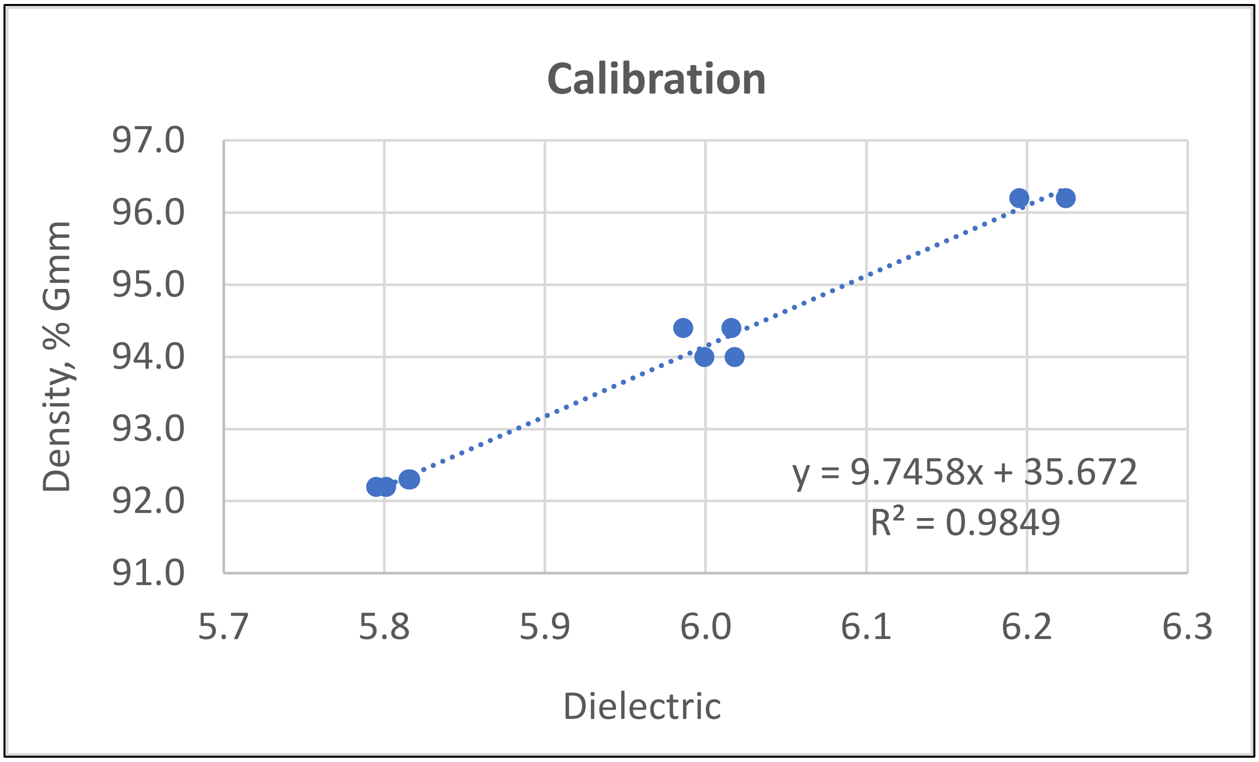
(c) Data Visualization Issues

The DPS data maps appear "wavy" and include gaps between the two adjacent DPS collection widths. These visualization issues are caused by the following:

- Low Precision GPS: The DPS equipment (RDM) was not high-precision RTK GPS. Therefore, there are location errors or drifts from the GPS measurements.
- Human-Induced Wanders: The DPS equipment is pushed manually during operation, causing wanders.
- Sensor Spacing: The sensors were spaced two feet from the center for four feet of total data collection width. Two runs were conducted or a total collection width of eight feet. Since the paved lane was approximate 12 feet, there are gaps in the DPS data map.

4.2.3.3 Density Correlation

The contractor made gyratory samples using loose mix sampled that day and provided them to MoDOT. The DPS equipment was used to measure the dielectric constants of the gyratory samples. The gyratory sample air voids (relative density) and corresponding dielectric measurements were plotted, and a linear trend line was obtained, as shown in Figure 9. According to the manufacturer, density correlations should include a low, mid, and high relative density range, as illustrated in Figure 9.



Source: Project Team (2021)

Figure 9. Graph. Calibration data from gyratory samples.

The calibration coefficient and constant were added to Veta to view the estimated density and air voids.

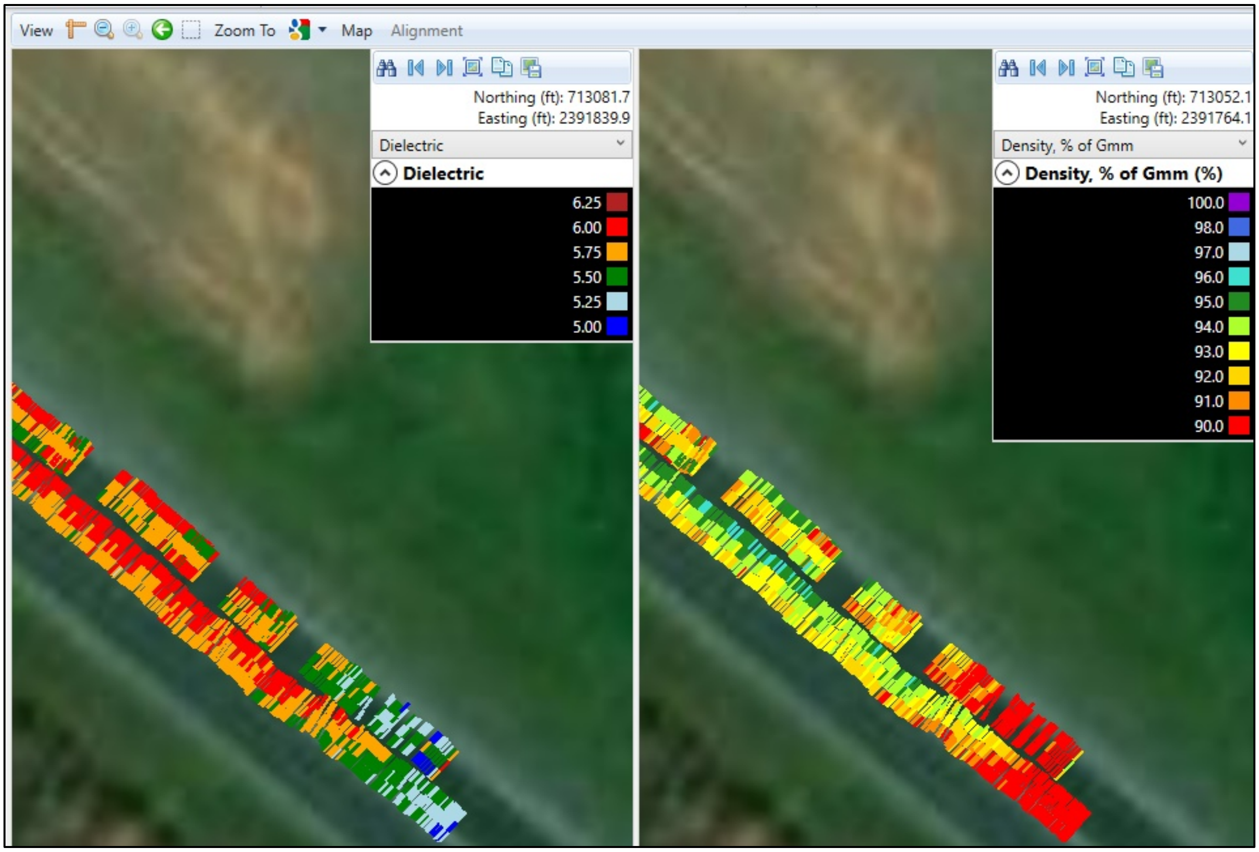
4.2.3.4 Data Highlights

This section includes results from the data analysis, including interesting findings and lessons learned.

(a) Low Dielectric at Transverse Joint

Low dielectric data was observed at the beginning of the panel at the transverse joint. The low dielectric data is illustrated in Figure 10. A photo of the transverse joint is shown in Figure 11. The contractor's IC data was imported to the project to troubleshoot the low density at the transverse joint. The data showed that the optimum pass count was met. However, the temperature data showed that the temperatures during breakdown rolling were relatively cool compared to the rest of the production temperatures. Therefore, the data shows that this area was not rolled at the optimum temperatures, as illustrated in Figure 12. It is not uncommon to have cooler temperatures at the start of paving since the equipment at startup is at ambient temperatures. However, the effects of cooler start temperatures are not easily identified or quantified if ICTs are not used.

Because the dielectric data was not collected with RTK high precision GPS, the IC (that uses RTK GPS) and DPS data cannot be compared precisely.

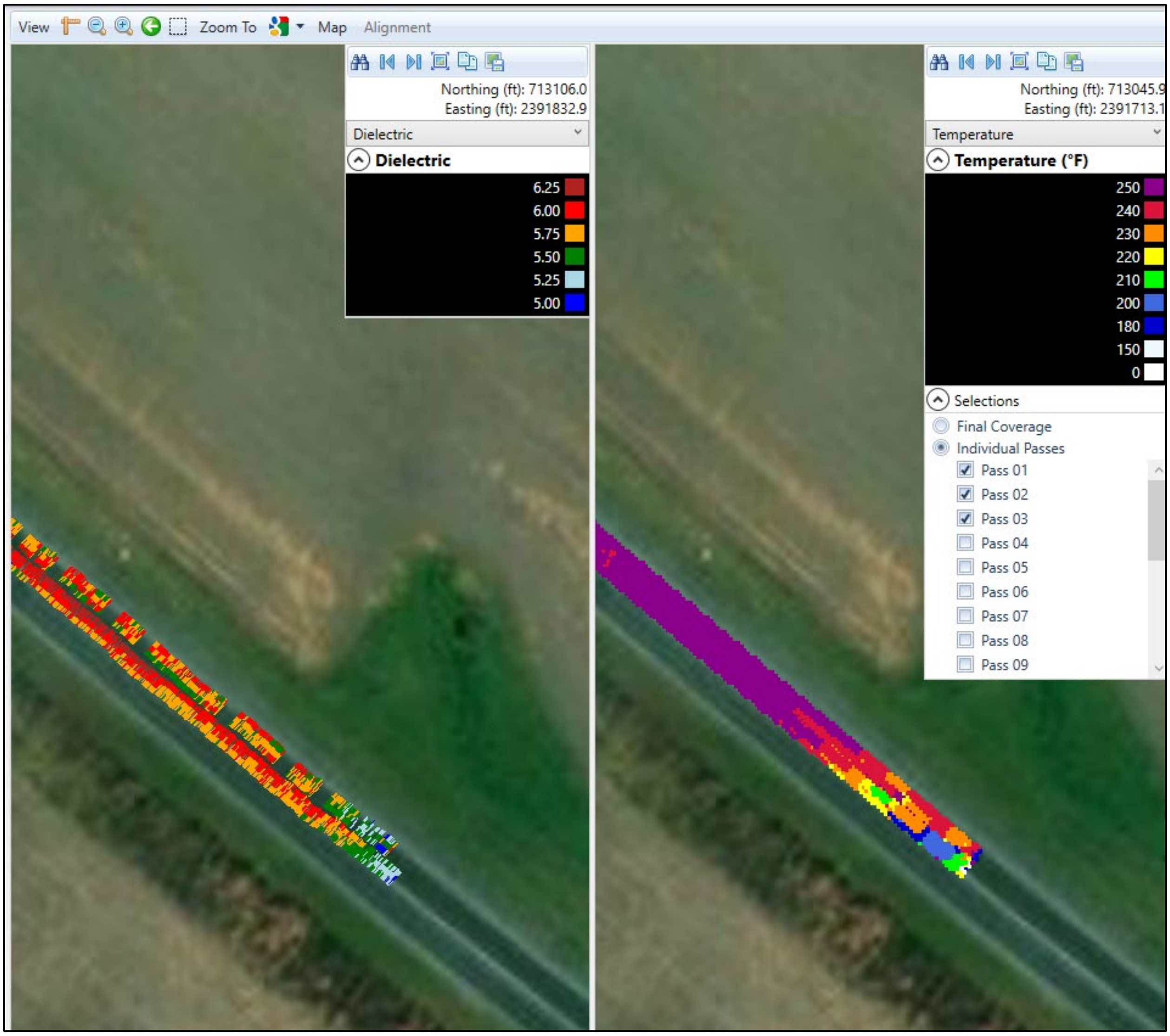


Source: Project Team (2021)

Figure 10. Screenshot. Relatively low dielectric data at the start of paving at the transverse joint.

Source: MoDOT (2021)

Figure 11. Photo. The transverse joint.



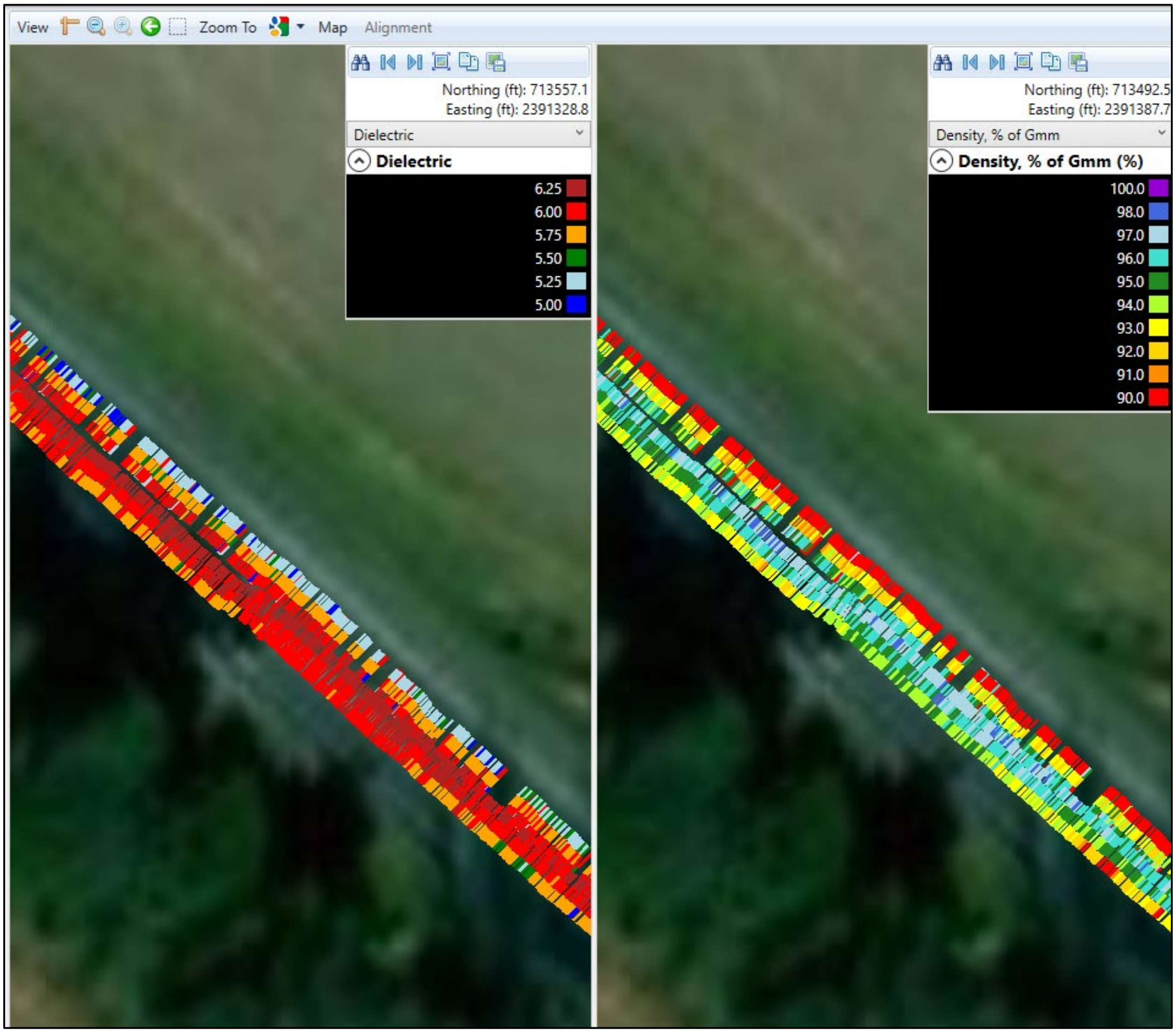
Source: Project Team (2021)

Figure 12. Screenshot. Cooler breakdown temperatures relative to the rest of production, with corresponding lower dielectric values.

(b) Low Dielectric Data at Edge/Rumble Strips

Low dielectric data and estimated relative density were observed at the edge of the data, as shown in Figure 13. The estimated relative density shows significantly lower values than the rest of the mat. The DPS data was compared to the IC data, illustrated in Figure 14. The optimum pass count appeared to be met, and compaction temperatures were generally consistent with the rest of the production temperatures, although edge temperatures did appear slightly cooler. However, ICMV data on the pavement edge was consistently lower relative to surrounding data. Lower ICMV indicates that the edge has lower stiffness relative to the surrounding area. Typically, the support layers of the pavement are weaker at the pavement edge, which may affect the compaction efforts.

Also, the overlay was placed over the existing rumble strip. The rumble strips are reflected through the overlay, as shown in Figure 15. Paving over the rumble strips could contribute to the lower stiffness values as compaction efforts will vary across the high and low elevations of the existing surface.



Source: Project Team (2021)

Figure 13. Screenshot. Low dielectric data (left) and estimated relative density (right) were observed at the data's edge.

Source: Project Team (2021)

Figure 14. Screenshot. IC pass count (top left,) IC temperature (top right), DPS (lower left), and IC ICMV (lower right) data.

Source: MoDOT (2021)

Figure 15. Photo. Rumble strips are shown reflecting through the overlay.

(c) Benefits of Full Coverage Data

DPS data was collected over a length of 3,200 feet. This section has only one core used for acceptance testing, as illustrated in Figure 16.

Source: Project Team (2021)

Figure 16. Screenshot. Location of single acceptance core.

This core does not identify any potential quality issues previously described in section (a) or section (b). Information and data collected using intelligent construction technologies are significantly more useful than spot tests for evaluating quality and troubleshooting issues.

Because the DPS GPS data was not precise geospatially, no direct correlation between the core and the DPS data was performed.

4.3 SUMMARY

The following points highlight the DPS pilot projects:

- There are issues with the data export files that the vendor needs to correct in a software update. The issues include generating coordinates in export files and including multiple timestamps and coordinates in each row of data. The vendor has been notified of the issues to date.
- The swerve test calibration did not "pass" before data collection. More guidance on the swerve test may be needed to perform this successfully.
- Preferably, RTK GPS should be used for all ICT so that the data can be directly compared.

- The DPS and IC data show areas of low dielectric and corresponding low temperatures and ICMV values. These data are a useful tool to understand the quality of the paved area.
- Information and data collected using ICTs with 100% coverage are significantly more useful than limited spot tests for evaluating quality and troubleshooting issues for paving.

CHAPTER 5 TASK 4-IC-PMTP PROJECT SUPPORTS

5.1 INTRODUCTION

The original work plan anticipated includes onsite and remote technical support. Due to the impact of COVID-19, there was limited onsite IC-PMTP project support in 2021, and most support was provided remotely. The project supports are summarized in the following sections.

5.2 TASK 4-1: ONSITE SUPPORT

Due to the impact of COVID-19, there was limited onsite IC-PMTP project support in 2021. The Consultant provided onsite support for Project Code 4. The details of the project support are summarized in the following sections.

5.2.1 Onsite Support for Project Code 4

5.2.1.1 Pilot Innovation Technologies

DPS equipment was piloted on the project. The details of the DPS pilot project are included in Chapter 4.

5.2.1.2 Data QA Training

The Consultant assisted MoDOT Field Office personnel with data QA processes, including collecting and analyzing IC pass count QA data and PMTP temperature QA data, as summarized in the following sections.

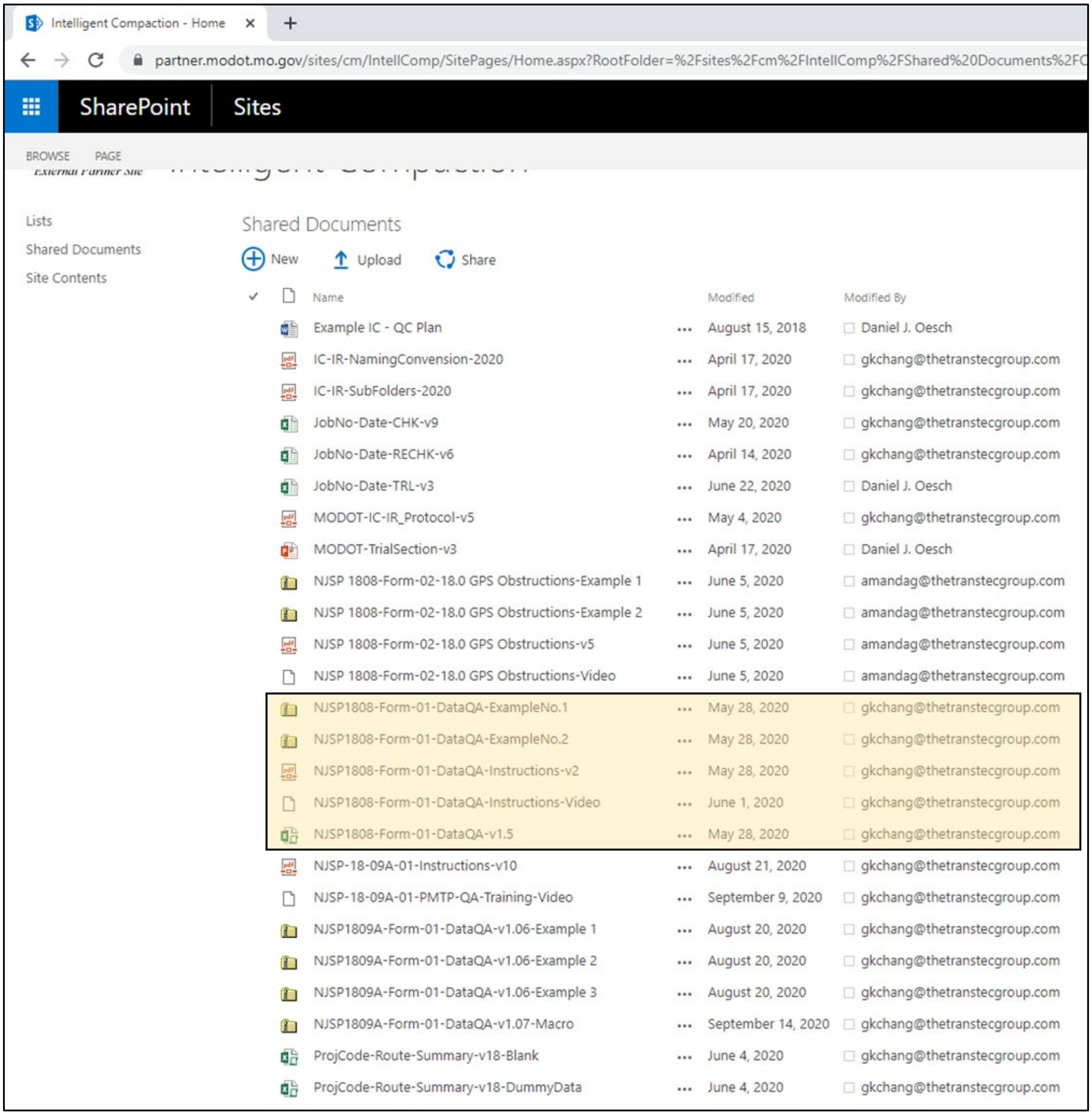
(a) IC Pass Count Data QA

This section summarizes the onsite IC pass count data QA training for Project Code 4.

During the data QA training, the Consultant went through each support item on SharePoint (illustrated in Figure 17). The instruction file for IC pass count data QA was printed and wire-bound to easily access in the field. The training materials for completing the IC data QA can be found on the IC/PMTP SharePoint site. The instructions and other support items include the following:

- Instruction file with step-by-step directions.
- Instruction video tutorial.
- Example data to complete practice analysis.
- Excel Marco sheet used for completing the analysis.

The Propeller DirtMate and hotspot were on site and were mounted on the roller. MoDOT staff had the DirtMate mounting location measurements uploaded to the SharePoint site. Project personnel did not know how to create a DirtMate file on the Propeller site, and therefore, no data had been collected to date. MoDOT personnel had many questions related to the DirtMate and hotspot. Therefore, it was recommended to bring both the DirtMate and hotspot to the office the following morning to troubleshoot. It was recommended that MoDOT mark the mounting location of the DirtMate on the roller so that it could be placed in the same location after troubleshooting. The DirtMate is illustrated in Figure 18, and the hotspot is illustrated in Figure 19.



Source: MoDOT (2021)

Figure 17. Screenshot. IC data QA support items on SharePoint.

Source: MoDOT (2021)

Figure 18. Photo. Propeller DirtMate.

Source: MoDOT (2021)

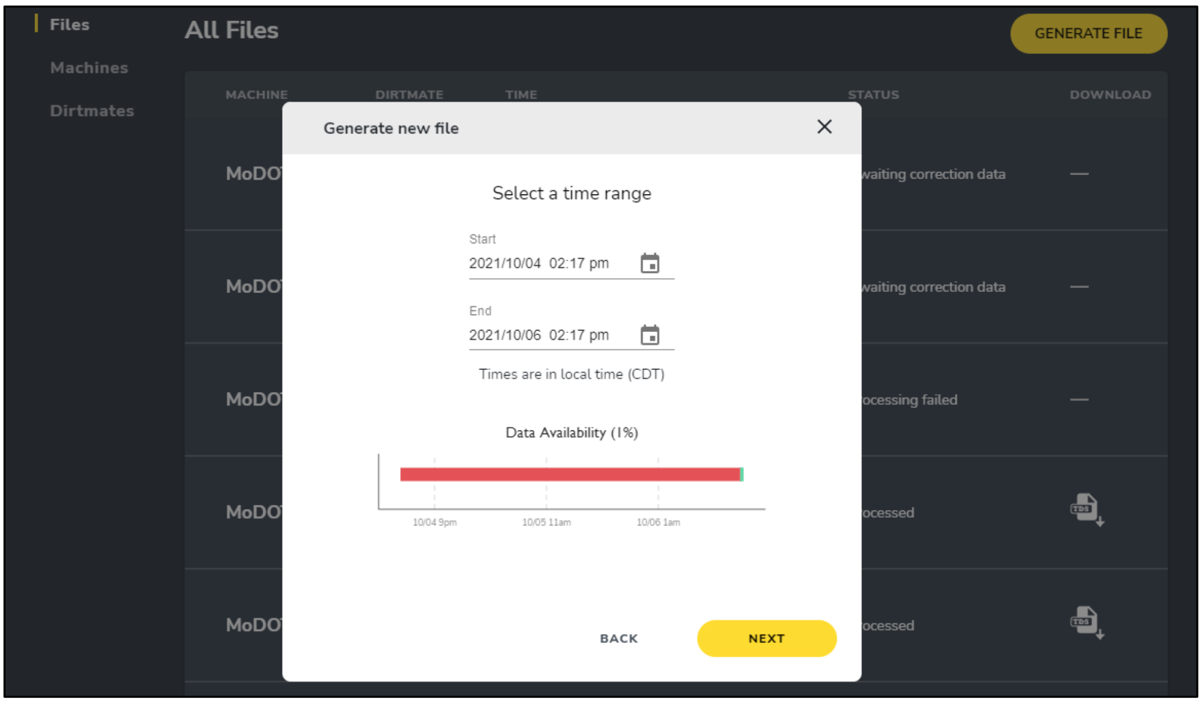
Figure 19. Photo. Propeller hotspot.

Upon arrival to the office for the training, the DirtMate was not connected to the hotspot, and it was unclear if the DirtMate was previously connected. Login credentials were used to connect the DirtMate to the hotspot. The “power” light was solid green, and the “network” light was blinking green, indicating that the DirtMate was on but not charging and that the DirtMate was sending data.

Once the “network” light went off, the participants went to the Propeller website to create a data file from the previous day. Unfortunately, only 1% of data was available between 10/04/2021 and 10/06/2021, as illustrated in Figure 20.

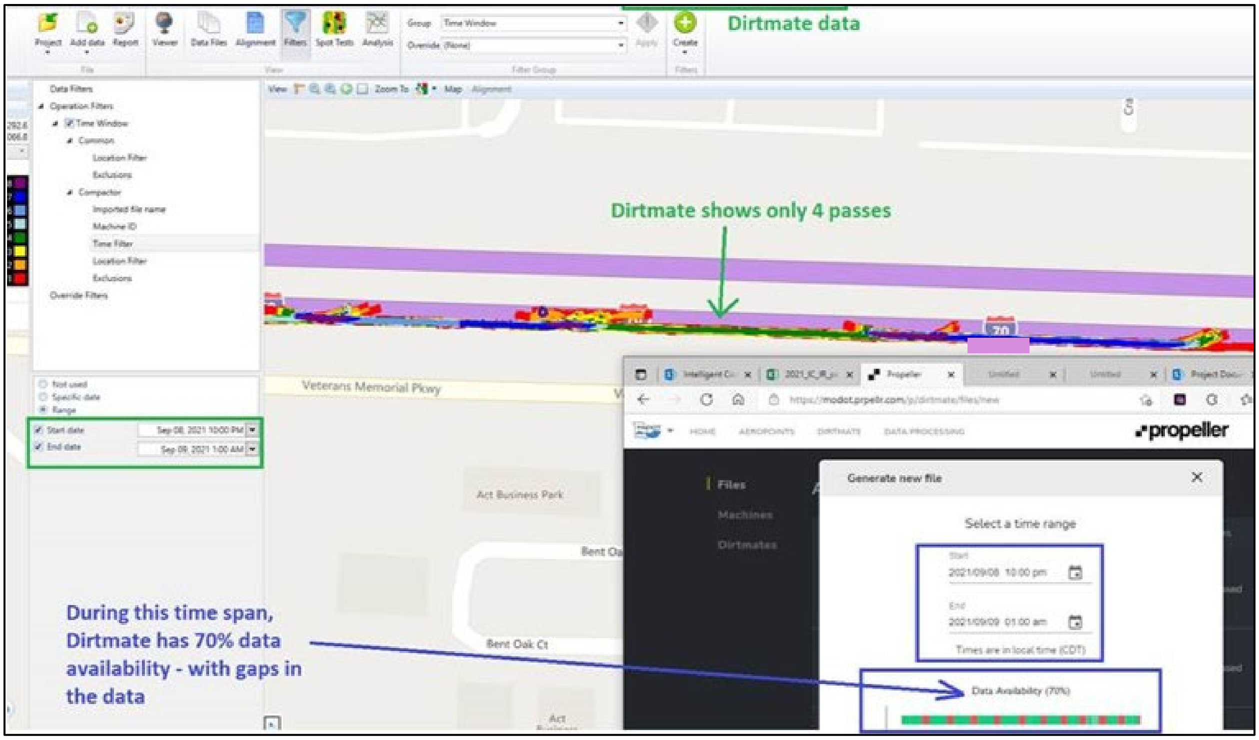
The group called Propeller to troubleshoot, but there was no response. It was recommended that the group reach out to Propeller for support. At the onsite support, MoDOT Field Office staff mentioned the following regarding Propeller support.

- At least two DirtMate devices were not used due to outstanding issues. Propeller mentioned sending a later version of DirtMate to MoDOT, but replacement devices had not been received.
- DirtMates from other projects had some data but not complete data. Therefore, the analyses from the previous projects were invalid. An example of incomplete data from the DirtMate is further illustrated in Figure 21 and Figure 22 (collected from another project).



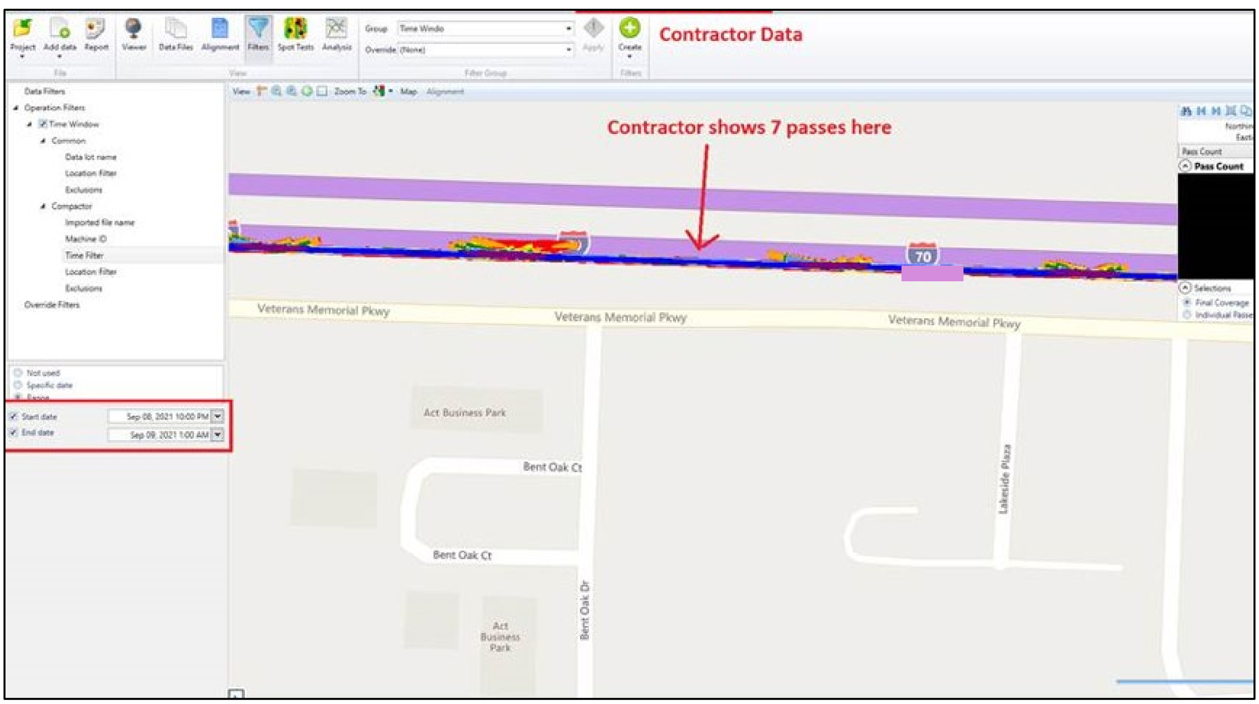
Source: Propeller (2021)

Figure 20. Screenshot. Propeller site shows only 1% of data available from 10/04/2021 to 10/06/2021.



Source: MoDOT (2021)

Figure 21. Screenshot. DirtMate file generation shows only 70% of the data is available.



Source: MoDOT (2021)

Figure 22. Screenshot. Corresponding contractor data pass count is higher than DirtMate pass count (DirtMate shows four passes compared to contractor's seven passes).

Because the DirtMate data collected on 10/05/2021 was invalid, the Consultant showed MoDOT personnel how to perform the analysis using the sample data from SharePoint.

Propeller attended the Feedback meeting held on November 30, 2021, to discuss solutions to the issues with the DirtMate. The details of this discussion are summarized in Chapter 9.

The following points highlight the IC Data QA support:

- There is confusion surrounding the correct setup of Propeller DirtMate and hotspot devices.
- Some DirtMate devices are not in use based on complete malfunction. Propeller has mentioned replacing these devices but has not done so yet.
- DirtMate devices are either completely malfunctioning or failing to collect complete data. Therefore, the data is invalid and can't be used.
- Propeller attended the feedback meeting to discuss some of the issues. The details of the discussion are summarized in Chapter 9.

(b) PMTP Temperature Data QA

This section summarizes the onsite PMTP temperature data QA training for Project Code 4.

The Consultant went through each support item on SharePoint (illustrated in Figure 23). The instruction file for PMTP pass count data QA was printed and wire-bound to easily access in the field. The instructions for completing the PMTP data QA can be found on the IC/PMTP SharePoint site. The instructions and other support items include the following:

- Instruction file with step-by-step directions.
- Instruction video tutorial.
- Example data to complete practice analysis.
- Excel Marco sheet used for completing the analysis.

There was no FLIR camera on the project site. MoDOT personnel had not recently distributed any FLIR cameras to the projects because little data collection occurred on previous projects. Therefore, the Transtec FLIR E5 camera was used to demonstrate procedures. The MoDOT central office personnel said they would deliver a MoDOT FLIR E5xt camera to the project during the following week.

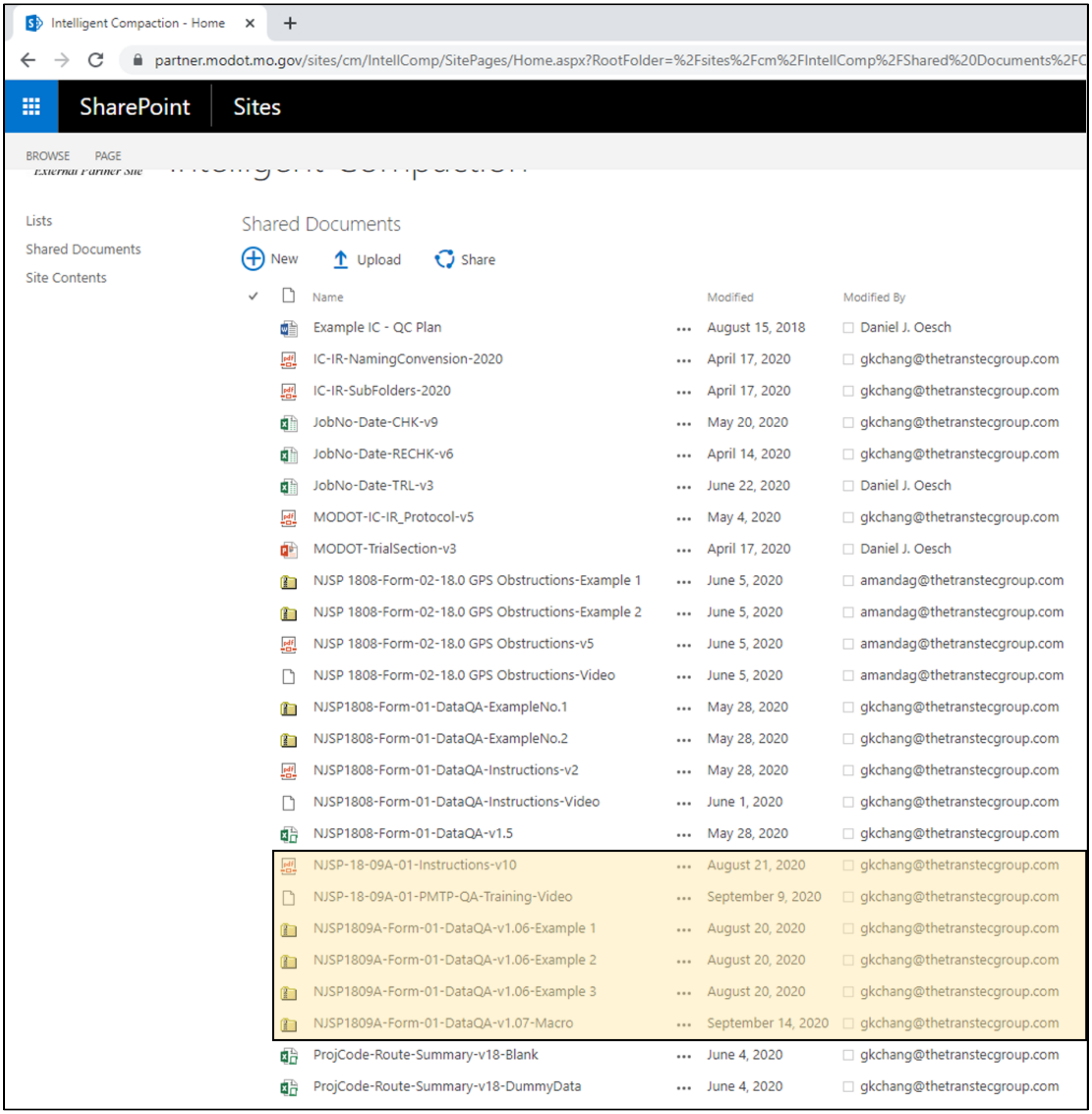
MoDOT personnel did not have a 2x2-foot reference object available to use as a reference marker. Therefore, the participants improvised using fabric testing sacks and the metal calibration plate from the DPS equipment. An example of the improvised reference object is illustrated in Figure 24. MoDOT was advised to use plywood or a more reliable reference object for future testing.

Three FLIR photos were taken with Transtec's FLIR E5 camera at the following times:

- 12:31 pm

- 12:36 pm
- 12:45 pm

This rate is more frequent than recommended. However, it was convenient to take several photos for training purposes. The photos were saved to SharePoint under the project file, and an example FLIR photo is shown in Figure 25.

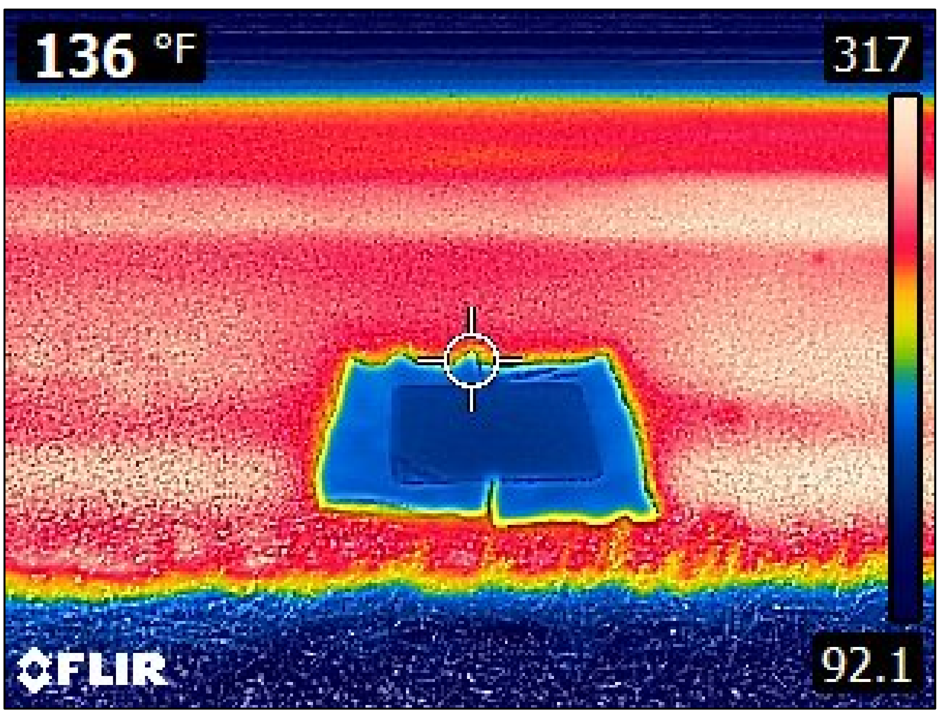


Source: MoDOT (2021)

Figure 23. Screenshot. PMTP data QA support items on SharePoint (highlighted).

Source: MoDOT (2021)

Figure 24. Photo. Improvised reference object met the dimensions required and stayed below 150˚F during testing.



Source: MoDOT (2021)

Figure 25. Photo. Example FLIR photo was taken according to the directions in the instruction file.

The following morning, the participants met at the MoDOT Field Office to analyze the data. The contractor data from the previous day was downloaded from SharePoint. Unfortunately, most of the data was invalid, and therefore, none of the FLIR E5 images had matching, valid contractor data for analysis. Therefore, the data could not be analyzed. It was recommended that the MoDOT project personnel notify the contractor immediately of the invalid data to avoid future issues with PMTP data collection.

Because the contractor data was invalid, the consultant showed MoDOT personnel how to perform the analysis using the sample data from SharePoint. The training included the entire process in the instructions file, including setting up the working folder.

5.3 TASK 4-2: REMOTE TECHNICAL SUPPORT

Table 4 summarizes the projects that received remote technical support. The project and contractor are identified using random codes. Only MoDOT personnel have access to the codes. Remote technical support was provided on an as-needed basis. Projects received support for the following reasons:

- The contractor requested support.
- The RE requested support.
- Issues were discovered during routine quality checks, analysis, or data management. More information regarding quality checks is described in section 5.4.

Table 4. Summary of projects that received remote technical support.

Contractor Code	Project Code	Project Support Description
7	2	The contractor was using new vendor software. The data was not uploading successfully in Veta. Upon inspection of the vendor export file, the Consultant realized that the file contained half pass data (e.g., each direction forward or backward is considered a half pass). Veta was modified to accept half pass data. The contractor was still using MOBA reporting for PMTP results, which is no longer accepted in the MoDOT specifications. The Consultant assisted the contractor with analyzing and reporting PMTP data in Veta. The compaction temperatures on the project were very low. The Consultant recommended that plant and paving temperatures be investigated.
8	8	The contractor used two vendors for IC data collection, and Veta only supports one vendor type. Assisted the contractor with specialized data analysis and management and recommended working with the RE to decide how to move forward. The contractor used a new PMTP vendor and needed assistance to import the data correctly in Veta. IC pass count data QA was collected for the project. The project staff had issues with data “halos,” a phenomenon where the DirtMate creates a falsely high pass count. The data “halos” were discussed at the feedback meeting and are detailed in Chapter 9.
12	11	The contractor was not analyzing the IC and PMTP data in one project. The consultant notified the contractor of the new protocols and assisted with the new analysis procedures using Veta 6.0.

Contractor Code	Project Code	Project Support Description
4	14	The contractor was having issues using exclusions correctly. Exclusions can only be used in the same filter as the boundary file (e.g., if the exclusion only applies to the IC data, the IC data must include the boundary coordinate data). The consultant provided instructions on how to use exclusions correctly.

5.4 TASK 4-3: DATA QA CHECKS

Random data quality checks were performed on the intelligent construction data uploaded to the SharePoint site. Standard quality checks included the following:

- Data management checks, including standard naming convention, file management, and missing or incomplete data.
- Data analysis checks, including correct filtering, legend customization, and analysis setup. Data analysis procedures are further described in section 6.2.
- Data reporting and transfer of results to the summary sheet.

The reoccurring data quality issues discovered during the data quality checks are summarized in Table 5. The reoccurring data quality issues are frequent, moderate, or infrequent. Ranking the issues will help better understand the most common data quality issues. It may be beneficial to discuss the most common data quality issues in future training sessions to minimize them in future construction seasons.

The data quality checks from 2020 are described in the 2020 annual report. The data quality issues from 2020 were emphasized in the 2021 training workshops, and many were not repeated.

Table 5. Summary of data quality issues discovered during data quality checks and frequency of occurrence.

Data Quality Issue	Description	Frequency of Occurrence (frequent, moderate, infrequent)	Recommendations
Incorrect naming conventions and data file management.	Standard naming conventions and file management were commonly incorrect.	Frequent	Data management is often not considered critical during data collection. However, if data management protocols are not followed, it is easy to lose data, and analysis becomes more complex and time-consuming. These protocols should be emphasized in future training sessions, and REs should be trained to check for proper data management. It is recommended that MoDOT adopt "data lot names" according to AASHTO PP 114-21. The Consultant recommended piloting AASHTO PP 114-21 data lot names for the 2022 construction season, as described in Chapter 9.
Incorrect setup of equipment.	Data headers are visible in the Veta data files screen. Vendors should include data headers according to relative AASHTO standards. In some cases, the PMTP paving width was less than the actual paving width, and therefore, the entire width of mat temperatures was not collected. Other common equipment issues included invalid IC machine name types, and some contractors used only one machine name for all rollers. If machines don't have unique names, it is impossible to filter by roller, making the proposed data QA procedures impossible to execute.	Moderate	Equipment setup varies by vendor, and contractors should work with their equipment vendors to correctly set up the equipment settings. In future training sessions, unique machine IDs for IC rollers should be emphasized so QA procedures can be executed (described in the 2020 report).
Using the wrong SharePoint Site	Several contractors uploaded IC data and project analysis to a SharePoint site other than the IC-PMTP SharePoint site. The Consultant can only access the data from the IC-PMTP project site.	Moderate	Many contractors and REs didn't realize that the data and reporting should be uploaded to the IC-PMTP site per the protocols. It is important to use the right IC-PMTP site so that the Consultant can provide contracted support and data QA checks.

Data Quality Issue	Description	Frequency of Occurrence (frequent, moderate, infrequent)	Recommendations
Incorrect analysis setup.	Some contractors did not customize the pass count legend to match the optimum pass, making the report challenging to review and understand. Some contractors also used incorrect analysis options.	Infrequent	Contractors should customize the pass count legend to efficiently use the coverage pie charts to match the optimum pass. Proper data analysis should be emphasized in future training sessions, and REs should be trained to check the reports for the correct analysis setup. New Veta 8.0 features can help identify when standard filtering options are not used.
Incorrect data transfer to the summary sheet.	The most common data transfer mistakes included incorrect MTOP (using the final coverage temperatures instead of the optimum pass), incorrect IC coverage (using final coverage instead of the optimum pass), and incorrect percent of target ICMV (incorrect target value). Less frequent transfer mistakes included typos during PMTP data transfer.	Infrequent	REs should be trained to check for the most common data transfer mistakes and perform quality checks on the contractor data. Future training sessions should emphasize the correct transfer of report results to the summary.
Analyzing PMTP and IC data separately.	Some contractors continued to analyze the data files in a separate project.	Infrequent	The analysis procedures changed significantly from Veta 5.2 and Veta 6.0 because now multiple data types can be analyzed in the same project. A learning curve is expected as the contractors learn the new procedures, and it is anticipated that this will become less frequent in future construction seasons.
Using multiple IC vendors on one project	Two contractors used multiple IC vendors on one project. Multiple IC vendors make analysis difficult since Veta can only support one IC vendor per project.	Infrequent	Contractors should be reminded that Veta only supports one IC vendor per project.

5.5 SUMMARY

Due to the impact of COVID-19, most IC-PMTP project support was conducted remotely in 2021. Remote support included assistance to REs and contractors during data analysis, and data quality checks were randomly performed on the data uploaded to the intelligent construction SharePoint.

Due to personnel turnover and evolving technology and protocols, it is recommended that training sessions and technical support are continued.

The most common data quality issues are summarized in Table 5. These were ranked as frequent, moderate, or infrequent. These commonly occurring issues should be emphasized in future training sessions to minimize the same issues in future construction seasons. This table should be a resource for REs to understand and watch for common mistakes during their QA checks of contractor data. “Train the trainer” training is recommended to support REs and MoDOT Field Office staff to aid in data QA checks.

CHAPTER 6 PROJECT DATA ANALYSIS AND RESULTS

6.1 PROJECT OVERVIEW

The projects completed during the 2021 construction season and the IC and PMTP equipment vendors used for each project are shown in Table 6. Contractors and projects are displayed anonymously by a code. The contractor and project codes are decoded in Appendix A (removed for the public version).

Three different IC vendors were used during the 2021 season, including Topcon retrofit, Trimble retrofit, and Volvo original equipment manufacturer (OEM). Moba Pave-IR and Caterpillar (CAT) were the PMTP vendors used.

Table 6. Summary of IC-PMTP projects.

Project Code	Contractor Code	IC System	PMTP System
1[a]	No Data	No Data	No Data
2	7	Trimble	Moba Pave-IR
3	12	Volvo	Moba Pave-IR
4	5	Trimble	Moba Pave-IR
5	5	Trimble	Moba Pave-IR
6	1	Volvo	Moba Pave-IR
7	8	Volvo	Moba Pave-IR
8	8	Volvo/Topcon	CAT
9[b]	No Data	No Data	No Data
10	5	Trimble	Moba Pave-IR
11	12	Volvo	Moba Pave-IR
12	5	Trimble	Moba Pave-IR
13[c]	No Data	No Data	No Data
14	4	Topcon	Moba Pave-IR
15	4	Topcon	Moba Pave-IR
16[d]	No Data	No Data	No Data

6.2 PROJECT ANALYSIS

Projects were analyzed in Veta using the procedures and requirements in the protocols and specifications. A summary of the data analysis process is described in this section.

6.2.1 Data Import and Legend Customization

The daily IC and PMTP data were imported to one project file using applicable coordinate systems. Multiple equipment types in one project were a new feature of Veta 6.0.

[a] Completed in 2020.
[b] Combined with project code 10.
[c] No data on SharePoint
[d] Not listed on SharePoint

The pass count legend was customized to reflect the optimum pass count established during the trial section.

6.2.2 Project Filters

The project filters were more complex than previous versions of Veta due to the new feature of supporting multiple data types in one project. Table 7 summarizes the filters that were used to analyze the data.

Table 7. Summary of filters used for analysis.

Filter Type	Filter Name	Applicable Equipment	Description
Data Filter	Temperature	PMTP	Filters the temperatures that are less than 180˚F.
Operation Filter	Common Location Filter	IC	Filters the IC data using a paved area boundary collected using GPS equipment. Custom endpoints are used as the start and stop locations for sublots.
Operation Filter	PMTP Location Filter Override	PMTP	Overrides the common location filter. This filter is required because the GPS precision does not meet the precision of the boundary GPS, and therefore, data may not fall within the boundary. Custom endpoints are used as the start and stop locations for sublots.
Operation Filter	Cold Edge and Ride Bracket	PMTP	Statistically removes cold edges of adjacent pavement or paver smoothing skis.

6.2.3 Spot Tests

The core locations and resulting densities were added to the spot tests screen. Adding the spot test locations and resulting values in Veta was not explicitly required in the specifications. Therefore, this was not always completed.

6.2.4 Analysis

6.2.4.1 IC Setup

The IC setup includes selecting final coverage, all passes, and individual pass data. Required data metrics for analysis include pass count, ICMV, and temperature. Sublot analysis was not required but was recommended as an additional quality control tool.

A cumulative pass count specification was set according to the optimum pass count established during the trial section. The pass count legend was customized to match the optimum pass count described in section 6.2.1. Acceptance was set at 90 percent.

A cumulative ICMV specification was set using the target ICMV determined during the trial section or determined during the first production day of paving. Acceptance was set at 75%. This specification is for information only and does not affect payment.

Veta 6.0 only allows for cumulative data specifications. The MoDOT temperature specification is based on the mean temperature at the optimum pass (MTOP). Veta does not have a feature at this time to support individual pass specifications, so contractors manually checked this.

6.2.4.2 PMTP Setup

PMTP sublots were analyzed at 150 feet, and Paver stops were removed from the analysis using the optional Veta function. The only required data metric for analysis was the temperature, but speed was recommended as an extra quality control tool.

The PMTP data were analyzed according to the differential specification described in AASHTO PP 80-17.

6.2.5 Reporting

PDF reports were generated for each system (IC and PMTP) and uploaded to SharePoint with associated data. The following results were pulled from the reports and manually input into the supplemental excel summary sheet:

- IC Overall coverage was reported for pass count data (based on the optimum pass).
- IC Overall acceptance percent of ICMV (percent of target value).
- IC MTOP
- PMTP number of low, moderate, and severe segregation classifications.

6.3 PROJECT RESULTS

This section includes a summary of IC and PMTP results from the 2021 construction season and 2017 through 2021.

6.3.1 2021 Construction Season

The following sections include the results for the 2021 construction season. The data were assessed for meeting data management, IC, and PMTP protocols. All IC and PMTP results are based on the contractor's submitted summary sheet. Some projects did not upload a summary sheet to the IC SharePoint site, as summarized in Table 8. Therefore, these project results are not included. Several contractors submitted the data to a different SharePoint site specific to their projects. *It should be emphasized in the future 2022 training programs that the data needs to be uploaded to the IC SharePoint site.*

6.3.1.1 Data Management Results

The data management protocols were revised for the 2020 and 2021 seasons. The data management revisions are described in the 2020 annual report. A learning curve for implementing the new protocols was anticipated. Several projects did not follow the standard naming conventions. While these management protocols may seem fastidious, they are essential for successful data management. Data organization will significantly impact finding the files for analysis, QA checks, and future research or assessment. Failure to implement standard naming conventions and folder structures could lead to misplaced or lost data and cause a delay in analysis activities.

The data management protocols include contractor data submission and RE data submission. Table 8 and Table 9 summarize the 2021 data management assessment for contractors and REs, respectively. The results below assess whether the data was submitted to the IC SharePoint site. Due to the anticipated learning curve of new protocols, the assessment does not evaluate whether the data met the exact naming convention or folder structure. However, it is recommended that data management be emphasized in training workshops before the 2022 construction season.

The legend for the tables is described as follows:

- Y (shaded green): Yes, data was submitted to IC SharePoint
- N (shaded orange): No, data was not submitted to IC SharePoint
- P (shaded yellow): Some data was submitted. Some data were incomplete or missing.
- N/A (shaded gray): no data was submitted for the project.

Table 8. Contractor data management results.

Project Code	Contractor Code	Trial Section Data	PMTP Data	IC Data	Daily Production Boundary	Spot Test Data	Veta Projects	Daily Contractor Forms	Summary Sheet
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	7	N	Y	Y	Y	Y	Y	N	Y
3	12	N	Y	Y	Y	P	Y	N	Y
4	5	Y	Y	Y	Y	Y	Y	Y	Y
5	5	Y	Y	Y	Y	Y	Y	Y	Y
6	1	N	Y	Y	N	N	Y	N	Y
7	8	Y	Y	Y	Y	P	Y	Y	Y
8	8	Y	Y	Y	Y	N	P	P	N
9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10	5	Y	Y	Y	Y	Y	Y	Y	Y
11	12	Y	Y	Y	Y	N	Y	Y	Y
12	5	Y	Y	Y	Y	Y	Y	Y	Y
13	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14	4	N	Y	Y	Y	Y	Y	Y	Y
15	4	N	Y	Y	Y	Y	Y	Y	Y
16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Most contractors submitted the required data to the IC SharePoint site, and the most common missing data is the trial section data. Contractors should be encouraged to submit their trial section data for verification.

Table 9. RE data management results.

Project Code	Contractor Code	RE Checklist	RE QA[a]	RE Diary
1	N/A	N/A	N/A	N/A
2	7	N	N	N
3	12	N	P	N
4	5	N	N	N
5	5	N	N	N
6	1	N	N	N
7	8	N	N	N
8	8	N	N	N
9	N/A	N/A	N/A	N/A
10	5	Y	N	Y
11	12	P	P	P
12	5	N	N	N
13	N/A	N/A	N/A	N/A
14	4	P	P	P
15	4	P	P	P
16	N/A	N/A	N/A	N/A

General observations from Table 9 include the following:

- Few REs are uploading the checklist and diary to SharePoint.
- REs may be completing the checklist and diary but not uploading them to SharePoint. These files are recommended to be uploaded to SharePoint to complete the database.
- Some REs could collect data QA, but few could perform the analysis successfully. More information on the data QA pilot projects is described in Chapter 3. Data QA training will be emphasized in the 2022 construction season.

6.3.1.2 IC Results by Project

The IC data are evaluated according to MoDOT specification NJSP-18-08. A summary of the criteria is as follows:

- IC coverage: IC coverage is based on the coverage within the daily paving boundary at the optimum pass. Coverage less than 70 percent is considered deficient, coverage between 70 and 90 percent is considered moderate, and coverage above 90 percent is considered passing.
- Target ICMV: The final coverage overall ICMV should be greater than 70 percent of the target ICMV. Segments that do not meet 70 percent are flagged but do not affect price adjustments. The overall ICMV result is for information only due to commercially available ICMV equipment limitations, as described in the following paragraph.

[a] The data QA procedures were only piloted in the 2021 construction season. Therefore, it was not expected to be completed for every project.

- Mean temperature at the optimum pass (MTOP): The overall mean temperature at the optimum pass shall be 180˚F. Segments that do not meet this requirement are considered deficient.
- Passing segments receive price incentives. Moderate segments receive no price adjustment. Deficient segments receive price disincentives.

Many contractors are not reporting the target ICMV results or are incorrectly reporting the target ICMV results. A few contractors have provided feedback as to why this data is missing. Some contractors do not understand how to correctly determine a target ICMV value, which is covered in the training materials but continues to be confusing. Other contractors admit they do not understand why they should report the information when repeatedly not meeting the target ICMV from the test section. Not meeting the target ICMV may be related to the following reasons:

- Many contractors are using equipment only capable of level 1-2 ICMVs. These ICMVs are the least sophisticated, not capable of measuring layer-specific properties, and do not provide valid solutions for the roller's decoupling or double-jumping from the pavement. Many material and equipment variables affect the level 1-2 ICMV measurement (FHWA 2017). Therefore, consistent ICMV may not be achievable.
- Despite the efforts made by contractors, it can be difficult to achieve the same conditions between test sections and mainline paving. Changes in roller speed, asphalt temperature, and other variables will affect the ICMV. A difference in conditions between the test section and mainline paving may cause an invalid target ICMV value.
- ICMV curves must be created using only vibratory compaction. It is important to filter out static passes to create a valid ICMV curve to determine a target value. Contractors using combined vibratory and static compaction efforts will produce invalid ICMV curves and thus an invalid target value.

Because the target ICMV is for informational purposes only, it is not critical to MoDOT's short-term implementation program. As equipment capable of collecting level 4-5 ICMVs becomes commercially available, it may become a critical IC evaluation and acceptance component. Because there is not enough valid ICMV data, the target ICMV are not included in this report.

A summary of the 2021 IC coverage (% of the optimum pass) is shown in Figure 26. The chart shows the average IC coverage, the segment classification thresholds, and the optimum pass count for each project.

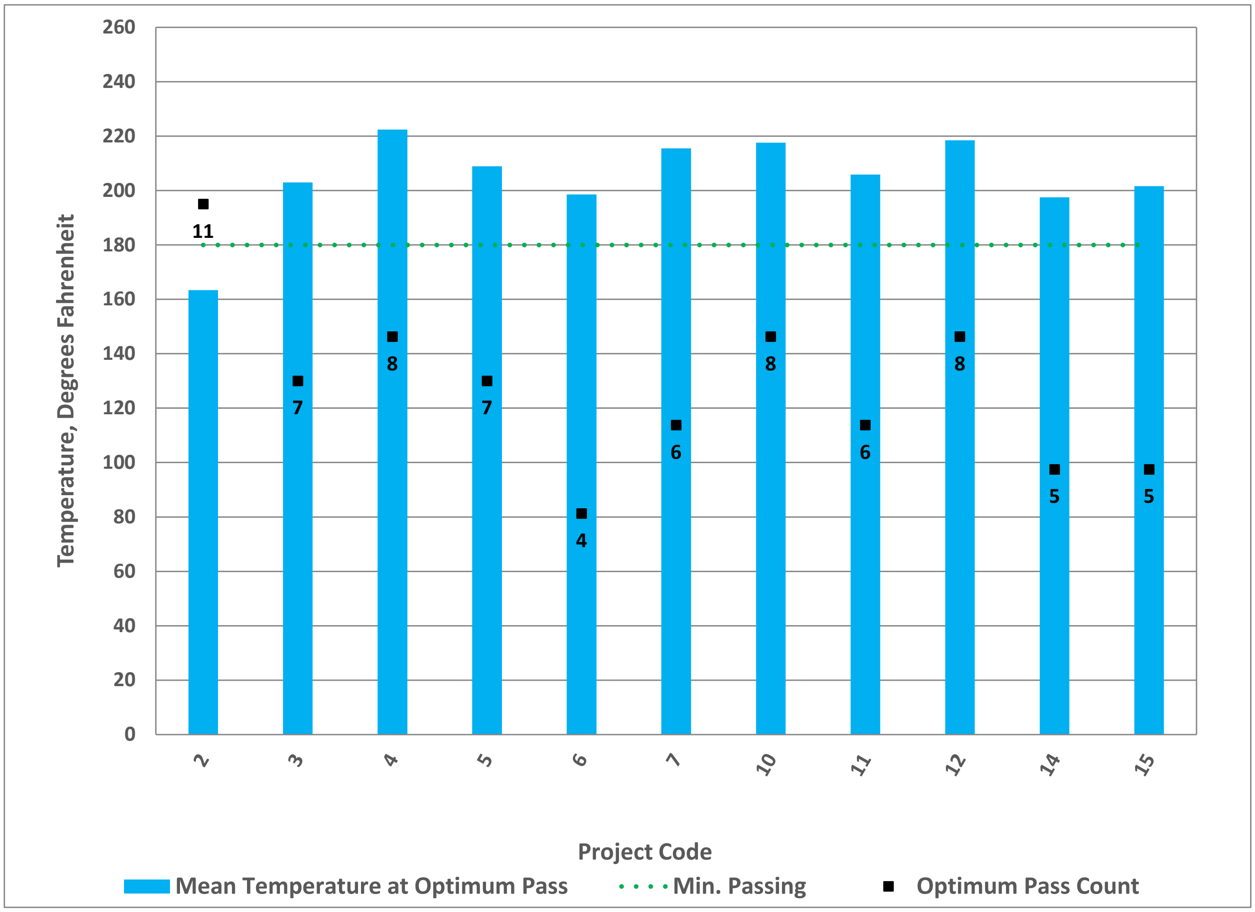
Source: Project Team (2021)

Figure 26. Chart. Average IC coverage per project and optimum pass counts.

General observations from Figure 26 include the following:

- Three projects are above the 90 percent (passing) threshold, eight are between the 70 (moderate) and 90 percent thresholds, and no projects are below the 70 percent threshold.
- Optimum pass counts range from four to eleven. There is no clear trend between optimum pass count and IC coverage.

A summary of the average MTOP for each project in 2021 is shown in Figure 27.



Source: Project Team (2021)

Figure 27. Chart. The average mean temperature at optimum pass count per project and optimum pass counts.

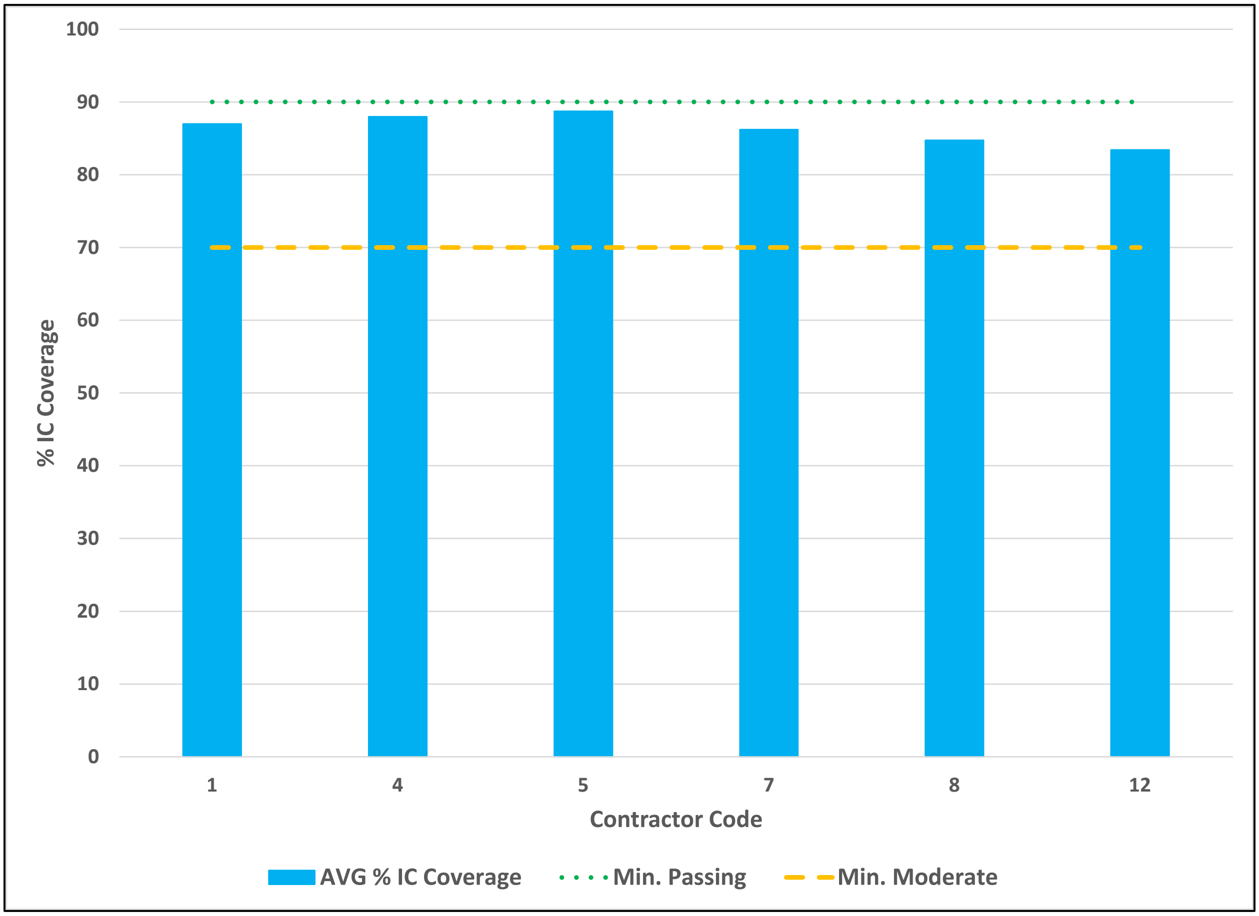
General observations from Figure 27 include the following:

- All projects have an overall average MTOP at or above 180 degrees.
- There is no clear trend between optimum pass count and MTOP.
- Project code number 2 had a higher pass count (11) than other projects and did not meet the MTOP.

Some projects had individual production days, or segments, with MTOP less than 180˚F. However, these were generally isolated (except for project code 2), resulting in overall averages above 180˚F.

6.3.1.3 IC Results by Contractor

A summary of the IC coverage (% of the optimum pass) is shown in Figure 28. The chart shows the average IC coverage for each contractor (average of results for all 2021 projects completed by the contractor).



Source: Project Team (2021)

Figure 28. Chart. Average IC coverage per contractor.

General observations from Figure 28 include the following:

- All of the contractors had average IC coverage above the moderate threshold.
- None of the contractors had IC coverage above the threshold for the price incentive (90%).
- IC coverage was consistent among contractors, with average coverage ranging from 83 to 89 percent.

6.3.1.4 PMTP Results

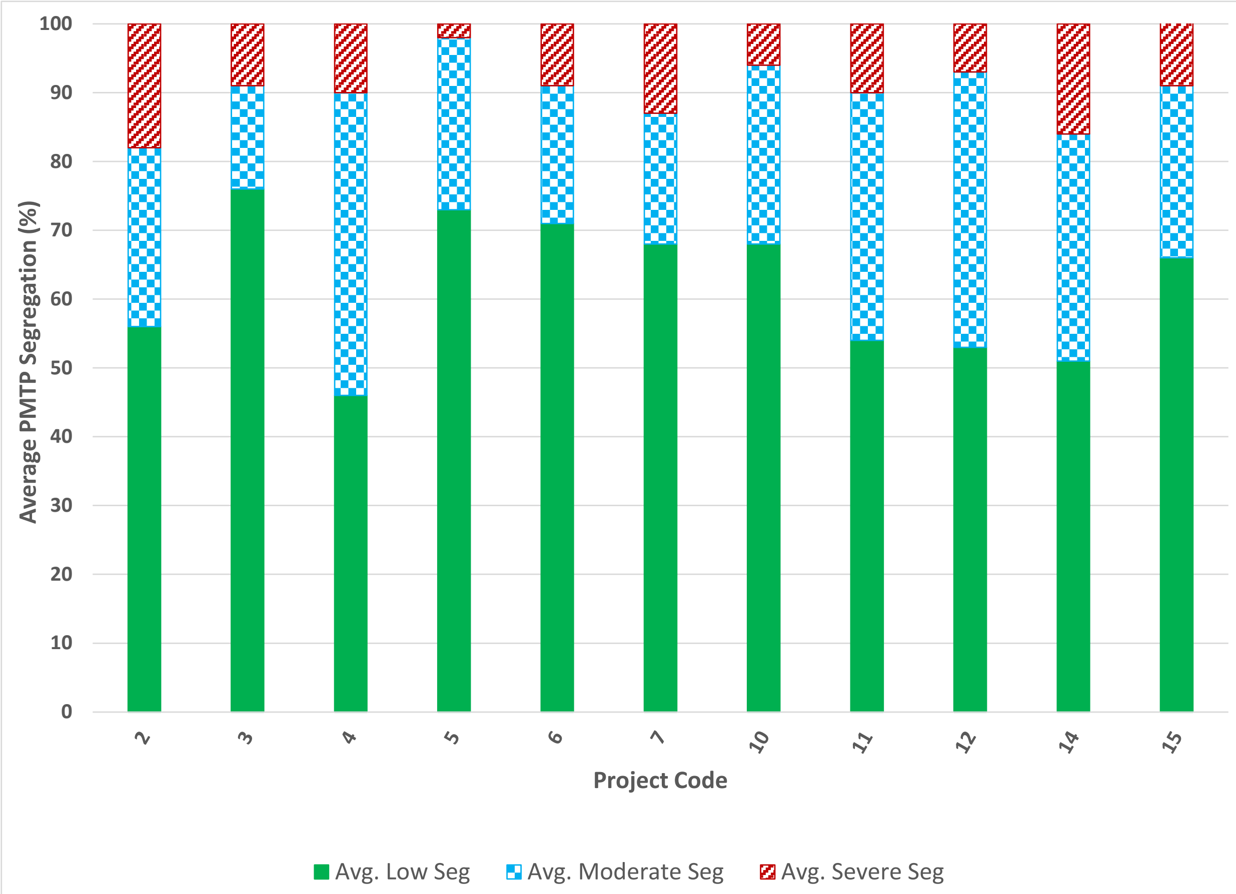
The IC data are evaluated according to NJSP-18-09. A summary of the criteria is as follows:

- The work shall be completed per AASHTO PP80-17. A summary of the temperature differential (TD) specification is shown in Table 10.
- Low thermal segregation receives price incentives, moderate thermal segregation receives no price adjustment, and severe thermal segregation receives a price disincentive.

Table 10. AASHTO PP80-17 temperature differential specification and thermal segregation categories.

Temperature Differential (TD)	Thermal Segregation Category
TD ≤25.0˚F	Low
25.0˚F < TD ≤ 50.0˚F	Moderate
TD > 50.0˚F	Severe

A summary of the PMTP results is shown in Figure 29. The chart shows the overall average thermal segregation category for each 2021 project.



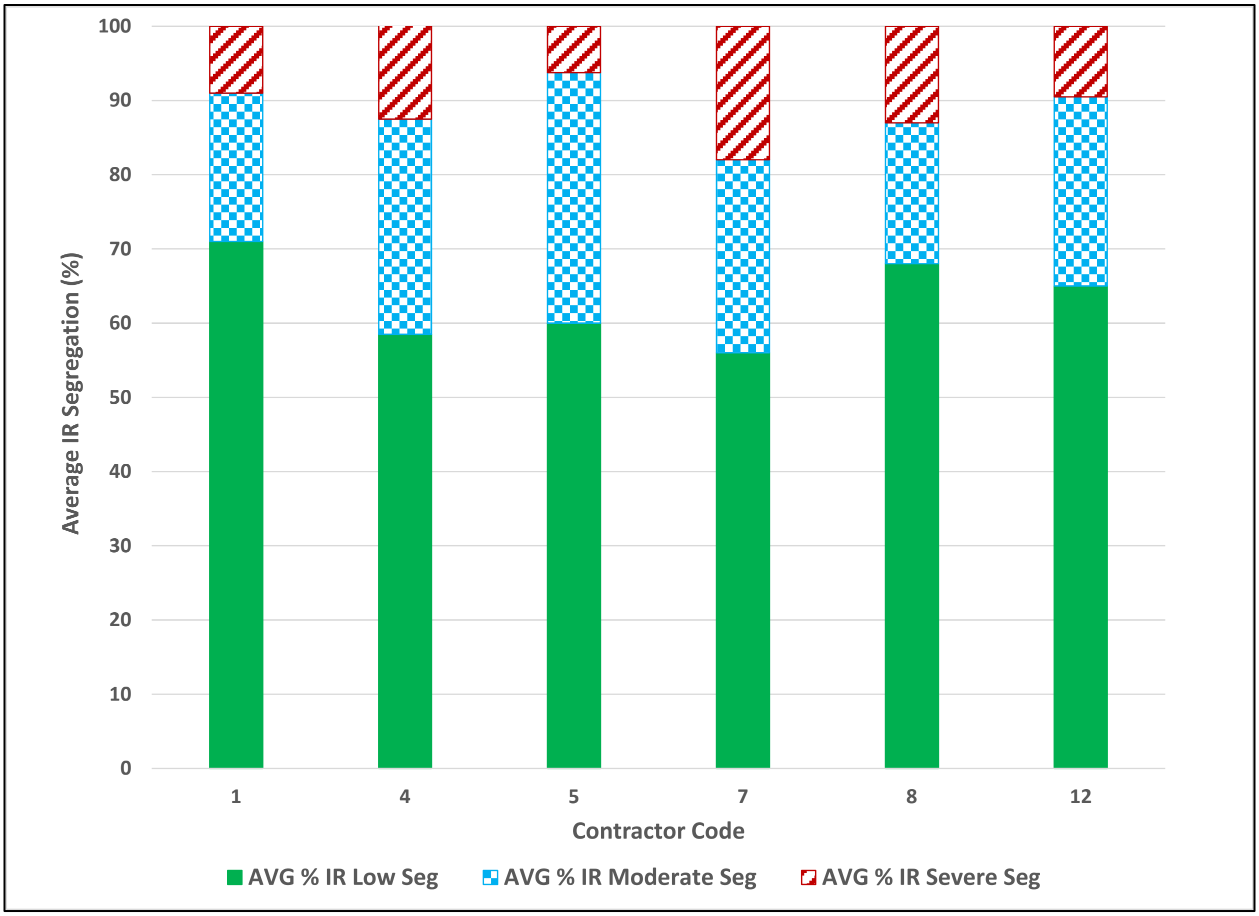
Source: Project Team (2021)

Figure 29. Chart. Average thermal segregation classification for each project.

General observations from Figure 29 include the following:

- Seven projects had less than 10 percent severe segregation.
- Four projects had between 10 and 20 percent severe segregation.
- No projects had more than 20 percent severe segregation.
- Three projects had over 70 percent low segregation.
- One project had less than 50 percent (half) low segregation

A summary of each contractor's overall average thermal segregation category (average of results for all 2021 projects completed by the contractor) is shown in Figure 30. All contractors had averaged 50 percent (half) low segregation and less than 20 percent severe segregation.



Source: Project Team (2021)

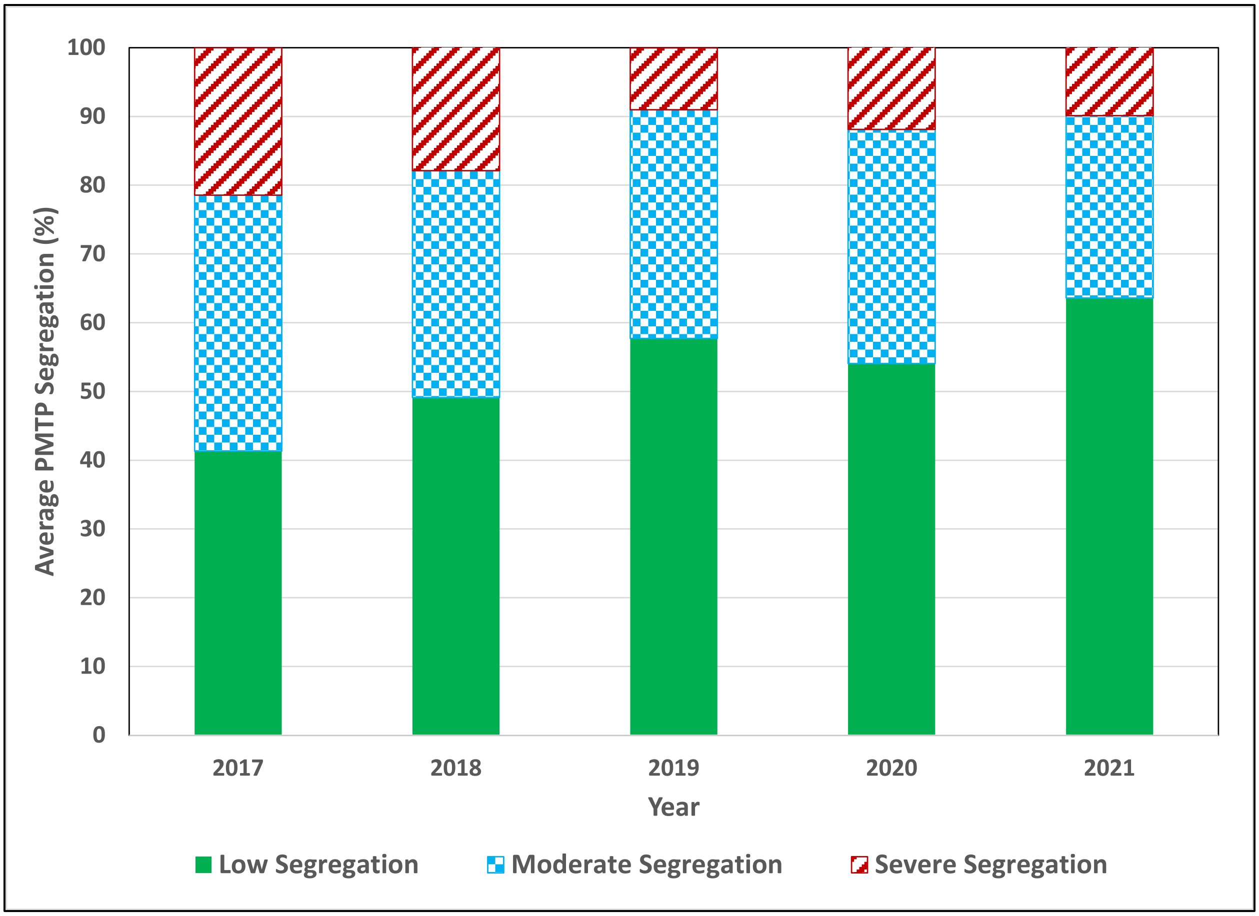
Figure 30. Chart. Average PMTP thermal segregation classification per contractor.

6.3.2 2017 Through 2021 Construction Seasons

Data from 2017 through 2021 were compiled to identify general trends.

6.3.2.1 PMTP Data Trends

The average thermal segregation classifications were averaged across all projects during each construction season. The average PMTP segregation classifications are illustrated in Figure 31.



Source: Project Team (2021)

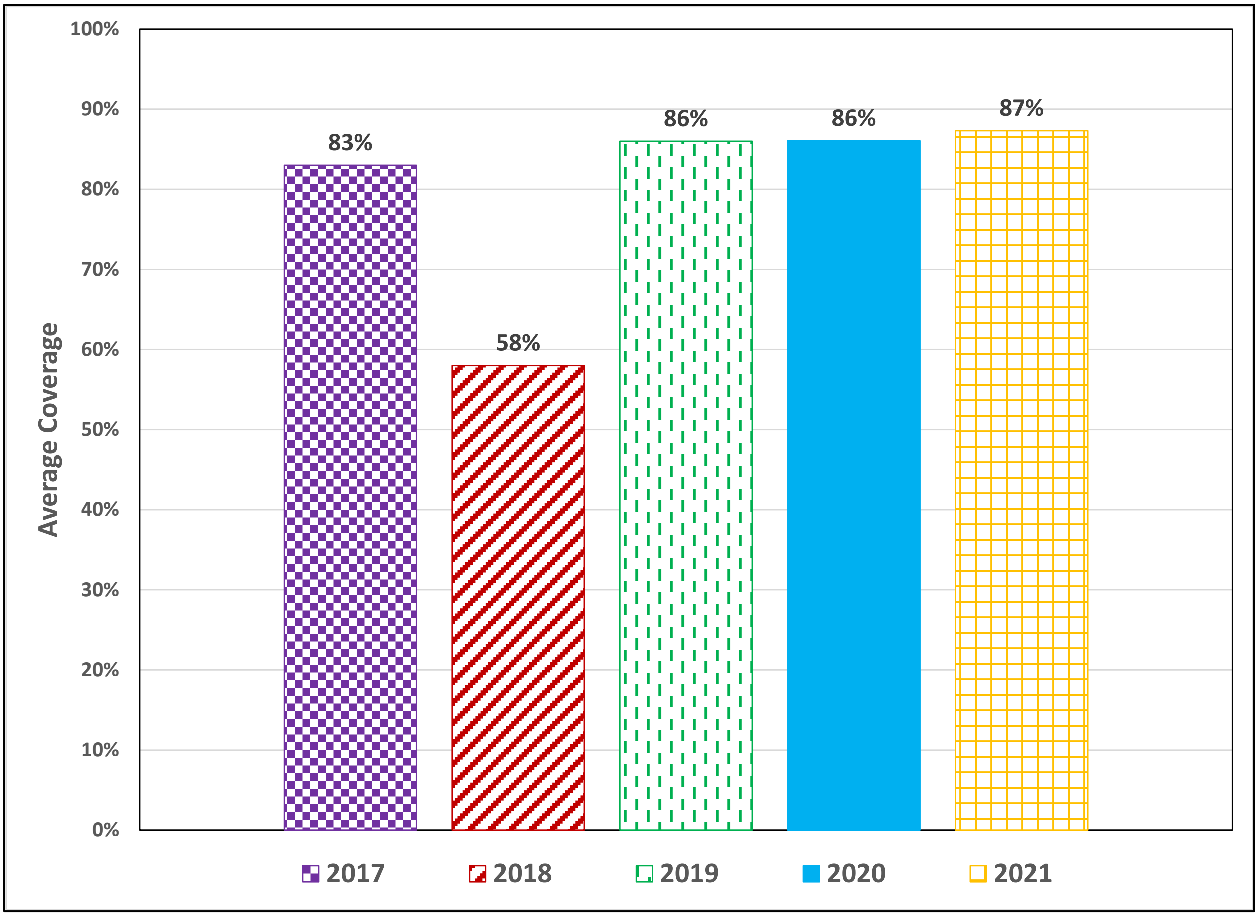
Figure 31. Chart. Average PMTP thermal segregation classification for all projects per construction season.

General observations from Figure 31 include the following:

- Low segregation (TD < 25˚F) increases from 2017 to 2019. There is a slight decrease of less than four percent from 2019 to 2020, followed by an increase in 2021.
- There was a slight decrease in moderate segregation (25.0˚F < TD ≤ 50.0˚F) from 2017 to 2018. No significant changes in moderate segregation are observed from 2018 to 2020, and there is a slight decrease in moderate segregation from 2020 to 2021.
- Severe segregation (TD > 50.0˚F) decreases from 2017 to 2019. There is a slight increase of less than four percent from 2019 to 2020, followed by a decrease in 2021.
- Overall, the PMTP data trend shows that using this technology may improve thermal segregation by promoting successful practices.

6.3.2.2 IC Coverage Data Trends

The average IC percent coverage was averaged across all projects during each construction season. The average IC percent coverage trends are illustrated in Figure 32.



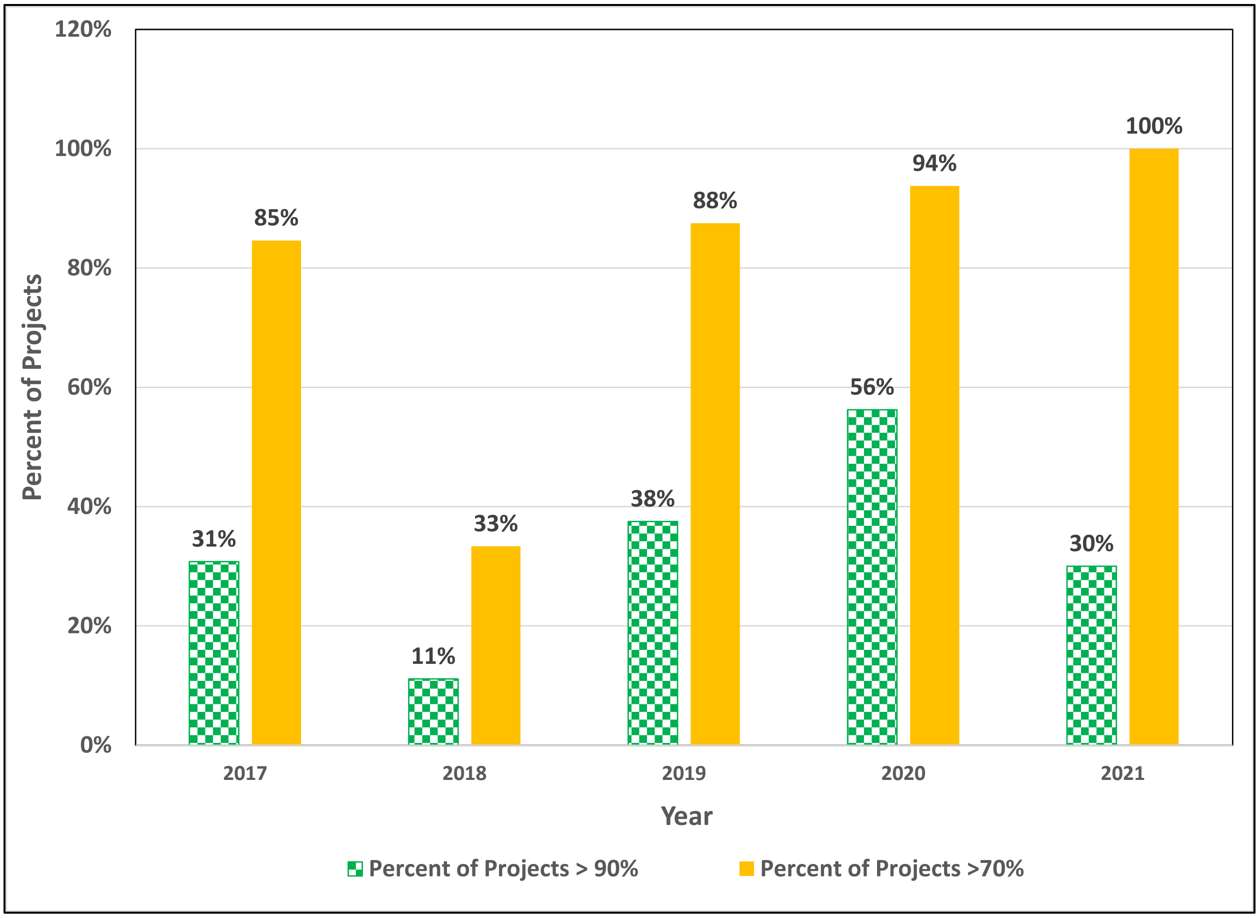
Source: Project Team (2021)

Figure 32. Chart. Average IC percent coverage for all projects per construction season.

General observations from Figure 32 include the following:

- The average IC percent coverage in 2017 was 83 percent, and the average IC percent coverage in 2019 and 2020 was 86 percent and 87 percent in 2021. IC coverage is consistent from 2019 to 2021.
- The year 2018 shows an average percent coverage of 58%. The low IC coverage is attributed to the learning curve associated with the technology and specifications. Nearly every project had onsite support in 2017, and the onsite support in 2018 was significantly less. Therefore, most contractors used the technology without additional technical support. The consistently higher IC percent coverage in 2019 through 2021 indicates that many contractors may better understand and implement the IC technology.

The same IC data were analyzed for the percent of projects that met the 70 percent threshold (moderate, no incentive, or disincentive) and the percent of projects that met the 90% threshold (passing, eligible for an incentive) illustrated in Figure 33.



Source: Project Team (2021)

Figure 33. Chart. Percent of projects that meet the 70 percent and 90 percent thresholds per construction season.

General observations from Figure 33 include the following:

- The percentage of projects that meet the 70 percent threshold increases each year, except for 2018. The lower coverage in 2018 is attributed to the learning curve associated with the technology, as previously described in Figure 32.
- In 2021 there was a decrease in projects that met the 90% threshold for price incentives. However, all projects met the 70 percent threshold.
- Consistent rolling patterns that meet the optimum pass specific to each project and the mix is widely recognized as a critical quality control measure. These trends indicate an improvement of this metric by using IC.

The MTOP has only been required per the protocols since the 2019 construction season. The average MTOP was 210˚F in 2019, 211˚F in 2020, and 203˚F in 2021. The MTOP trend indicates that achieving the minimum MTOP of 180˚F is reasonable, achievable, and consistent since implementation in the specification and protocols.

6.4 SUMMARY

The strengths of the 2021 construction season are summarized as follows:

- A higher percentage of projects in 2021 achieved the 70 percent IC coverage threshold than any other year since implementation in 2017. This may indicate acceptance of technology by contractors, increased understanding, and successful implementation of IC.
- Thermal segregation classifications are similar to those of 2019. Since its implementation in 2017, there have been more low segregation classifications and less severe segregation classifications. This may indicate acceptance of technology by contractors, increased understanding, and successful implementation of IC.
- In general, the contractors follow intelligent construction protocols and data analysis. There was an improvement in data analysis understanding from 2020 to 2021.

The lessons learned and areas for improvement based on the data analysis results of the 2021 construction season are summarized as follows:

- Some contractors are not including spot test data in Veta. Spot test data will become increasingly important as MoDOT fully implements intelligent construction and reduces pavement coring. Emphasis on spot test data should be considered in future training sessions.
- The contractors are struggling to report the correct percent of target ICMV. ICMV is for informational purposes only and does not affect price adjustments. However, even the level I/II ICMV data can still be a valuable quality metric. ICMV data analysis and selection of a target value should be emphasized so that contractors can better understand and use ICMV data on their projects.
- Few REs submit their diaries and intelligent construction data checks to the intelligent construction SharePoint Site. It is recommended that REs begin uploading their diaries and data checks to SharePoint for successful data management.
- Contractors and MoDOT personnel do not consistently follow data management, including naming convention and folder management. Data management should be emphasized during the 2022 construction season. It is recommended that MoDOT pilot the AASHTO PP 114 Data Lot Names in 2022, as described in Chapter 9.

CHAPTER 7 TASK 5-PAVEMENT PERFORMANCE TRACKING

7.1 CORRELATING THE PMTP SEGREGATION DATA WITH LABORATORY PERFORMANCE TESTS

The results of the PMTP temperature segregation and performance test correlation were summarized in the 2020 report. An IC-PMTP project conducted by MoDOT in 2017 was considered a case study to develop this correlation. The temperature data from a MOBA Pave-IR PMTP were analyzed in Veta to identify the uniform sections (areas with relatively low thermal segregation) and non-uniform sections (areas with relatively high thermal segregation) within a 150-foot long sublot. The thermal segregation index (TSI) was calculated for each section. Cores were taken and tested within each test section to calculate the cyclic fatigue index parameter S_{app} as the laboratory performance test. The correlations between temperature differential and Sapp and TSI and S_{app} showed that fatigue resistance (S_{app}) generally decreases with increasing TSI and temperature differential. The separate correlations for uniform and non-uniform sections were not strong enough to conclude and require more data.

7.2 IC-BASED DENSITY MODEL

7.2.1 Density Model Description

Chang et al. (2014) developed a model to estimate the HMA density at different times and locations based on IC measurement values. Extensive field measurement (in-place density) and laboratory data collection, data analysis, and IC measurements are required to use this model. This model was developed using field data from across the country. The multivariate nonlinear model is described in Figure 34:

$$\rho(i,j) = \rho_0 + (\rho_{max} - \rho_0) \times e^{-\left[\frac{a_1 ICMV(i,j) + a_2 f(i,j) + a_3 V_R(i,j) + a_4 (T(i,j) - T_r)}{j}\right]^{\beta}} + \varepsilon(i)$$

Where:

ρ is the density with GPS location index *i* and time index *j*,

ρ_0 is the initial density (pass count=0),

ρ_{max} is the maximum density G_{mm},

T and T_r are mat temperature and reference temperature, respectively,

f is the vibration frequency,

V_R is the roller speed, and

$\varepsilon(i)$ is the fixed effect error term across the location.

Figure 34. Equation. The multivariate nonlinear model was used to estimate density using IC data.

7.2.2 Data Collection and Analysis

The HMA density results in the MoDOT projects from 2017 to 2020, either from NDG or laboratory tests, were gathered in a spreadsheet by the Consultant. To find the missing density data, the Consultant followed up with those projects' REs in the spring and winter of 2021 and filled out some missing data. A total of 1,600 spot tests were identified, among which 1,000 HMA density data were collected. The main reasons for the remaining missing data are (1) the data spreadsheets were not completed at the time of construction, and it is difficult to track down the data now (2) the RE is no longer with MoDOT and has been replaced. The Consultant is currently compiling the density data from 2021 projects.

7.2.3 Results of IC-Based Density Prediction

Once the missing spot test and IC data from 2021 projects from the REs are received, the IC-based density model described above will be used to estimate the density at any time and location of the pavement.

7.3 SUMMARY

The correlations between temperature differential and Sapp and TSI and S_{app} showed that fatigue resistance (S_{app}) generally decreases with increasing TSI and temperature differential.

The IC-based HMA density model will estimate the in-place density of pavement at any location and time, which requires collecting as much density and IC data as possible per project. Past HMA density data from NDG or laboratory testing from 2017 to 2021 is being collected for future analysis efforts.

CHAPTER 8 TASK 6-FEEDBACK MEETING AND EXECUTIVE BRIEFING

8.1 INTRODUCTION

The 2021 feedback meeting was a hybrid meeting held on Tuesday, November 30, 2021, in Jefferson City and via Microsoft Teams. This chapter summarizes key discussions from the feedback meeting and recommendations for future construction seasons.

8.2 MEETING AGENDA

The meeting agenda from the feedback meeting is shown in Table 11. The morning and late afternoon sessions were closed meetings with MoDOT personnel and the research Consultant (Transtec). The midday sessions were open to all contractors, vendors, and MoDOT personnel.

Table 11. Feedback meeting agenda.

Time	Location	Topic	Participants
8:00 AM – 9:00 AM	MoDOT office	Closed Project Meeting	MoDOT Field Office staff, MoDOT Research staff, the Consultant (Transtec), and designated MoDOT REs
9:00 AM – 9:15 AM	Break	Break	Break
9:15 AM – 12:00 PM	MoDOT office and video conference	Open 2020-2021 IC-PMTP project results and feedback	MoDOT, Transtec, contractors, and vendors
12:00 PM – 1:00 PM	Break	Break	Break
1:00 PM – 2:00 PM	MoDOT office and video conference	The Path Forward – How can MoDOT Help You	MoDOT, Transtec, contractors, and vendors
2:00 PM – 2:15 PM	Break	Break	Break
2:15 PM – 3:15 PM	MoDOT office	Closed Debriefing and Future Planning	MoDOT leadership, MoDOT Field Office staff, MoDOT Research staff
3:15 PM	Adjourn	Adjourn	Adjourn

8.3 KEY DISCUSSIONS

The following sections summarize the key discussions held during the meeting.

8.3.1 Data Management

There was a learning curve with data analysis in 2020 due to significant changes from Veta 5.2 to Veta 6.0 (as detailed in the 2020 annual report). Veta 6.0 allows users to import multiple equipment types into one project. Therefore, the data filtering process was different from previous versions. In 2021 few contractors struggled with data filtering and analyzing projects according to specifications and protocols.

Data management, including naming convention and folder organization, needs improvement. Current protocols require contractors to name files and organize data into the appropriate folders manually, and many contractors still choose their naming convention and folder organization despite published protocols. A new AASHTO provisional practice (PP) titled 114 "Data Lot Names for use with Intelligent Construction Technologies" was recently published. AASHTO PP 114 includes protocols for including data lot naming conventions in the data files or simply "in data" once stored in the Cloud database. In other words, the data DOT-specific naming convention is within the data, not simply just in the file's name.

The data lot naming convention is necessary for the automated Veta filter group generation and is supported by the future Veta Web (estimated deployment in 2024). Therefore, it is recommended that MoDOT pilot AASHTO PP 114 in 2022 and 2023. Since the data lot naming convention is set up daily for each operation (e.g., paving a specific lane), onsite technical support and training will be needed for contractors and IC-PMTP dealers. Piloting AASHTO PP 114 will prepare vendors and contractors for entire data lot naming implementation in Veta Web and ultimately improve data management and streamline and standardize data management.

8.3.2 Data QA

Several challenges were associated with Data QC for IC pass count and PMTP temperature data verification, and challenges were briefly summarized in Chapter 3. General issues with Data QA were mainly from a lack of understanding and training and limited resources (personnel) to perform the analysis. Due to COVID-19, training and resources were limited. The staffing/resources and training discussions are described in sections 8.3.3 and 8.3.4, respectively.

Specific discussions regarding each data QA process are described in the following sections.

8.3.2.1 IC pass count data QA

The biggest challenge with IC pass count data QA was related to the equipment, and the equipment vendor attended the feedback meeting to propose resolutions to the issues. The equipment issues and proposed resolution from the vendor are summarized in Table 12.

Table 12. IC pass count data QA equipment issues and resolutions.

Issue	Description	Proposed Resolution
Equipment Failure	Several DirtMates completely malfunctioned and would not hold a charge or collect data.	New editions of the equipment are more stable and durable. The old DirtMates should be replaced with new editions.
Missing Data	Few projects were able to collect 100% data using the DirtMates. Therefore, data QA could not be performed.	New editions of the equipment are more stable and durable. The old DirtMates should be replaced with new editions. The missing data may be related to the hotspot connection, and the vendor recommended discussing other alternatives to avoid this issue in the future.

Issue	Description	Proposed Resolution
Data "Halos"	DirtMate still collects data when stationary while the GPS drifts around the area. The continuous collection of the stationary roller creates a spot, or "halo," with falsely high pass count data. The falsely high pass count is significantly higher than the optimum pass count (typically over 20 passes). Therefore, it is statistically significant.	The Consultant will meet with the equipment vendor research and development team to explain the halo issue and describe how IC vendors overcame the issue.

8.3.2.2 PMTP Temperature Data QA

The most common issues associated with PMTP temperature data QA and the proposed resolutions are summarized inTable 13.

Table 13. PMTP temperature data QA equipment issues and resolutions.

Issue	Description	Proposed Resolution
Invalid Event Marker	The purpose of the event marker was not explained in detail. Therefore, several REs used event markers that were not the correct dimensions. The vendor data spacing varies but is generally around 12 by 12 inches. Therefore, the event marker must be larger than the data spacing to be viewed in Veta.	It is recommended that all REs be provided a designated event marker before the 2022 season. The event marker should be heat resistant and meet the criteria of the data QA protocols.
Invalid Images	Some REs did not follow the instructions for taking FLIR thermal pictures. This instruction was on SharePoint but not in the specifications since PMTP data QA was still being piloted.	Onsite training and explaining the purpose of the pilot project will aid REs in following the protocols. Laminating a quick reference guide with the event marker may improve the images.
Time Stamps	The timestamps of the FLIR camera and roller vendor should match, which requires coordination with the contractor.	Onsite training and explaining the purpose of the time clocks will aid REs in following the protocols.
Incomplete PMTP Data	Incomplete PMTP data was observed during the onsite field support from Project Code 4. The details of the data issues are described in section 5.2.	Contractors are responsible for collecting the data per the specifications. Contractors should be encouraged to contact vendors when data loss occurs.

8.3.3 Staffing and Resources

A participating RE at the meeting described losing 50 to 60 percent of project staff and limitations with properly implementing IC-PMTP protocols, including data QA. Staff limitations lead to rotating staff through different projects, making it difficult to keep trained personnel who understand the IC/PMTP technologies, Veta analysis, and data QA procedures. Sometimes IC-

PMTP data are not reviewed until after the project is complete, eliminating the opportunity to use the data to improve operations and quality.

The district requested assistance with daily QA checks of the contractor data and running the data QA analysis. MoDOT Field Office staff would like to assist with IC-PMTP support but must receive proper training on the procedures. It is recommended that the Consultant provide interim support to districts while simultaneously training MoDOT Field Office staff to assist in the future. Specific proposed training programs are described in sections 8.3.4 and Chapter 9.

8.3.4 Training

The consensus was that in-person training was preferred over remote training if possible, depending on COVID-19 protocols. At this time, limited in-person meetings and training are allowed per MoDOT's policies. The following feedback was made regarding training:

- Before projects start, MoDOT prefers annual in-person workshops followed by refresher training (just-in-time training, or JITT).
- Spend more time on hands-on exercises rather than IC-PMTP theory.
- Schedule the annual in-person training in February or March before projects start.
- Schedule JITT training regionally to coincide with the start of projects.
- Upload training videos on the MoDOT IC-PMTP site. Make the site easier to navigate so that training materials are easily accessed.

8.3.5 Miscellaneous

8.3.5.1 IC Boundary Collection

A common request is to make the boundary collection for IC data more efficient. There are commercially available technologies that can collect IC boundaries at traffic speed, and such technologies can be piloted in future construction seasons.

8.3.5.2 Dielectric Profiling Systems

An FHWA loaned Rolling Density Meter (RDM 2.0), a GPR-based DPS technology, was piloted on selected projects in 2021 to measure dielectric constant profiles, which can be correlated against cores or gyratory samples to predict density. The 2021 RDM pilot projects had mixed success due to the GSSI sensor and software issues. Additional products such as Earth Science Systems (ESS) and 3D RADAR can be considered for further DPS pilot studies.

8.3.5.3 Updated AASHTO Standards

AASHTO PP 81 "Standard Practice for Intelligent Compaction Technology for Embankment and Asphalt Pavement Applications" will be published as AASHTO R 111 in 2022. AASHTO PP 80 "Standard Practice for Continuous Thermal Profile of Asphalt Mixture Construction" will be published in AASHTO R 110 in 2022. The MoDOT specifications and protocols should be updated to reflect the updated standards.

8.3.5.4 DPS

At this time, MoDOT does not plan to purchase a DPS. If possible, they will keep and pilot the FHWA loaned DPS in the 2022 season. The Field Office mentioned logistical and safety challenges with collecting data behind the finish roller, and it was particularly unsafe at night with limited lighting on the project. If the technology evolves to be vehicle-mounted and data can be collected at traffic speeds, MoDOT may be interested in investing in the technology at that time.

8.4 RECOMMENDATIONS FOR 2022 AND BEYOND

There are 15 IC-PMTP projects scheduled for 2022. The 2022 projects reference the 2021 specifications for IC and PMTP. Recommendations for MoDOT's IC-PMTP program based on the lessons learned in the 2020-2021 construction seasons are described in the following sections.

8.4.1 Training

A description of recommended training services for 2022 is summarized in Table 14.

Table 14. Recommended training for 2022.

Training	Description
Statewide IC-PMTP Workshop	• The statewide workshop should be a one-day, in-person classroom event to prevent overnight travels for MoDOT staff. • The 2022 and 2023 training should be held in early March or before the first project starts. • The training should be held in a big conference room at the MODOT office on Missouri Blvd. • The training should focus on understanding the IC, PMTP (and DPS) technologies, and Veta analysis to fulfill the MODOT IC and PMTP specifications requirements. • The training should not include hands-on equipment practices.
Train-the-Trainers (TTT)	• A "train-the-trainers" workshop should be a half-day to one-day, in-person classroom event. • A TTT should be conducted on the following day after the statewide training for the MoDOT Field Office team and selected MoDOT staff. • TTT aims to gradually prepare MODOT staff to provide in-house technical support to IC-PMTP projects.
Just-in-Time-Training (JITT)	• JITT should be a half-day, in-person classroom and equipment practice event. • Any JITT should be scheduled close to the start of the first projects of the "region" (e.g., combining two districts) for the upcoming project contractors and MODOT REs/inspectors. • JITT should focus on hands-on data QA equipment operation (DirtMate GPS tracker and FLIR camera) and Veta analysis. • The data QA equipment operation during the practices should be recorded as videos.

Training	Description
	• Propeller is anticipated to provide DirtMate support either remotely or in person.
MoDOT Training Page	• Create a dedicated training web page on the MODOT website that does not require login information. • The webpage should include organized training PPT, videos, instruction files, and Veta/Excel Macro examples. • The training videos should include data QA equipment field operation and step-by-step Veta/Excel Macro analyses.

8.4.2 IC-PMTP Protocols and Specifications

The data management folder structure and data file naming convention (compatible with MoDOT's project file naming convention) should be updated. The new AASHTO PP 114 "Data Lot Names for use with Intelligent Construction Technologies" standard should be implemented and piloted in 2022 and 2023. Data lot naming convention is not a file naming convention. Instead, "data lot names" are included in the header block of data. Implementing the data lot naming is compatible with the automated Veta filter group generation. It is recommended to be adopted in future MODOT IC-PMTP specifications after piloting it in 2022 and 2023.

The IC pass count data QA should be updated to address the issues in 2020-2021, e.g., DirtMate should not be switched between rollers; the rollers should be named correctly in the IC data (e.g., using equipment models or serial numbers).

The PMTP temperature data QA should be updated to address the issues in 2020-2021, e.g., The purpose of the event marker was not explained in detail; laminating the instructions and checklist on the event marker should be helpful.

The updated IC-PMTP protocols should be compatible with respective AASHTO PMTP (R 110) and IC (R 111) standards, as well as ICT data standard (R 39) and Data Lot standard (PP 114).

8.4.3 Project Support

Technical support for 2022 and 2023 projects is recommended. The level of technical support for each selected IC-PMTP project should be determined by MoDOT based on its specific needs. The Consultant project support will be coordinated as follows:

- MoDOT's Field Office team will help manage the projects and schedule the appropriate support level (onsite or remote).
- The Consultant will work with vendors for IC/PMTP support to assist contractors in setting up the AASHTO data lot naming convention before projects start.
- The Consultant will participate in preconstruction meetings to coordinate project support. MoDOT Field Office staff will provide the Consultant with the contractor and MODOT REs contacts for each project.
- MoDOT Field Office staff may also perform the project data QA analysis. The Consultant should assist if needed.

Project support will be either remote or onsite. Onsite field support will target projects whose personnel have little or no prior field experience or lack staff and resources.

8.4.4 Pilot Innovative Technologies

Under MoDOT's instructions, the Consultant should pilot innovative technologies, including but not limited to:

- Efficient Boundary Measurements: New technologies for boundary measurements include:
  - Paver-mounted GPS to obtain paving boundary.
  - Mobile LiDAR scanning on pavement surface to the centerline of pavements can be used to offset the pavement lane edges to create the boundary in Veta.
- Dielectric Profile System (DPS): A FHWA loaned Rolling Density Meter (RDM 2.0), a GPR-based DPS technology, was piloted on selected projects in 2021 to measure dielectric constant profiles, which can be calibrated against cores to predict density. DPS will potentially be an acceptance tool. The 2021 RDM pilot projects had mixed success due to the GSSI sensor and software issues. Additional products such as Earth Science Systems (ESS) and 3D RADAR can be considered for further DPS pilot studies.

8.4.5 Pavement Performance Tracking

Under the direction of MoDOT, the Consultant should continue the performance pavement tracking for selected MoDOT IC-PMTP projects since 2017. The work may include, but not be limited to:

- Investigate the relationship between the IC-PMTP data and core density data using the FHWA IC In-Place Asphalt Density model.
- Investigate and document the field performance observations by MoDOT REs that appear to correlate with IC-PMTP data.

8.4.6 Feedback and Reporting

It is recommended to continue the valuable feedback meetings and reporting to track the progress of the IC-PMTP implementation and continue to reach MoDOT's IC-PMTP goals.

CHAPTER 9 CONCLUSIONS AND RECOMMENDATIONS

9.1 LESSONS LEARNED AND RECOMMENDATIONS

The lessons learned during each of the project tasks are summarized below.

9.1.1 Task 1 – Training Program

Intelligent construction technologies are advancing and changing, and Veta analysis software continues to evolve with technology. Therefore, training will always be a significant part of the success of intelligent construction implementation. It is recommended that general IC-PMTP analysis workshops be held every year as a refresher and to introduce new data collection advancements and analysis.

The data QA procedures are complex and require engineering judgment and a basic understanding of Veta and IC-PMTP project analysis. Most REs have not had to perform any analysis in Veta before the data QA procedures, and there was a learning curve. Therefore, it is recommended that more data QA training be held before the 2022 construction season. These training can be held in refresher training, TTT training, and JITT training.

9.1.2 Task 2 – IC-PMTP Data QA

MoDOT is one of the leading State DOTs focused on implementing data QA procedures for intelligent construction. The long-term goal of data QA is to implement a tool in Veta to automate the process. The Consultant is working with the FHWA, the Transportation Pooled Fund (TPF) Veta study, the National Road Research Alliance (NRRA), and the International Society for Intelligent Construction (ISIC) to study the feasibility of simplifying data QA. Until the process is implemented in Veta, the complex analysis procedures are the best solution for the data QA requirements.

COVID-19 brought many challenges to the 2020 and 2021 construction season, including:

- Reduced work hours for MoDOT personnel (2020 only).
- Limited resources for MoDOT projects.
- Restrictions to travel and Consultant training opportunities.

Additionally, MoDOT IC-PMTP staff were restructured, and the new Field Office team did not have the past years of IC-PMTP knowledge and experience. The restructuring of staff and COVID-19 related challenges made it difficult to pilot the Data QA protocols, and therefore, these should continue to be piloted in the 2022 season.

9.1.3 Task 3 – Pilot Innovation Technologies

DPS was piloted on several MoDOT projects, and one of the projects received field support from the consultant. The technology showed value as several potentially low-quality areas were identified using the DPS. However, there were limitations to the technology, including low-precision GPS, data export files issues, logistical challenges, and safety concerns with data collection.

The logistical challenges with collecting data behind the finish roller relate to contractor-controlled traffic closures, and safety concerns are exacerbated at night with limited lighting on the project. If the technology evolves to be vehicle-mounted and data can be collected at traffic speeds, MoDOT may be interested in investing in the technology at that time.

9.1.4 Task 4 – IC-PMTP Project Supports

Due to the impact of COVID-19, most IC-PMTP project support was conducted remotely in 2021. Remote support included assistance to REs and contractors during data analysis, and data quality checks were randomly performed on the data uploaded to the intelligent construction SharePoint Site.

Data management and the correct setup of data headers and equipment in the vendor software were the most common issues. It is recommended that AASHTO PP 114 Data Lot "Names for use with Intelligent Construction Technologies" be piloted in 2022 to aid in standard naming convention and prepare contractors to use the automated filter naming feature in Veta Web (2024 and beyond).

Other common issues include using the wrong SharePoint site to upload data and data analysis and reporting mistakes. Even minor mistakes can be the difference between price incentive or disincentive. Therefore it is important to perform quality checks on contractor data. It is recommended that quality checks be performed in 2022 and beyond by the Consultant and MoDOT Field Office or project staff.

9.1.5 Project Analysis and Results

Most contractors collect, analyze, and report the data per the specifications and protocols. The biggest challenges are data management (naming convention and folder organization). It is recommended that data management be a focus of 2022 training, particularly with the piloting of AASHTO PP 144. The IC and PMTP trends since implementation in 2017 show an increase in IC coverage, an increase in low thermal segregation, and a decrease in severe thermal segregation.

9.1.6 Task 5 – Pavement Performance Tracking

The data is still being collected under Task 5 and will be continued under future contracts.

9.1.7 Task 6 – Feedback Meeting

The feedback meeting was held on November 30, 2021. The key discussions were related to a need for increased training. Different training programs, including TTT and JITT, are recommended for the 2022 and 2023 seasons.

9.2 SUMMARY

There were many new procedures implemented in 2020 and 2021. Significant changes include a new version and changes to analysis software and new data QA procedures. Learning curves were expected with these changes, and the learning curve was steepened with the effects of COVID-19 and the lack of onsite support. Despite these challenges, the overall outcome of 2020 and 2021 was successful.

The implementation of data QA is critical to MoDOT's full IC-PMTP implementation. Data QA will continue to be a key focus in 2022 and beyond, and training and technical support will be critical for successful implementation.

Overall, the trends in IC-PMTP data results show higher IC pass count coverage, lower and less severe temperature segregation in the asphalt mat, and consistent compaction temperatures compared to previous years. These trends indicate that intelligent construction technologies improve successful construction practices, which may lead to higher quality pavements

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