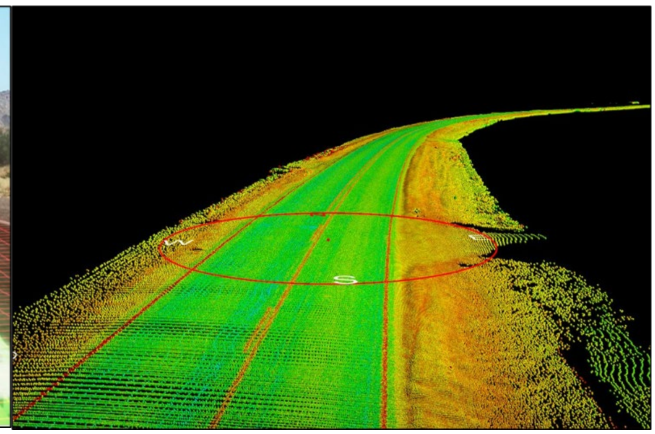
Consultant Support for Intelligent Compaction and Paver-Mounted Thermal Profiling Projects in 2022-2023



May 2023
Final Report

Project number TR20221
MoDOT Research Report number cmr 23-010

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
cmr 23-010		

4. Title and Subtitle	5. Report Date
Consultant Support for Intelligent Compaction and Paver-Mounted Thermal Profiling Projects in 2022-2023	March 2023 Published: May 2023
	6. Performing Organization Code
7. Author(s) Dr. George K. Chang, P.E. (https://orcid.org/0000-0002-4945-8827) Amanda Gilliland, P.E. Dr. Abbas TaghaviGhalesari	**8. Performing Organization Report No.**
9. Performing Organization Name and Address The Transtec Group, Inc. 6111 Balcones Drive Austin, TX 78731	**10. Work Unit No.**
	11. Contract or Grant No. MoDOT project # TR202221
12. Sponsoring Agency Name and Address Missouri Department of Transportation (SPR-B) Construction and Materials Division P.O. Box 270 Jefferson City, MO 65102	**13. Type of Report and Period Covered** Final Report (March 2022-April 2023)
	14. Sponsoring Agency Code

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. MoDOT research reports are available in the Innovation Library at https://www.modot.org/research-publications.

16. Abstract

Due to the success of the MoDOT 2017-2021 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 2022 and 2023. To ensure the continued success of the MoDOT IC-PMTP projects in 2022 and beyond, MoDOT has procured Consulting Support for the selected IC-PMTP projects in 2022-2023 and implemented many initiatives such as data quality assurance (QA), performance tracking, and future acceptance with IC-PMTP data. This report is Part 1 of the Task 8 deliverable – 2022 Final Report.

17. Key Words	18. Distribution Statement
Compaction; Temperature segment analysis; Paving; Intelligent compaction; Thermal profiles; Roller; Paver; Asphalt; Overlay; Quality control	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified.	Unclassified.	73	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

MoDOT Project No. TR202221

CONSULTANT SUPPORT FOR INTELLIGENT COMPACTION AND PAVER-MOUNTED THERMAL PROFILING PROJECTS IN 2022-2023

2022 ANNUAL REPORT

Submitted to:

Missouri Department of Transportation

1617 Missouri Blvd.

Jefferson City, MO 65102

March 2023

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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, U.S. Department of Transportation, or Federal Highway Administration. This information does not constitute a standard or specification.

ACKNOWLEDGMENTS

The authors graciously thank MoDOT for funding the Intelligent Compaction (IC) and Paver-Mounted Thermal Profiler Systems (PMTPs) projects. The authors would also express gratitude towards those IC and PMTPs vendors, dealers, and contractors for their assistance and cooperation during the field projects and subsequent data collection and analysis.

EXECUTIVE SUMMARY

MoDOT's Intelligent Compaction and Paver-Mounted Thermal Profiling (IC-PMTP) projects (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 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 March 2022 to April 2024, spanning approximately 26 months. This report is a summary of the completed work in 2022, and the work completed during 2023 will be included in a future report.

Year-to-year 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 since implementation in 2017. These trends indicate that intelligent construction technologies improve successful construction practices, which may lead to higher-quality pavements.

Highlights in 2022 include the following:

- Successful implementation of an enhanced training program.
- Enhanced training materials for MoDOT inspection staff, including guides to check contractor submittals and collect verification data.
- Successful project supports and data quality checks, including data QA support.
- Successful use of LiDAR data to collect boundary measurements (in place of hand-held equipment).
- Successful data QA procedures show that the proposed methods are acceptable tools for data verification. Some challenges related to data collection persist but are reduced from previous years.

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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

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

S_{app}: Cyclic fatigue index parameter

SOW: Scope of Work

TPF: Transportation Pooled Fund

TSI: Thermal Segregation Index

TTT: Train-the-Trainers

UTM: Universal Transverse Mercator

CHAPTER 1 INTRODUCTION

1.1 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, 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 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

1.3 STRUCTURE OF REPORT

This 2022 annual report is a deliverable for Task 8. The rest of this report is structured by task, as summarized in Table 1.

Table 1. Summary of the report.

Chapter	Description of Tasks
Chapter 1	Introduction
Chapter 2	Summary of Task 2 – IC-PMTP Protocol
Chapter 3	Summary of Task 3 – IC-PMTP Training Program
Chapter 4	Summary of Task 4 – IC-PMTP Project Supports
Chapter 5	(No associated task) Summary of Project Results
Chapter 6	Summary of Task 5 – Pilot Innovative Technologies
Chapter 7	Summary of Task 6 – Pavement Performance Tracking

Chapter	Description of Tasks
Chapter 8	Summary of Task 7 - Feedback Meeting and Executive Briefing
Chapter 9	Summary of Task 9 – Data QA Equipment
Chapter 10	Conclusions and Recommendations

CHAPTER 2 TASK 2-IC-PMTP PROTOCOL

2.1 INTRODUCTION

IC-PMTP protocols were revised minimally 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 following sections.

2.2 REVISIONS TO THE SUMMARY SHEET

The summary sheet was revised to include an instruction page. The instructions page includes general assistance with using the summary sheet and enabling macros. The summary sheet was also updated to support "mixed fleets," as further described in section 5.3.1.

2.3 REVISIONS TO THE DATA QA PROCEDURES

Several changes were made to the ICT data QA program based on lessons learned from piloting original methods during previous seasons. The following changes were made to IC and PMTP data QA in the 2022 construction season:

- Upgraded Dirtmates. Propeller's solution to past data loss issues was to use Dirtmate GEN 3 equipment instead of the older generations used in previous construction seasons. The solar panels charging efficiency and battery life of the new generations are improved.
- Upgraded the hotspot equipment. The data transmission device was changed from a Wi-Fi hotspot to Daily Use Gateway (DUG) for IC data QA. The DUG continuously transfers data to the cloud faster than the hotspots when connected to a cellular network. Therefore, the data loss in this season was significantly reduced.
- Used Veta filters to remove erroneous data. Data halos (extra data collected while the roller is stationary) still exist in Dirtmate data (reference the 2021 annual report for more details). Speed filters were used to filter data halos, which worked well during the 2022 season.
- Increased event marker size and supplied event marker to project staff. A 2-foot by 2-foot event marker was used this season since the 1-foot by 1-foot event marker could not be well identified because of the grid size of PMTP data. The event marker was provided for all projects. A handle was attached to aid in the event marker placement and removal.
- Updated PMTP macro tool. The data QA macro tool was updated with several improvements in raw and filtered data visualization, data processing, and reporting. One of the outputs is the quantile results that facilitate comparing FLIR and PMTP data distribution. The Research Team continues to streamline the PMTP data QA tool.
- Updated Training Materials. New training materials included PMTP data QA data collection videos and reference guides (further described in Chapter 4).

2.4 SUMMARY

The IC-PMTP protocols were slightly revised to update the summary sheet and data QA procedures.

CHAPTER 3 TASK 3-IC-PMTP TRAINING PROGRAM

3.1 INTRODUCTION

Based on the 2022 IC-PMTP final report, one of the main recommendations was to increase training efforts. Therefore, a new training program was implemented in 2023. A summary of the training program is shown in Table 2. Details for each training are summarized in the following sections.

Table 2. 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 staff 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 GPS tracker and FLIR camera) and Veta analysis. Training videos were made during JITT to use as future training tools.
MoDOT Training Page	A SharePoint navigator tool was made to organize the training materials and site content to make it easier to use.

3.2 STATEWIDE IC-PMTP WORKSHOPS

Two statewide workshops were held as follows:

- March 14, 2022, Statewide Training for MoDOT.
- March 15, 2022, Statewide Training for Contractors.

3.2.1 Training Agenda

An example training agenda is shown in Figure 1. Each workshop was geared towards the appropriate audience (e.g., contractors or MoDOT staff).

Statewide IC-PMTP Veta
WORKSHOP FOR MODOT Staff

Monday, March 14, 2022

Hybrid (Onsite and GotoWebinar Online Training)

OBJECTIVES

- ✓ To understand the basics of the Intelligent Compaction (IC) and Paver-Mounted Thermal Profiles (PMTP) technologies and Veta software.
- ✓ To understand DOT IC/PMTP specifications and how to meet the requirements.
- ✓ To understand the IC/PMTP data collection, data analysis, and troubleshooting.
- ✓ To practice hands-on Veta analysis to understand in-depth IC/PMTP.

WORKSHOP AGENDA

AM
09:00 am Session 1 – IC Data Collection and Analysis
10:10 am Break
10:30 am Session 2 – PMTP Data Collection and Analysis
12:00 pm Break

PM
01:00 pm Session 3 – Other Data Collection & Data Management
02:00 pm Break
02:15 pm More Veta Hands-on Exercises and Qs-&-As
03:00 pm Adjourn

Handouts

Please download the following handouts before the workshops

- Veta 7.0 quick reference guide
    - MoDOT SharePoint
    - ICT website
- Workshop Handouts
    - MoDOT SharePoint
    - ICT Website

Intelligent Construction website: http://www.IntelligentConstruction.com/

1

Figure 1. Screenshot. Statewide IC-PMTP workshop agenda.

3.2.2 Summary of Statewide Training Workshops

The statewide training workshops aim to prepare all contractors and MoDOT project staff for the upcoming IC-PMTP projects. The training is hands-on and entry-level to walk participants step-by-step through the data collection, analysis, and reporting. The workshops also are used as refresher courses and include updates to protocols or Veta software as needed. Therefore, statewide training workshops are suitable for all IC-PMTP project participants.

3.3 TRAIN THE TRAINERS (TTT)

3.3.1 Training Agenda

The TTT was held on March 16, 2022. The training agenda for the TTT is shown in Figure 2. The attendees included MoDOT Field Office staff.

Statewide IC-PMTP Veta
TRAIN-THE-TRAINERS WORKSHOP

Wednesday, March 16, 2022
Onsite/MoDOT Office: 1617 Missouri Blvd, Jefferson City, MO 65102-0270

OBJECTIVES

- ✓ To understand the advanced topics of the Intelligent Compaction (IC) and Paver-Mounted Thermal Profiles (PMTP) technologies and Veta software.
- ✓ To practice hands-on Veta analysis to understand in-depth IC/PMTP and Data QA Tools.
- ✓ To practice hands-on

WORKSHOP AGENDA*

08:00 am Session 1 – IC-PMTP In-Depth Data Analysis

10:10 am Break

10:30 am Session 2 – IC-PMTP Data QA Analysis

12:00 pm Adjourn

* The agenda can be flexible to meet attendees' needs.

Handouts

Please download the following handouts before the workshops

- Veta 7.0 quick reference guide
  - MoDOT SharePoint
  - ICT website
- Workshop Handouts
  - MoDOT SharePoint
  - ICT Website

Intelligent Construction website: http://www.IntelligentConstruction.com/

Figure 2. Screenshot. Train-the-Trainers workshop agenda.

3.3.2 Summary of TTT 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 (Figure 3). During the TTT, the Research Team and Field Office staff thoroughly covered data collection and analysis procedures.

Figure 3. Photograph. A Dirtmate Gen 3 is mounted on a rental car with the new DUG nearby to send data to the cloud.

Data QA data analysis procedures for IC pass count and PMTP temperature were covered in the classroom training session.

3.4 JUST-IN-TIME-TRAINING (JITT)

3.5 JITT PROGRAM

3.5.1 Training Agenda

The JITT sessions were tailored to specific district attendees, so the exact content varies. An example training agenda for a JITT session is shown in Figure 4.

IC-PMTP Veta
JUST-IN-TIME TRAINING (JITT)

Date: June 2, 2022
Location: 282 County Road 523, Poplar Bluff, MO 63901

OBJECTIVES

- ✓ To practice the complete process of analyzing and reporting Intelligent Compaction (IC) and Paver-Mounted Thermal Profiles (PMTP) data with Veta software.
- ✓ To go through all required MoDOT forms (checklist and summary sheets) and data submission to SharePoint (file naming convention and project subfolders)
- ✓ (MoDOT staff) To practice the IC/PMTP QA data collection, analysis, and troubleshooting.

*TRAINING AGENDA**

AM (Contractors and MoDOT)

08:00 am	IC and PMTP Data Analysis
10:00 am	Break
10:10 am	Forms and Data Management/Q&A - SharePoint DocHelper Navigator.
11:00 am	Break (Adjourn for contractors)

PM (MoDOT only)

12:30 pm	MoDOT Inspector Checklist
01:30 pm	Background on Data QA
02:00 pm	Break
02:15 pm	PMTP Data QA with Flir data collection.
03:00 pm	IC Data QA with Dirtmate data collection.
03:45 pm	End

* The agenda can be customized to meet the specific needs of contractors and MoDOT staff.

CONTACTS

JITT Facility:	Donald Hills, (573) 472-9013, Donald.Hills@modot.mo.gov
MoDOT:	Jason Blomberg, (573) 526-4338, Jason.Blomberg@modot.mo.gov
Transtec:	Amanda Gilliland, (512) 927-7118, AmandaG@TheTranstecGroup.com

REFERENCES

IC-PMTP Document Helper SharePoint Navigator

Note: If you cannot access the IC-PMTP Document Helper SharePoint Navigator by logging into the ICT SharePoint site, please email Jonathan Varner at jonathan.varner@modot.mo.gov to request access.

Figure 4. Screenshot. Example JITT agenda.

3.5.2 JITT locations and Dates

The JITT locations, facilities, dates, and attendees are summarized in Table 3.

Table 3. Summary of JITT.

JITT Location	Facility	Date	Attendees
Elwood, KS	Herzog plant and materials lab.	3/17/2022	KC District project offices, Herzog personnel.
Columbia, MO	Fabick CAT facility.	3/23/2022	Central District project inspectors only and ESS and Capital personnel.
Linn Creek, MO	Capital Paving facility.	3/24/2022	NE, SW, and Central District inspectors.
St. Charles, MO	St. Charles District office.	6/1/2022	STL District inspectors and NB West personnel.
Poplar Bluff, MO	Poplar Bluff District office.	6/2/2022	SE District inspectors and APEX personnel.

3.5.3 Summary of JITT Training

The JITT data QA training was hands-on and focused on QA data collection and verification of contractor submittals. When contractor staff was present, the training included data collection, analysis, and reporting in Veta. The training sessions are summarized below.

3.5.3.1 IC Pass Count QA Data Collection Training

The DUG and Dirtmate were displayed and passed around so all attendees could see the equipment. The DUG was set up in the classroom (Figure 5) so attendees could see how the equipment was put together and used. Protocols for using the DUG were summarized.

Figure 5. Photograph. Setting up the DUG during JITT.

3.5.3.2 PMTP Temperature Data Collection Training

The FLIR camera and event marker were passed around so attendees could take practice photos. Unfortunately, it is challenging to facilitate the exact conditions of a paving operation for the example photos.

3.5.3.3 Checking Contractor Submittals

During the Elwood, KS JITT, MoDOT personnel requested a quick reference guide for reviewing contractor submittals, and this was developed and uploaded to SharePoint. During the future JITTs, the inspector's review guide was shown, and an example dataset was used to go through the process. Key inputs that generate price incentives, such as project length and IC and PMTP results, were emphasized.

3.5.3.4 Contractor Submittals

When contractors were present at the JITT, the project setup, data analysis, and reporting in Veta were covered in the JITT.

3.5.4 Feedback from JITT Programs

The feedback received by JITT attendees was positive, and meeting in a more personal setting (compared to a statewide workshop) made it easier to understand district-specific needs and questions. Some of the valuable outcomes or lessons learned from the JITT are summarized in the following sections.

3.6 DOCUMENT HELPER SHAREPOINT NAVIGATOR

A common response during the 2021 feedback meetings was better organizing the materials on SharePoint. Therefore, the Document Helper SharePoint Navigator (DocHelper) was created to help users navigate the site. The first screen of the DocHelper is shown in Figure 6.

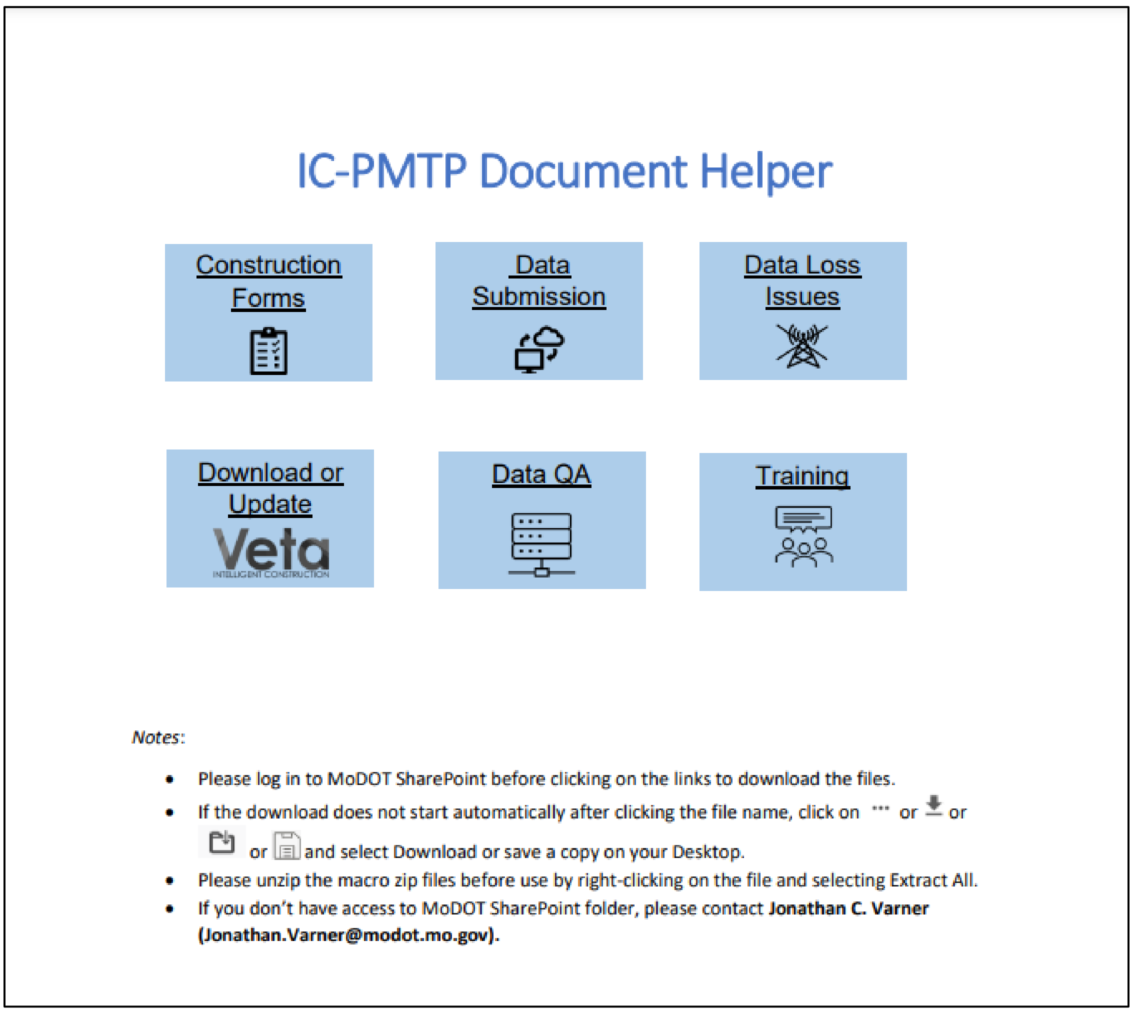
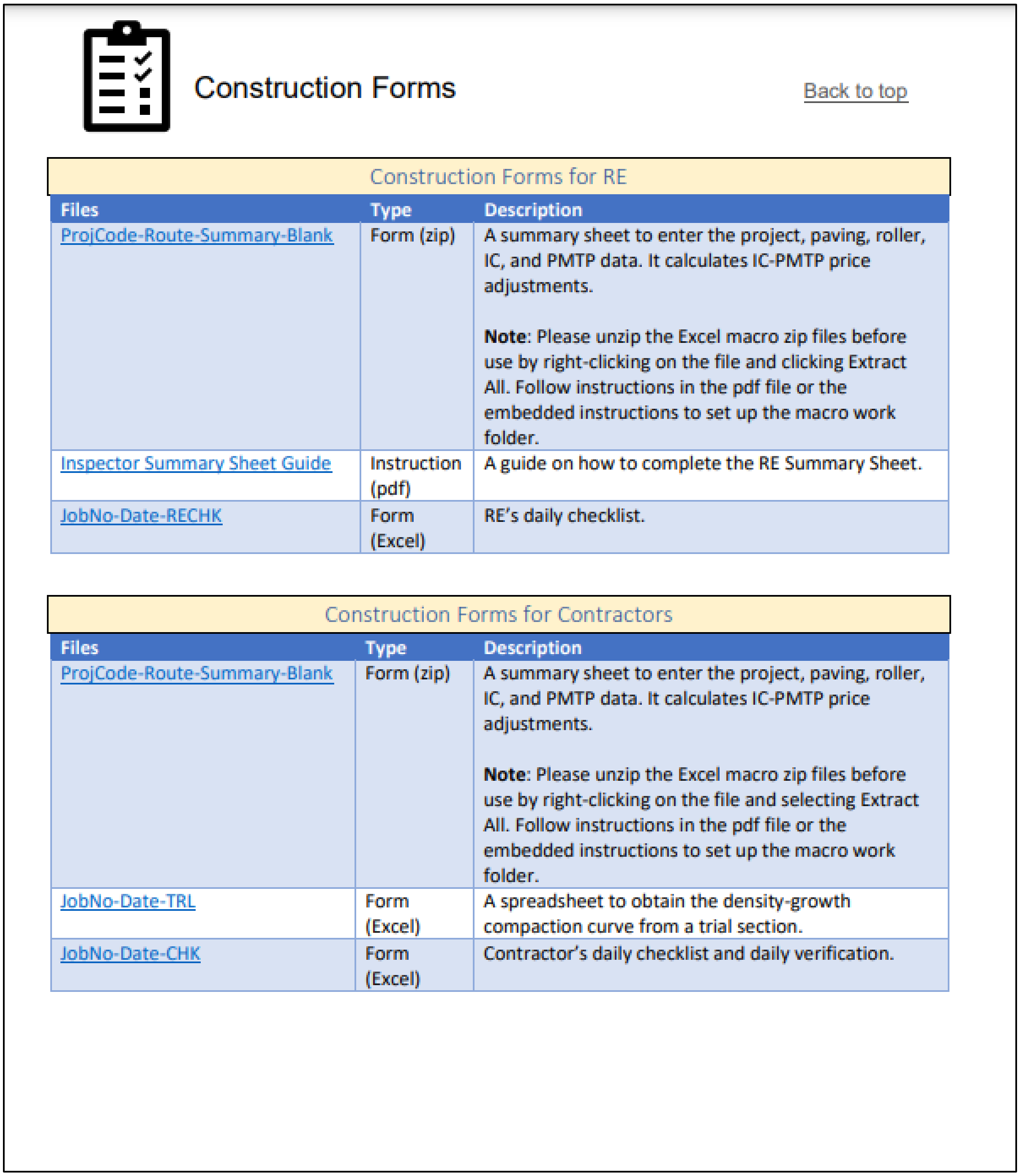


Figure 6. Screenshot. The first screen of the IC-PMTP DocHelper

The DocHelper uses links to help users navigate the contents of SharePoint. For example, clicking on the construction forms "button" leads users to a list of needed documents, as shown in Figure 7. The list of documents makes it easy to access and download all the needed forms.



Construction Forms

Back to top

Construction Forms for RE		
Files	**Type**	**Description**
ProjCode-Route-Summary-Blank	Form (zip)	A summary sheet to enter the project, paving, roller, IC, and PMTP data. It calculates IC-PMTP price adjustments. **Note**: Please unzip the Excel macro zip files before use by right-clicking on the file and clicking Extract All. Follow instructions in the pdf file or the embedded instructions to set up the macro work folder.
Inspector Summary Sheet Guide	Instruction (pdf)	A guide on how to complete the RE Summary Sheet.
JobNo-Date-RECHK	Form (Excel)	RE's daily checklist.

Construction Forms for Contractors		
Files	**Type**	**Description**
ProjCode-Route-Summary-Blank	Form (zip)	A summary sheet to enter the project, paving, roller, IC, and PMTP data. It calculates IC-PMTP price adjustments. **Note**: Please unzip the Excel macro zip files before use by right-clicking on the file and selecting Extract All. Follow instructions in the pdf file or the embedded instructions to set up the macro work folder.
JobNo-Date-TRL	Form (Excel)	A spreadsheet to obtain the density-growth compaction curve from a trial section.
JobNo-Date-CHK	Form (Excel)	Contractor's daily checklist and daily verification.

Figure 7. Screenshot. Example of the DocHelper construction forms page.

3.7 SUMMARY

Several new training sessions were included in the 2022 training program. The new training sessions helped target some areas that needed improvement based on the 2021 findings. It is recommended that the training program is carried through 2023.

CHAPTER 4 TASK 4-IC-PMTP PROJECT SUPPORTS

4.1 INTRODUCTION

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

4.2 TASK 4-1: ONSITE SUPPORT

Project supports were typically "piggybacked" onto the JITT sessions, and ongoing projects in the vicinity of the JITT were visited and supported. Remote support typically included onsite assistance with data analysis (contractors) and data QA collection (MoDOT staff).

4.3 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 uploading data to SharePoint. Several contractors had issues uploading content to SharePoint, which was random and not resolved. If the issue persists, MoDOT IT staff should look into the cause.
- Contractors were using mixed fleets and needed assistance generating pass-count coverage and mean temperature at the optimum pass (MTOP) using mixed fleets. More information on mixed fleets is in section 5.3.1
- MoDOT project staff requested assistance with checking contractor submittals and price adjustments.
- MoDOT project staff requested assistance with data QA collection.
- MoDOT project staff inquired if the Dirtmate Data was being uploaded correctly, and MoDOT staff had no way of knowing if data was transmitted through the DUG. More information on this issue is in section 5.3.2.

4.3.1 Mixed Fleets

Mixed fleets are when multiple roller vendors are used on a project (e.g., one Volvo IC roller and one Topcon retrofit roller). Veta 7.0 only supports one roller vendor per project due to the following reasons:

- Vendors use different "grid sizes" for their gridded data. Because data grid sizes influence roller pass counting, it is impossible to mix different grid sizes in a Veta project. The solution requires ungridded data from mixed fleet data to allow Veta to perform the gridding and pass counting.
- Each vendor uses a different ICMV methodology and cannot be mixed even after the above ungridded data.

At least one contractor used mixed fleets during the 2022 season. Other contractors planned to use mixed fleets but were able to avoid it since they aren't supported in Veta. As a note, MnDOT does not allow mixed fleets for the above reasons.

Some changes were made in Veta 8.0 to import multiple types of ICMV from the same vendor's data, either ungridded or gridded. The data import rules are as follows:

- For ungridded data – different ICMV in different data files may be imported.
- For gridded data – different ICMVs within the same data file may be imported.
- ICMV will be listed in the drop-down menu and viewed individually. Different ICMV types cannot be combined.

Protocols were developed as a work-around to manage mixed fleet data during the 2022 season. There are two scenarios for how mixed fleets can be used, and the protocols for each scenario are described in Table 4

Table 4. Protocols for each mixed fleet scenario.

Scenario 1	Scenario 2
Rolling Pattern – tandem breakdown – each breakdown roller is a different vendor.	Rolling pattern – breakdown roller/s are the same vendor – intermediate roller is a different vendor
Solution – mathematically split the boundary into "right" and "left" sides. (e.g., each breakdown roller is doing 7 passes, one on the left side, one on the right side).	Solution - split the pass count according to the roller (e.g., the breakdown is doing 4 passes and intermediate is doing 3 passes) and do a weighted average.
Execution –mathematically split the boundary (averaging right and left boundary points before sorting them). Select scenario 1 in the summary sheet and input the requested values.	Execution – Select scenario 2 in the summary sheet, and Veta will weigh the final coverage based on pass distribution.

The summary sheet was updated to support mixed fleets, as shown in Figure 8. In 2022 only contractors who had mixed fleets used the updated summary sheet. It is recommended that the new summary sheet is introduced in the 2023 training seasons.

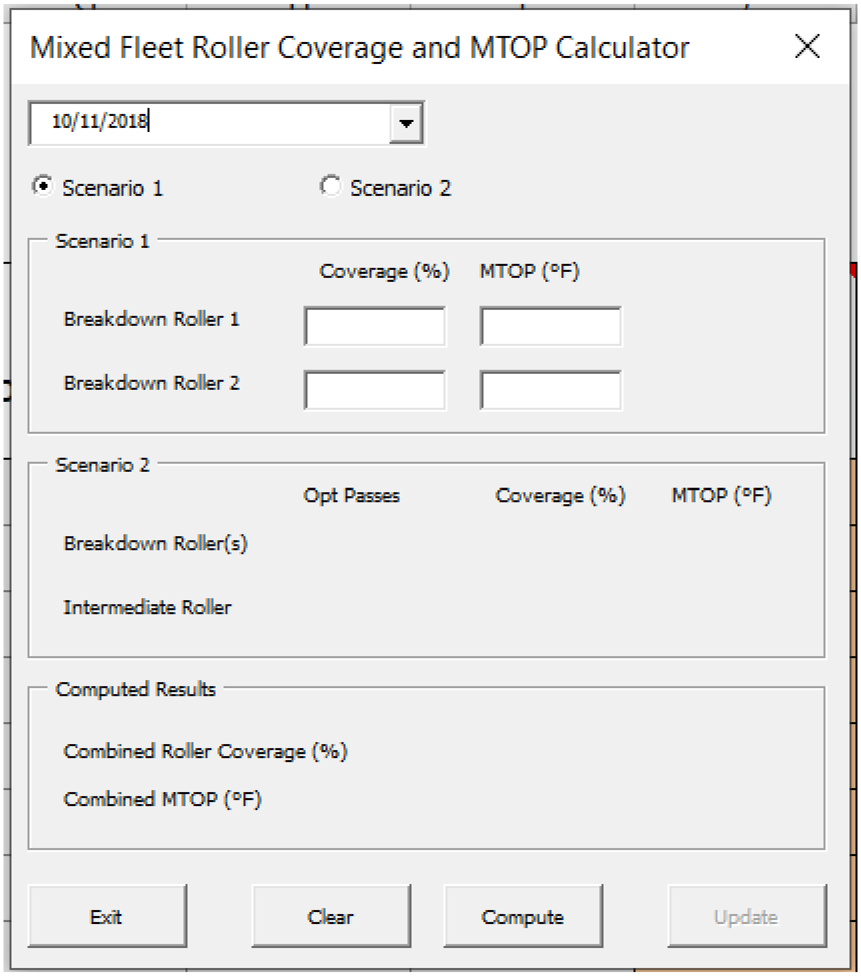


Figure 8. Screenshot. Mixed fleet calculator in the summary sheet.

4.3.2 Dirtmate Data Transmission

DUGs were piloted in 2022 to reduce data loss associated with data transmission. Overall, there was less data loss in 2023. However, Propeller did not provide a tool to show data transmission progress or completion. MoDOT project staff were instructed to stay within a clear line of sight of the roller for 30 minutes to transmit a day's worth of data. Later in the season, the time was increased to 60 minutes. Most MoDOT staff reported doing this at the start of a shift. MoDOT requested a method from Propeller to show data transmission. Propeller recommended using a data diagnostic tool in future seasons to allow the project staff to see how much data was left on the Dirtmate. When the data on the Dirtmate reaches 0 percent, the data transmission is complete. It is recommended that this new tool is to be piloted in 2023.

4.4 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 analysis procedures are further described in section 6.2.4.
- 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. Discussing the most common data quality issues in future training sessions may be beneficial to minimize them in future construction seasons.

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
Not using custom endpoints in filters.	Many projects did not have custom endpoints. The Veta estimated endpoints are only reliable when alignment files are used.	Frequent	Contractors should use custom endpoints to ensure the sublots are calculated properly.
Incorrect naming conventions and data file management.	Standard naming conventions and file management were commonly incorrect.	Moderate	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. Despite improvement from previous seasons, incorrect naming conventions and data file management still occur. Using data lot names per AASHTO PP 114 should be piloted in the 2023 season so that MoDOT can move towards the standard AASHTO conventions.
Incorrect setup of equipment.	Data headers are visible in the Veta data files screen. In some cases, the PMTP paving width was less than the actual paving width; 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.
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 separate Veta projects.	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.

4.5 DATA QA SUPPORT

The Consultant supported the Field Office in reviewing data QA for IC pass count and PMTP temperatures. Efforts included generating new training materials and facilitating meetings with Propeller to address Dirtmate data issues. These efforts were documented in detail under the final report of the companion project titled Implementation of Data Quality Assurance (QA) for Innovative Technologies at MoDOT (Chang et al., 2022).

4.6 SUMMARY

In-person technical support took place on the projects near JITTs. Remote support included assistance to REs and contractors during data analysis. Data quality checks were randomly performed on the data uploaded to the intelligent construction SharePoint.

Mixed fleets with more than one IC roller vendor per project require unique considerations when calculating pass-count coverage or MTOP. Two scenarios for mixed fleets were identified, and protocols were established to account for mixed fleets. The summary sheet was updated to include each scenario.

One of the most common requests from MoDOT project staff was a tool to monitor data transmission when using the DUG. A data diagnostic tool from Propeller will be piloted in the 2023 season.

The most common data quality issues identified during data checks are summarized and 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. Some of these issues were recurring from previous years, and despite improvements, they continue to need improvement.

CHAPTER 5 SUMMARY OF PROJECT RESULTS

5.1 PROJECT OVERVIEW

The projects completed during the 2022 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).

Different IC vendors were used during the 2022 season, including Topcon retrofit, Trimble retrofit, Caterpillar/Trimble (CAT/Trimble IC) original equipment manufacturer (OEM), and Volvo OEM. MOBA PAVE-IR and Caterpillar/Trimble Thermal Camera (CAT/Trimble TC) were the PMTP vendors used.

Table 6. Summary of IC-PMTP projects.

Project Code	Contractor Code	IC System	PMTP System[a]
12	1	Trimble	MOBA
7	2	Trimble	MOBA
7	3	Trimble	MOBA
5	4 and 5	Trimble	MOBA
12	6	Trimble	MOBA
5	7	Trimble	MOBA
2	8	Topcon	MOBA
2	9	Topcon	MOBA
1	10	Volvo	MOBA
1	11	Volvo	MOBA
8	12	CAT/Trimble & Volvo	CAT/Trimble
5	15	Trimble	MOBA
4	16	Topcon	MOBA
13	17	Volvo	MOBA
13	18	Volvo	MOBA
13	19	Volvo	N/A
13	20	Volvo	N/A
7	21	Trimble	N/A

5.2 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.

[a] N/A refers to surface leveling projects that used IC only.

5.2.1 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.

5.2.2 Project Filters

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 hot paver smoothing skis.

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

5.2.4 Analysis

5.2.4.1 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 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.

5.2.4.2 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. The new method, Thermal Segregation Index (TSI), will be used in the future due to its improved algorithm to identify longitudinal thermal streaks.

5.2.5 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.

5.3 PROJECT RESULTS

This section includes a summary of IC and PMTP results from the 2022 construction season and cumulative results from 2017 through 2022.

5.3.1 2022 Construction Season

The following sections include the results for the 2022 construction season. The data were assessed for meeting data management, IC, and PMTP protocols.

5.3.1.1 Data Management Results

The data management protocols include contractor data submission and RE data submission. Table 8 and Table 9 summarize the 2022 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 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 required for the project (projects 19-21 were surface leveling projects. Therefore, trial sections, PMTP data, and spot test data were not required).

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
12	1	Y	Y	Y	Y	P	Y	Y	Y
7	2	Y	Y	Y	Y	Y	Y	N	Y
7	3	Y	Y	Y	Y	Y	Y	N	Y
5	4 and 5	Y	Y	Y	Y	Y	Y	Y	Y
12	6	Y	Y	Y	Y	P	Y	Y	Y
5	7	Y	Y	Y	Y	Y	Y	Y	Y
2	8	Y	Y	Y	Y	P	Y	Y	Y
2	9	Y	Y	Y	Y	P	Y	Y	Y
1	10	N	Y	Y	N	P	Y	N	Y
1	11	N	Y	Y	Y	Y	Y	Y	Y
8	12	N	Y	Y	Y	P	Y	Y	Y
5	15	Y	Y	Y	Y	Y	Y	Y	Y
4	16	Y	Y	Y	Y	Y	Y	N	Y
13	17	N	Y	Y	Y	N	Y	Y	Y
13	18	N	Y	Y	Y	N	Y	Y	Y
13	19	N/A	N/A	Y	Y	N/A	Y	Y	Y
13	20	N/A	N/A	Y	Y	N/A	Y	Y	Y
7	21	N/A	N/A	Y	Y	N/A	Y	Y	Y

All 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 Dirmate File[a]	FLIR Images
12	1	N	N/A	Y
7	2	N	N/A	Y
7	3	Y	N/A	Y
5	4 and 5	N	N/A	Y
12	6	Y	N/A	Y
5	7	N	N/A	Y
2	8	N	N/A	Y
2	9	Y	N/A	Y
1	10	N	N/A	Y
1	11	N	N/A	Y
8	12	N	N/A	Y

[a] The Dirtmate files were generated by the Field Office staff and Transtec.

Project Code	Contractor Code	RE Checklist	RE Dirmate File[a]	FLIR Images
5	15	N	N/A	Y
4	16	N	N/A	N
13	17	N	N/A	Y
13	18	N	N/A	Y
13	19	N	N/A	N/A
13	20	N	N/A	N/A
7	21	N	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.
- Nearly all project staff uploaded FLIR photos to SharePoint.

Due to the complexity of the data QA analysis, in 2022, project staff were only responsible for collecting the data. Analysis was performed by the Field Office and the Consultant (Transtec). Therefore, the Dirtmate files were not required to be uploaded to SharePoint. Eventually, the analysis for data QA should be incorporated into Veta to simplify procedures.

5.3.1.2 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.
- 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.

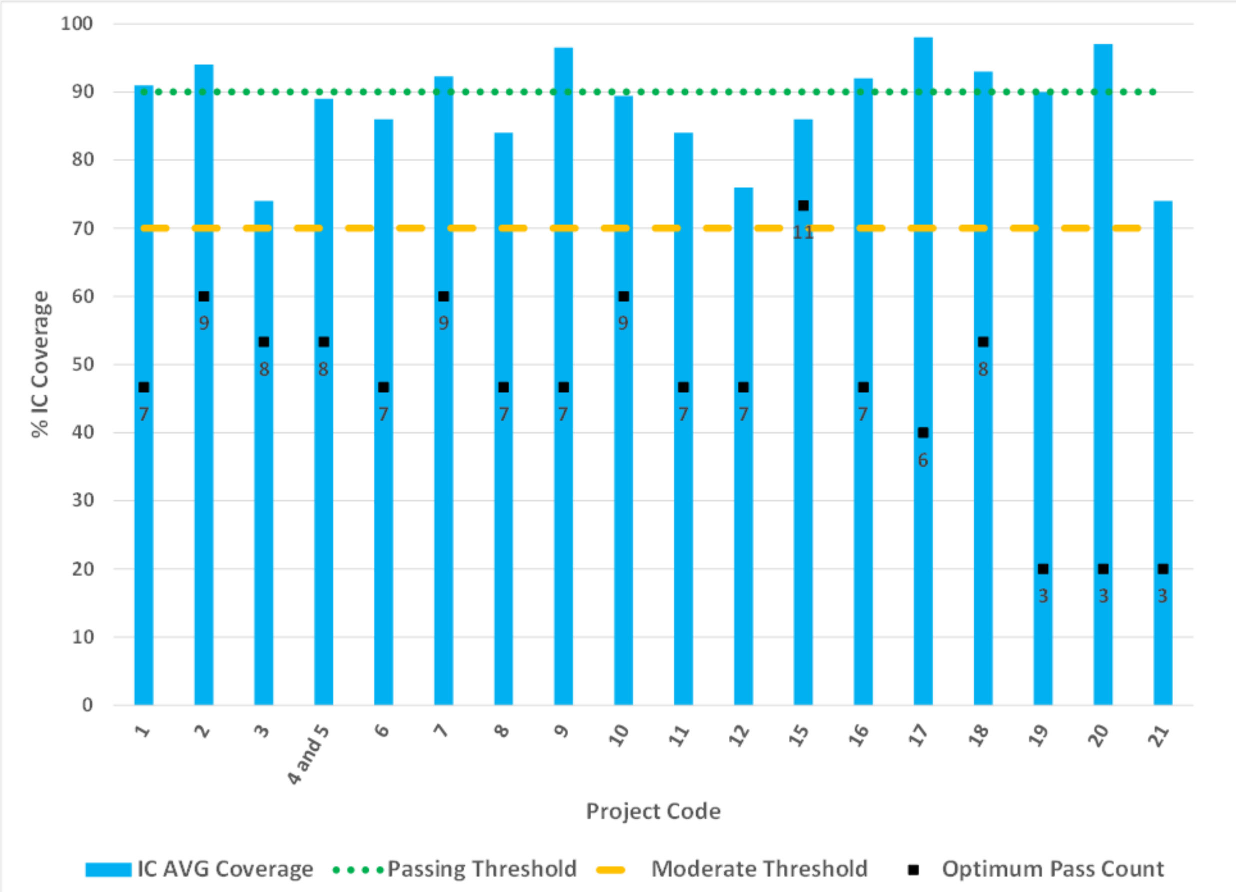
Many contractors are not reporting the target ICMV results or are incorrectly reporting the target ICMV results. A few contractors have provided feedback as to why this data is missing. Some contractors do not understand how to correctly determine a target ICMV value, which is covered in the training 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 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 2022 IC coverage (% of the optimum pass) is shown in Figure 9. The chart shows the average IC coverage, the segment classification thresholds, and the optimum pass count for each project.



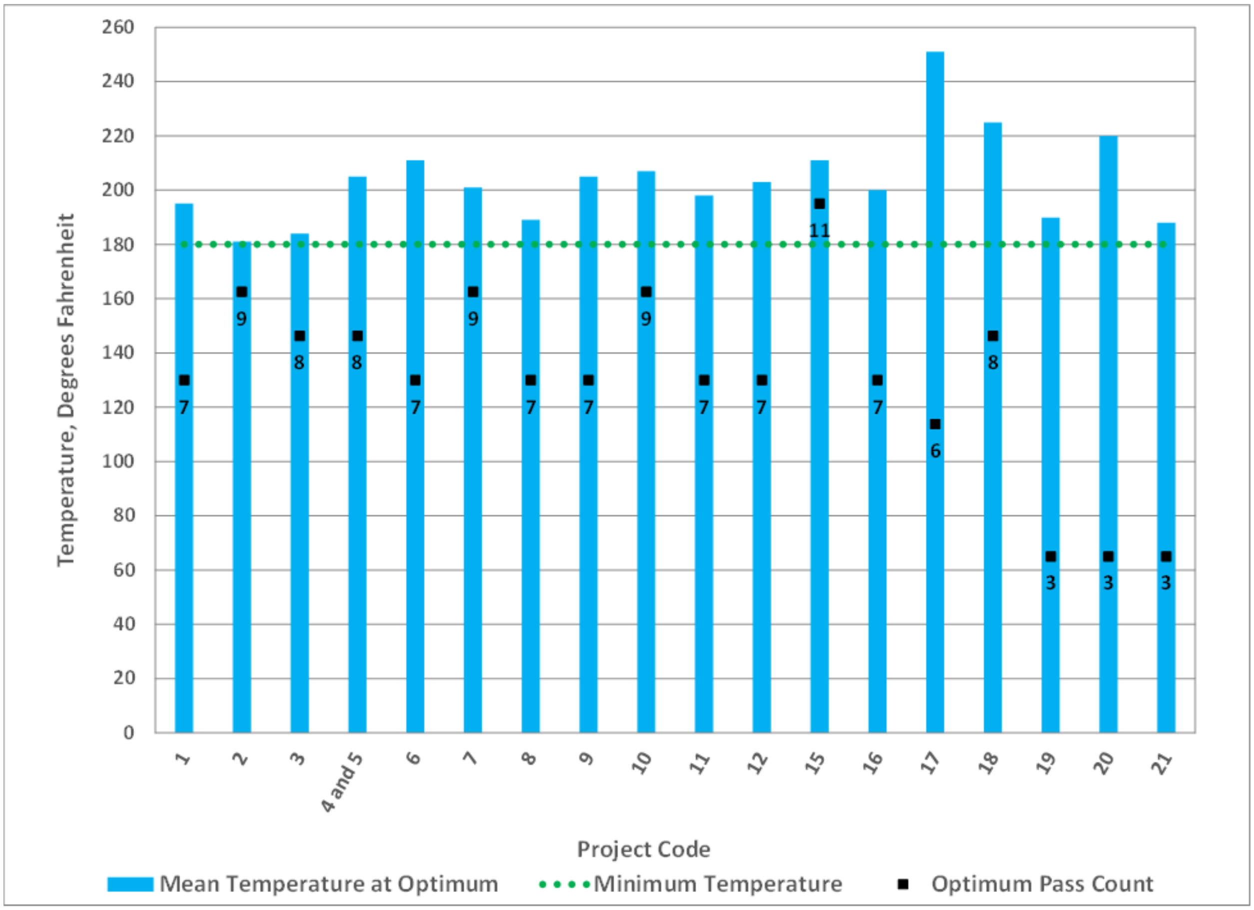
Source: Project Team (2022)

Figure 9. Chart. Average IC coverage per project and optimum pass counts.

General observations from Figure 9 include the following:

- Eight projects are above the 90 percent (price incentive) threshold, and none are below the 70 percent threshold.
- Optimum pass counts range from three (surface leveling projects) to eleven. There is no clear trend between optimum pass count and IC coverage.

A summary of the average MTOP for each project in 2022 is shown in Figure 10.



Source: Project Team (2022)

Figure 10. Chart. The average mean temperature at optimum pass count per project and optimum pass counts.

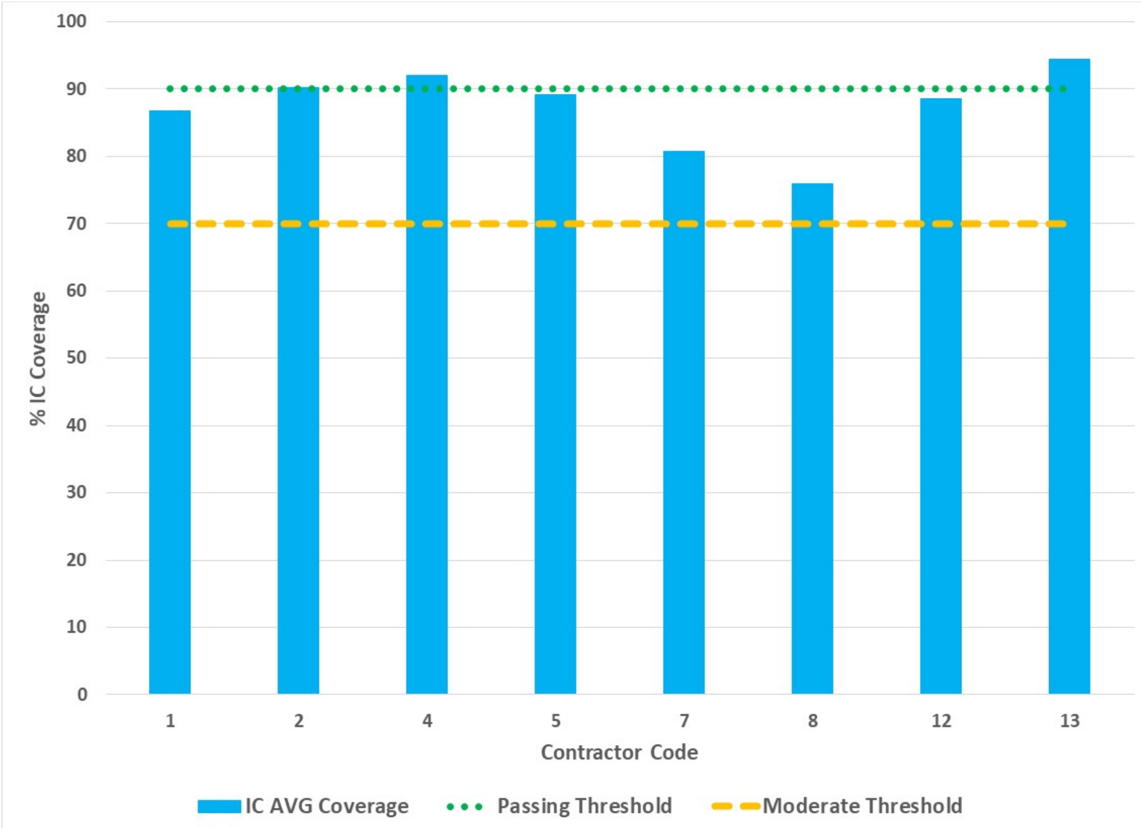
General observations from Figure 10 include the following:

- All projects have an overall average MTOP at or above 180ºF.
- There is no clear trend between optimum pass count and MTOP.
- Project code number 15 had a higher pass count (11) than other projects but still met the MTOP.
- Project code 2 had the lowest MTOP with a pass count of 9.

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

5.3.1.3 IC Results by Contractor

A summary of the IC coverage (% of the optimum pass) is shown in Figure 11. The chart shows the average IC coverage for each contractor (average results for all 2022 projects completed by the contractor).



Source: Project Team (2022)

Figure 11. Chart. Average IC coverage per contractor.

General observations from Figure 11 include the following:

- All of the contractors had average IC coverage above the moderate threshold.
- Two of the contractors had IC coverage above the threshold for the price incentive (90%).

5.3.1.4 PMTP Results

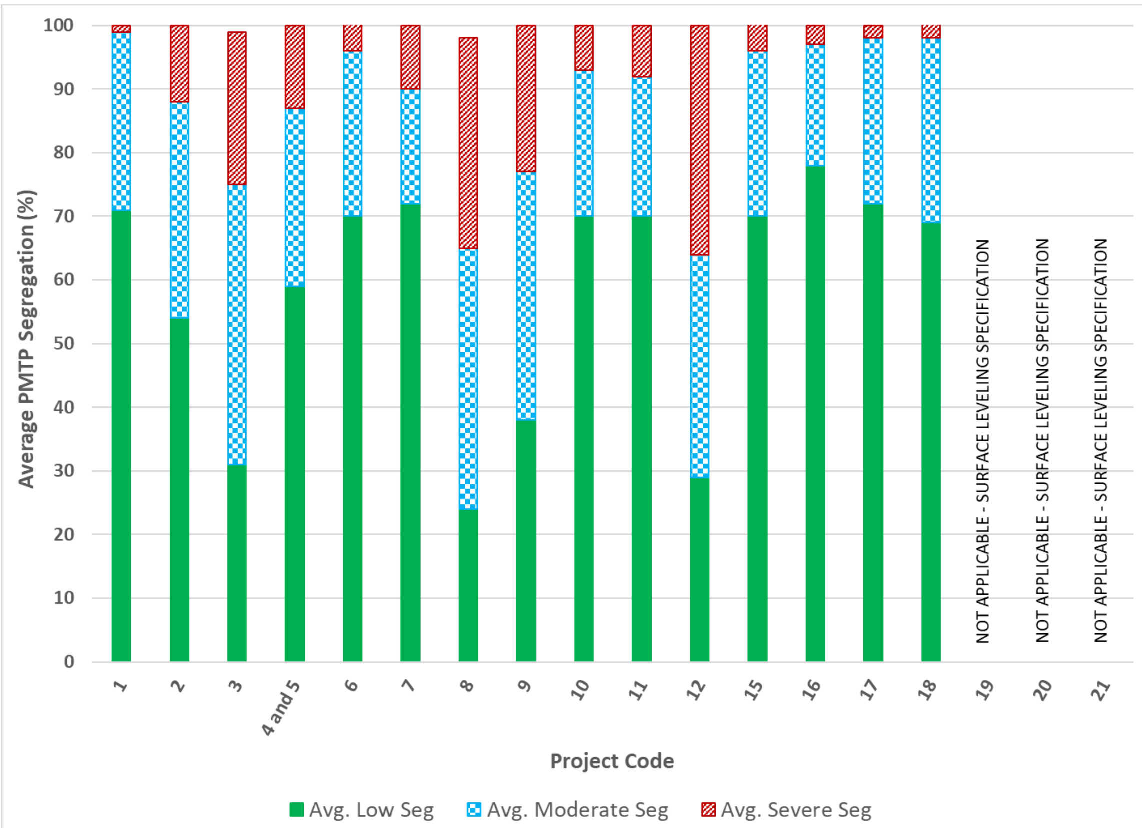
The IC data are evaluated according to NJSP-18-09. A summary of the criteria is as follows:

- The work shall be completed per AASHTO R 110-22. A summary of the Differential Range Statistics (DRS) 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 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 12. The chart shows the overall average thermal segregation category for each 2022 project.



Source: Project Team (2022)

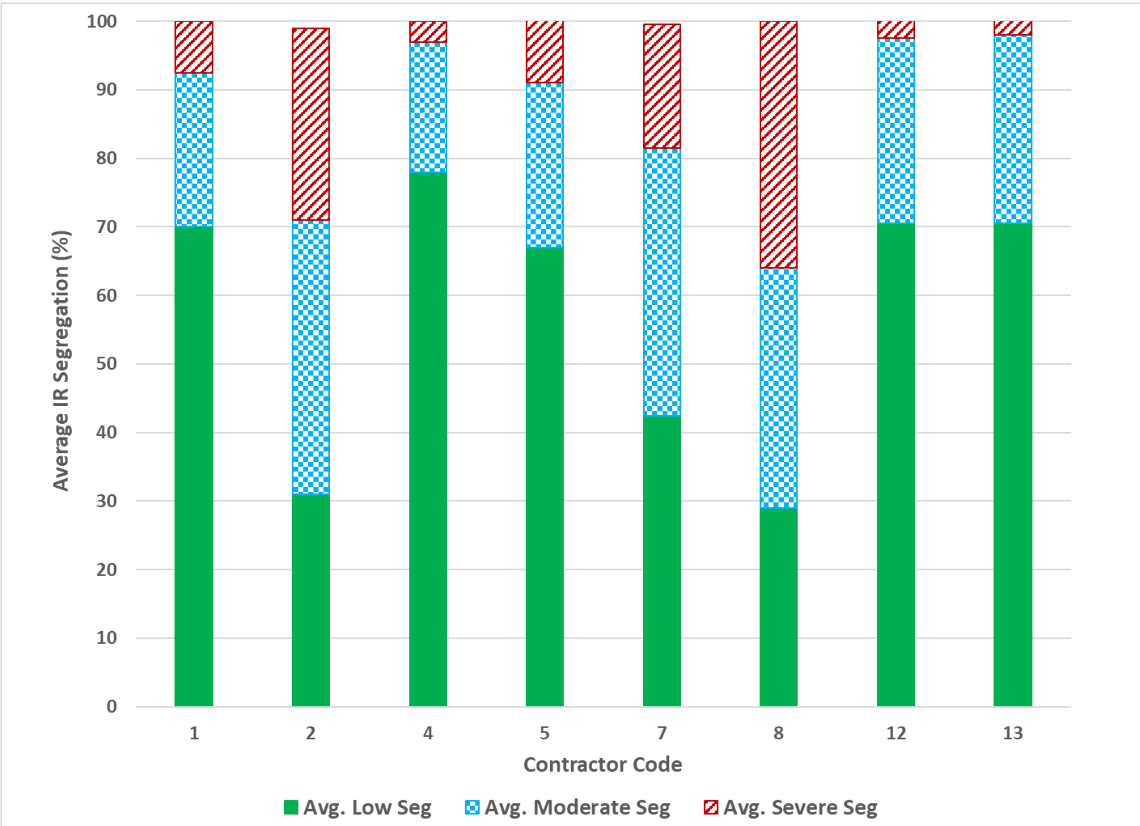
Figure 12. Chart. Average thermal segregation classification for each project.

General observations from Figure 12 include the following:

- Nine projects had less than 10 percent severe segregation.
- Two projects had between 10 and 20 percent severe segregation.
- Four had more than 20 percent severe segregation.
- Eight projects had at or over 70 percent low segregation.
- Four projects had less than 50 percent (half) low segregation

- Projects 19, 20, and 21 were surface leveling projects, and PMTP was not required.

A summary of each contractor's overall average thermal segregation category (average of results for all 2022 projects completed by the contractor) is shown in Figure 13.



Source: Project Team (2022)

Figure 13. Chart. Average PMTP thermal segregation classification per contractor.

The following observations are made from Figure 13:

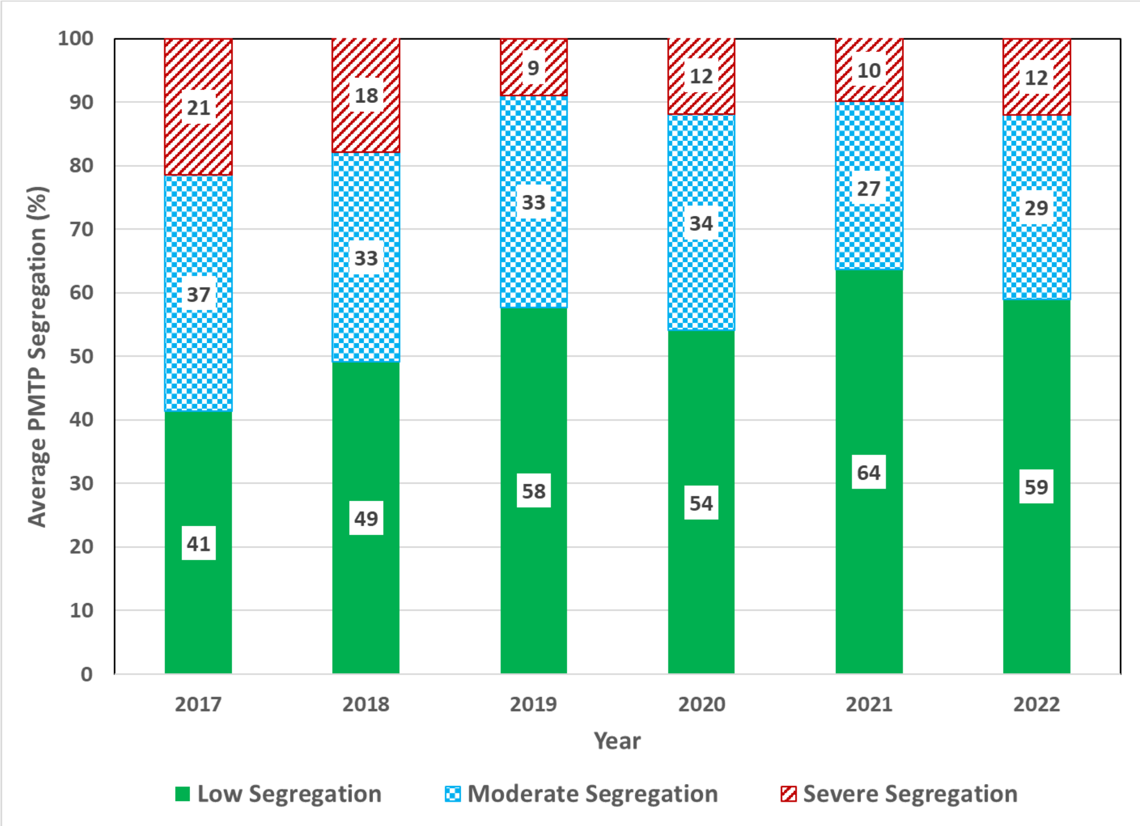
- Contractors 2 and 8 had the highest severe segregation and lowest low segregation.
- Contractors 4, 12, and 13 had less than 5 percent severe segregation and at or above 70 percent low segregation.

5.3.2 2017 Through 2022 Construction Seasons

Data from 2017 through 2022 were compiled to identify general trends.

5.3.2.1 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 14.



Source: Project Team (2022)

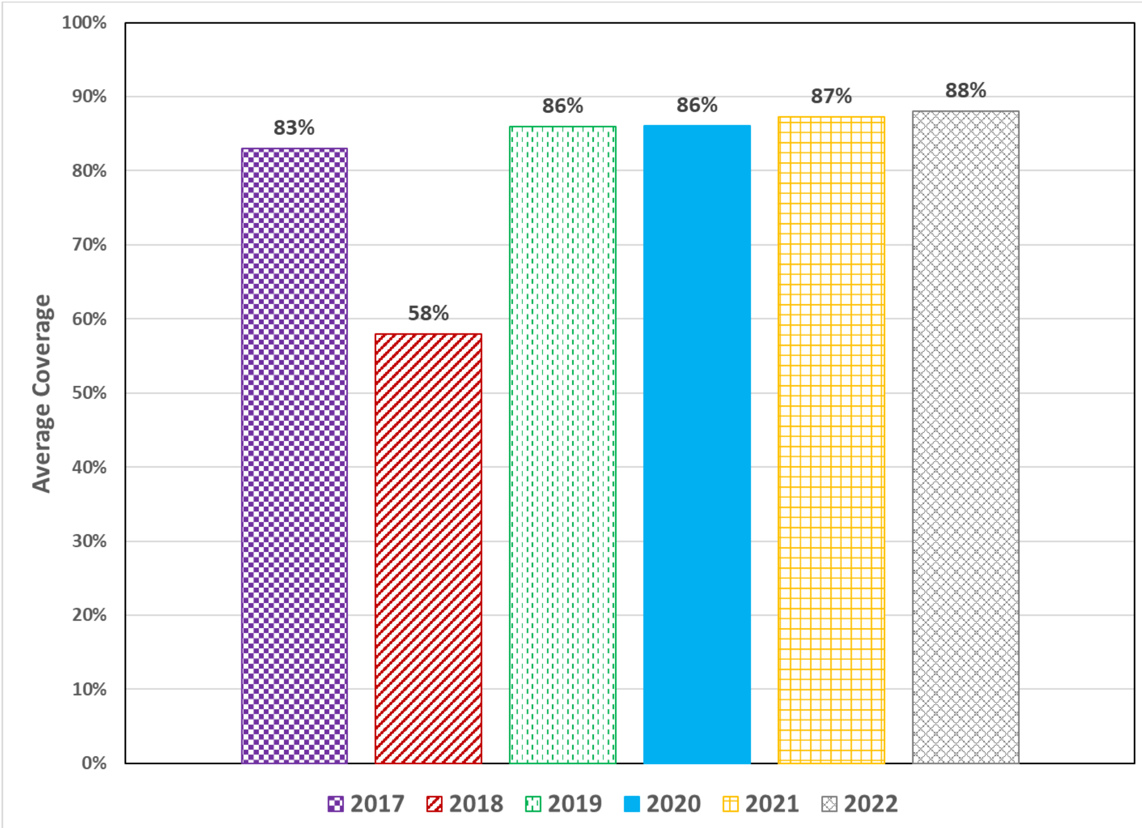
Figure 14. Chart. Average PMTP thermal segregation classification for all projects per construction season.

General observations from Figure 14 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. 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 2022.
- 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 2022.
- Overall, the PMTP data trend shows that using this technology improved thermal segregation by promoting successful practices.

5.3.2.2 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 15.



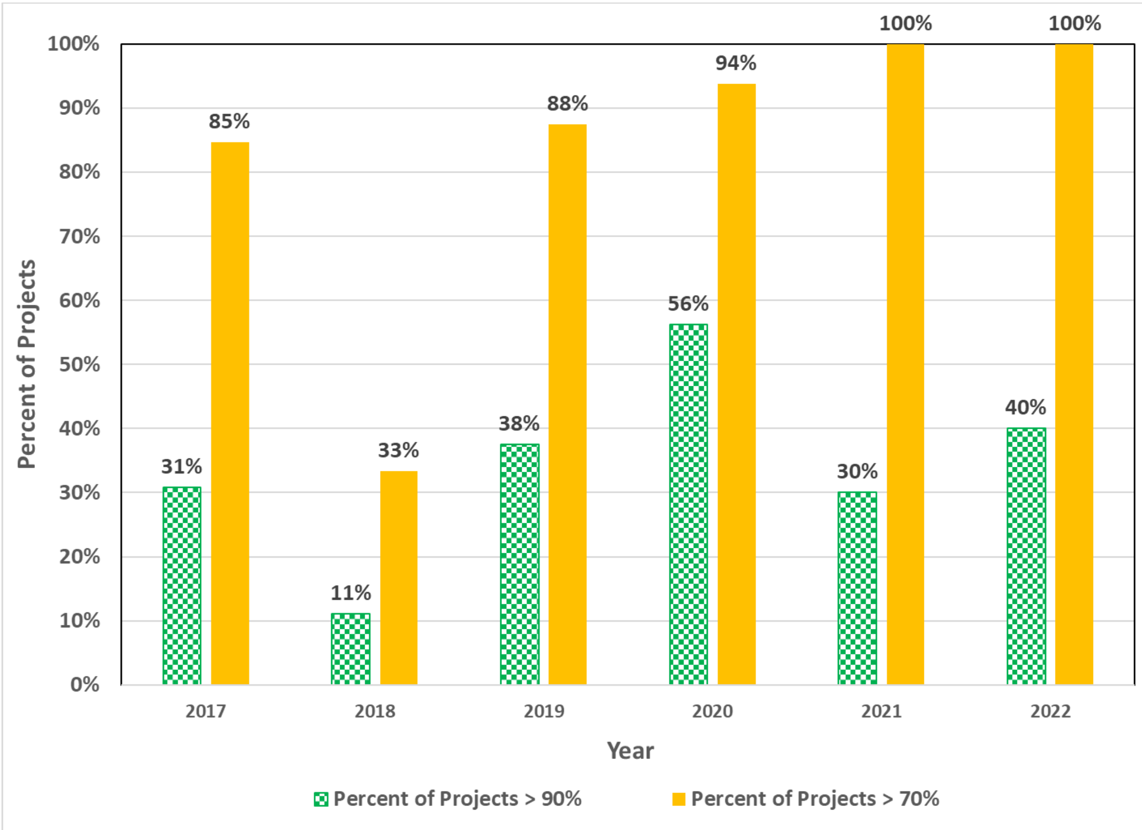
Source: Project Team (2022)

Figure 15. Chart. Average IC percent coverage for all projects per construction season.

General observations from Figure 15 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 2022 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 16.



Source: Project Team (2022)

Figure 16. Chart. Percent of projects that meet the 70 percent and 90 percent thresholds per construction season.

General observations from Figure 16 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.
- In 2021 there was a decrease in projects that met the 90% threshold for price incentives. However, all projects met the 70 percent threshold. In 2022 the percentage of projects that met the 90% threshold increased.
- 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, and 204 ˚F in 2022. The MTOP trend indicates that achieving the minimum MTOP of 180˚F is reasonable, achievable, and consistent since implementation in the specification and protocols.

5.4 SUMMARY

The strengths of the 2022 construction season are summarized as follows:

- A higher percentage of projects in 2022 achieved the 70 percent IC coverage threshold than any other year since implementation in 2017 (tied with 2021). This may indicate acceptance of technology by contractors, increased understanding, and successful implementation of IC.
- Thermal segregation classifications are similar to those of 2021. 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 2021 to 2022.

The lessons learned and areas for improvement based on the data analysis results of the 2022 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.

Although improved since 2021, contractors and MoDOT personnel do not consistently follow data management, including naming conventions 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 2023.

CHAPTER 6 TASK 5 – PILOT INNOVATIVE TECHNOLOGIES

Under this task, the Consultant will assist with piloting new technologies for boundary measurements or using Dielectric Profiling Systems (DPS).

6.1 DIELECTRIC PROFILING SYSTEMS

At this time, MoDOT is not implementing DPS equipment. MoDOT is an active member of the Transportation Pooled Fund (TPF)-5(443) DPS for Continuous Asphalt Mixture Compaction Assessment.

6.2 NEW TECHNOLOGIES FOR BOUNDARY MEASUREMENTS

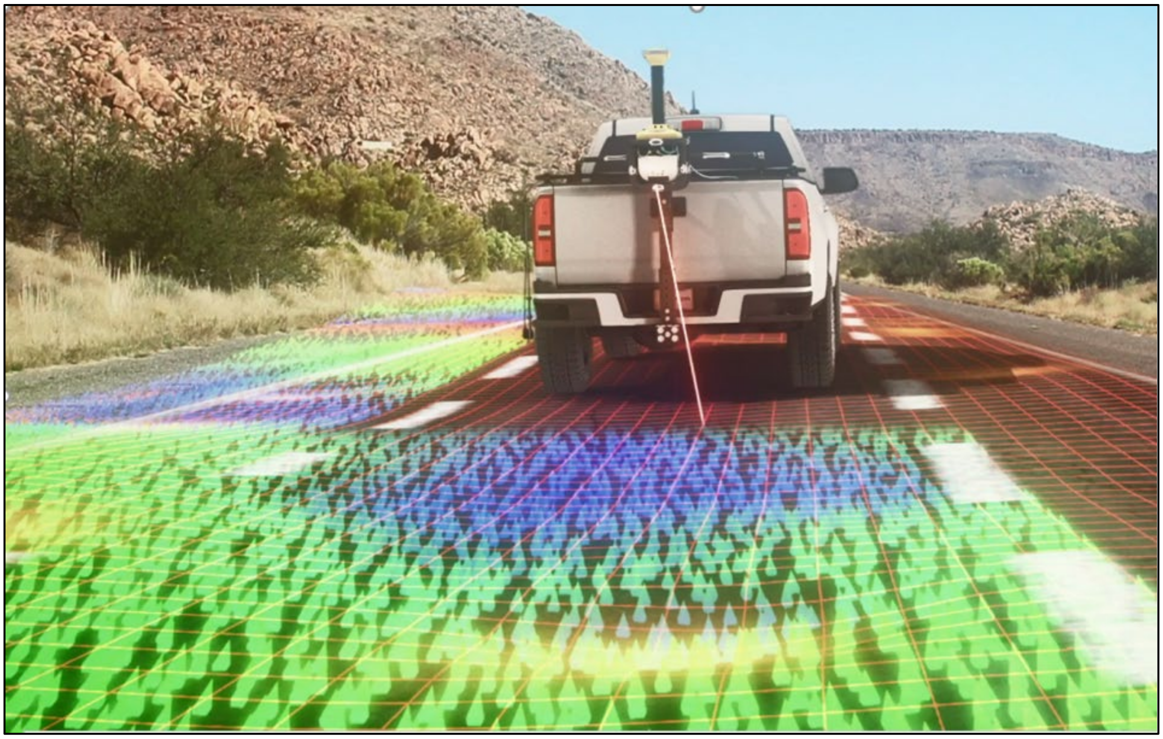
The technologies considered include:

- High-precision Paver-mounted GPS to obtain paving boundary.
- Vehicle-mounted mobile LiDAR scanning to generate a boundary alignment file or a center line alignment. The latter can be offset to create a boundary in Veta.

Contractor code 1 used a LiDAR system during the 2022 construction season to generate an alignment file for a paving boundary. The technology details are summarized in the following sections as an example.

6.2.1 Data Collection

The contractor used Topocn's RD-M1 system to collect point cloud surface data. The RD-M1 was mounted to a vehicle, and data was collected at highway speeds. An illustration of how the data is collected is shown in Figure 17.



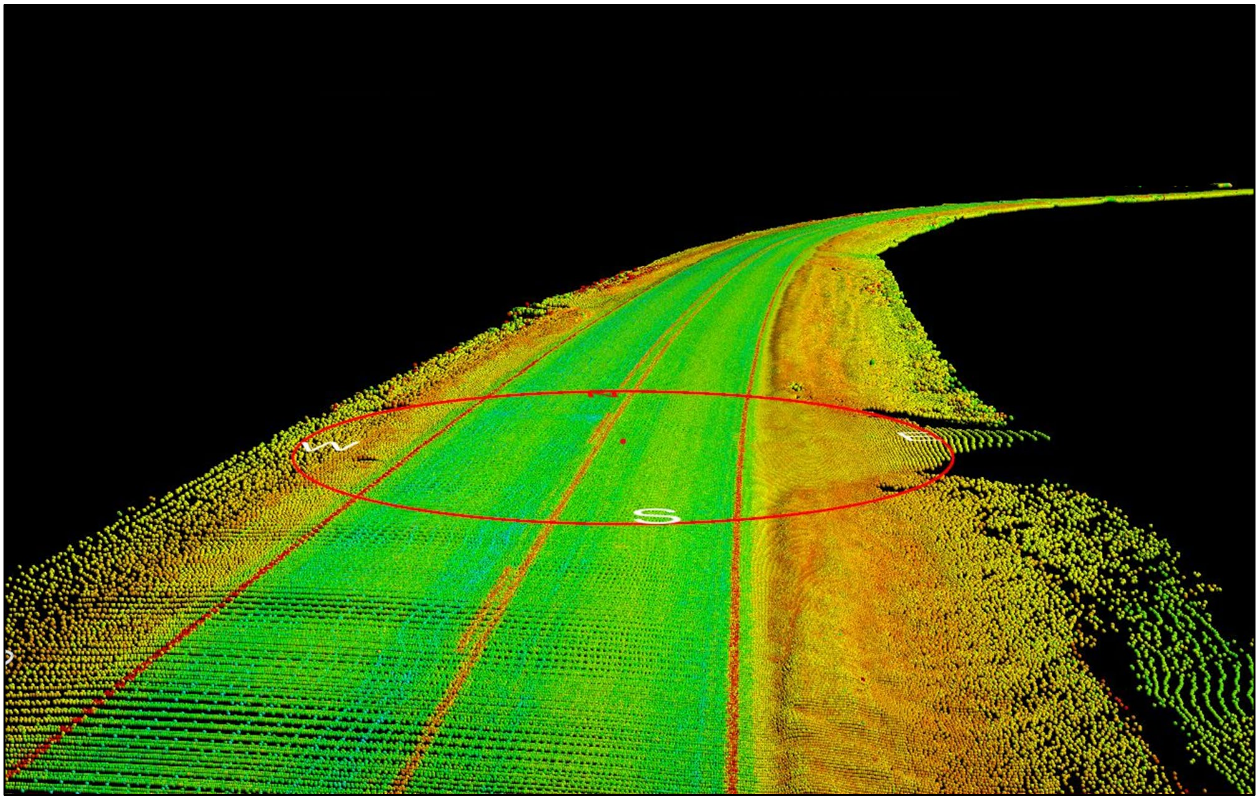
Source: Topcon (2022)

Figure 17. Illustration. Example of the alignment collection equipment.

6.2.2 Data Processing

The contractor collected the LiDAR data along the roadway and generated the alignment file before the project commenced. The data is collected in live traffic and requires no closures, and the data was post-processed using Topcon Magnet software.

The alignment file was generated by selecting points along the existing centerline paint lines. The requirements for the boundary in MoDOT's specifications are ± 2 inches. It was not verified if this method meets the specified tolerances. Although, visually, the boundary data appeared to collect a valid paved area.



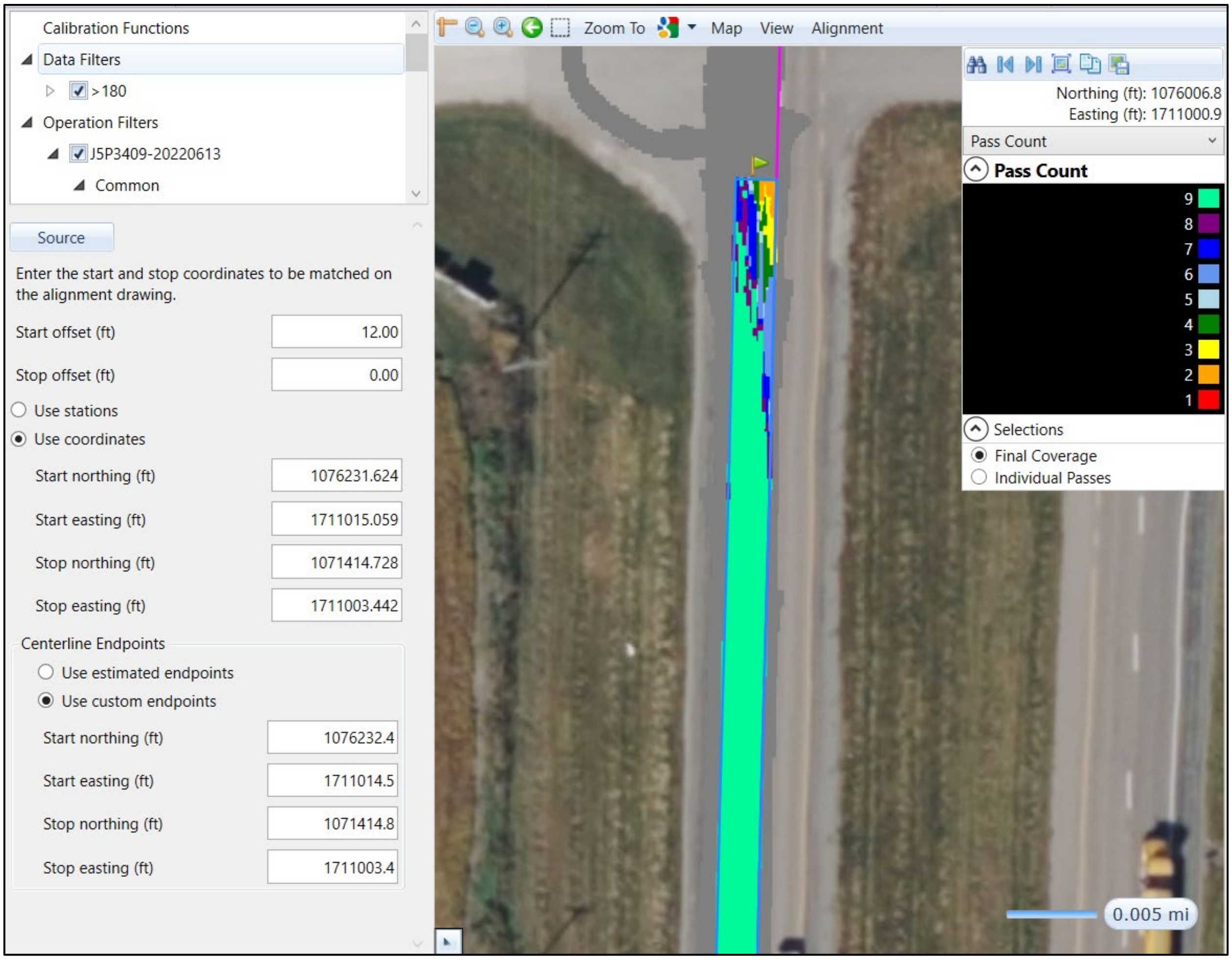
Source: Topcon (2022)

Figure 18. Illustration. Example of point cloud data used to generate alignment file.

The alignment file was exported as a LandXML file, which is compatible with Veta software.

6.2.3 Veta Example

An example of the contractor's alignment file in Veta is shown in Figure 19. The alignment file is the solid pink line shown. The left taskbar shows that offsets from 0 (centerline) to 12 feet were used to generate the lane width. There was no stationing in the alignment file, so the contractor used GPS coordinates to mark the start and stop of the day's production.



Source: Project team (2022).

Figure 19. Screenshot. Example in of the contractor alignment file used to generate a boundary.

6.2.4 Feedback

Contractor code 1 reported that generating the boundary was safer and more cost-effective. Although it took approximately two weeks to collect and generate the boundary, it reduced efforts during production.

The method of using LiDAR technology was presented during the feedback meeting to promote the use of IC boundary production.

6.3 SUMMARY

MoDOT has not elected to move forward with DPS equipment at this time. MoDOT is active in the TPF for DPS equipment.

The LiDAR method appears to be a valid way for contractors to generate IC boundary data. The method is being used by contractor code 1. The equipment is vehicle mounted, and the data can be collected during live traffic at traffic speeds. The alignment file generated using the LiDAR method is compatible with Veta. Contractor code 1 generated the project alignment file approximately two weeks before paving production and had positive feedback about the procedures.

Additional methods of intelligent boundary collection may be piloted in 2023.

CHAPTER 7 TASK 6 -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 required more data.

7.2 IC-BASED ASPHALT DENSITY MODEL

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

7.2.2 Data Collection and Analysis

The Consultant is currently compiling the density data from 2022 projects.

7.2.3 Results of IC-Based Density Prediction

Once the missing spot test and IC data from 2022 (and previous years) 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 2022 is being collected for future analysis efforts.

CHAPTER 8 TASK 7 - FEEDBACK MEETING AND EXECUTIVE BRIEFING

The 2022 feedback meetings were held from December 14, 2022, to December 15, 2022. 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.

8.1 MEETING AGENDA

The meeting agendas from the feedback meeting are shown in Table 11, Table 12, and Table 13. 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.

Table 11. Wednesday, 12/14/2022 MoDOT Internal Meeting

Time	Topic	Attendees
8:00 AM – 10:00 AM	2022 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	
10:15 AM – 12:00 PM	Planning for the 2023 season.	MoDOT Field Office Team MoDOT RE and inspection staff FHWA MoDOT representative IC-PMTP Consultant – Transtec Group

Table 12. Wednesday, 12/14/2022 (continued) Missouri Industry Meeting

Time	Location	Topic	Participants
1:00 PM – 2:45 PM	MODOT office and video conference	2022 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		
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 13. Thursday, 12/15/2022 MoDOT Management Meeting

Time	Topic	Attendees
8:00 AM – 10:00 AM	Discussion on revisions to PMTP specification, updates on Dirtmate data app (pending availability of Propeller)	MoDOT Field Office Team IC-PMTP Consultant – Transtec Group Propeller (pending availability)
10:00 AM – 10:30 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
10:30 AM – 11:00 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
11:00 AM - 11:30 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
11:30 AM – 12:00 PM	Open discussion and Q&A.	MoDOT Management MoDOT Field Office Team FHWA MoDOT representative IC-PMTP consultant – Transtec Group

8.2 KEY DISCUSSIONS

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

8.2.1 Revisions to PMTP specification

The Field Office staff plans to make changes to the PMTP specification. The new specification will be used for the 2024 construction season. The following changes were discussed:

- Require higher quality GPS. The specifications require an x and y tolerance of ± 4 feet. Since the IC data (real-time kinematic (RTK) GPS) and PMTP data GPS' are incompatible, extra efforts are required to exclude the IC boundary from the PMTP data analysis. Then, time filters must be used to create sections for PMTP data. Requiring more accurate GPS data for PMTP equipment will allow filtering with the boundary, significantly reducing filtering efforts.
- Change from the Differential Range Statistics (DRS) thermal segregation classification to the Thermal Segregation Index (TSI). Each method of thermal segregation classification is in the latest AASHTO R 110-22 Standard Practice for Continuous Thermal Profile of Asphalt Mixture Construction and supported in Veta. More information on the rationale for switching to TSI is in section 9.2.1.1.
- Revise language to require full paving width data collection and clarify another language as needed.

8.2.1.1 DRS versus TSI study

Minnesota DOT (MnDOT) reported issues with longitudinal cracking from thermal segregation. According to the TRR paper "*Quantification of Thermal Uniformity for Asphalt Paving Using the Thermal Segregation Inde*x" (Tanquist et al., 2022), the DRS method cannot reliably identify some types of thermal segregation, such as longitudinal thermal streaks. Therefore, MnDOT and the Transtec Group developed the TSI method. The TSI is a composite index of the transverse semivariogram index (TSVI) and standard deviation (StDev) for sublots of 45.7m (150 ft) in length. StDev represents the overall sublot temperature variation and is comparable with the DRS method. TSVI is directional to evaluate the geospatial uniformity across the transverse direction of the mat to identify longitudinal bands of thermal segregation. TSVI and the StDev can be weighted uniquely in the composite index, and the default ratio is 50 percent for each.

MoDOT Field Office staff reported wanting to move towards the TSI classifications to reduce thermal longitudinal cracking. Therefore, the Consultant analyzed most of the 2022 PMTP data through DRS and TSI classifications in Veta to compare the results. The results of the comparison are shown in the following figures. All results were presented at the 2022 MO industry meeting.

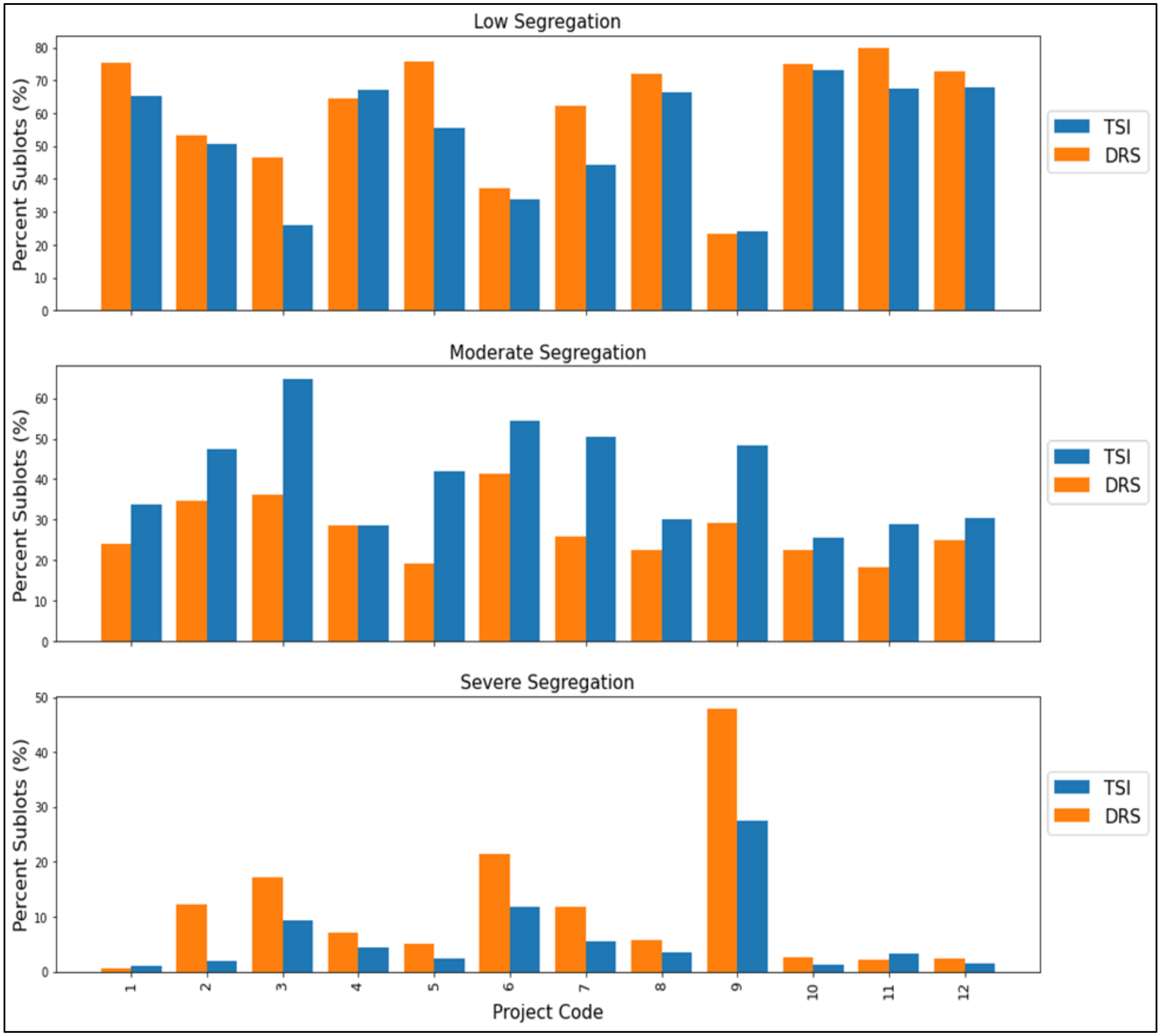


Figure 21. Chart. Comparison of TSI and DRS classifications for low, moderate, and severe thermal segregation.

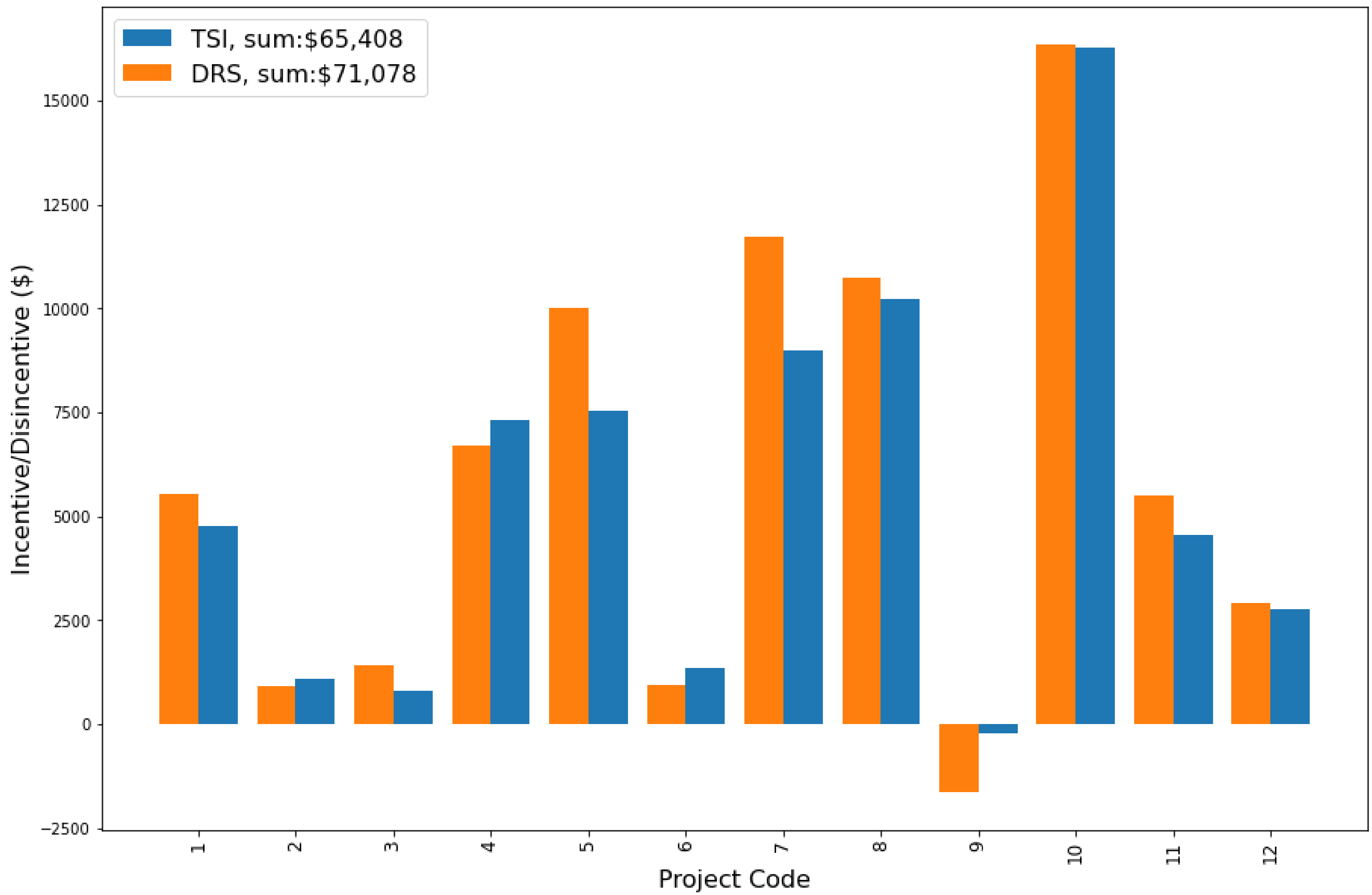


Figure 22. Chart. Comparison of DRS and TSI price adjustments.

Overall, most projects had the following trends when using TSI methods:

- Decreasing low and severe segregation.
- Increasing moderate segregation.
- Minimal effect on price adjustments.

8.2.2 Revisions to the IC specifications

Several projects had IC GPS issues in the 2022 season. These were identified using the Dirtmate data QA data. The poor GPS quality did not statistically match the data QA data, and upon further observation, RTK GPS was not used to collect the IC data. The causes are reported by some contractors with the cellular coverage issue when using MoDOT's Virtual Reference System (VRS). Therefore, some contractors changed the IC system GPS tolerance to coarse to keep IC collecting data with poor GPS precisions.

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 GPS precision issues.

8.2.3 Data QA

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 2022 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.

8.2.3.1 IC Pass Count

In some instances, the verification could not be completed due to one or more of the following reasons (listed in order of most common occurrence):

- Dirtmate data was missing (partially or completely, or the file could not be processed).
- Contractors did not set up the rollers with unique machine IDs to allow filtering by machine ID in Veta.

Because the most common issue with the data QA comparison is missing Dirtmate data, emphasis was made to make data transmission using the DUG more transparent in the field. Propeller recommended using a diagnostic tool that shows the status of the DUG and Dirtmate and the percentage of data on the Dirtmate. Examples of the data diagnostic tool are shown in Figure 23. The "Data in Queue" field can be used to track connection to the DUG data transmission. When the field reads 0%, data transmission is complete. This tool will be piloted in the 2023 season to try and mitigate data loss.

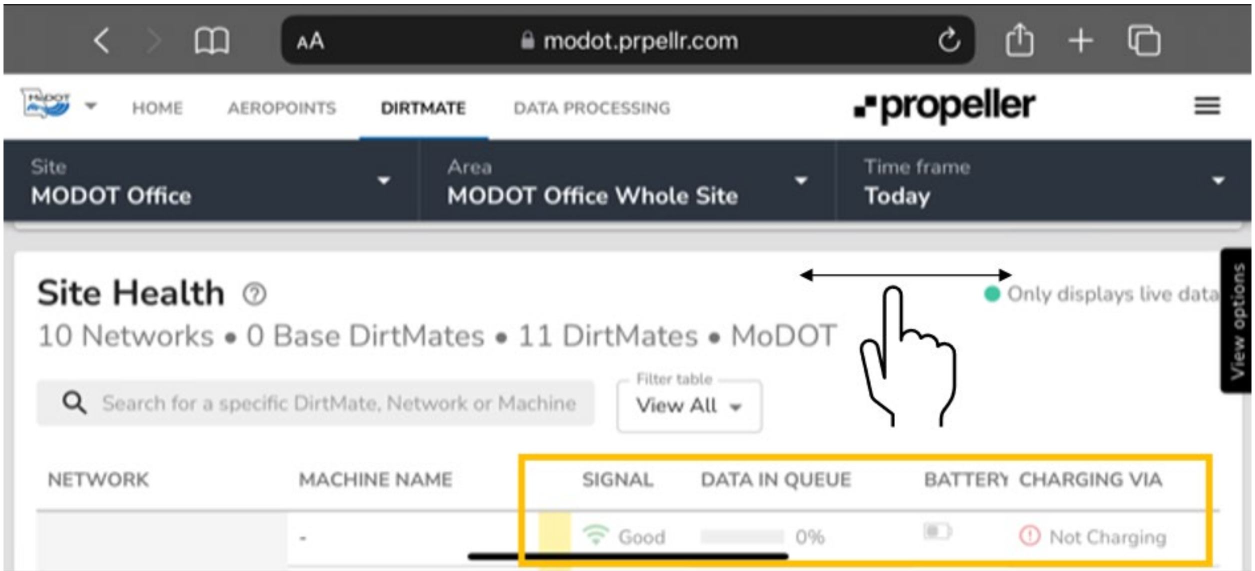


Figure 23. Screenshot. Example of scrolling through the data diagnostic tool to see the details of Dirtmate data transmission.

The comparison criteria for the differences between Dirtmate and contractor IC data are summarized in Table 14.

Table 14. 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 14 are met, the verification result is "pass." If any criteria are not met, the outcome is "fail." Figure 24 shows the results from the IC pass count data QA analysis (based on 6 projects over 67 paving days).

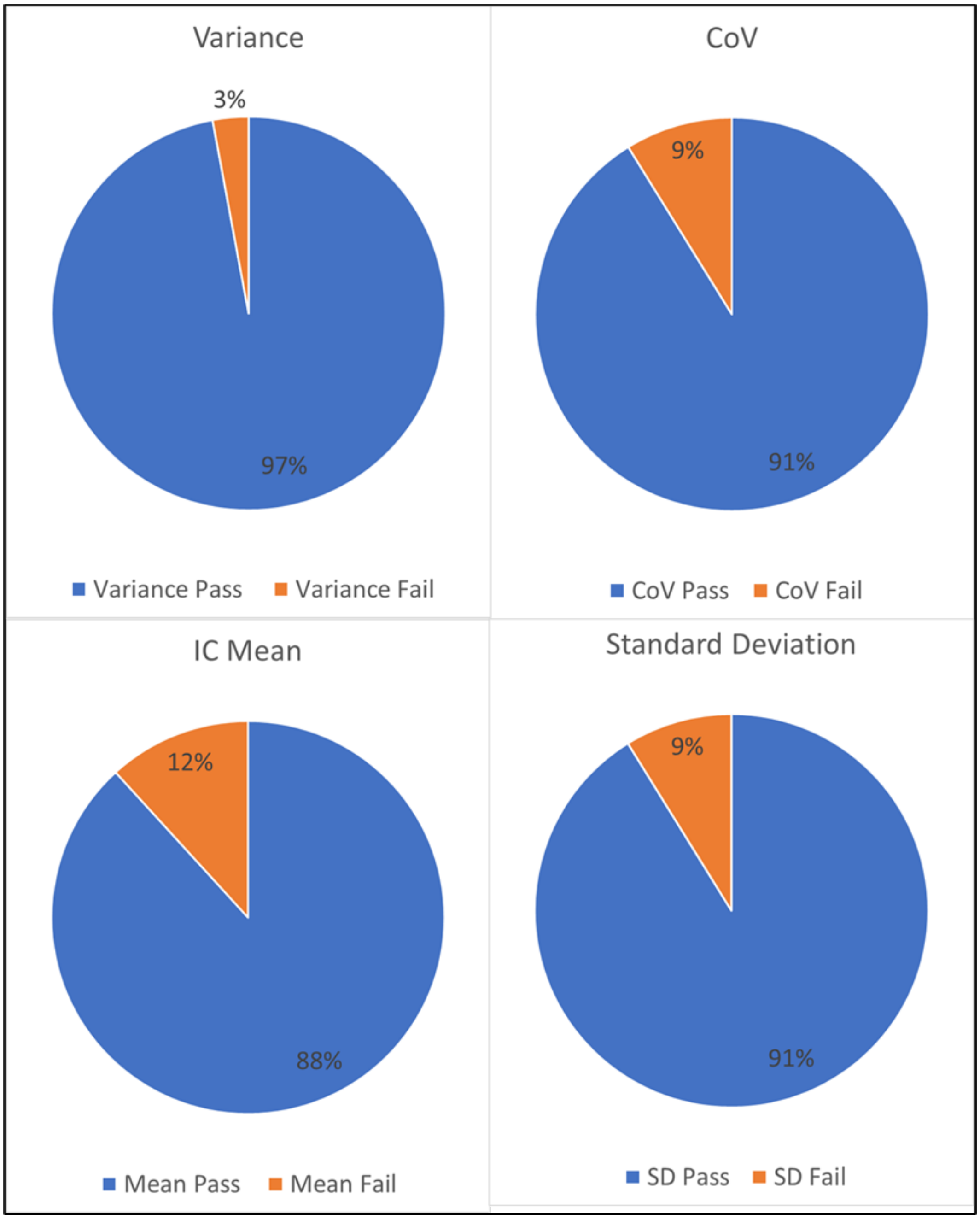


Figure 24. Chart. Summary of results from the IC data verification.

In cases where the outcome was "fail," the most common issue was that the contractor data used low accuracy (not RTK) GPS (described in section 9.2.2). Based on these results, the data verification process appears to work well and detect issues with contractor data.

8.2.3.2 PMTP Temperature

In some instances, the verification could not be completed due to one or more of the following reasons (listed in order of most common occurrence):

- Invalid event marker (not identified in data).
- Invalid FLIR photo – excessive weeds, paver, or roller images in the photo (Figure 25).
- Invalid contractor data – missing or erratic data.
- Invalid contractor data – too many "cold spots" less than 200 degrees in the area near the event marker.
- Error during analysis (using the macro tool).

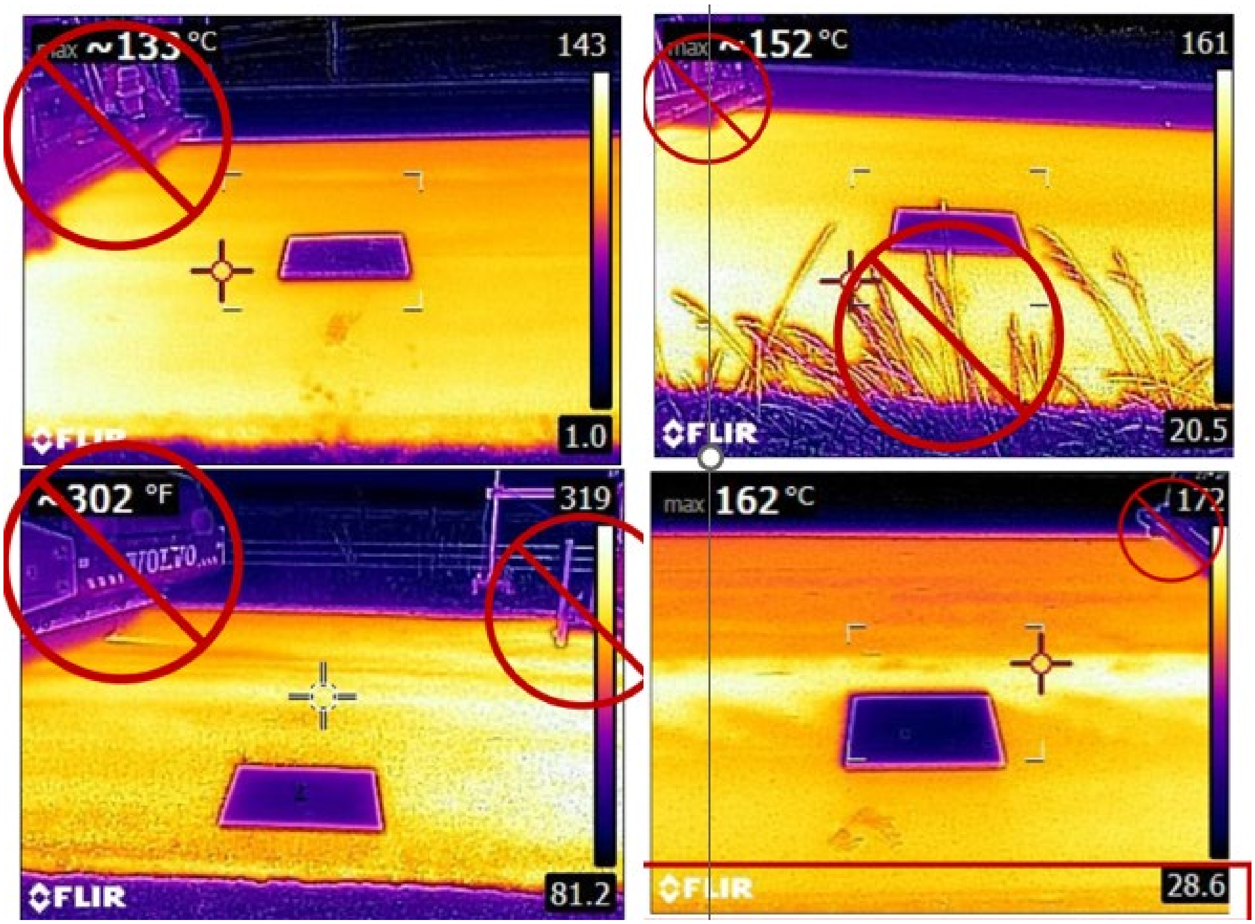


Figure 25. Illustration. Examples of invalid FLIR photos.

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 26). 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 is placed on the edge of the driving lane, as shown in Figure 27.

Figure 26. Illustration. Example of placing the event marker directly behind the screed.

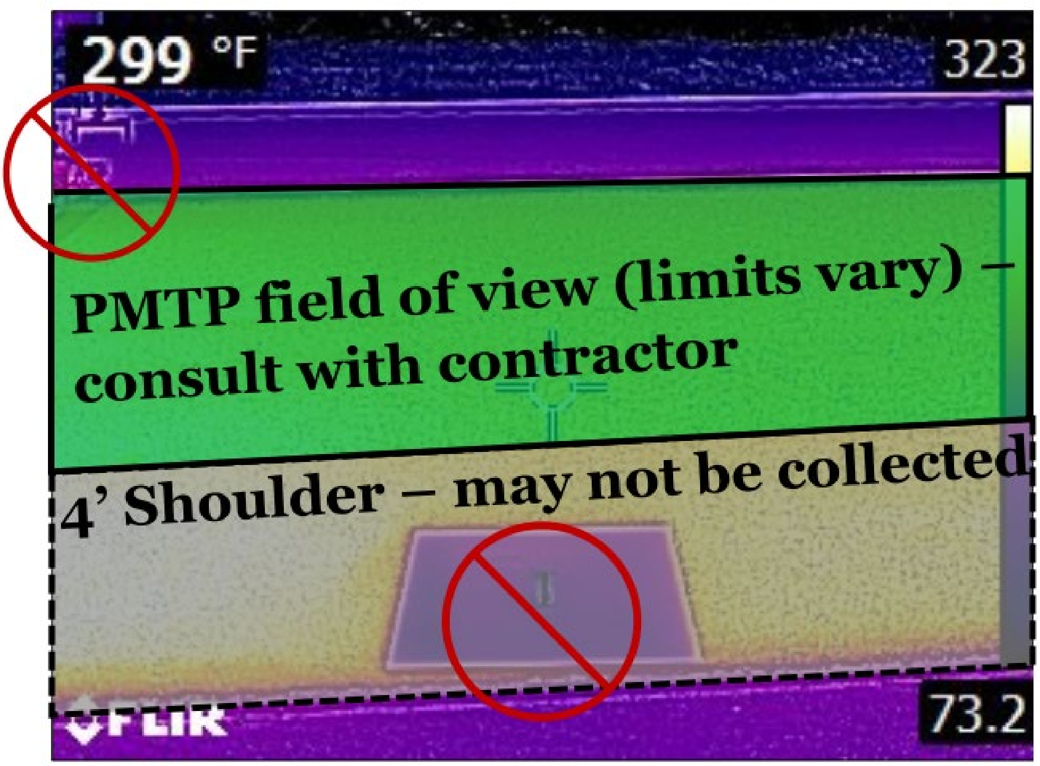


Figure 27. Illustration. Example of placing the event marker on the shoulder.

Some of these issues were realized early in the construction season, and additional training tools were created to assist project staff with taking better FLIR photos. A training video and a "Common Issues" guide were posted to SharePoint. It is recommended that these training materials are reviewed at the 2023 spring workshops to aid MoDOT staff.

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 data QA data are shown in Figure 28 (based on 14 projects over 336 paving days). Different statistical comparisons were made (using percentiles), and no criteria using percentiles has been established at this time.

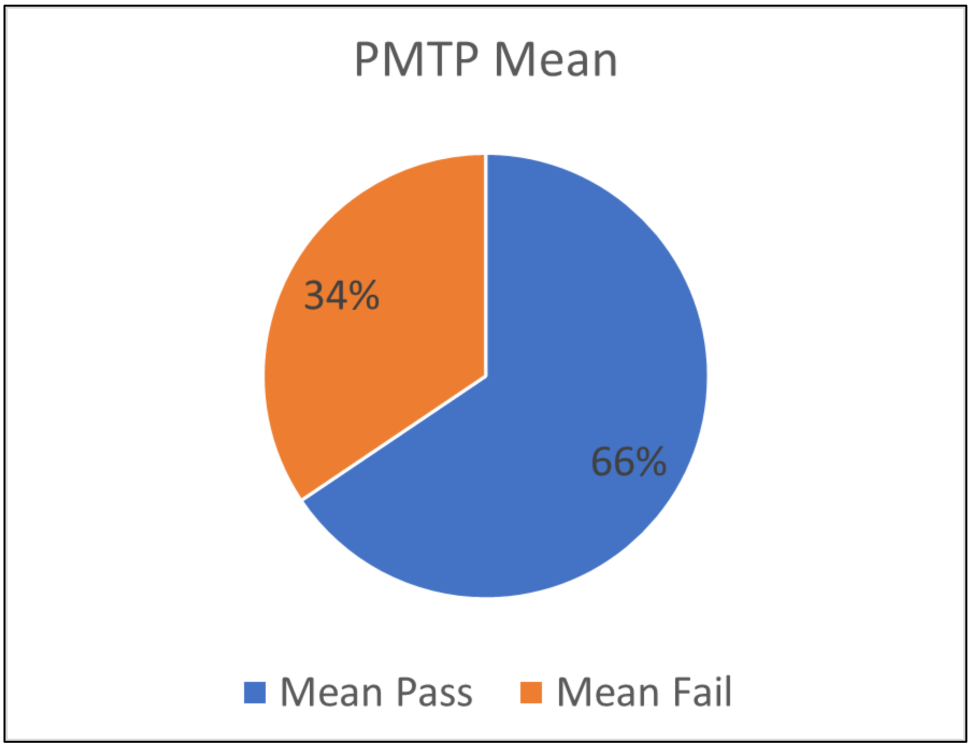


Figure 28. Chart. Summary of results from the PMTP data verification.

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 humans stepping off the screen 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 (as shown in Figure 27). 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 phot and valid event marker.

8.2.4 Training Program

Overall, the feedback for the 2022 training program was positive. The JITTs were useful to MoDOT staff and contractors. Some recommendations include tailoring the MoDOT project staff statewide workshops to check contractor submittals rather than building an IC-PMTP project in Veta step-by-step. These modifications will be implemented in the 2023 MoDOT statewide training workshop.

In 2023, JITT will be available to contractors and MoDOT staff upon request.

8.2.5 Future Statewide Implementation

MoDOT would like to move towards the goal of full IC-PMTP implementation. During the management meeting, staffing needs and resources were discussed, and MoDOT sees a need for a full-time consultant or staff in the future to achieve full implementation.

8.2.6 IC Boundary Collection

A presentation was made during the feedback meeting to show how LiDAR data can be used to collect alignment files using vehicle-mounted equipment (as described in section 7.2). MoDOT plans to specify using automated intelligent boundary collection methods in future seasons to improve safety on the project.

8.3 SUMMARY

The feedback meetings were useful in evaluating successes and lessons learned in 2022. The key takeaways are as follows:

- Some revisions to the PMTP specifications will be made for the 2024 season, including switching to the TSI (from DRS), requiring better quality GPS, and changing the language to require full paving width data collection.
- Some revisions to the IC specifications regarding using GPS base stations in areas with poor cellular coverage (in place of cellular correction networks) may help with IC data quality.
- The data QA verification methods appear to work successfully when the QA data is collected successfully.
- The training program implemented in 2022 was successful. One change that could be implemented in 2023 is to tailor the MoDOT project staff training towards checking contractor submittals (instead of creating a Veta project from scratch).
- Statewide implementation of IC-PMTP may require adding staff or hiring a full-time consultant.
- Collecting alignment files using LiDAR is safer than manual collection in the field. One method was presented during the industry meeting, and future specifications may require boundary collection that does not require manual collection using hand-held GPS equipment.

CHAPTER 9 TASK 9 – DATA QA EQUIPMENT

This task was to supply IC pass count data QA equipment to MoDOT to use in the 2022-2023 season. The new equipment that was supplied is as follows:

- Nine total DUG units.
- Seven total "generation 2" Dirtmate GPS sensors with 24 months service license.

The new equipment was procured to mitigate some data loss issues experienced in 2021. More details on the new 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 TASK 10 – RECOMMENDATIONS AND CONCLUSIONS

10.1 LESSONS LEARNED AND RECOMMENDATIONS

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

10.1.1 Task 2 – IC-PMTP Protocol

The changes to the IC-PMTP protocols were minimal in 2022. Key changes included adding some instructions to the summary spreadsheet, including setting up permissions to enable Excel macros. Methods to calculate roller data using mixed fleets were also included.

Some changes were made to the Data QA procedures. New generation Dirtmates and DUGs were purchased to mitigate data loss. Event makers used for PMTP data QA were enlarged and provided to the project staff.

10.1.2 Task 3 – IC-PMTP Training Program

New training programs were implemented in 2022. Training included JITT, TTT, and the conventional statewide workshop. The statewide workshops were held separately for MoDOT staff and contractor staff. The enhanced training was useful and positive feedback was received.

New training materials include the DocHelper SharePoint Navigator, data QA training tools, and an inspector guide for checking contractor submittals. These materials were useful and positive feedback was received.

10.1.3 Task 4 – IC-PMTP Project Supports

The project supports included field support, remote support, and data quality checks. Common support requests from MoDOT personnel were related to checking contractor submittals. Common support requests from contractor staff were related to analyzing data in Veta.

The most common data issues found during quality checks are as follows (listed in order of most common occurrence):

- Not using custom endpoints in filters.
- Incorrect naming conventions and data file management.
- Incorrect setup of equipment.
- Using the incorrect SharePoint Site
- Incorrect analysis setup
- Incorrect data transfer to the summary sheet
- Analyzing PMTP and IC data separately.

10.1.4 Project Analysis and Results

Year-to-year trends show that IC pass count coverage is consistently improving since its implementation in 2017. Thermal segregation is reduced as contractors improve paving practices.

The 2022 data trends are as follows:

- Two contractors showed significantly more severe and less low segregation than others.
- All contractors averaged above the 70 percent threshold for pass count coverage, and three met or exceeded the 90 percent threshold.
- All contractors averaged MTOP above 180 °F.

10.1.5 Task 5 – Pilot Innovation Technologies

One contractor successfully uses LiDAR data to extract an alignment file compatible with Veta. The alignment file generates boundaries using offsets and start and stop coordinates. The data collection uses vehicle-mounted equipment that can be driven in live traffic and at traffic (highway) speeds. The resulting point cloud data shows the existing surface. The alignment file is generated using the centerline paint lines. The contractor says they prefer the LiDAR method over collecting paving production boundaries by hand. The technology was presented at the industry feedback meetings. Other intelligent boundary collection methods may be piloted in 2023.

MoDOT has not elected to move forward with DPS technology at this time. However, they remain active in (TPF)-5(443) DPS for Continuous Asphalt Mixture Compaction Assessment.

10.1.6 Task 6 – Pavement Performance Tracking

The data is still being collected under Task 6 and will be continued through 2023.

10.1.7 Task 7 – Feedback Meeting

The feedback meeting was held on December 14-15, 2022. The key takeaways include the following:

- PMTP specifications will be updated to include TSI classifications, better-quality GPS, and language to clarify full paving width data collection.
- It may be useful to revise IC specifications to require a GPS base station when cellular coverage (and the cellular correction network) is poor. This revision may mitigate IC GPS issues.
- The data QA methods seem to work as data verification tools. The most common issues with the data QA procedures are as follows:
    - For IC pass count data QA, Dirtmate data loss is the most common issue. A diagnostic tool showing data transmission progress from Propeller will be piloted in 2023.

    - For PMTP temperature data QA, invalid FLIR images and issues with the event maker are the most common issues. The promotion of the training materials in 2023 will be used to resolve these issues.
- The 2022 training program received positive feedback. The JITT will be offered in 2023 by request.
- MoDOT may need to hire a full-time consultant to cover the staffing needs as they move toward full implementation. IC-PMTP staff would provide support and training to project staff.
- LiDAR data is being used successfully to collect boundary data with vehicle-mounted equipment in live traffic at traffic (highway) speeds. MoDOT may specify using intelligent boundary collection methods in the future to promote safety.

10.2 SUMMARY

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 since implementation in 2017. These trends indicate that intelligent construction technologies improve successful construction practices, which may lead to higher-quality pavements.

The implementation of data QA is critical to MoDOT's full IC-PMTP implementation. Data QA will continue to be a key focus in 2023 and beyond, and training and technical support will be critical for successful implementation.

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