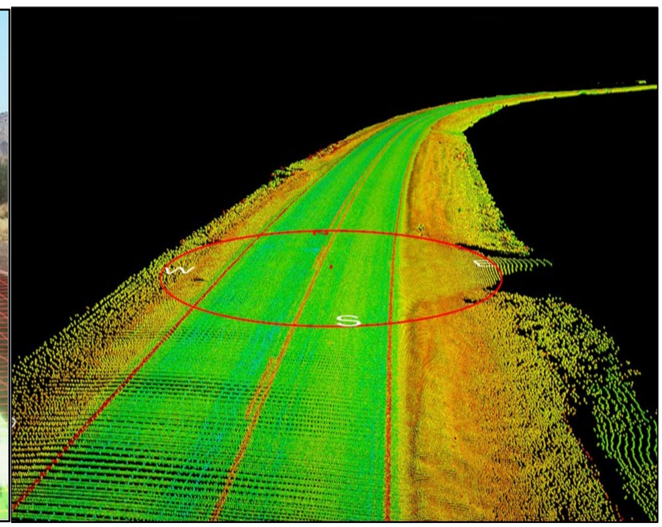
Consultant Support for Intelligent Compaction and Paver-Mounted Thermal Profiling Projects in 2022-2023



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16. Abstract

MoDOT's Intelligent Compaction (IC) and Paver-Mounted Thermal Profiling (PMTP) projects from 2017 to 2021 showed improvements in paving quality, leading to an extension of these projects into 2022 and 2023. The aim was to procure consulting services to maintain the success of IC-PMTP projects. The project spanned 26 months, from March 2022 to April 2024, with this report summarizing the progress in 2023. Key trends since 2017 include increased IC pass count coverage, reduced temperature segregation, and consistent compaction temperatures, indicating enhanced construction practices and pavement quality. MoDOT is dedicated to further developing the IC-PMTP program, focusing on statewide implementation, evolving specifications, comprehensive training, and employing innovative technologies. The 2023 highlights include the adoption of automated boundary collection methods, evolving IC and PMTP specifications with new classifications and price adjustments, a detailed training program, and plans to address cellular or GPS coverage issues in future projects.

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Disclaimer

The opinions, findings, and conclusions expressed in this document are those of the investigators. They are not necessarily those of the Missouri Department of Transportation, US Department of Transportation, or Federal Highway Administration. This information does not constitute a standard or specification.

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List of Abbreviations and Acronyms

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

DUG: ....Daily Use Gateway

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

JITT: ....Just-in-Time-Training

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

SOW: ....Scope of Work

TPF:...............................Transportation Pooled Fund

TSI:................................Thermal Segregation Index

TTT:...............................Train-the-Trainers

UTM: ....Universal Transverse Mercator

Executive Summary

MoDOT's Intelligent Compaction and Paver-Mounted Thermal Profiling (IC-PMTP) projects from 2017-2021 demonstrated paving quality improvements on numerous field projects. Therefore, MoDOT established a plan to include additional IC-PMTP projects in 2022 and 2023. The primary goal of this project was to ensure the continued success of the MoDOT IC-PMTP projects in 2022 and beyond. MoDOT procured consulting support (this project) for selected IC-PMTP projects in 2022-2023 and continued with 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 March 2022 to April 2024 in 26 months. This report is a summary of the completed tasks in 2023. The 2022 report was another report.

Year-to-year trends in IC-PMTP data results show increasing IC pass count coverage, decreasing severe temperature segregation in the asphalt mat, and more consistent compaction temperatures over time since 2017. These trends indicate that intelligent construction technologies help contractors improve successful construction practices, which may lead to higher-quality pavements.

MoDOT is committed to advancing the IC-PMTP program, with plans for statewide implementation in upcoming seasons. The focus remains on adapting specifications, enhancing training, supporting project staff through innovative technologies, and continually improving the IC-PMTP program.

Highlights in 2023 include the following:

Several contractors have adopted alternative methods for measuring paving boundaries that do not require a person to collect the data with hand-held receivers. This aligns with MoDOT's future specifications to improve safety using automated paving boundary data collection.

The IC and PMTP specifications are evolving. The future specifications have new segment classifications and price adjustments. The specifications are still under development, and feedback from the industry is being considered. The new specifications will be released in 2024, with implementation in late 2024 or 2025.

A comprehensive IC-PMTP-Veta training program was implemented in 2022 and 2023, per the recommendations of the 2021 final report. This included statewide workshops, Train-the-Trainers sessions, and Just-in-Time Training sessions. Updates to the MoDOT Training Page on the SharePoint navigator tool were made to reflect these changes.

There were several projects that reported issues with data loss due to poor cellular and/or GPS coverage. Future specifications will require project reconnaissance so that issues with GPS or cellular coverage can be addressed before the project begins.

A mechanistic model for estimating in-situ density of HMA from the IC data was proposed along with the additional data items required for successful training and validation of the proposed model.

Chapter 1. Introduction

Background

The MoDOT 2017-2021 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 2022 and 2023. The primary goal of this project was to ensure the continued success of the MoDOT IC-PMTP projects in 2022 and beyond. MoDOT procured consulting support (this project) for selected IC-PMTP projects and implemented many initiatives such as data quality assurance (QA), performance tracking, future acceptance with IC-PMTP data, and others, as described below.

Project Scope and Summary of Work Plan

This project's Scope of Work (SOW) included seven (7) main tasks from 03/01/2022 to 4/30/2024, spanning approximately 26 months. The tasks of this project are listed as follows:

- Task 1 – Kick-Off Meeting
- Task 2 – IC-PMTP Protocol
- Task 3 – IC-PMTP Training Program
- Task 4 – IC-PMTP Project Supports
- Task 5 – Pilot Innovative Technologies
- Task 6 – Pavement Performance Tracking
- Task 7 – Feedback Meeting and Executive Briefing
- Task 8 – Final Reports
- Task 9 – Data QA Equipment

Structure of Report

This 2023 annual report is a deliverable for Task 8. The rest of this report is structured by task, as summarized in Table 1. This report only includes the work completed in 2023. There is a separate 2022 annual report which summarizes the 2022 efforts (Chang et al., 2023).

Table 1. Structure of the report.

Chapter	Titles
Chapter 1	Introduction
Chapter 2	Task 2 – IC-PMTP Protocol
Chapter 3	Task 3 – IC-PMTP Training Program

Chapter 4	Task 4 – IC-PMTP Project Supports
Chapter 5	Summary of Project Results
Chapter 6	Task 5 – Pilot Innovative Technologies
Chapter 7	Task 6 – Pavement Performance Tracking
Chapter 8	Task 7 - Feedback Meeting and Executive Briefing
Chapter 9	Task 9 – Data QA Equipment
Chapter 10	Conclusions and Recommendations

Chapter 2. Task 2-IC-PMTP Protocol

Introduction

IC-PMTP protocols were revised minimally in 2022 to address some issues found in the 2020-2021 projects. The updates included changes to the IC-PMTP summary sheet and data QA procedures as described in the 2022 report (Change et al., 2023).

In 2023, several specification changes were planned for pilot testing during late 2024 and 2025 projects, with implementation scheduled for subsequent seasons. Training materials will be updated in future projects based on the specification changes. Details of these changes are summarized in the following sections.

Proposed Specification Changes

IC Specification Section 405

The significant changes proposed for the IC specification include the following:

- Updated from "NJSP-18-08" to "Section 405".
- Removed a section on "Formatted Raw Data" and updated the requirements for "Raw Data" to allow user credentials for direct download in lieu of data files.
- Added a requirement to include "anticipated cellular service throughout the entire project" in the IC Quality Control Plan.
- Changed the "Daily Production Boundaries" to be collected in a means that automates the boundary collection without a hand-held rover (e.g., LiDAR technology or other).
- Changed the segment classification (where a segment is one day's production) as follows:
- Passing segments – minimum of 85% coverage at the optimum pass.
- Moderate segments – between 70-85% coverage at the optimum pass.
- Deficient segments – less than 70% coverage at the optimum pass.
- All segments with a mean temperature of less than 180 F at the optimum pass will be considered deficient.
- The incentives and disincentives were removed.
- A section on deficient segments was added, stating that if the density for a deficient segment has not been already declared unacceptable, then an additional density verification shall be performed. The location of the density verification shall be marked by the Engineer based on the coverage shown in Veta. The results of the density verification shall determine actions taken, as shown in Table 2 (SP and BP mixtures other than SMA) and Table 3 (SMA mixtures).

Table 2. Actions for density verification of all SP and BP mixtures other than SMA.

Field density (percent of laboratory max. theoretical density)	Actions to be taken as a result of additional density verification
92.0 to 97.0 inclusive	Continue with PWL.
97.1 to 98.0 or 90.0 to 91.9 inclusive	The lower of 100% Pay or PWL Deduct.
Above 98.0 or below 90.0	Remove and Replace Limits as defined by the Engineer based on density results and coverage shown in Veta.

Table 3. Actions for density verification of SMA mixtures.

Field density (percent of laboratory max. theoretical density)	Actions to be taken as a result of additional density verification
Above 94.0	Continue with PWL.
92.0 to 93.9 inclusive	The lower of 100% Pay or PWL Deduct.
Below 92.0	Remove and Replace Limits as defined by the Engineer based on density results and coverage shown in Veta.

PMTP Specification Section 406

The significant changes proposed for the PMTP specification include the following:

- Updated from "NJSP-18-09" to "Section 406".
- Added a section for "Required Measurements," including the following:
    - The collection of data shall include shoulder pavement when placed simultaneously with the mainline. The shoulder paving data will be filtered out using Veta during data processing.
    - PMTPS measurements are not required on auxiliary lane tapers, ramps, shoulders (not paved simultaneously with mainline), cross-overs, non-continuous turn lanes, loops, bypass lanes, acceleration/deceleration lanes, intersecting streets, roundabouts, and partial lane width widenings.
    - PMTPS measurements are not required for a total net paving length of less than 2 lane miles.
    - PMTPS measurements are not required on asphalt lift thicknesses less than 1 inch.

- Changed the GNSS requirements from an accuracy of ± 4 feet to ± 2 inches in the x and y directions.
- Changed several texts/sections to align with AASHTO R110.
- Added a section for "QA Testing" as follows:
    - The Engineer will use a Forward Looking InfraRed (FLIR) camera to verify the contractor's PMTP system (FLIR 2024). QA tests shall be taken at random locations twice per day. The contractor shall assist the Engineer with the placement of the event marker. The QA tests shall compare favorably using the FLIR data QA tool according to the instructions found in the IC-PMTP Document Helper located on the Intelligent Compaction SharePoint site. If results do not compare favorably, the contractor's PMTPS shall be verified by the manufacturer. In the case that the PMTPS is required to be sent off to the manufacturer and the contractor is not able to provide a replacement, the contractor will be allowed to continue paving with the verification of the FLIR camera for acceptance only.
- The "Thermal Segregation" categories were redefined, as shown in Table 4.
- The "Incentive/Disincentive" categories were updated, as shown in Table 5.

Table 4. Redefined thermal segregation categories.

Differential Range Statistics (DRS)	**Thermal Segregation Category**
DRS ≤ 25.0°F	Low
25°F < DRS ≤ 35°F	Moderate
35°F < DRS ≤ 50°F	Moderate-High
DRS ≥ 50°F	Severe

Table 5. Modified price adjustments.

Thermal Segregation Category	**Adjustment per 150 ft. Sublot**
Low	
Moderate	100% Pay
Moderate-High	
Severe	Unacceptable Material

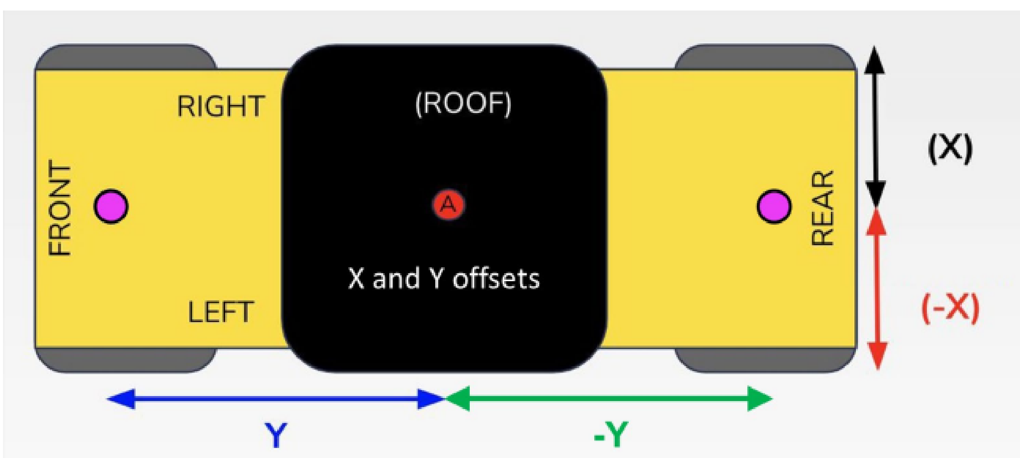
The specifications are still being revised, and final versions and information will be available under the 2024-2025 project reports.

Training Material Updates

DirtMate Quick Reference Guide

The DirtMate is a GPS tracking equipment that MoDOT selected to use an IC-pass count QA device (Propeller, 2024). The DirtMate Quick Reference Guide was updated in 2023 to reflect data QA changes and improve its utility for MoDOT project staff. The main changes were as follows:

- Updated the document to include more details about the DUG setup with updated photos for connecting the cables to the DUG.
- Improved instructions for installing the DirtMate and measuring its location with respect to the measurement drum (Figure 1). Previously, all measurements were made from the front drum. This was an invalid approach since some vendors reference the rear drum for IC data. A note was added clarifying that most vendors use the front drum for the measurement drum (+y), while Volvo uses the rear drum (-y).
- A box was added with directions to set the construction shift to either day or night by contacting Propeller. During the 2022 season, it was discovered that setting up a "sleep" mode helps to keep the DirtMates charged.
- Directions for using Propeller's "Data Diagnostics" tool were added. The "Data Diagnostics" was implemented to aid MoDOT project staff in knowing when the data transmission from the DirtMate using the DUG was completed. Data transmission issues were one of the common issues reported in 2022. The new diagnostics tool shows the DirtMate location, whether it is online or offline, the data transferred when it was last connected to the DUG, the DUG it was last connected to, signal health, battery life, charging status, and data in the queue (Figure 2).

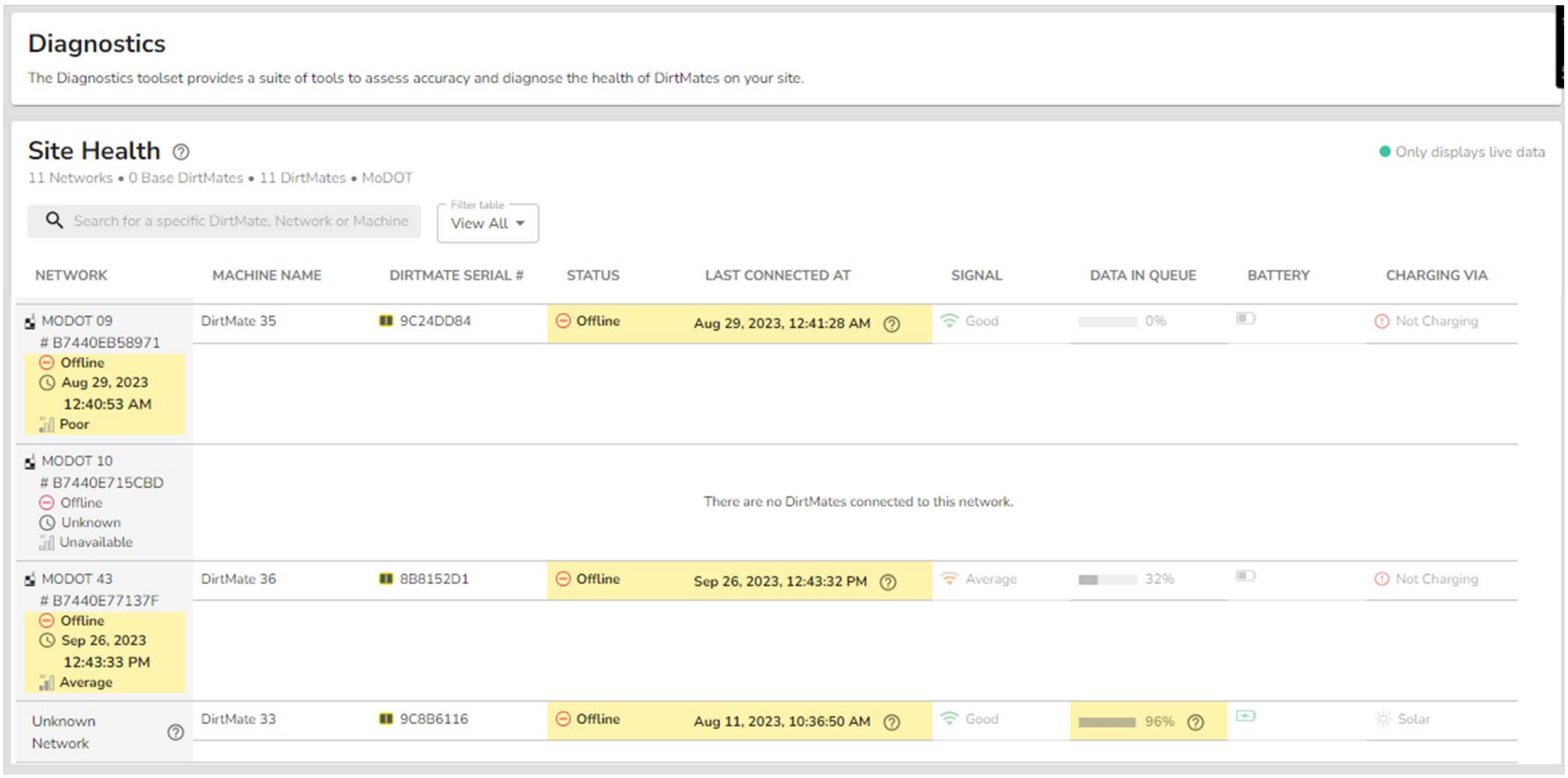


NOTE: Most vendors use the front drum for the measurement drum (+y). Volvo uses the rear drum (-y). Check with your equipment supplier to determine which drum is the measurement drum.

Source: DirtMate

Figure 1. Illustration. Updated graphic for measuring up the DirtMate.

A screenshot shows the DirtMate Diagnostics page. The snip shows a few examples of DirtMates in the "network" column. Other columns include machine name, DirtMate serial number, status (online or offline), time last connected, signal strength, percent data in the queue, battery life, and whether it is charging.



Source: DirtMate

Figure 2. Screenshot. The Diagnostics page for the DirtMates.

MoDOT Inspector Sheet Guide

The MoDOT Inspector Sheet Guide was developed in 2022 as a tool to help MoDOT project staff verify contractor submittals. The guide was updated in 2023 based on some feedback from MoDOT project staff. Updates included the following:

- Additional details were added to the "Filters Review" section to illustrate how to verify that the contractor correctly filtered the data.
- The Analysis and Results sections were expanded to provide more guidance on ensuring that the results from the Veta project were accurately transferred to the summary sheet.
- An email template was included as an example of the steps to take if errors are discovered that require correction from the contractor.

Summary

In 2022, minimal revisions were made to the IC-PMTP summary sheets and data quality assurance (QA) procedures. These were documented in a report released last year. Moving into 2023, significant specification changes were planned for future seasons. Pilot tests for new specifications are scheduled for late 2024 projects, with full implementation set for 2025 and beyond.

Training materials also received modifications and updates. The DirtMate Quick Reference Guide and the MoDOT Inspector Sheet Guide were updated with improved instructions, better visual aids, and more details to assist project staff.

Chapter 3. Task 3-IC-PMTP Training Program

Introduction

Based on the 2021 IC-PMTP final report, one of the main recommendations was to increase training efforts. Therefore, a new training program was implemented in the 2022 and 2023 seasons. A summary of the training program is shown in Table 6.

Table 6. Summary of the IC-PMTP training program.

Training	Description
Statewide IC-PMTP Workshop	Two statewide workshops were held – one for contractors and one for MoDOT staff.
Train-the-Trainers (TTT)	A "train-the-trainers" workshop was held to assist MODOT interns in providing in-house technical support to IC-PMTP projects.
Just-in-Time-Training (JITT)	JITT training sessions were held near the start of the first projects of the "region" for the contractors and MoDOT REs/inspectors. JITT focused on hands-on data QA equipment operation (DirtMate GNSS tracker and FLIR camera) and Veta analysis.
MoDOT Training Page	The SharePoint navigator tool was updated to reflect all changes to training materials.

Descriptions of the 2023 training efforts are summarized in the following sections.

Statewide IC-PMTP Workshops

Two statewide workshops were held as follows:

- February 21, 2023, Statewide Training for MoDOT.
- March 08, 2023, Statewide Training for Contractors (Veta 101).

The MoDOT training workshop was a hybrid training that focused on reviewing contractor submittals and completing the data QA procedures using the DirtMate (to verify IC pass count) and FLIR cameras (to verify PMTP temperature).

The contractor training (Veta 101) was an introductory training on how to complete an IC-PMTP Veta project according to MoDOT protocols. The training walked participants step-by-step through the data collection, analysis, and reporting. The workshops are also used as refresher courses and include updates to protocols or Veta software as needed. The contractor training was recorded and posted to the IC SharePoint. The MoDOT personnel training was not recorded due to technical difficulties.

MAPA sponsored "Black to Basics"

Although not funded under this project, it is worth noting that another IC-PMTP training workshop was held at the Missouri Asphalt Pavement Association's annual "Black to Basics" conference in Columbia, MO, on February 22 and February 23, 2023. The topics covered advanced use of Veta to enhance contractor QC. Sessions included using alignment files for location filters, understanding the Thermal Segregation Index (TSI), understanding MoDOT's IC data QA procedures using the DirtMate, and using the new heat loss curves in Veta.

Train the Trainers (TTT)

Two TTT sessions were held on June 15, 2023, and June 21, 2023. These training sessions were held remotely through teleconferencing. The purpose of the TTT sessions was to train the new MoDOT interns on the data QA procedures.

Several follow-up training and Q&A sessions were held ad hoc to assist with data QA. The current data QA procedures are tedious and require proficiency in Veta. Therefore, teaching the processes from scratch proved challenging. It is recommended that future TTT sessions last a minimum of four hours each to ensure adequate teaching time. Additionally, self-paced training modules may be useful to aid interns or new MoDOT staff with IC-PMTP training.

The TTT aimed to help Field Office staff prepare to support the project staff during the upcoming season. The training primarily focused on Data QA procedures. A representative from Propeller was onsite to support the new DirtMate and DUG equipment. The DirtMate Gen 3 device was mounted on a rental car to facilitate practice data collection. During the TTT, the Research Team and Field Office staff thoroughly covered data collection and analysis procedures.

Just In Time Training (JITT)

Training Agenda

The JITT sessions were tailored to specific attendees, so the exact content varies. Two JITTs were in person, and two were held through teleconferencing.

JITT locations and Dates

The JITT locations, facilities, dates, and attendees are summarized in Table 7. The JIT data QA training was hands-on and focused on QA data collection and verification of contractor submittals. The contractor training included data collection, analysis, and reporting in Veta.

Table 7. Summary of JITT.

JITT Location	Facility	Date	Attendees
Springfield, MO	APAC Office	07/12/2023	APAC personnel, Ozark Laser
Springfield, MO	MoDOT Springfield Office	07/12/2023	Springfield Office personnel and surrounding districts.
Teleconferencing (MS Teams)	Blevins	08/08/2023	Blevins personnel.
Teleconferencing (MS Teams)	WL Miller	08/30/2023	WL Miller personnel.

Document Helper SharePoint Navigator

A general comment during the 2021 Feedback Meetings was better organizing the materials on SharePoint. Therefore, the Document Helper SharePoint Navigator (DocHelper) was created in 2022 to help users navigate the site. The DocHelper was updated in 2023 with links to new training materials. The details of the DocHelper can be found in the 2022 report.

Summary

The training program for MoDOT was updated in 2022 to include TTT and JITT and separate the spring workshops into "contractor" and "MoDOT personnel." Due to the success of the new training program in 2022, it was carried through 2023. MoDOT personnel guides were refined to aid project staff in checking contractor submittals and performing contractor data verification.

Chapter 4. Task 4-IC-PMTP Project Supports

Introduction

The project support included onsite and remote support. The project supports are summarized in the following sections.

Task 4-1: Onsite Support

Most project supports were held remotely. There was one onsite support trip for a project that was piloting an innovative boundary collection method. This support session is summarized in 0.

Task 4-2: Remote Technical Support

Remote support was facilitated through Microsoft Teams (MS Teams). Common support requests are as follows:

- Contractors requested assistance with data analysis.
- Contractors requested technical equipment support – referred to equipment vendors.
- Contractors were having issues with data loss.
- Contractors requested support with innovative boundary collection (this topic is covered in detail in 0).
- MoDOT project staff requested assistance with data QA collection or analysis.
- MoDOT project staff or contractor staff had questions about how to report days with multiple sections in one line in the summary sheet.

Some of the common support requests are summarized in more detail in the following sections.

General Analysis Questions

There were several common general analysis questions related to filtering and analysis, as follows:

- Using the boundary for IC data only and excluding it from PMTP data.
- Using time stamps to filter PMTP data.
- Setting custom start and stop locations for both IC and PMTP data.
- Ensuring the IC legend is customized to match the optimum pass.

Data Loss

There were several issues with data loss during the 2023 season. The issues and potential solutions associated with data loss were discussed during the Feedback Meeting and summarized in 0.

GNSS Quality

There were several issues with GNSS quality during the 2023 season. The issues and potential solutions associated with GNSS quality were discussed during the Feedback Meeting and summarized in 0.

Task 4-3: Data Quality 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 reporting and transfer of results to the summary sheet. Data QA Support

Summary

Onsite support was held on one project – aiming to implement alternative methods for collecting the IC boundary. These efforts are summarized in Chapter 7. Several projects struggled with GNSS precision. This topic was covered in depth during the Feedback Meeting, and potential solutions for upcoming seasons are summarized in 0.

Remote support was held through emailing and teleconferencing. Many questions were related to filtering and analysis. Random data quality checks were performed on projects to ensure proper data management, filtering, analysis, and reporting.

Chapter 5. Summary of Project Results

Project Overview

The projects that had data uploaded to SharePoint during the 2023 construction season and the IC and PMTP equipment vendors used for each project are shown in Table 8. Some of the originally planned projects were delayed or did not have data uploaded to SharePoint. Contractors and projects are displayed anonymously by a code. The contractor and project codes are decoded in Appendix A (removed for the public version).

Table 8. Summary of IC and PMTP systems.

Project Code	Contractor Code	IC System	PMTP System
1	7	Trimble	PAVE-IR
2	5	Trimble	PAVE-IR
3	14	Volvo	PAVE-IR
4	2	Topcon Retrofit	PAVE-IR
5	6	Trimble	PAVE-IR
6	13	Volvo	PAVE-IR
7	8	Trimble	PAVE-IR
8	13	Volvo	PAVE-IR
9	12	Trimble	PAVE-IR
10	7	Trimble	PAVE-IR

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.

Data Import and Legend Customization

The daily IC and PMTP data were imported to one project file using applicable coordinate systems. The pass count legend was customized to reflect the optimum pass count established during the trial section.

Project Filters

Table 9 summarizes the filters that were used to analyze the data.

Table 9. 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 GNSS 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 GNSS precision of the PMTPS does not meet the precision of the boundary GNSS, 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 hot paver smoothing skis.

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 is not explicitly required in the specifications. Therefore, this was not always completed.

Analysis

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 to generate compaction curves.

A cumulative pass count specification was set according to the optimum pass count established during the trial section. The pass count legend should be customized to match the optimum pass count to facilitate visualization.

A cumulative ICMV specification was set using the target ICMV determined during the trial section or during the first production day of paving. This specification (greater than 70 percent) is for information only and does not affect payment.

The MoDOT temperature specification is based on the mean temperature at the optimum pass (MTOP). Veta does not have a feature to support this specification, so contractors manually check for this.

PMTP Setup

PMTP sublots were analyzed at 150 feet, and paver-stops were removed as per AASHTO R 110-22 specification. The required data metric for analysis was temperature segregation, but speed was recommended as an extra quality control tool.

The PMTP data were analyzed according to the Differential Range Statistics (DRS) described in AASHTO R 110-22.

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.

Project Results

This section includes a summary of IC and PMTP results from the 2023 construction season and cumulative results from 2017 through 2023.

2023 Construction Season

The following sections include the results for the 2023 construction season. The data were assessed for meeting data management, IC, and PMTP protocols.

Data Management Results

The data management protocols include contractor data submission and Resident Engineer (RE) data submission. Table 10 and Table 11 summarize the 2023 data management assessment for contractors and REs, respectively. The results below assess whether the data was submitted to the IC SharePoint site. The assessment does not evaluate whether the data met the exact naming convention or folder structure. However, it is recommended that data management continue to be emphasized in training workshops since several projects did not meet the protocols.

The legend for the tables is described as follows:

- Y (shaded green): Yes, data was submitted to IC SharePoint
- N (shaded red): No, data was not submitted to IC SharePoint
- P (shaded yellow): Some data was submitted. Some data were incomplete or missing.

Table 10. 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	**7**	Y	Y	Y	Y	Y	Y	N	Y
2	**5**	Y	Y	Y	Y	Y	Y	Y	Y
3	**14**	Y	Y	Y	N	N	Y	Y	Y
4	**2**	N	Y	Y	N	N	Y	N	Y
5	**6**	Y	Y	Y	Y	Y	Y	Y	Y
6	**13**	N	Y	Y	Y	N	Y	Y	Y
7	**8**	N	Y	Y	Y	P	Y	Y	Y
8	**13**	N	Y	Y	Y	P	Y	Y	Y
9	**12**	Y	Y	Y	Y	N	Y	Y	Y
10	**7**	Y	Y	Y	Y	N	Y	Y	Y

All contractors submitted the required data to the IC SharePoint site, and the most commonly missing data are the trial section data and spot test data. Contractors should be encouraged to submit any missing data for verification and record keeping.

Table 11. RE data management results.

Project Code	Contractor Code	RE Checklist	RE DirtMate Files	FLIR Images	Analysis Complete
1	**7**	N	Y	Y	Y
2	**5**	N	Y	Y	Y
3	**14**	N	Y	N	P
4	**2**	N	Y	Y	Y
5	**6**	N	N	Y	P
6	**13**	N	Y	Y	Y
7	**8**	N	Y	Y	Y
8	**13**	N	N	N	N
9	**12**	N	Y	Y	Y
10	**7**	N	N	N	N

General observations from Table 11 include the following:

- REs are not 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.
- Nearly all project staff uploaded FLIR photos to SharePoint.
- Nearly all projects had DirtMate data available to generate files.

Due to the complexity of the data QA analysis, in 2023, project staff were only responsible for collecting the data. Analysis was performed by the Field Office interns and the Consultant (Transtec). The Field Office interns generated DirtMate files, performed all verification analyses, and uploaded the results to SharePoint. The results were discussed in detail during the Feedback Meeting as summarized in 0.

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.

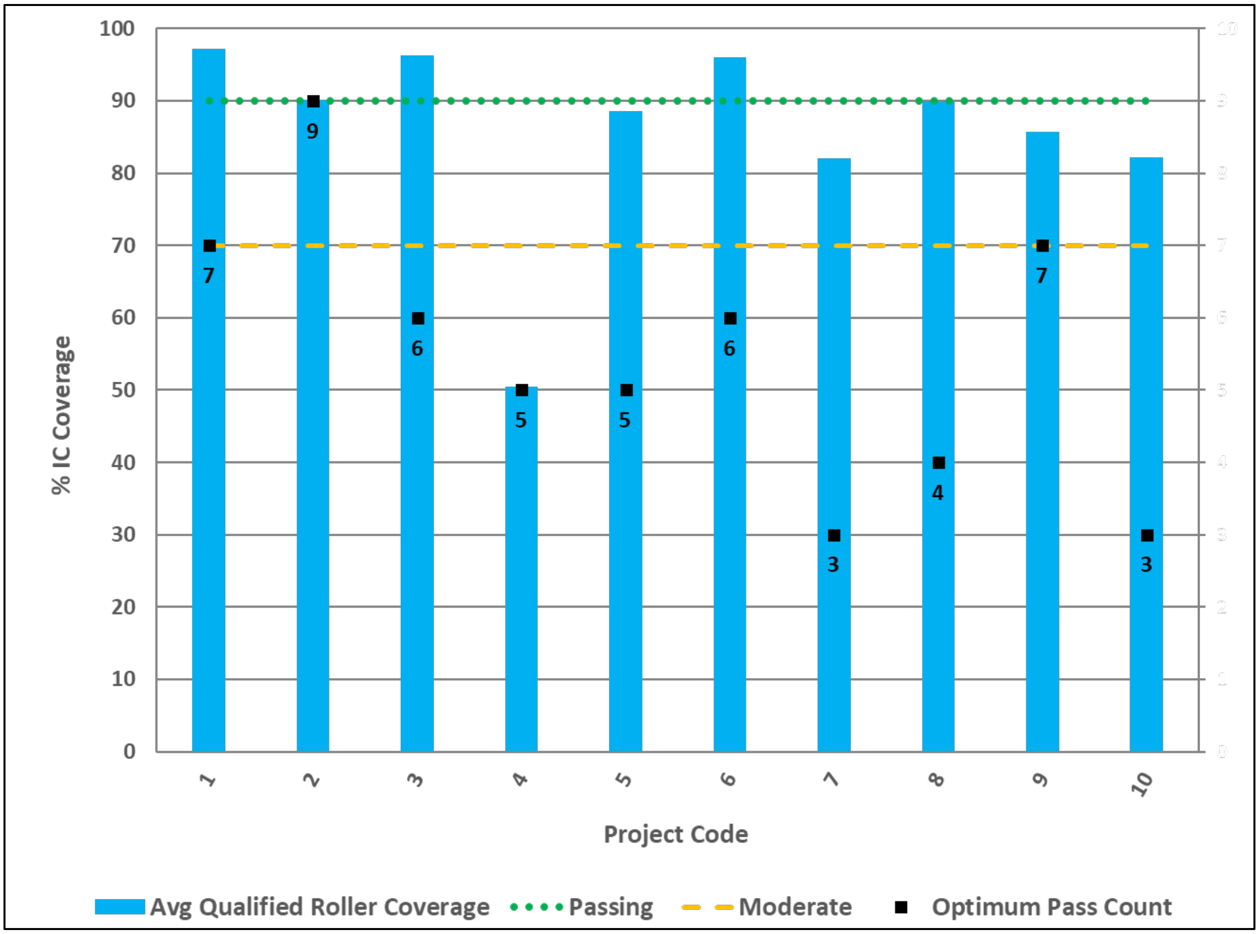
- The mean temperature at the optimum pass (MTOP): The overall mean temperature at the optimum pass shall be 180˚F. Segments that do not meet this requirement are considered deficient.
- Passing segments receive price incentives. Moderate segments receive no price adjustment. Deficient segments receive 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 that is only capable of level 1-2 ICMVs. These ICMVs are the least sophisticated, unable to measure 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 Level 1-2 ICMVs. A difference in conditions between the test section and mainline paving may cause an invalid target ICMV value.
- ICMV compaction 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 ICMVs are not included in this report.

A summary of the 2023 IC coverage (% of the optimum pass) is shown in Figure 3. The chart shows the average IC coverage, the segment classification thresholds, and the optimum pass count for each project.



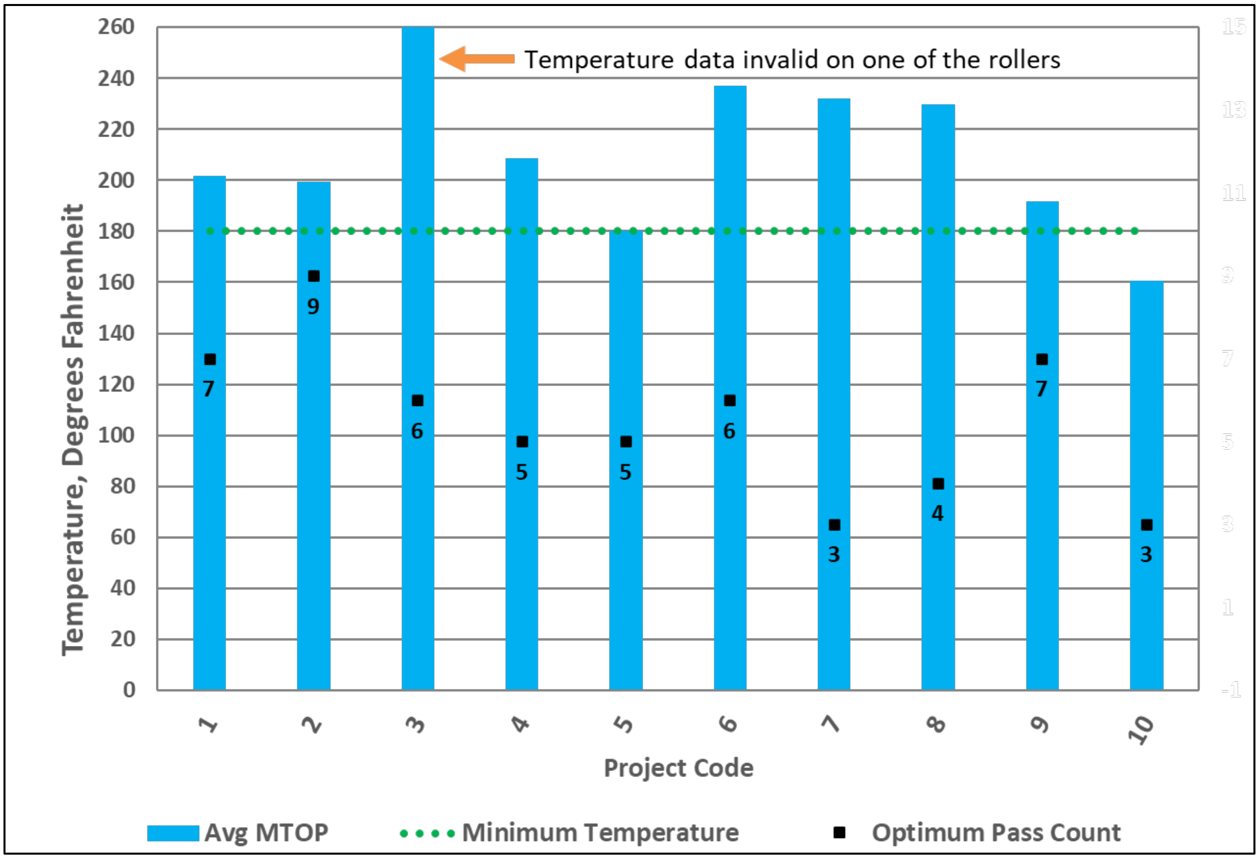
Source: Project Team (2023)

Figure 3. Chart. Average IC coverage per project and optimum pass counts.

General observations from Figure 3 include the following:

- Five projects are at or above the 90 percent (price incentive) threshold, and one is below the 70 percent threshold.
- Optimum pass counts range from three to nine. There is no clear trend between optimum pass count and IC coverage.
- Project code 4 shows a pass count coverage of 50%. Upon investigation of the data, it appears that one of the rollers had a lot of missing data. However, there are no notes in the project summary sheet that mention issues with IC data collection.

A summary of the average MTOP for each project in 2023 is shown in Figure 4.



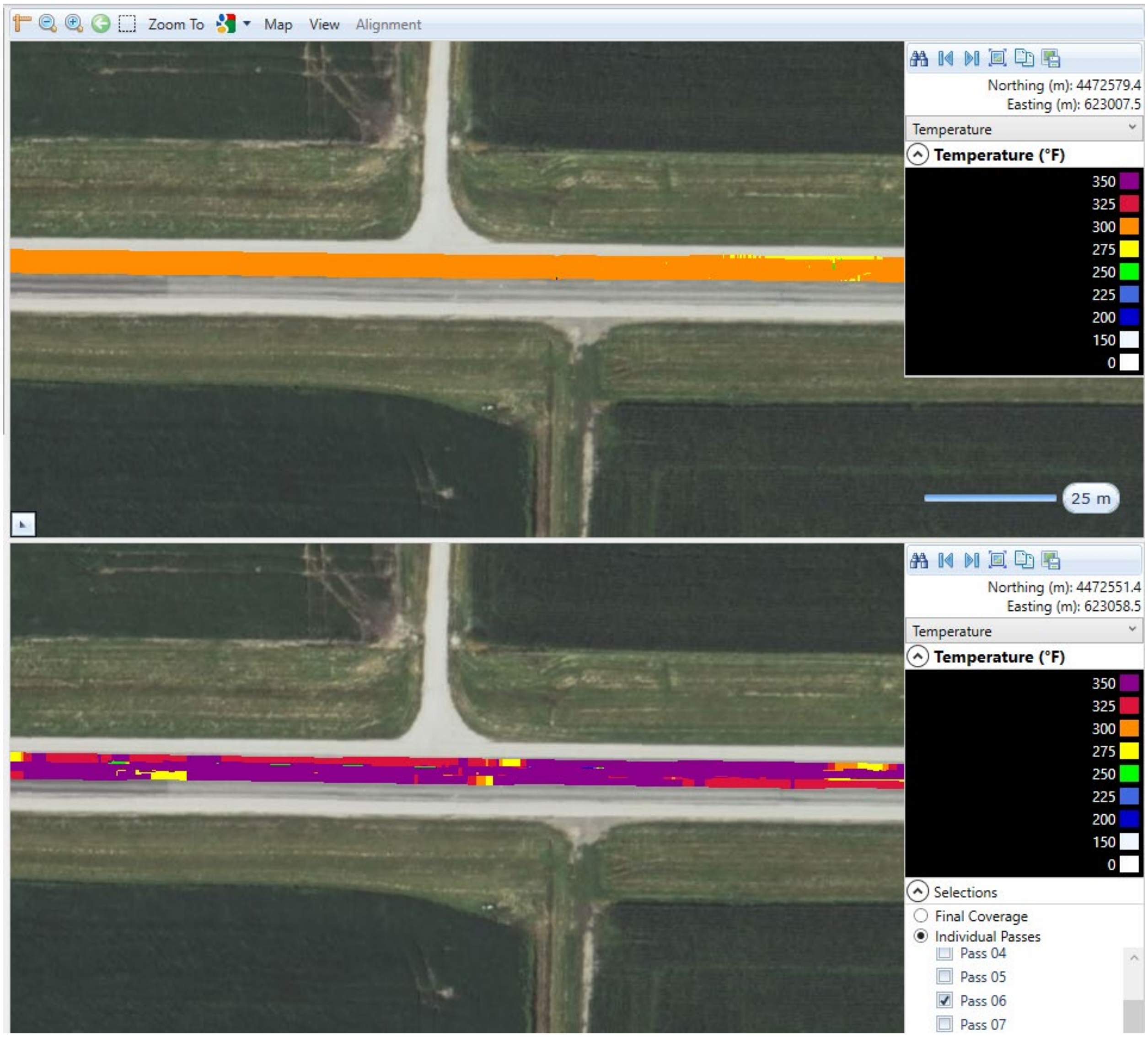
Source: Project Team (2023)

Figure 4. Chart. The average mean temperature at optimum pass count per project and optimum pass counts.

General observations from Figure 4 include the following:

- All projects have an overall average MTOP at or above 180ºF except project code 10.
- There is no clear trend between optimum pass count and MTOP.
- Project code 3 had a significantly high MTOP. Upon further investigation of the project data, this project appears to have erroneously high-temperature data from one of the sensors, as illustrated in Figure 5. The upper map shows the PMTP data averaging around 300°F. The lower map shows IC temperatures as high as 350°F. It is recommended that contractors verify the temperature sensors daily per the protocols.

Some projects had individual production days, or segments, with MTOP less than 180˚F. However, these were generally isolated, resulting in averages above 180˚F. In some cases, the MTOP at the beginning of the project was lower, and adjustments to paving temperatures were made to achieve the threshold of 180ºF.

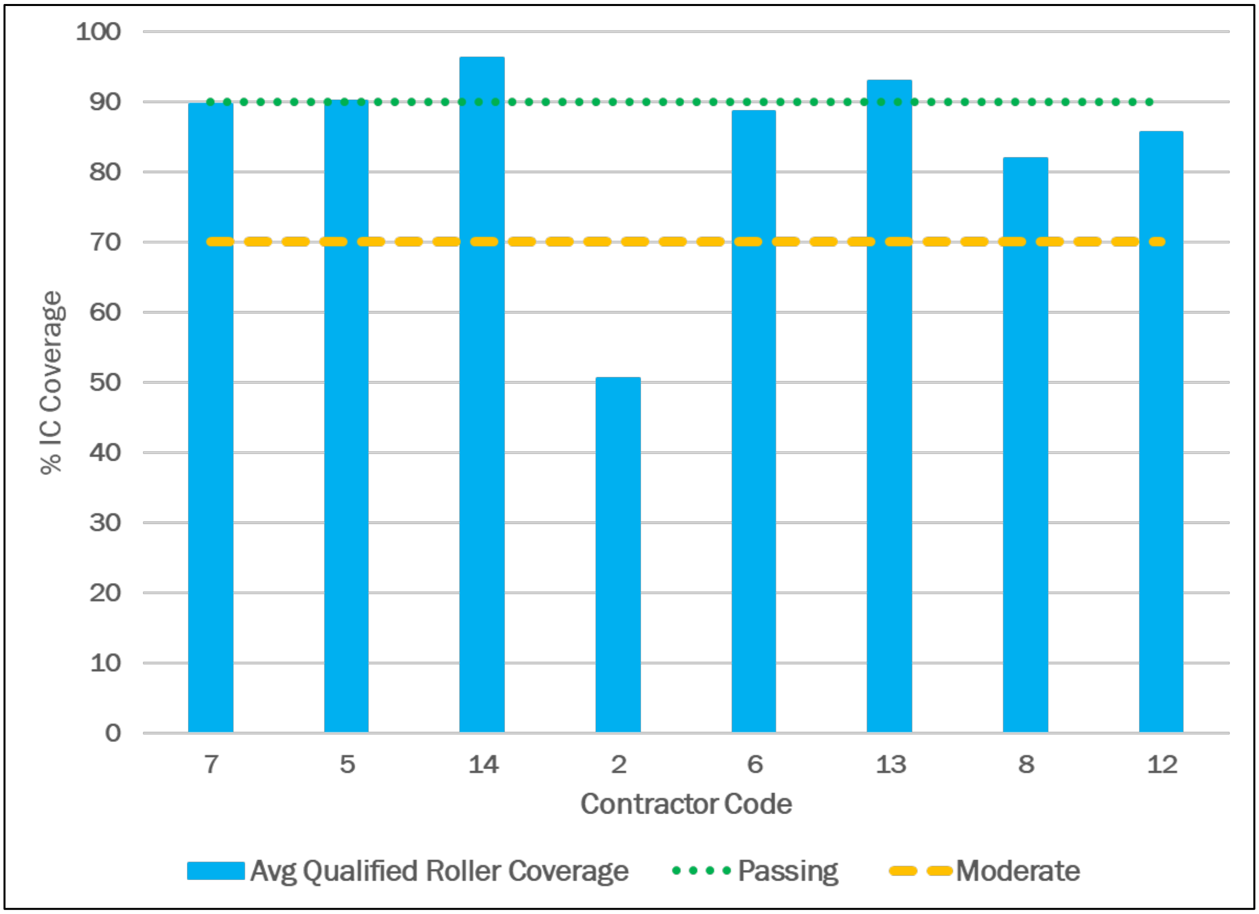


Source: Project Team (2023)

Figure 5. Screenshot. Example of high temperatures from IC data.

IC Results by Contractor

A summary of the IC coverage (% of the optimum pass) is shown in Figure 6. The chart shows the average IC coverage for each contractor (average results for all 2023 projects completed by the contractor). Many contractors only had one IC-PMTP project in 2023.



Source: Project Team (2023)

Figure 6. Chart. Average IC coverage per contractor.

General observations from Figure 6 include the following:

- Contractor code 2 did not meet the 70% threshold. All other contractors averaged above the 70% threshold.
- Two contractors averaged above the 90% incentive threshold.

PMTP Results

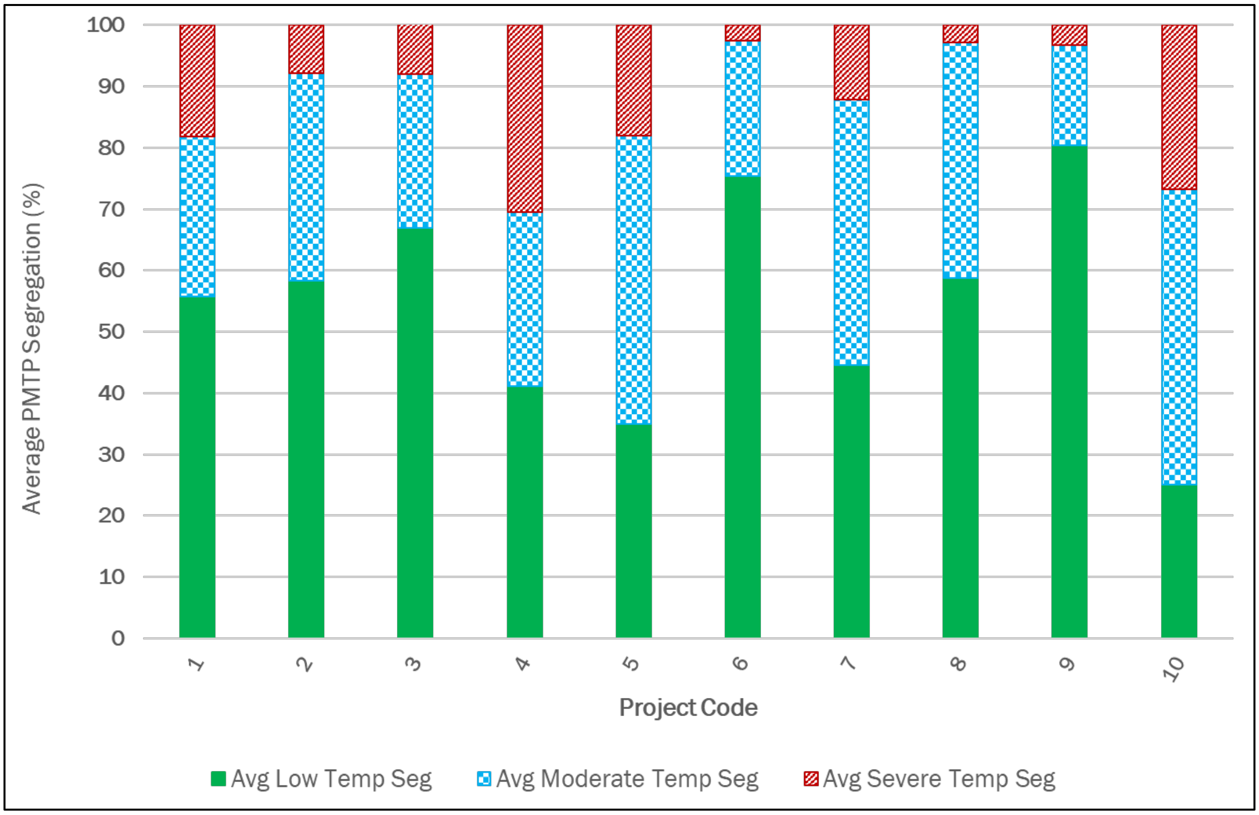
The IC data are evaluated according to NJSP-18-09. A summary of the criteria is as follows:

- The work shall be completed per AASHTO R 110-22. A summary of the Differential Range Statistics (DRS) specification is shown in Table 12.
- Low thermal segregation receives price incentives, moderate thermal segregation receives no price adjustment, and severe thermal segregation receives a price disincentive.

Table 12. AASHTO R 110-22 Thermal Segregation categories based on Differential Range Statistics.

Differential Range Statistics (DRS)	Thermal Segregation Category
DRS ≤ 25.0˚F	Low
25.0˚F < DRS ≤ 50.0˚F	Moderate
DRS > 50.0˚F	Severe

A summary of the PMTP results is shown in Figure 7. The chart shows the overall average thermal segregation category for each 2023 project.



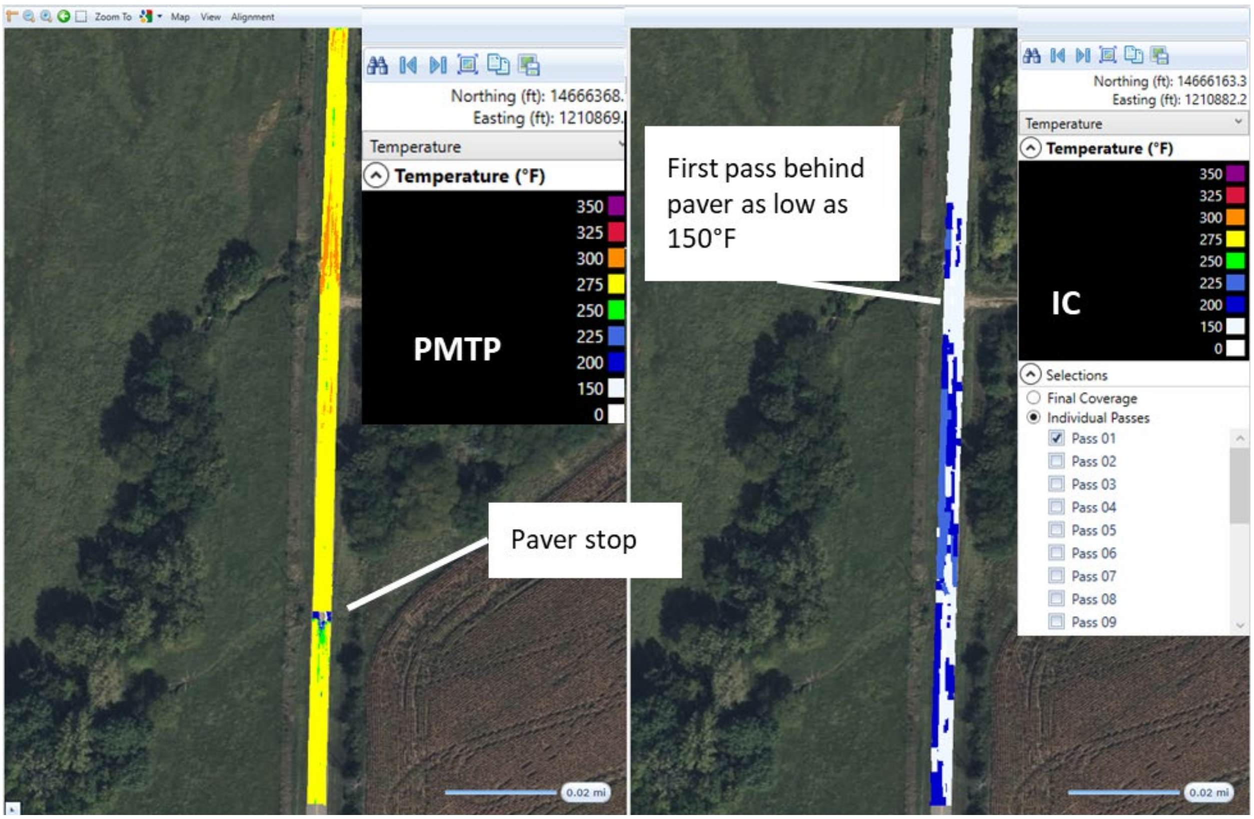
Source: Project Team (2023)

Figure 7. Chart. Average thermal segregation classification for each project.

General observations from Figure 7 include the following:

- Half (five) of the projects had less than 10 percent severe segregation.
- Two projects had between 10 and 20 percent severe segregation.
- Two projects had more than 20 percent severe segregation.

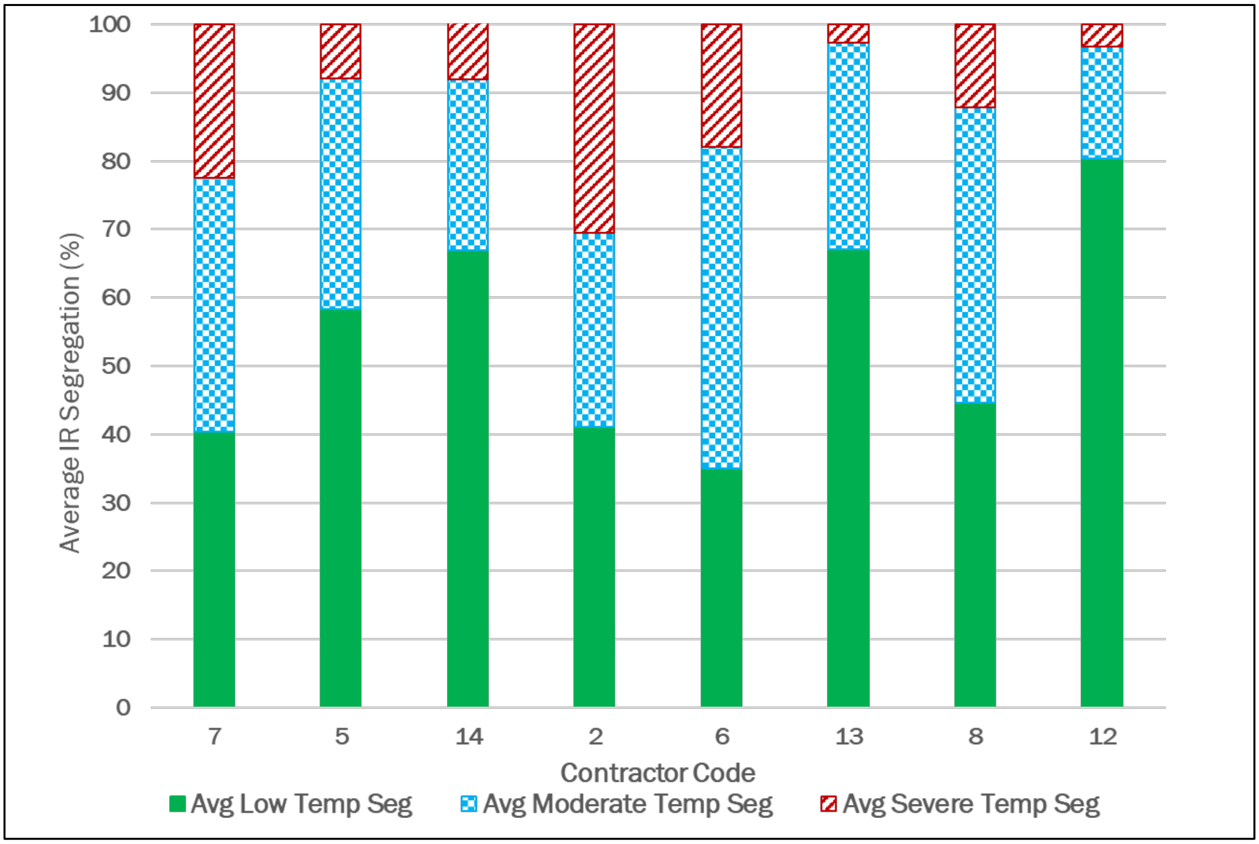
- Project code 10 had the least low segregation and nearly 30 percent severe segregation. This project also had the lowest IC MTOP. The data shows issues related to temperatures. The project was paved through October 2023, one of the latest projects of the season. An example of the project data is shown in Figure 8. The time stamps between the PMTP data and IC data were conflicting. The IC timestamps came before PMTP data. Therefore, the time between the paver and rollers could not be verified. The IC temperature sensors should be verified to ensure they are reading accurately.



Source: Project Team (2023)

Figure 8. Screenshot. Example of low breakdown temperatures and PMTP segregation.

A summary of each contractor's overall average thermal segregation category (average of results for all 2023 projects completed by the contractor) is shown in Figure 9.



Source: Project Team (2023)

Figure 9. Chart. Average PMTP thermal segregation classification per contractor.

The following observations are made from Figure 9:

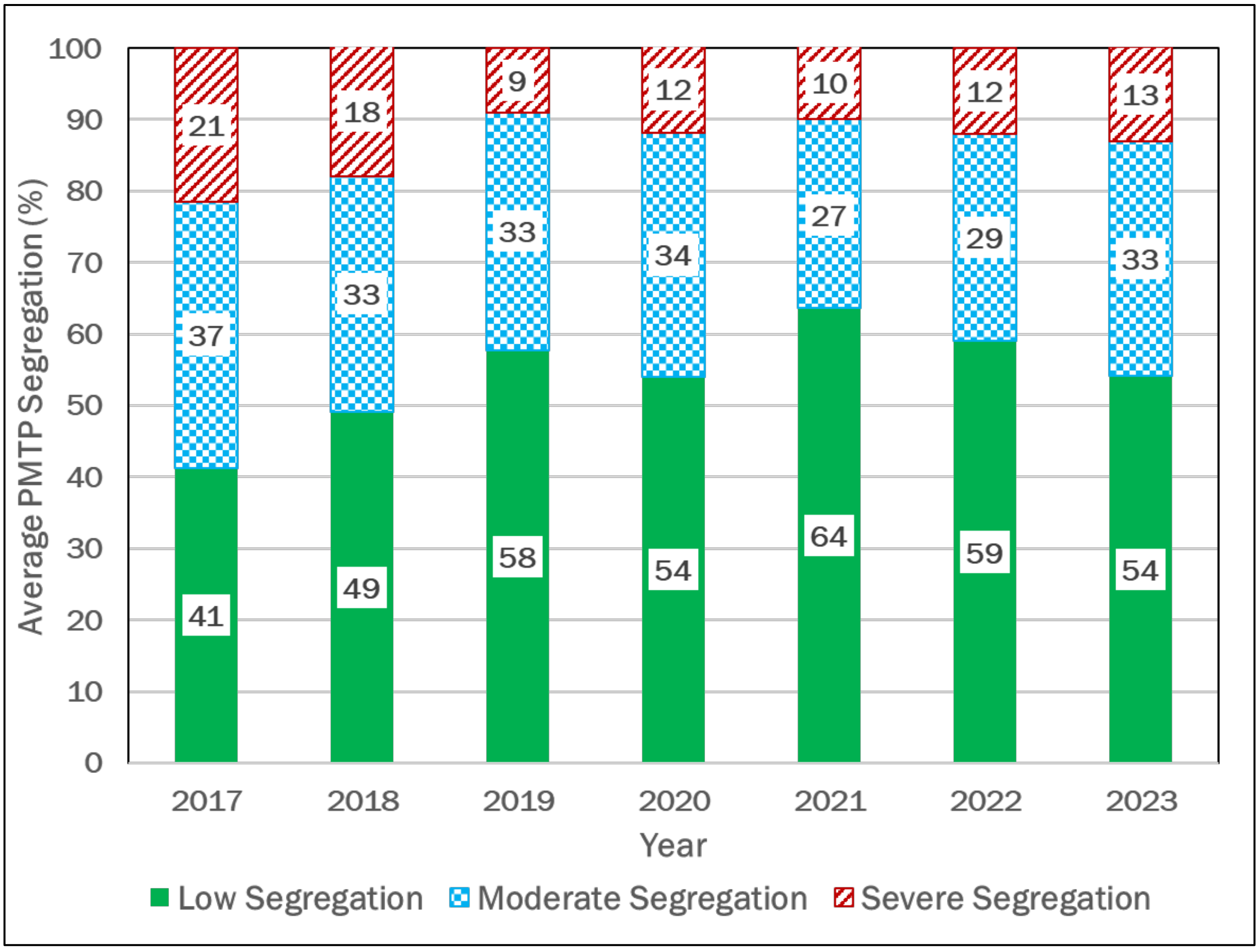
- Contractor codes 7, 6, and 2 had the highest severe segregation and fewest low segregation.
- Contractors 12 and 13 had less than 5 percent severe segregation and 80 and 68 percent low segregation, respectively.

2017 Through 2023 Construction Seasons

Data from 2017 through 2023 were compiled to identify general trends.

PMTP Data Trends

The thermal segregation classifications were averaged across all projects during each construction season. The average PMTP segregation classifications are illustrated in Figure 10.



Source: Project Team (2023)

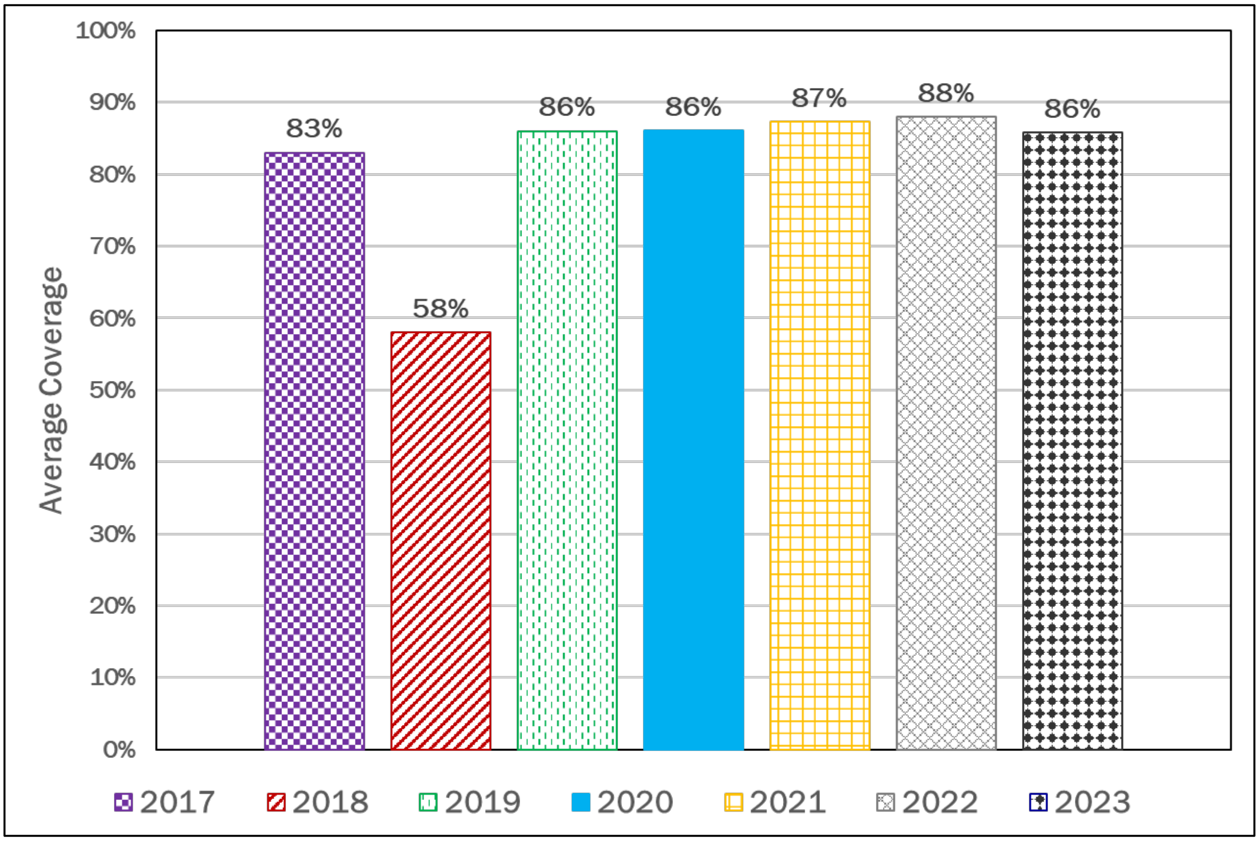
Figure 10. Chart. Average PMTP thermal segregation classification for all projects per construction season.

General observations from Figure 10 include the following:

- Low segregation (DRS < 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 and a slight decrease in 2022 and 2023. However, the low segregation remains higher than the implementation in 2017.
- There was a slight decrease in moderate segregation (25.0˚F < DRS ≤ 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 and a steady increase from 2021 to 2023.
- Severe segregation (DRS > 50.0˚F) decreases from 2017 to 2019. There is a slight increase of less than four percent from 2019 to 2020, and it remains relatively stable through 2023.
- Overall, the PMTP data trend shows that using this technology improved thermal segregation by promoting successful practices.

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 11.



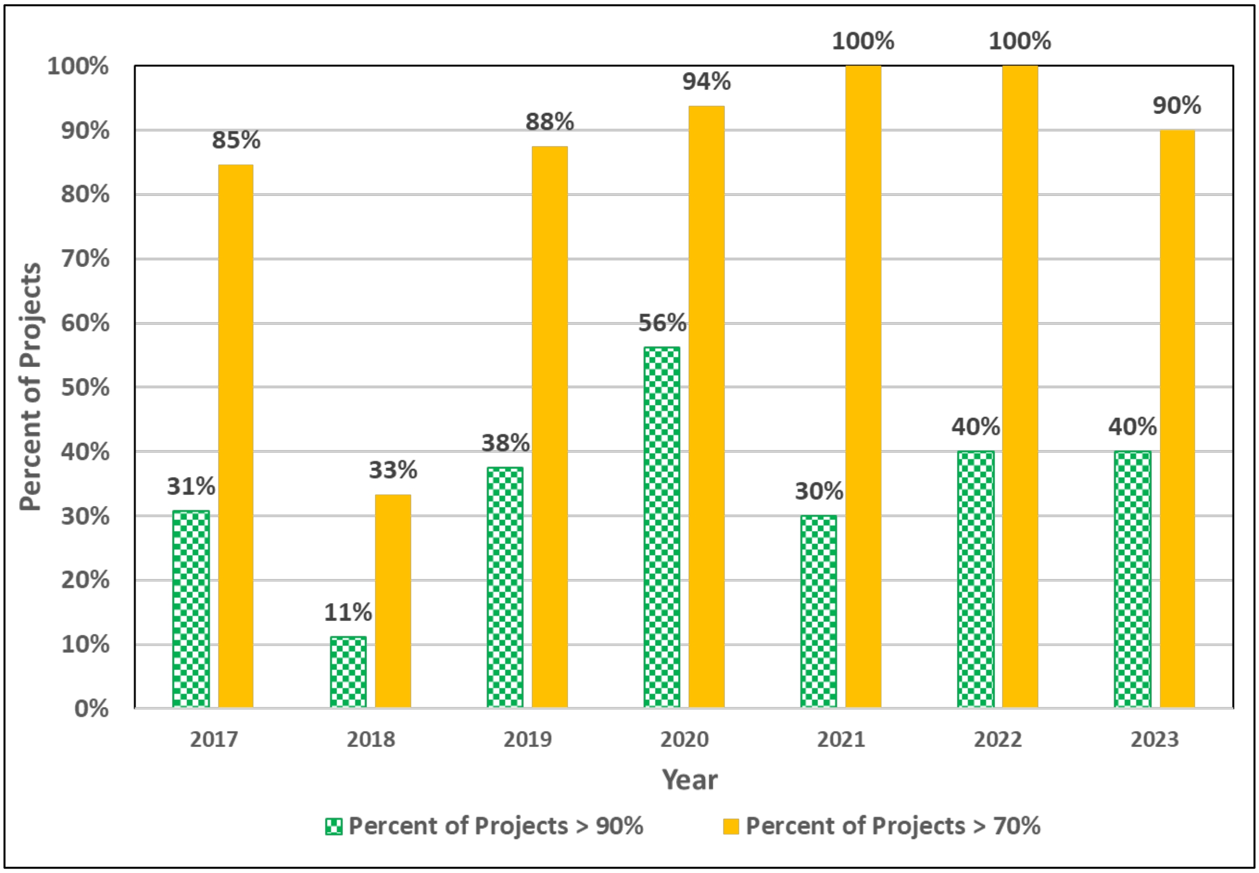
Source: Project Team (2023)

Figure 11. Chart. Average IC percent coverage for all projects per construction season.

General observations from Figure 11 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 2022.
- 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 2023 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 12.



Source: Project Team (2023)

Figure 12. Chart. Percent of projects that meet the 70 percent and 90 percent thresholds per construction season.

General observations from Figure 12 include the following:

- The percentage of projects that meet the 70 percent threshold increases each year, except for 2018 and 2023. The lower coverage in 2018 is attributed to the learning curve associated with the technology. There was one project in 2023 that had only 50% coverage. There appeared to be significant amounts of missing data in that project.
- In 2021, there was a decrease in projects that met the 90% threshold for price incentives. The number of projects that met the 90% threshold remained consistent in 2022 and 2023.
- These trends indicate an improvement in 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, 203˚F in 2021, 204 ˚F in 2022, and 210 ˚F in 2023. The MTOP trend indicates that achieving the minimum MTOP of 180˚F is reasonable, achievable, and consistent since implementation in the specification and protocols.

Summary

The strengths of the 2023 construction season are summarized as follows:

- IC coverage and PMTP thermal segregation trends show improvement with the technology since implementation. Low IC coverage results may be related to data loss and not poor roller coverage.
- In general, most contractors follow intelligent construction protocols and data analysis.

The lessons learned and areas for improvement based on the data analysis results of the 2023 construction season are summarized as follows:

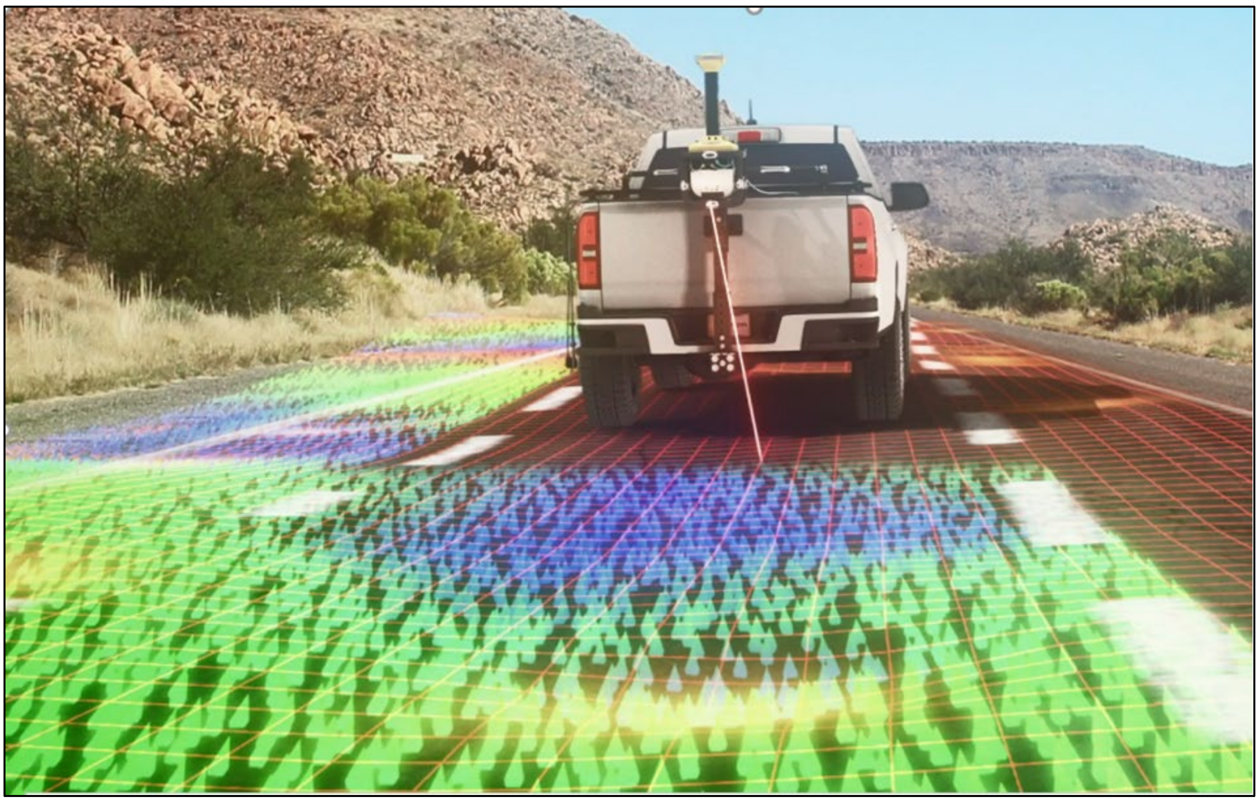
- Some contractors are not including spot test data in Veta. As MoDOT fully implements intelligent construction and reduces pavement coring, spot test data will become increasingly important. Emphasis on spot test data should be considered in future training sessions.
- The contractors are struggling to report the correct percentage of target ICMV. ICMV is for informational purposes only and does not affect price adjustments. However, even the level 1-2 ICMV data can still be a valuable quality metric. ICMV data analysis and selecting 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.
- One project showed erroneous data being collected on one of the temperature sensors. Equipment verification is important to ensure reliable data are collected. The MoDOT protocols require daily verification, and this should be emphasized in future training sessions.
- The project with the highest thermal segregation also had the lowest MTOP. This project was paved through October. No spot test data were available to see if the low compaction temperatures affected density.

Although improved since implementation, consistency in data management, including naming conventions and folder management, by some contractors and MoDOT personnel requires further improvement. Data management should be emphasized during the 2024 construction season.

Chapter 6. Task 5 – Pilot Innovative Technologies

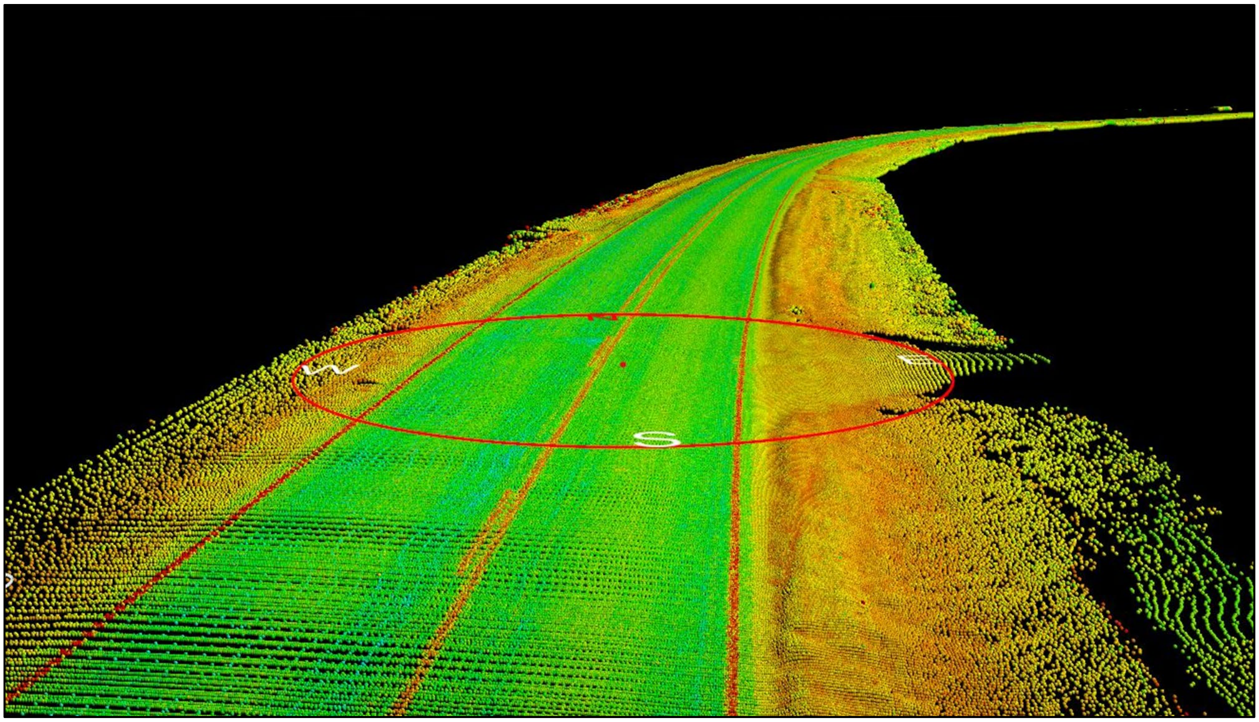
Alternative Methods for Boundary Collection

One of the future specification changes in 2025 and beyond is related to boundary collection. Future specifications will only allow automated boundary collection or methods that do not require personnel to carry hand-held receivers. In 2022, one contractor piloted LiDAR-based vehicle-mounted technology to collect LiDAR surface data (Figure 13). The LiDAR data were post-processed to select a centerline boundary using the existing lane striping (Figure 14). In 2023, three contractors used LiDAR technology to collect data to extract a boundary. More details on the processes using LiDAR technology are summarized in the 2022 final report.



Source: Topcon (2022)

Figure 13. Illustration. Example of the alignment collection equipment.



Source: Topcon (2022)

Figure 14. Illustration. Example of point cloud data used to generate alignment file.

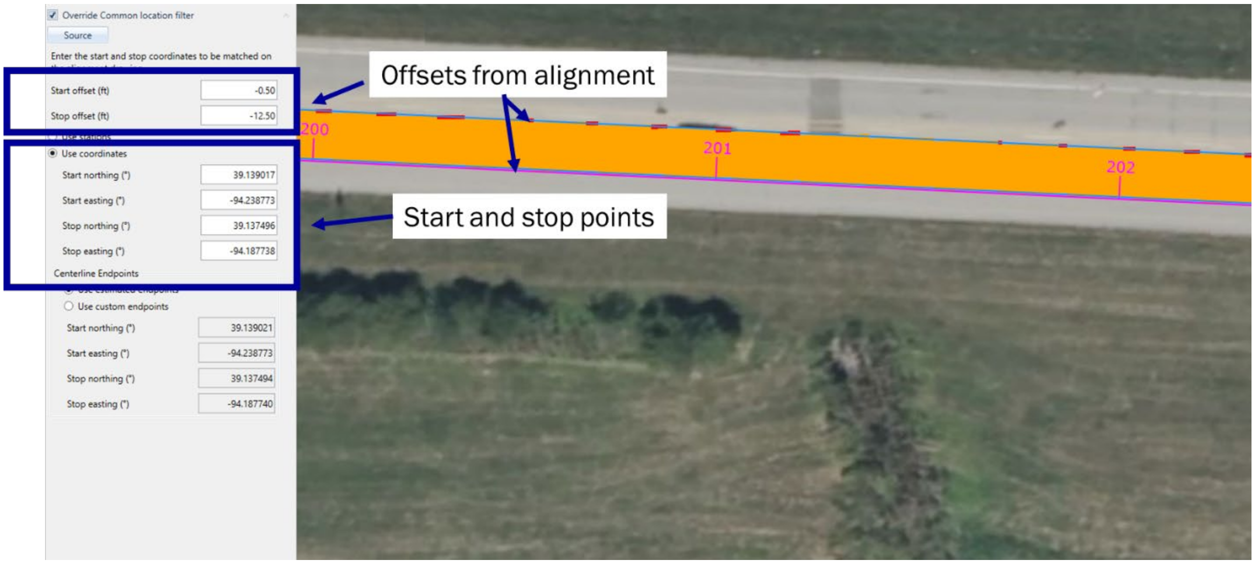
In 2023, an alternative method of mounting the receiver to the paver was piloted. The pilot project mounted a Trimble R780 (450 MHz) GNSS rover equipped with an Inertial Measurement Unit (IMU) for tilt compensation. This system was linked via Bluetooth to a Trimble TSC7 Data Collector, programmed to auto-collect data at intervals of 100 feet. The GPS rover was mounted on a pole and affixed to the screed's outer edge, as illustrated in Figure 15. The receiver and data collector were powered by the paver.

Source: Project Team (2023).

Figure 15. Photo. GPS receiver mounted to paver.

Data collection began around 08:25 AM and lasted for approximately two hours, covering about 4080 feet of paving. The collected data, exported as a *.dxf file, was then processed using Trimble Business Software. An alignment file was generated using the "Corridor" function, and the final alignment was exported as a *.landXML file.

This landXML file was then imported into Veta, where the offset feature was used to generate a boundary with the alignment file. An example of the offset filters in Veta is shown in Figure 16.



Source: Project Team (2023)

Figure 16. Screenshot. Example of the alignment file and offset filtering.

This method of boundary collection was successful, and the contractor continued mounting the receiver to the paver for the duration of the project. A few considerations when using this method are as follows:

- The receiver may interfere with the paving crew, especially if charging cords are not properly secured.
- If there are any malfunctions with the receiver or data collector, they may stop collecting the boundary. The paving crew can be trained to check the equipment periodically to ensure function.
- Daily setup and take-down of equipment are required. Manual post-processing using CAD-type software is needed.

Both methods of automated boundary collection were discussed during the Feedback Meeting. A summary of the discussion is in 0.

Summary

Two methods of alternative boundary collection were successfully piloted in 2022 and 2023. In 2023, four contractors used alternative methods for boundary collection. Three contractors used LiDAR technology, and one contractor mounted a receiver to the paver and collected points every 100 feet. Both methods require some post-processing to generate a Veta-compatible alignment file. The future 2025 specifications will require automated boundary collection.

Chapter 7. Task 6 -Pavement Performance Tracking

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 S_{app}, 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 required more data.

IC-Based Asphalt Density Model

Model Description

Chang et al. (2014) developed a model to estimate the HMA in-field density based on IC measurements. This model was based on data from nine field projects across the US with extensive IC data collection and spot tests. This model is a multivariate nonlinear panel model described as follows:

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

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

ε(i) is the fixed effect error term across the location.

Figure 17. The multivariate nonlinear model was used to estimate density using IC data (Chang et al., 2014).

This model is based on statistical regression analysis, and it was found that the regression parameters obtained by fitting the data from the nine field projects resulted in models with atypical parametric sensitivity. For instance, in more than one field project, final density was found to be inversely related to the ICMV measured and was also found to be more sensitive to parameters such as the speed of the roller and temperature. Therefore, the model proposed may not be particularly suited to predict the density of the compacted HMA layer from IC data.

Alternatively, a model based on the mechanistic behavior of the HMA layer and that of the IC system is best suited to predict the density of the HMA layer from IC data. The development of such a model would encompass the following steps:

- The layer-specific ICMV should be obtained from the composite ICMV (HMA + foundation) and foundation ICMV. This may be achieved using simplistic methods such as springs in series or more involved methods available in the literature, such as the one described in Fathi el al. (2021).
- The layer-specific ICMV obtained for a particular roller speed, vibration frequency, and amplitude may be normalized to a reference roller speed, frequency, and amplitude using equations analogous to the stress-dependent dynamic master curve equation (Pellinen and Witczak, 2002).
- Finally, the ICMV at reference conditions can be used to determine the density of the asphalt layer using equations derived from laboratory data reported in the literature (Shu and Huang 2008).

Currently, there are a few considerations in the development of this mechanistic model. The following list summarizes key items that would be needed to develop the model:

- Data collected from the various IC projects do not include pre-map IC data for the foundation layer. This makes it difficult to decouple the ICMV measured into HMA layer-specific ICMV.
- The use of time-temperature-stress superposition principles used with the master curve equation is most suitable for the dynamic moduli of the HMA. While level 1-2 ICMVs may be used as proxies for the stiffness of HMA, a better-correlated model is possible with level 3 ICMVs, which measure mechanistic properties of the HMA layer such as moduli (E_{vib}) or stiffness (k_s).
- For accurate calibration of the model, pass-by-pass density measurements are likely to provide more fitting data over the range of temperatures and densities observed during the compaction process.

Summary

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

The earlier proposed IC-based HMA density model had shortcomings in terms of capturing the trends associated with ICMV measured and densities. The current proposed "mechanistic" model requires additional data items and technology that can aid in estimating the in-place density of pavement at any location and time. Limited HMA density data from NDG or laboratory testing from 2017 to 2022 were collected for future analysis efforts. It is proposed for future research to improve the IC-based HMA density model with further field data for model training and validation.

Chapter 8. Task 7 – Feedback Meeting and Executive Briefing

The 2023 Feedback Meetings were held from December 13, 2023, to December 14, 2023. The hybrid meetings were held in Jefferson City and via Microsoft Teams. This chapter summarizes key discussions from the Feedback Meeting and recommendations for future construction seasons.

Meeting Agenda

The meeting agendas from the Feedback Meeting are shown in Table 13, Table 14, and Table 15.

The morning sessions were closed meetings with MoDOT personnel and the research Consultant (Transtec). The Wednesday midday session was open to all contractors, vendors, and MoDOT personnel. The Thursday meetings were reserved for MoDOT upper management.

Table 13. Wednesday, 12/13/2023 MoDOT Internal Meeting agenda.

Time	Topic	Attendees
8:00 AM –10:00 AM	2023 IC-PMTP project results and feedback.	MoDOT Field Office Team MoDOT RE and inspection staff FHWA MoDOT representative IC-PMTP Consultant – Transtec Group
10:00 AM – 10:15 AM	Break	Break
10:15 AM – 12:00 PM	Planning for the 2024 season.	MoDOT Field Office Team MoDOT RE and inspection staff FHWA MoDOT representative IC-PMTP Consultant – Transtec Group

Table 14. Wednesday, 12/13/2023 (continued) Missouri Industry Meeting agenda.

Time	Location	Topic	Participants
1:00 PM – 2:45 PM	MODOT office and video conference	2023 IC-PMTP project results and feedback	MoDOT Field Office Team MoDOT RE and inspection staff FHWA MoDOT representative IC-PMTP Consultant – Transtec Group IC-PMTP project contractors IC-PMTP equipment vendors and dealers
2:45 PM – 3:00 PM	Break	Break	Break
3:00 PM – 4:00 PM	MODOT office and video conference	The Path Forward – How can MoDOT Help You	MoDOT Field Office Team MoDOT RE and inspection staff FHWA MoDOT representative IC-PMTP Consultant – Transtec Group IC-PMTP project contractors IC-PMTP equipment vendors and dealers

Table 15. Thursday, 12/14/2023 MoDOT Executive Briefing agenda.

Time	Topic	Attendees
8:00 AM –8:30 AM	Introduction to intelligent construction technologies focusing on intelligent compaction (IC) and paver-mounted thermal profiling (PMTP). Description of equipment and benefits.	MoDOT Management MoDOT Field Office Team FHWA MoDOT representative IC-PMTP consultant – Transtec Group
8:30 AM –9:00 AM	MoDOT's experiences with IC and PMTP 2017-present. Description of current specifications/protocols and overall results and trends.	MoDOT Management MoDOT Field Office Team FHWA MoDOT representative IC-PMTP consultant – Transtec Group
9:00 AM -9:30 AM	MoDOT's future with IC and PMTP. Where we want to go and how to get there.	MoDOT Management MoDOT Field Office Team FHWA MoDOT representative IC-PMTP consultant – Transtec Group
9:30 AM – 10:00 AM	Open discussion and Q&A.	MoDOT Management MoDOT Field Office Team FHWA MoDOT representative IC-PMTP consultant – Transtec Group

Key Discussions

The following sections summarize the key discussions held during the meetings, summarized by topic.

IC Coverage

In 2023, there were issues related to IC coverage. Most of the reported issues involved data loss or issues related to GNSS. GNSS issues were primarily attributed to factors such as dense tree canopies, winding road layouts, and occasional equipment malfunctions. Some issues may have been related to poor cellular coverage. Cellular data is used for two purposes with IC data. It may be used to transmit the data from the on-board computer to the vendor's storage cloud. It may also be used when Virtual Reference Systems (VRS) are used.

To address the issues related to cellular connectivity, the adoption of Global SIM cards was suggested. These SIMs, capable of connecting to multiple service providers, could potentially offer a more reliable and consistent cellular connection, thereby reducing the likelihood of data interruptions.

A more thorough investigation of the suitability of GNSS equipment for specific projects could be beneficial. Areas with poor cellular coverage but good satellite coverage may need base stations instead of VRS networks. Also, a manual download of data may be needed if the data cannot be pushed using a cellular connection to the cloud. Jobs with heavy tree canopy, winding roads, or canyons may not be good candidates for IC if satellite coverage is poor. Such reconnaissance efforts may be included in future specifications.

Equipment Issues

Faulty IC temperature sensors were discussed. Industry personnel gave the following considerations for common thermal sensor issues:

- Thermal sensor obstruction by dirt, oil vapors, or condensation can result in temperatures lower than the actual ones being recorded.
- Wiring and electrical issues can result in higher than actual temperatures being recorded.
- These issues can be mitigated by performing a daily check with hand-held thermal sensors before operations begin for the day.

IC Data Verification Using DirtMates

Transmitting the data from the DirtMate to the storage cloud is tedious and requires that MoDOT project staff set up a Daily Use Gateway (DUG) hot spot. The DUG can take up to an hour to transmit data to the cloud. There are web-based diagnostics tools that show basic functions such as the percent of data stored on the DirtMate and their location. These tools can be used to check data transmission but may not be user-friendly or intuitive. MoDOT will meet with the manufacturer of the verification device in early 2024 to see if improvements have been made to data transmission.

PMTP Data Verification Using FLIR Cameras

FLIR image collection was discussed. Overall, the quality and amount of FLIR images used for data QA have improved. Common issues are as follows:

- Placing the event marker correctly – it is recommended that the contractor paving staff aid as needed to place the event maker behind the screed.

- Timestamps – FLIR timestamps match PMTP time stamps. It is recommended to always synchronize the time between the FLIR camera and contractor equipment before taking the image. Ideally, vendors should determine the time of the contractor equipment based on GNSS.
- Timing of images – the two FLIR images should be taken a few hours apart so that the time stamps are not too close to cause issues with matching the correct FLIR image.

Other technologies that could be used for PMTP data verification were discussed. Drones or another temperature measuring device that could be mounted to the paver were discussed. Such techniques are in the early stages of research and not ready for implementation.

Veta Web and Interface with AASHTOWare

Veta MDMS & Web is expected to be released in Spring 2024. Migration of IC, PMTP, and DPS features from the desktop to the web version will be conducted in 2024. The Veta team has been meeting with AASHTOWare to plan for the interface between Veta Web and AASHTOWare. MoDOT uses AASHTOWare and is interested in how the two platforms will interface. At this time, Veta-AASHTOWare interfaces are in the early planning stages, and the details are not finalized.

Revisions to the IC Specifications

Proposed changes to IC specifications were summarized in 0. The proposed changes were discussed during the Feedback Meeting. Several projects had IC GNSS issues in the 2023 season. Sometimes, the issues are related to poor cellular coverage (when VRS networks are used), and sometimes, the issues are related to poor satellite coverage in areas of dense tree canopies, canyons, or other obstructions. In areas where cellular coverage is poor, VRS is not recommended. During the Feedback Meeting, the recommendation was made to require on-ground base stations in areas where cellular network coverage is poor. This way, it will mitigate GNSS precision issues. More reconnaissance for GNSS and cellular coverage on projects will be required in future specifications.

There are no price adjustments related to IC in future specifications. Instead, the IC data will be tied to the density price adjustments. Deficient segments will be subject to density verification. There was a discussion about compensating based on the percentage of IC data collected, with a lack of data potentially leading to no payment. The current bid prices for IC work vary significantly among contractors, ranging from less than $1 to over $10,000.

Future specifications will require automated methods of boundary collection, as described in 0.

These specifications are still under review and may change before implementation in 2025.

Revisions to the PMTP Specifications

Proposed changes to PMTP specifications were summarized in 0. Future PMTP specifications will use "near" RTK GNSS. Using a GNSS that has accuracy and precision similar to IC data will simplify data analysis for contractors. Many of the issues related to data loss that were discussed during the IC specification changes apply to PMTP data, and the language in the future specs will be similar to that of the IC specs.

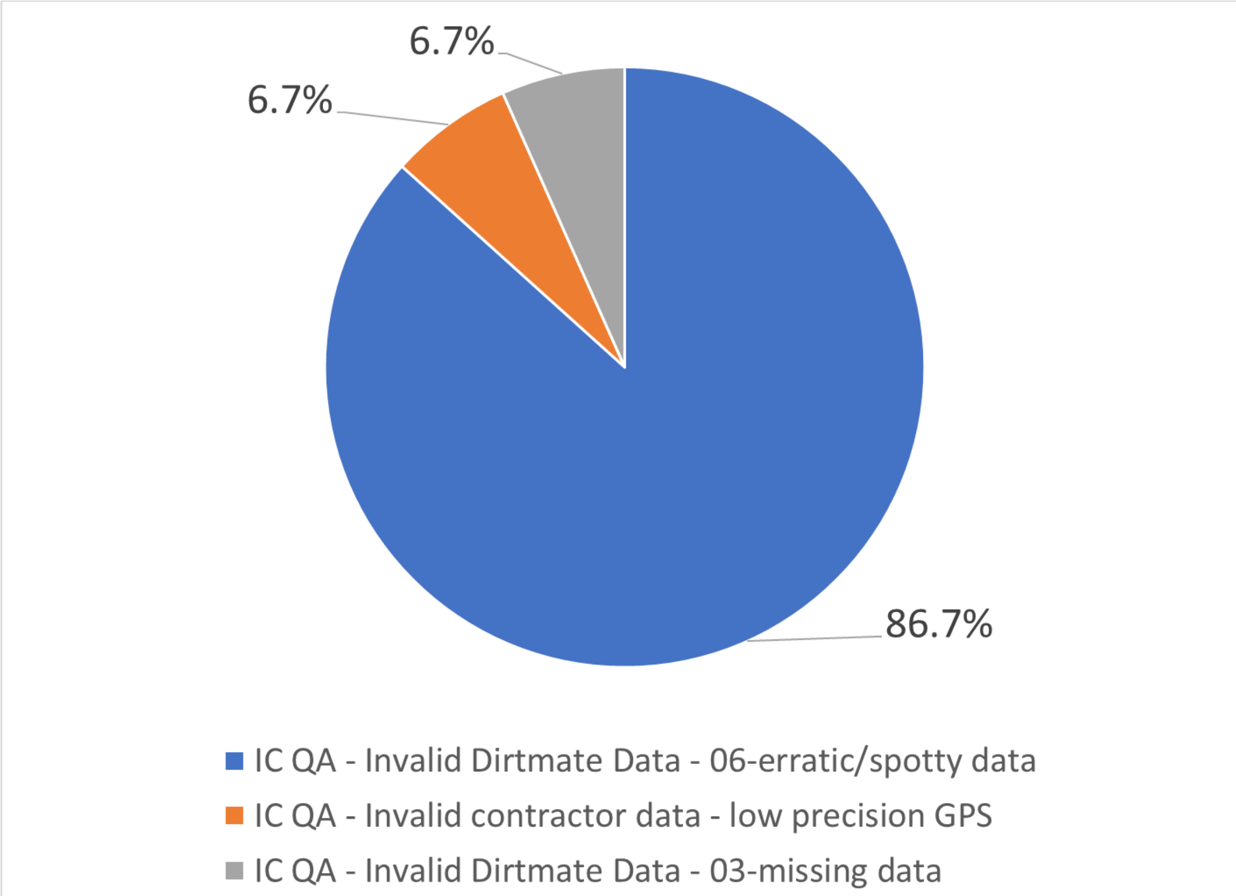
The incentive/disincentive structure was reviewed, and some updates were discussed, including the possibility of changing the limits of the incentive/disincentive structure. There were discussions on what segregation threshold should be labeled as "unacceptable" and what corrective actions could be used to resolve these sections. There is an industry meeting in early 2024 where MoDOT will meet with contractors to discuss price adjustments further.

Data QA (Verification of Contractor Data)

The results from some of the data QA projects were reported in the MoDOT internal meeting. The results presented were based on the analysis performed by the consultant. The findings from the 2023 IC and PMTP data QA efforts are summarized in the following sections. More information on the procedures can be found in the Data QA companion report (Chang et al., 2022) and previous IC-PMTP support final reports.

IC Pass Count

Of the 30 days of data where DirtMate files were generated, 57 percent of files were analyzed and compared to contractor data. If the files couldn't be completed, an error was recorded. The errors that prevented analysis are summarized in Figure 18.



Source: Project Team (2023)

Figure 18. Chart. Errors associated with IC data verification.

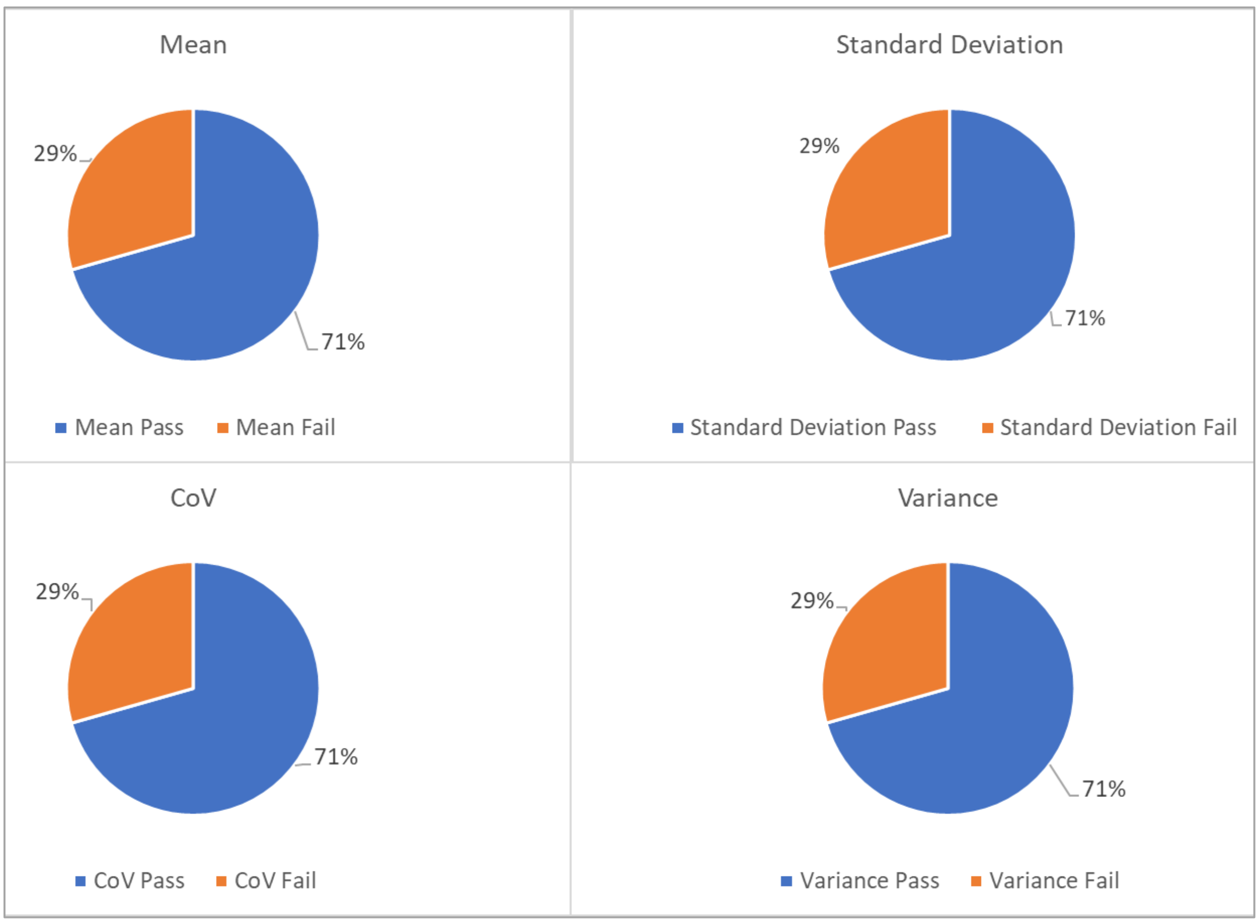
The most common error was related to invalid DirtMate data. The Project Team and MoDOT will meet with the verification device vendor in 2024 to discuss how to minimize errors with the data.

The comparison criteria for the differences between DirtMate and contractor IC data are summarized in Table 16.

Table 16. Comparison criteria for the differences between DirtMate and IC data.

Statistic	Threshold
Mean	0.00%
Standard Deviation	5.00%
Coefficient of Variance (CoV)	10.00%
Variance	15.00%

If all the criteria in Table 16 are met, the verification result is "pass." If any criteria are not met, the outcome is "fail." Figure 19 shows the results from the IC pass count data QA analysis.



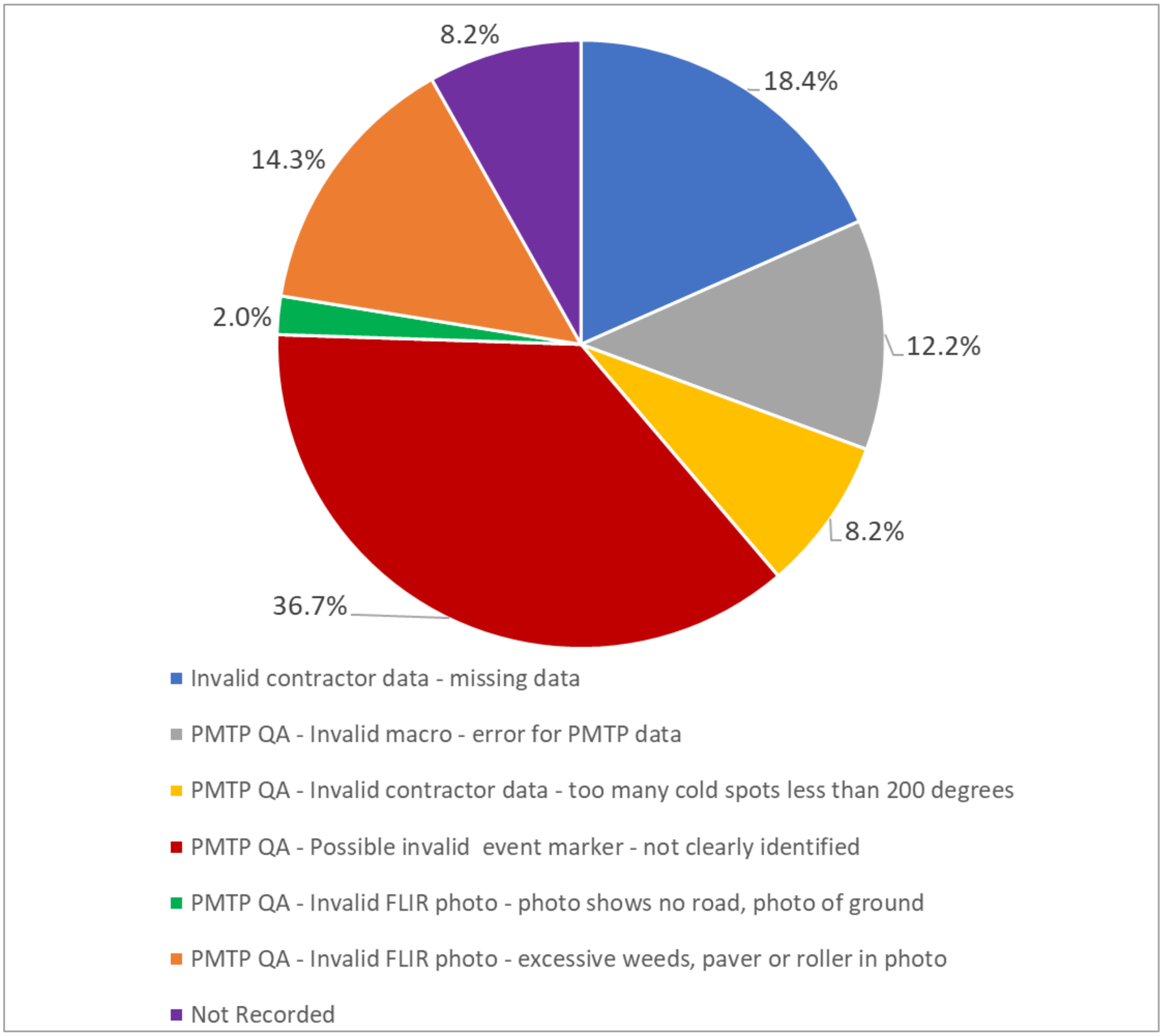
Source: Project Team (2023)

Figure 19. Chart. Summary of results from the IC data verification.

In cases where the outcome was "fail," the most common issue was that the contractor data used low accuracy (not RTK) GNSS. The data verification devices (DirtMates) use post-processing to correct their raw signals by matching the MoDOT VRS signals with timestamps to provide high-precision data. However, it is not "Real-time kinematic"". There is an advantage over RTK since it can still collect data if the cellular coverage is poor (to provide real-time access to MoDOT VRS). In contrast, IC vendors use "Real-Time Kinematic," as it is required in the specification and by the operator to determine if sufficient coverage has been achieved. Therefore, IC may result in data loss or low GNSS accuracy (e.g., GNSS float precision) within sections of poor cellular coverage. It is recommended that only areas where RTK GNSS precision is achieved using IC and DirtMate are used for comparison purposes.

PMTP Temperature

Of the 70 FLIR images taken, 59 percent of images were analyzed and compared to contractor data. If the files couldn't be completed, an error was recorded. The errors that prevented analysis are summarized in Figure 20.



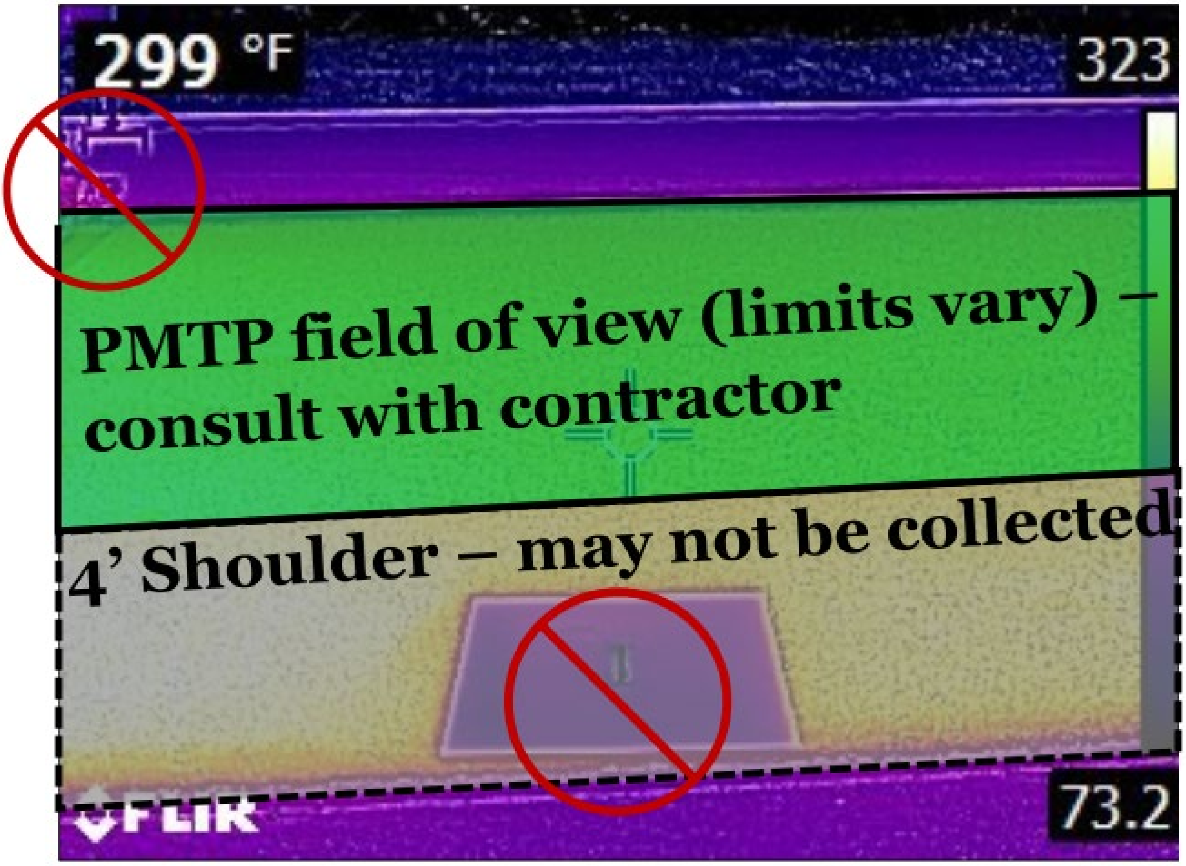
Source: Project Team (2023)

Figure 20. Chart. Errors associated with PMTP data verification.

Some of the common issues with invalid event markers were related to placing the event marker. The event marker should be placed directly behind the screed so that contractor PMTP equipment can scan it (Figure 21). In some cases, MoDOT staff placed the event marker too late, which was not picked up in contractor scans. Another common issue was placing the event marker at the edge of the pavement on a shoulder. Shoulders do not require PMTP data; in some cases, the contractor set up the PMTP equipment to collect driving lanes only and exclude shoulders. In this case, it is recommended that the event marker be placed on the edge of the driving lane, as delineated in Figure 22. There were still some issues related to the FLIR photos, although invalid photos were greatly reduced compared to 2022.

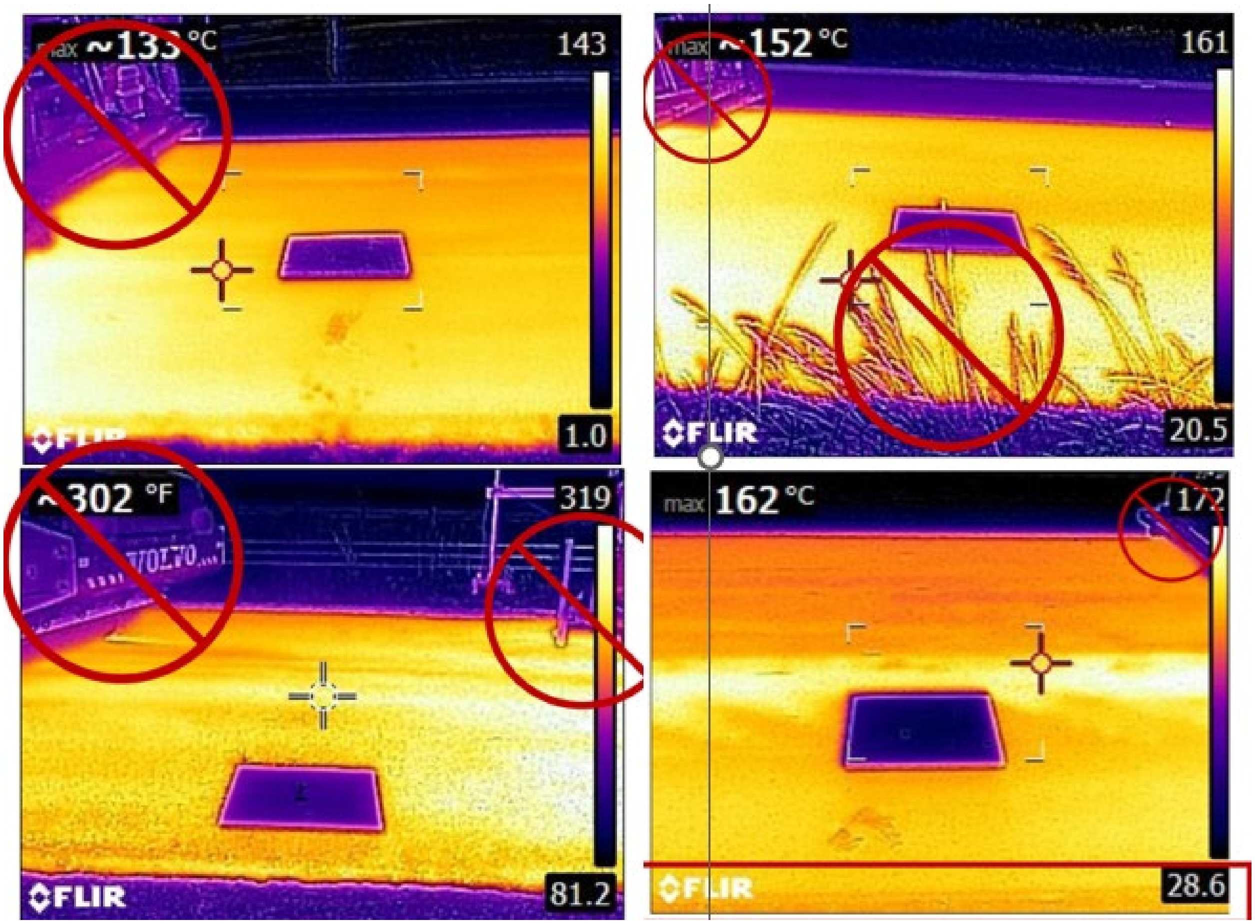
Source: Project Team (2022)

Figure 21. Illustration. Example of placing the event marker directly behind the screed.



Source: Project Team (2022)

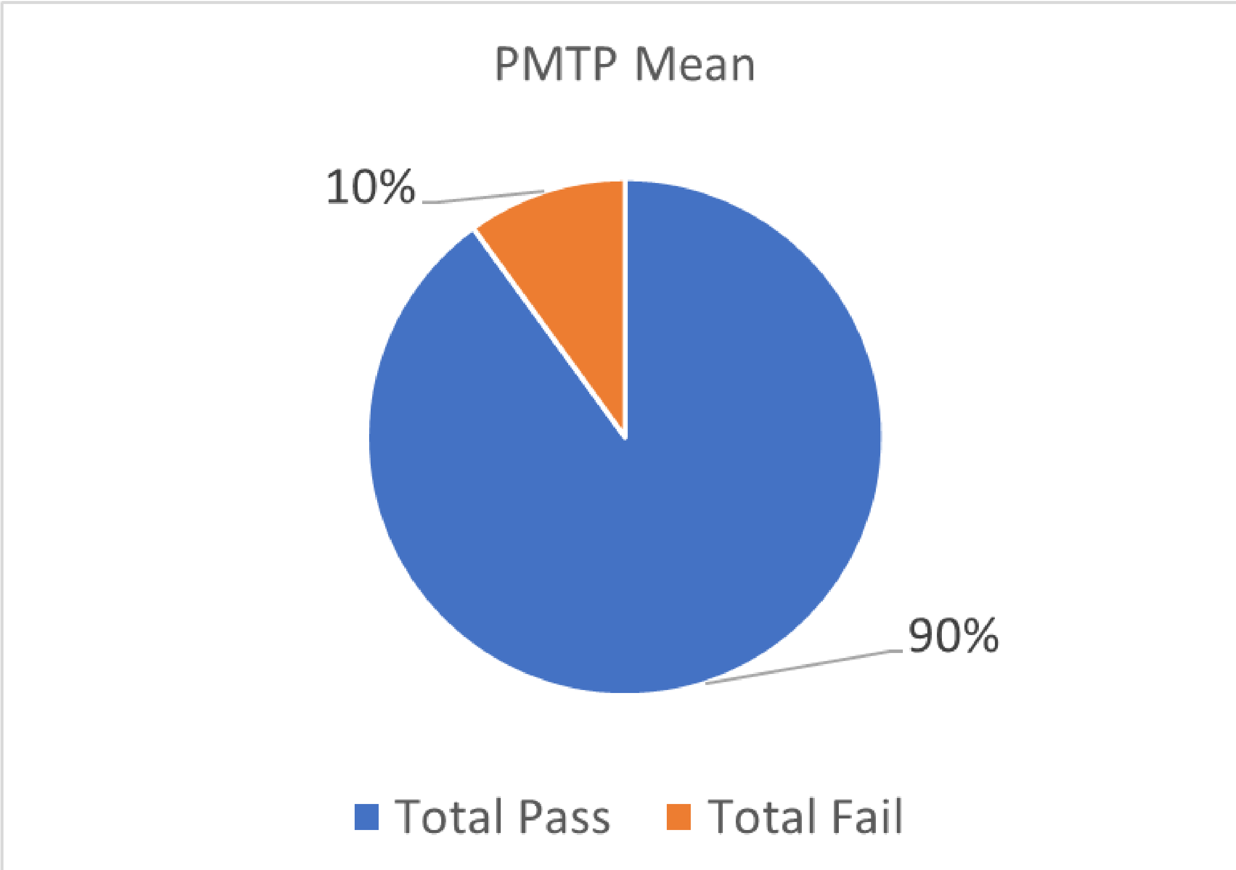
Figure 22. Illustration. Example of placing the event marker on the shoulder.



Source: Project Team (2022)

Figure 23. Illustration. Examples of invalid FLIR photos.

The comparison criteria between FLIR photos and contractor PMTP data are based on the mean temperature, and the threshold allows a 0.06% difference for a "passing" outcome. The results from the analyzed PMTP QA data are shown in Figure 24. Total pass equals 90 percent, and total fail equals 10 percent.



Source: Project Team (2023)

Figure 24. Chart. Summary of results from the PMTP data verification.

In instances where the verification did not meet the passing criteria, the most common reason was related to possibly invalid event markers. Sometimes, there were multiple cold spots, and identifying the event marker was challenging. Multiple cold spots may be caused by humans stepping off the screed or on the mat during placement. It can be challenging to place the event marker when shoulders are being paved with the driving lane, but PMTP data is not collected along the shoulder (as shown in Figure 22). Therefore, it is recommended that specification language requires collecting full-width paving data and filtering out shoulders in Veta. This language would allow the placement of the event marker at the edge of the pavement for data verification.

Based on the results, the method appears to work well for data verification when the data collection results in a valid FLIR photo and valid event marker.

Training Program

Overall, the feedback for the 2023 training program was positive. The 2024 training program will include two spring training sessions in late February, similar to the ones conducted in 2023. Train the Trainers

(TTT) sessions will be held to aid the Field Office as needed during the season. JITT will not be held in 2024, but remote support will be available to MoDOT project staff and contractors.

Summary

The key discussions in the meetings focused on various challenges and potential solutions based on the 2023 feedback.

For IC Coverage, the main issues in 2023 were data loss and GNSS challenges due to poor satellite connection and poor cellular coverage. The adoption of Global SIM cards and a more thorough assessment of GNSS equipment for specific projects were proposed as solutions.

Equipment issues, particularly with IC temperature sensors, were also discussed. Obstructions (dirt, oil, vaper) and electrical problems leading to inaccurate readings were discussed, with daily checks using hand-held sensors recommended for verification.

For PMTP data verification, topics include continuous training for FLIR image collection and addressing issues with event marker placement and timestamp synchronization. Other technologies, like drones, are being considered for data verification but are still in the research stages.

For verifying IC data, there were discussions about the challenges with the DirtMate device. It has a complex process for sending data to the cloud, needs a Daily Use Gateway (DUG) hotspot, and has limited web-based tools for diagnosis. Planning meetings will be held to see if the processes can be improved for the 2024 season.

Additionally, the interface between the upcoming Veta MDMS & Web release and AASHTOWare was a topic of interest, especially for MoDOT. Revisions to IC specifications included discussions on using on-ground base stations in areas with poor cellular coverage and more detailed project reconnaissance for GNSS and cellular coverage.

The proposed future specifications were discussed. The specifications are still under development, and discussions included segment classifications, corrective actions, price adjustments, and other details. There will be an industry discussion in early 2024 to finalize some of the future specification language.

Chapter 9. Task 9 – Data QA Equipment

This task was to supply IC pass count and PMTP temperature data verification equipment to MoDOT to use in the 2022-2023 season.

Twenty FLIR E5-XT thermal cameras with National Institute of Standards and Technology (NIST) calibration were purchased in 2023. The new equipment was procured to expand the data verification equipment supply so that more project offices could have FLIR thermal cameras.

More details on the data verification procedures and equipment are covered in the final report from the companion project, Implementation of Data Quality Assurance (QA) for Innovative Technologies at MoDOT (Chang et al., 2022).

Chapter 10. Conclusions and Recommendations

The conclusions from each of the project tasks are summarized below.

Task 2 – IC-PMTP Protocol

Specification changes were proposed in 2023, targeting pilot testing in 2024 or 2025, with full implementation in the following years. These changes include updates in IC and PMTP specifications, such as new requirements for data collection, segment classification, quality control plans, and adjustments in incentives/disincentives. Additionally, significant updates were made to training materials like the DirtMate Quick Reference Guide and the MoDOT Inspector Sheet Guide, focusing on enhanced instructions, improved visual aids, and comprehensive details to support project staff better.

Task 3 – IC-PMTP Training Program

Following the 2021 IC-PMTP final report's recommendation, a comprehensive training program was implemented in 2022 and 2023 to enhance skills in IC-PMTP. Key components included statewide workshops for contractors and MoDOT staff, TTT sessions to train MoDOT interns and Field Office staff with in-house technical support skills, and JITT sessions for targeted hands-on practice. Additionally, the MoDOT Training Page was updated on the SharePoint navigator tool to reflect these changes. The "Black to Basics" conference, although not directly funded by this project, provided advanced training on Veta usage. TTT sessions, held remotely, aimed to train MoDOT interns in data QA procedures, with suggestions for longer sessions and self-paced modules for future training. JITT varied in content based on attendees, with a focus on QA data collection and verification. The SharePoint navigator, "Document Helper," was updated to organize training materials better.

Task 4 – IC-PMTP Project Supports

2023 onsite support was limited, with a single session focusing on a pilot project for an alternative boundary collection method mounting a receiver to the paver screed. Remote support, primarily facilitated via Microsoft Teams, addressed various needs: contractors sought assistance with data analysis, technical equipment issues, data loss, and questions about innovative boundary collection. MoDOT staff commonly requested help with data QA and reporting challenges. Common analysis questions involved data filtering, custom start/stop locations, and legend customization for IC and PMTP data. The 2023 season faced several instances of data loss and GNSS quality issues, with potential solutions discussed in Feedback Meetings. Data quality checks on SharePoint involved standard naming conventions, file management, correct filtering, legend customization, and accurate data reporting. Overall, remote support focused on troubleshooting, with a particular emphasis on filtering, analysis, and ensuring high-quality data management and reporting practices.

Project Analysis and Results

Not all planned projects proceeded as expected, with some delays and missing data uploads. Ten projects had data uploaded to SharePoint.

The project results chapter summarizes the assessment for data management, IC and PMTP protocols compliance, and overall performance. The IC results are evaluated against MoDOT specification NJSP-18-08, focusing on pass count coverage, target ICMV, and MTOP. Challenges were noted in reporting target ICMV. Issues with data loss and erroneously high-temperature data were observed.

PMTP results, based on NJSP-18-09, were also assessed, focusing on thermal segregation categories. The project's overall strength lies in the improvement shown in IC coverage and PMTP thermal segregation trends since the technology's implementation. However, areas for improvement include better inclusion of spot test data, accurate reporting of target ICMV by contractors, consistent data management, and ensuring equipment verification for reliable data collection. The report suggests emphasizing these aspects in future training sessions and data management protocols.

Overall trends in performance show that since implementation, low thermal segregation has increased, severe segregation has decreased, and IC pass count coverages and temperatures have remained consistent.

Task 5 – Pilot Innovation Technologies

In 2022 and 2023, two alternative methods for boundary collection were successfully piloted as part of a move towards automated boundary collection required in future specifications. The 2022 final report summarizes the use of LiDAR-based vehicle-mounted technology to collect surface data and post-process it for boundary selection. In 2023, three contractors adopted LiDAR technology for this purpose.

An alternative approach piloted in 2023 involved mounting a Trimble GNSS rover on the paver. Data was set to auto-collect every 100 feet and was post-processed to generate a Veta-compatible alignment file. Both methods demonstrated effectiveness in automated boundary collection but required some post-processing. These developments align with the upcoming specification changes emphasizing automated, non-manual boundary collection techniques.

Task 6 – Pavement Performance Tracking

Limited data were collected under Task 6 for the performance tracking efforts. A FHWA IC-based HMA density model was evaluated, and a new mechanistic approach was proposed. It is proposed for future research to improve the IC-based HMA density model with further field data for model training and validation.

Task 7 – Feedback Meeting

The key discussions in the 2023 Feedback Meetings addressed several areas of interest and concern:

- IC Coverage Issues: Data loss and GNSS-related problems were prevalent in 2023, often due to obstacles like dense tree canopies and winding roads or equipment malfunctions. Poor cellular coverage was also a significant factor, affecting data transmission and VRS connections. Solutions such as Global SIM cards for consistent cellular connections, base stations for areas with poor cellular coverage, and more GNSS equipment suitability assessments for specific projects were proposed.

- Equipment Issues: Faulty IC temperature sensors can give erroneous readings. Obstructions like dirt or oil vapors and electrical issues lead to inaccurate temperature readings. Daily checks with hand-held sensors are required in the project protocols, and these should be emphasized in future training sessions.
- IC Data Verification using DirtMates: The process of transmitting data from DirtMates to the cloud was complex and time-consuming, involving setting up a Daily Use Gateway (DUG) hotspot. Web-based diagnostic tools, while available, were not user-friendly. A meeting with the manufacturer was planned for 2024 to discuss possible improvements.
- PMTP Data Verification using FLIR Cameras: Improved quality and quantity of FLIR images for data QA were noted, with recommendations to aid event marker placement and synchronize timestamps between FLIR cameras and contractor equipment. The use of drones or other temperature-measuring devices was discussed as future possibilities.
- Veta Web and Interface with AASHTOWare: The upcoming release of Veta MDMS & Web in 2024 and its interface with AASHTOWare, particularly for MoDOT, was a topic of interest, with details still in the early planning stages.
- Revisions to IC Specifications: The Feedback Meeting covered the proposed changes to IC specifications, including the use of on-ground base stations in areas with poor cellular coverage and more detailed project reconnaissance for GNSS and cellular coverage. The proposed segment classifications were discussed. The specifications are still under development and are subject to change before being released.
- Revisions to PMTP Specifications: Future PMTP specifications will likely use "near" RTK GNSS for simplified data analysis. Discussions included the new limits of thermal segregation classification and the new incentive/disincentive structure. The specifications are still under development and are subject to change before being released.
- Data QA (Verification of Contractor Data): Results from data QA projects were reported, with findings summarized in the Data QA companion report. There are still issues related to data collection, and these will continue to be emphasized in future training sessions.
- Training Program: Positive feedback was received for the 2023 training program. Plans for 2024 included two spring training sessions and "Train the Trainers" sessions. There are no scheduled JITT sessions in 2024, but remote support will be available to contractors and MoDOT staff.

Summary

MoDOT plans to move forward with IC-PMTP implementation, targeting statewide implementation in the future. MoDOT will continue to focus on evolving specifications, comprehensive training, flexible support mechanisms, piloting new innovative technologies, and continuous improvement of the IC-PMTP program and pavement construction quality.

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