TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
[TBA]		

4. Title and Subtitle	5. Report Date
Consultant Support for Intelligent Compaction and Paver-Mounted Thermal Profiling Projects in 2020-2021 2020 Final Report	March 15, 2021 Published: [TBA]
	6. Performing Organization Code
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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 # TR202021
12. Sponsoring Agency Name and Address Missouri Department of Transportation (SPR) Construction and Materials Division P.O. Box 270 Jefferson City, MO 65102	**13. Type of Report and Period Covered** 2020 Final Report (March 2020-Dec 2020)
	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 2017-2019 Intelligent Compaction and Paver-Mounted Thermal Profiling (IC-PMTP) projects that demonstrate the paving quality improvements on numerous field projects, MoDOT has established a plan that includes additional IC-PMTP projects in 2020 and using IC-PMTP data for acceptance in 2021. To ensure the continued success of the MoDOT IC-PMTP projects in 2020 and beyond, MoDOT has procured Consulting Support for the selected IC-PMTP projects in 2020-2021 and implemented many initiatives such as data quality assurance (QA), performance tracking, and future acceptance with IC-PMTP data. This report is the deliverable of Task 7 – Final Report for the 2020 work.

17. Key Words	18. Distribution Statement
Compaction; temperature seg 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.	56	

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

MoDOT Project No. TR202021

CONSULTANT SUPPORT FOR INTELLIGENT COMPACTION AND PAVER-MOUNTED THERMAL PROFILING PROJECTS IN 2020-2021

2020 ANNUAL REPORT

Submitted to:

Missouri Department of Transportation

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February 2021

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ACKNOWLEDGEMENTS

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

Due to the success of the MoDOT 2017-2019 Intelligent Compaction and Paver-Mounted Thermal Profiling (IC-PMTP) projects that demonstrated the paving quality improvements on numerous field projects, MoDOT is continuing with IC-PMTP implementation. The primary goal of this project is to ensure the continued success of the MoDOT IC-PMTP projects in 2020 and beyond and help MoDOT achieve the goal of using the IC-PMTP data for acceptance by 2021. Therefore, MoDOT has procured consulting support for the selected IC-PMTP projects in 2020-2021 and implemented initiatives such as data quality assurance (QA), performance tracking, and future acceptance with IC-PMTP data. The Scope of Work (SOW) for this project includes seven (7) main tasks from 3/16/2020 to 4/29/2022, for approximately 25 months.

This report is a summary of work completed in 2020. The primary findings are as follows:

- In-person training was disrupted by COVID-19. However, remote training was generally successful. There were many learning curves in 2020 because of the new features of analysis software and new data QA analysis procedures. Training will be critical in 2021 for the continued success of intelligent construction implementation.
- There are still many common issues associated with IC-PMTP data analysis. These include improper data file management, not following standard naming convention, incorrect use of data filters, using old and outdated protocols, and incorrect transfer of results to the summary sheet. MoDOT resident engineers (REs) and project engineers should make sure to regularly check for these common issues. The Consultant will continue to check for these issues in random QA checks in 2021.
- The implementation of IC-PMTP is successful based on the data trends observed. There was a higher percentage of projects in 2020 that achieved the 70 percent and 90 percent IC coverage thresholds than any other year since implementation in 2017. Since implementation in 2017, there are more low segregation classification and less severe segregation classifications. This may indicate acceptance of technology by contractors, increased understanding, and successful implementation of IC.
- MoDOT is one of the leading State DOTs focused on implementing data QA procedures for intelligent construction. The data QA procedures developed and piloted during 2020 are complex and require a basic understanding of Veta software and engineering judgment for successful implementation. Long term goals include adding a feature in Veta to automate the data QA process. Until then, the Excel macro tools that were developed are the best solution. These state-of-the-art procedures will continue to have a steep learning curve and training and technical support are recommended. Two different thermal camera models (E5, E85) were evaluated for PMTP temperature QA. Based on the analysis results, the E5 is recommended for the 2021 season.
- The temperature segregation index (TSI) and the cyclic fatigue index parameter S_{app} were calculated for different sublots and a comparison between laboratory test results and in-situ parameters was conducted. The established correlation needs improvement after collecting additional data. Once a sufficient amount of data is available, a nonlinear model will be used to estimate the HMA density at different times and locations based on IC measurement values.

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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
EDV:	Estimated Density Value (Volvo)
FOV:	Field Of View
GNSS:	Global Navigation Satellite System
GPR:	Ground Penetrating RADAR
GPS:	Global Positioning System
HCQ:	HAMM Compaction Quality system
HMA:	Hot Mix Asphalt
IC:	Intelligent Compaction
ICMV:	Intelligent Compaction Measurement Values
IMU:	Inertial Measurement Unit
IR:	Infrared Scanning
ISIC:	International Society for Intelligent Construction
MATC:	Mobil Asphalt Technology Center
MTOP:	Mean Temperature at Optimum Pass
MTV:	Material Transfer Vehicle
NDG:	Nuclear Density Gauge
NRRA:	National Road Research Alliance
OEM :	Original Engineering/Equipment Manufacturer
PDH:	Professional Development Hour

PMTPS: Paver-Mounted Thermal Profile Systems

PPK: Post-Processed Kinematic

PPM: PaveProj Program (MOBA)

QA: Quality Assurance

QC: Quality Control

RAP: Recycled Asphalt Pavements

RAS: Recycled Asphalt Shingles

RDM: Rolling Density Meter

RE: Resident Engineer

RTK: Real-time kinematic positioning system

S_{app}: Cyclic fatigue index parameter

SOW: Scope of Work

TPF: Transportation Pooled Fund

TSI: Thermal Segregation Index

UTM: Universal Transverse Mercator

CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

Due to the success of the MoDOT 2017-2019 Intelligent Compaction and Paver-Mounted Thermal Profiling (IC-PMTP) projects that demonstrated the paving quality improvements on numerous field projects, MoDOT is continuing with IC-PMTP implementation. Therefore, MoDOT has procured the Transtec Group (Consultant) to provide consulting support for the selected IC-PMTP projects in 2020-2021. The primary goal of this project is to ensure the continued success of the MoDOT IC-PMTP projects in 2020 and beyond. This project includes the implementation of many initiatives such as data quality assurance (QA), performance tracking, and future acceptance protocols with IC-PMTP data.

1.2 PROJECT SCOPE AND SUMMARY OF WORK PLAN

The Scope of Work (SOW) for this project includes seven (7) main tasks from 3/16/2020 to 4/29/2022, for approximately 25 months. The tasks of this project are listed as follows.

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

1.3 STRUCTURE OF REPORT

This report is the 2020 deliverable for Task 7. Table 1 outlines the organization of the report.

Table 1. Outline of this report (Task 7 deliverable).

Chapter	Description of Tasks
Chapter 1	Introduction
Chapter 2	Summary of Task 1 – IC-PMTP Training Program
Chapter 3	Summary of Task 2 – IC-PMTP Data QA
Chapter 4	Summary of Task 3 – Pilot Innovative Technologies
Chapter 5	Summary of Task 4 – IC-PMTP Project Supports
Chapter 6	(No associated task) Summary of Project Results.
Chapter 7	Summary of Task 5 – Pavement Performance Tracking
Chapter 8	Summary of Task 6 – Feedback Meeting and Executive Briefing
Chapter 9	Recommendations and Conclusions

CHAPTER 2 TASK 1-IC-PMTP TRAINING PROGRAM

2.1 INTRODUCTION

Training materials were upgraded to reflect the technological advancements of IC and PMTP and updated MoDOT specifications. Updates were also made to reflect the new features of Veta analysis software. The upgrades included changes to the IC-PMTP protocols to reflect the new analysis procedures and specification changes. The upgrades to IC-PMTP training materials are described in the following sections.

2.2 TASK 1-1: TRAINING MATERIALS UPDATE

Under MoDOT's instructions, the IC-PMTP training materials were updated according to the new analysis procedures. The new procedures considering the enhancements made in the latest version of Veta 6.0. The new training materials include the following:

- Training agenda.
- Presentation (PowerPoint) materials.
- Updated MoDOT IC-PMTP protocol.

Each of the training materials is further described in the following sections.

2.2.1 Training Agenda

The training materials and agenda are based on a 6-hour training for the targeted MoDOT staff and contractors and include the following elements:

- IC: understanding the technology, field operations, data collection, and hands-on analysis with Veta 6.0.
- PMTP: understanding the technology, field operations, data collection, and hands-on analysis with Veta 6.0.
- MoDOT 2020 IC-PMTP protocol.
- Veta hands-on exercises.

1.1.1. Presentation Materials

The training materials include updated and new presentation files in MS PowerPoint and a .pdf file of 12 step by step hands-on exercises examples for Veta 6.0. A quick reference guide for Veta 6.0 was also developed and distributed. Veta 6.0 included a new feature that allowed IC and PMTP data to be combined analyzed in one project. This is more efficient for data analysis. However, a learning curve was anticipated with the new analysis procedures.

All workshop materials were uploaded to the MoDOT SharePoint for Intelligent Compaction.

2.2.2 IC-PMTP Protocol

The MoDOT IC-PMTP protocol was updated as follows:

- Simplified naming convention and file management recommendations (compared to previous construction seasons). Instructions for data submission to MoDOT's SharePoint folders.
- Updated project summary Excel spreadsheet with macros.
- Updated step-by-step instructions for data collection, data analysis, and reporting.
- Created a quick reference guide to feature the changes to Veta 6.0.
- Created instructions for analyzing and reporting data with GPS obstructions.
- Created instructions, tools, and procedures for data QA.

The updated MoDOT IC-PMTP Protocol and supporting documents were uploaded to the MoDOT SharePoint for Intelligent Compaction.

Each of the updated protocol elements is further described in the following sections.

2.2.2.1 Naming Convention and File Management

The new file management system and data file naming convention are summarized in Table 2 and Table 3, respectively. These were simplified from previous years to minimize the total number of folders.

Table 2. SharePoint file management and names of folders

Folder Names	File Types
Raw_IC_Data	Raw daily IC data files (NA when using direct download to Veta)
Raw_IR_Data	Raw daily PMTP data files (NA when using direct download to Veta)
Contractor_Reports	1. Trial section NDG spot tests spreadsheet, 2. Daily contractor forms, 3. Daily production boundary/coring locations, 4. Daily Veta project files, 5. Overall project summary spreadsheet
MoDOT_Reports	1. Daily RE checklists, 2. Inspectors raw data QA files (DirtMate, FLIR), 3. Overall project data QA summary sheet, 4. RE diaries

Table 3. Data file naming convention.

Data Type	Responsibility	Data File Names	Examples
Raw IC Data	Contractor	JobNo-Date-ICD.Extension	1P2345-20200601-ICD.CSV
Raw IR Data	Contractor	JobNo-Date-IRD.Extension	1P2345-20200601-IRD.paveproj
Trial Section	Contractor	JobNo-Date-TRL.xlsx	1P2345-20200601-TRL.xlsx
Daily Contractor Check List and Form	Contractor	JobNo-Date-CHK.xlsx	1P2345-20200601-CHK.xlsx
Daily Production Boundary and Core Locations	Contractor	JobNo-Date-GPS.xlsx	1P2345-20200601-GPS.xlsx
Daily Veta Project File	Contractor	JobNo-Date-ICIR.vetaproj	1P2345-20200601-ICIR.vetaproj
Project Summary Sheet	Contractor	JobNo-Route-Summary.xlsx	1P2345-RT12-Summary.xlsx
Daily RE/Inspector Check List and Form	RE/Inspector	JobNo-Date-RECHK.xlsx	1P2345-20200601-RECHK.xlsx
Daily RE/Inspector Diary	RE/Inspector	JobNo-Date-REDAY.docx	1P2345-20200601-REDAY.docx
Raw Data QA Files (DirtMate)	RE/Inspector	JobNo-Date-DMT.tds	1P2345-20200601-DMT.tds
Raw Data QA Files (FLIR)	RE/Inspector	JobNo-Date-FLR.Extension	1P2345-20200601-FLR.jpg
Data QA Veta Files (DirtMate)	RE/Inspector	JobNo-Date-DMT.vetaproj	1P2345-20200601-DMT.vetaproj
Data QA Veta Files (FLIR)	RE/Inspector	JobNo-Date-FLR.vetaproj	1P2345-20200601-FLR.vetaproj
Data Summary Sheet	RE/Inspector	JobNo-Route-DataQA-Summary.xlsx	1P2345-RT12-DataQASummary.xlsx

2.2.2.2 Excel Summary Sheet

The Excel Summary Sheet macro file for MoDOT IC-PMTPs projects was updated as version 18 for the 2020 construction season.

The changes to the updated summary sheet are as follows:

- A cover sheet with instructions was added.
- The sheet was password protected.

- IC Results: One column was added for "Pass Count QA (pass/fail)." This column is filled out accordingly after the data QA is completed.
- IC Results: A section was added to allow for GPS obstructions to be removed from the data according to the 2020 MoDOT specifications.
- IC Results: The final segment classification was revised to include a check for mean temperature greater than 180˚F at optimum pass count. Segments that do not meet this requirement are classified as "Deficient" per MoDOT specifications.
- PMTP Results: One new column was added for "Temperature QA (pass/fail)."
- PMTP Payment: The "Bonus-Deduct ($)" was updated according to the 2020 MoDOT specifications.

2.2.2.3 Analysis Tools and Examples

The step-by-step instructions and sample data were updated to reflect the changes made to the new features of Veta 6.0. The most significant change in Veta 6.0 is the ability to upload multiple data types (IC and PMTP) to one project. Data filtering is more complex when multiple data types are uploaded. The instructions were updated to address the different filtering procedures and consider potential differences in data's GPS precision. The analysis procedures are further described in Chapter 6. A two-page quick reference guide was developed. The quick reference guide summarizes analysis methods and highlights the new features of Veta 6.0.

2.2.2.4 IC GPS Obstructions Instructions and Examples

The 2020 MoDOT IC specification (NJSP 18-08A) includes the following clauses related to GPS obstruction:

18.0 GPS Obstructions. Isolated areas influenced by a GPS obstruction may be excluded from % roller coverage computation provided that the following conditions are satisfied:

- *The position data is present.*
- *The GPS Reception Mode as recorded by the onsite equipment indicates that an obstruction is present.*
- *The location is properly flagged in the Veta project file, and the location is identified in the bi-weekly report.*
- *The total of these areas is no more than 5% of any single day's production.*

The Consultant developed detailed instructions on how to implement the above specification. This procedure includes six steps. Note that most GPS obstructions only affect RTK GPS data. This procedure is written for RTK GPS data loss, which is primarily for IC data at this time. Veta 6.0 does not allow for exclusions without a location filter. Therefore, this procedure only applies to data that has a location filter (boundary). The steps for GPS obstructions are as follows:

1. Obtain and view GPS vendor's data loss report or similar records.
    a. The vendor should have a report to show if and when GPS obstructions were present during data collection.
    b. Data loss areas should be verified against the vendor GPS summary report using data timestamps, as described in Step 4.

2. Create a new filter group for exclusions named “Exclusions.”
    a. A new filter group is required so that the data can be analyzed with and without exclusions to ensure that these areas’ total is no more than 5% of any single day’s production per the specifications.
3. Apply the boundary to the Compactor Location Filter.
    a. Create an operation filter in the new “Exclusions” filter group and name it “Exclusions.”
    b. Under “Compactor” check the box next to “Override Common location filter.”
    c. Under “Compactor” click “Location Filter.”
    d. Click “Source” then “Custom.”
    e. Copy and paste the boundary coordinates into the compactor location filter. Note that this is required to “snap” the exclusion to the boundary as further described below. Note that a common location filter is not required in the “Exclusions” filter group.
4. Create exclusion filters
    a. Zoom into the area with data loss.
    b. Verify that the data loss area matches the vendor GPS loss report using the “search” tool. Right-click on data near the data loss area and select “Search” to bring up the search box.
    c. Under the “Exclusions” filter group ”Compactor” Right-click “Exclusions” and select “Create exclusion.”
    d. Name the exclusion with the date and time the data loss began (example: 20200521-1100).
    e. Click “Source” then “Custom.”
    f. Draw a box around the entire area to be excluded, make sure all data fits within the box. Create the corners of the box by right-clicking on the map and selecting “Add location.” Alternatively, if coordinates of the extent of data loss are known, they can be typed in. The box must be created by selecting four points in a clockwise or counterclockwise direction.
    g. Create multiple exclusions for data loss as applicable, giving each exclusion a unique name.
5. Analyze using the “Override” feature.
    a. Under “Setup,” select the button next to “Use other filter group (s)”.
    b. Click the drop-down arrow next to “Miscellaneous” and check the boxes next to your project filter group and the “Exclusions” filter group. This will provide analysis results with exclusions and without exclusions.
    c. Setup the rest of the analysis following standard project requirements.
    d. Run the analysis.
6. Enter IC results from filter groups with and without exclusions in the project summary sheet.

The training materials included a recorded video file and a detailed instruction guide. A few examples using sample data were included.

2.2.2.5 IC-PMTP Data QA Instructions and Examples

The IC pass count data QA instructions consist of the DirtMate installation and data collection by the Propeller company and the Veta filtering and analysis for the IC and DirtMate data and Excel data QA macro analysis.

The PMTP temperature data QA instructions consist of the FLIR thermal camera setup, operation, data collection, and the Veta filtering and analysis for the IC and DirtMate data and Excel data QA macro analysis.

The QA for IC and PMTP are further described in Chapter 3.

The training materials included presentation files in MS PowerPoint, a recorded video file, and a detailed instruction guide. A few examples using sample data were included.

2.3 TASK 1-2: TRAINING WORKSHOPS

The following sections describe the training workshops completed in 2020. Due to the impact of COVID-19, all training workshops were completed online.

2.3.1 IC-PMTP Training Workshops

A 6-hour IC-PMTP training workshop was conducted via GotoWebinar (GotoWebinar, 2020) for selected MoDOT staff and contractors on April 16, 2020. There were 50 attendees. All attendees received certificates of completion with 6 units of Professional Development Hours (PDH).

2.3.2 IC-PMTP Data QA Training for Resident Engineers

A 1-hour IC Pass Count Data QA training workshop was conducted via GotoWebinar for selected MoDOT staff and contractors on August 4, 2020.

A 1-hour PMTP Temperature Data QA with FLIR Camera training workshop was conducted via GotoWebinar for selected MoDOT staff on September 9, 2020.

2.4 SUMMARY

Due to the impact of COVID-19, all training workshops were conducted online in 2020. All online workshops were recorded and posted on the MoDOT SharePoint for Intelligent Compaction. The IC-PMTP training materials and protocols were updated to reflect the technological advancements in IC and PMTP data collection and analysis.

The data QA procedures are complex and require engineering judgment and a basic understanding of Veta and IC-PMTP project analysis. Therefore it is recommended that more training workshops for data QA are held before the 2021 construction season.

CHAPTER 3 TASK 2-IC-PMTP DATA QA

3.1 INTRODUCTION

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

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

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

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

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

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

3.2 TASK 2-1: DATA QA PLAN AND TOOLS

3.2.1 IC Pass Count Data QA

The 2020 MoDOT IC specification (NJSP 18-08A) includes the following clauses related to data QA:

21.0 Quality Assurance. "Quality Assurance will be performed by means of a commission furnished, commission retained magnetic GPS system attached to the top of any IC roller. Thermal Sensors may also be installed by means of a magnetic mount. The units will be solar-powered. The contractor will provide the engineer access to these systems and accommodate the presence of the device on the IC Roller."

To perform data QA on the pass count reported by IC equipment, a machine tracking system called DirtMate manufactured by Propeller was used.

3.2.1.1 DirtMate System

The DirtMate system was used to track IC pass count on the project sites. The DirtMate device is a GPS rover mounted onto active IC machines using magnets and brackets (Propeller, 2020). DirtMates are solar-powered. The built-in real-time kinematic and post-processed kinematic (RTK/PPK) GPS receiver collects elevation data from the ground underneath the machine in real-time, while an inertial measurement unit (IMU) tracks machine vibration to determine utilization metrics (idle, working, off). The data is transferred to a supplied network gateway by a wireless transmitter. A separate hotspot device is used to connect the DirtMate to the network.

This device was first tested in a MoDOT parking lot to verify its performance and feasibility to use in the MoDOT pilot studies. Part of the feasibility study was ensuring data could be imported into Veta software.

The installation process for the DirtMate device on the IC roller, cellular hotspot setup, network connection, data retrieval from the web portal, and Veta compatible file generation was summarized and presented by the manufacturer in a MoDOT webinar. All instruction files and videos were uploaded to the MoDOT Intelligent Compaction SharePoint site.

3.2.1.2 Pass Count Analysis Tool

The Consultant developed an Excel spreadsheet macro tool to evaluate IC pass count data through a comparison of IC data with DirtMate data. This tool, the instructions to generate input files, and examples were uploaded to the MoDOT SharePoint under Intelligent Compaction. The IC pass count QA analysis procedure is summarized in the following steps:

1. DirtMate Analysis
    a. Download DirtMate data and rename it as “ProjectCode-Date-DMT.tds”
    b. Import it to Veta and save as “ProjectCode-Date-DMT.vetaproj,” and create a Filter Group and an Operation filter with specified a time window under Compactor/Time Filter/Range (e.g., 30 min. to 15% of the operation period depending on whether there is data loss in the IC data).
    c. Analyze the IC pass count of the final coverage data.
    d. Create an Excel report by selecting the Overall Pass Count results and save them in the data QA folder. The Excel report filename is automatically generated as “Filename – Compactor – FilterGroupName-Final Coverage. -AnalysDate.xlsx”
2. IC Analysis
    a. Obtain IC data “ProjectCode-Date-ICD.zip” from the contractor corresponding to the DirtMate data.
    b. Import it to Veta and save it as “ProjectCode-Date-IC.vetaproj,” and create a Filter Group and an Operation filter with the same time window as the DirtMate analysis.
    c. Analyze the IC pass count of the final coverage data.
    d. Create an Excel report by selecting the Overall Pass Count results and save them in the data QA folder. The Excel report filename is automatically generated as “Filename – Compactor – FilterGroupName-Final Coverage- AnalysDate.xlsx.”
3. QA Macro Analysis
    a. Open NJSP1808-Form-01-DataQA-v1.X.xlsm and click “enable contents” if prompted by Excel.
    b. Click the “Clear Contents” button.
    c. Click the “Select IC Report” button to select the Excel IC report generated previously.
    d. Click the “Select DirtMate Report” button to select the Excel DirtMate report generated previously.
    e. Click the “Compare Results” button to generate the data QA results. Examine the results and verify the Project Code and QA Date.
    f. Click the “Print PDF Report” button to generate the QA report in which the filename is automatically set as “ProjectCode-Date-ICQA.pdf.”
    g. Send this PDF report to the contractor to update their project summary sheet.

3.2.2 PMTP Temperature Data QA

The 2020 MoDOT IC specification (NJSP 18-09A) includes the following clauses related to data QA:

9.0 Quality Assurance. “*The Engineer will record spot temperature readings with a calibrated infrared thermometer. 2 QA test sets each consisting of 3 spot readings at the lane quarter points will be taken for each full production day. The test sets will be taken at random locations. The contractor will assist the engineer with determining the GPS location of each spot reading location. The recorded temperature will be within 12ºF of the temperature recorded by the thermal scanner for each location. If 4 readings from any 2 consecutive test sets fall outside of the 12ºF range, then conflict resolution will be initiated to determine corrective action.*”

There are limitations with using spot temperatures and thermal profiler data. Therefore, MoDOT requested assistance with developing a QA procedure using a thermal camera. Several pilot studies were conducted using a thermal camera manufactured by FLIR. Two cameras were used in the 2020 season, including:

- FLIR E5
- FLIR E85

The goal of the pilot studies was to evaluate the cameras for feasibility and develop a new PMTP data QA method to replace the current PMTP Data QA requirement under NJSP-18-09A. The workflow includes collecting and filtering PMTP data, taking thermal images, and analyzing using an Excel spreadsheet macro. The procedure is summarized below.

3.2.2.1 FLIR Thermal Camera Operation

Two models, E5 and E85, were used for temperature data QA (FLIR, 2020). The technical details of the two camera models can be found on FLIR's webpage. A comparison between the two cameras showed that FLIR E85 has superior GPS for image tagging, has better thermal sensitivity (ability to distinguish objects with different temperatures), and higher resolution. Therefore, the E85 was initially purchased for the project. However, it has a lower field of view (FOV) than FLIR E5, meaning that its images cover a smaller area of pavement per image. Both cameras were used to collect data and further evaluate each model during the pilot studies.

Training and operation of the FLIR cameras was a learning curve. The camera timestamp must match the time stamp of the PMTP equipment. The clocks on the PMTP unit and FLIR camera must be synchronized before use. It was recommended that the REs participating in the pilot studies reviewed the manufactures instructions before using the camera on the project.

The following procedures were developed for taking FLIR images in the field:

1. Wait at least one hour or 4-5 truck-loads of asphalt after the start of paving. Ensure the PMTP system is functioning by observing the thermal maps of the real-time display.
2. Determine a safe and adequate location to take a FLIR camera measurement. It is recommended that a spotter accompany the camera operator. The spotter should make sure the person focused on the camera is not in the path of moving equipment or trucks.
3. Place an event marker of a 2-feet by 2-feet wooden board or similar on the near edge of the paved asphalt surface behind the paver screed. <u>Ensure the object is within the PMTP field of view (FOV)</u>.
4. Wait until the paver has moved a safe distance (10 to 15 ft). Measure the asphalt surface temperature by positioning the FLIR camera perpendicular to the paving direction at 5-feet height and 6-feet offset from the inner edge, tilting the camera toward the asphalt mat by covering both near and far edges of the paved area with the event marker in the center of FOV. Save the image file as ProjectCode-Date-FLIR-1.jpg.
5. Repeat Steps 2-4 for another two random locations at least one hour apart. Save the data files as ProjectCode-Date-FLIR-N.jpg. (N is a sequential number of FLIR images taken). *Note that the file naming convention is strict. Any failure to follow this naming convention will render the QA analysis invalid. The date should refer to the day when*

paving starts (nightshift paving may span two dates). All file names must use the same date convention to avoid confusion.

6. Once the images are taken, they should be uploaded to the MoDOT SharePoint in the corresponding project folder.

3.2.2.2 PMTP Data QA Analysis Tool

The Consultant developed an Excel spreadsheet macro tool to perform the analysis and comparison of temperature data from PMTP and FLIR thermal camera (E5 or E85). After PMTP data were collected and before uploading into the macro analysis tool, a filter must be applied to ensure the PMTP data matches the time and location at which the thermal images were taken. The procedure to apply this filter is described below:

1. Import the contractor's PMTP data to Veta or use the contractor's Veta file.
2. Create a Veta filter group as "PMTP-DataQA-N," with N corresponding to the corresponding FLIR image file. Use the FLIR timestamp as a center point to create a Veta operation filter that uses a time filter from minus 1~2 min. to plus 1~2 min. from the FLIR image timestamp. Turn on the cold edge filter. Apply the filter and search for the event marker (< 180° F) in the PMTP temperature map.
3. If there is no event marker present, declare the data invalid, and try other FLIR locations to repeat the above steps. If the event marker cannot be found, the QA data set is invalid. If the event marker is found, adjust the time filter's bounds to ensure the length is about 100 feet to allow the edge filter to function.
4. Use the Veta Report feature to export the filtered PMTP data to a text file. Change the file name to ProjectCode-Date-PMTP-QA-N.txt.

After identifying both the thermal image and the associated filtered PMTP data, use the latest version of the MODOT PMTP Data QA Excel macro tool to perform QA data analysis and reporting, as follows:

1. Click the Clear Contents button.
2. Import the FLIR image. A DOS window will flash, and dialogue will signal the completion of import. Examine the FLIR-Map and FLIR-filt-Map map to confirm the majority of cold edges are filtered out. This step may take from 15 seconds to 2 minutes for the program to complete.
3. On the Main sheet, clicking the Import PMTP Data to import the PMTP QA text file. The dialogue box will signal import completion.
4. Select the applicable camera, the paving direction, and the FLIR position (as shown in Instructions in the MoDOT SharePoint folder). Click the "Process PMTP Data" to perform the PMTP data processing and crop the PMTP to match the FLIR data. The dialogue box will signal import completion. Examine the PMTP-Map to confirm the map matches the Veta map. Examine the PMTP-crop tab to confirm the matched zig-zagged trapezoidal footprint of the FLIR image with the event marker is close to the map's near edge. If not, the paving directions may need to be adjusted. Note: the FLIR E5 and E85 have different approximated footprints.
5. On the Main sheet, click Compare Results to perform statistics of the matched data sets and determine pass or fail for QA. The dialogue will signal the analysis completion.

6. Click the Produce the PDF. The report is automatically named ProjectCode-Date-PMTP-QA.pdf. The dialogue box will signal the completion when the report is generated. Open the PDF file and confirm the results.

Further instructions, pictures, and examples on how to use this Excel macro analysis tool were given through virtual training. The related videos and instructions files, along with sample data, are available in the MoDOT SharePoint folder.

3.3 TASK 2-2: PILOT DATA QA PROJECTS

Data QA for IC pass count and PMTP temperature profile was conducted on several pilot projects. The purpose of the pilot projects was to demonstrate the feasibility and gather enough data to establish reasonable acceptance tolerances. A summary of the pilot project efforts is shown in Table 4.

Note that Table 4 only represents the data QA efforts that were completed by MoDOT personnel. The Consultant performed some data QA to establish the data QA evaluation procedures, set preliminary tolerances, and develop training materials. The Consultant QA efforts are not summarized in Table 4.

The data in Table 4 are summarized by contractor code and project code to protect the contractor's identity. These contractor details are available to MoDOT personnel only. The tables that decipher the codes (for MoDOT personnel) are included in Chapter 6.

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.
- Pass (shaded green): Analysis passed the QA procedures.
- Fail (shaded orange): Analysis passed the QA procedures.
- NA (shaded yellow): Not applicable as the analysis was not completed.

Table 4. Summary of data QA pilot project efforts.

Project Code	Contractor Code	Flir Images Collected	DirtMate Setup Completed	DirtMate Data Uploaded	PMTP Analysis Complete	IC Pass Count Analysis Complete	PMTP Pass/Fail	IC Pass Count Pass/Fail
2	7	Y[a]	N	N	N	N	NA	NA
3	2	N	Y[b]	N	N	N	NA	NA
7	1	Y[a]	N	N	N	N	NA	NA
11	4	Y	N	N	N	N	NA	NA
12	5	Y	N	N	Y	N	PASS	NA
16	9	Y	N	N	Y	N	PASS	NA
18	6	Y	Y	Y	Y	Y	PASS	FAIL[c]
21	10	N	Y	Y	N	Y	NA	FAIL[d]
23	12	Y	N	N	N	N	NA	NA
24	12	Y	N	N	N	N	NA	NA
25	8	Y	N	N	Y	N	PASS	NA

[a] The Flir clock did not match the PMTP clock and the data was considered invalid.
[b] Setup was completed but no data was uploaded to SharePoint.
[c] The analysis was not performed correctly. The data was not filtered by machine ID. Therefore, the results are invalid.
[d] The DirtMate data has pass count “halos” with a falsely high pass count. This is causing the data analysis to fail. An example of a data “halo” is illustrated in Figure 1.

Lessons learned from the data QA pilot studies include the following:

- *IC pass count analysis fails:* Table 4 shows that the IC pass count QA efforts typically did not pass. There were a few issues encountered during the pilot studies, including:
    - The contractor did not set up the machine ID correctly. Therefore, the roller that had the DirtMate installed count is not filtered from the other rollers on the project.
    - Issues with the DirtMate data. Some DirtMate data included data “halos,” as illustrated in Figure 1. The data halos are illustrated as purple circles. The legend indicates that these locations have a pass count of 20 or higher. These data halos are infrequent and small. However, the impact of the higher pass count is statistically significant. It is recommended that these data halos are avoided during data QA evaluation until the cause of the error is determined.
- *DirtMate hotspot*: A common issue was the connection of hotspots with DirtMate devices. Sometimes there was confusion regarding the purpose of the hotspot. The operator should make sure that the DirtMate is on (the power light is solid on or fast blinking, meaning that it is charging) and is connected to the hotspot (network light is fast blinking). It is recommended to leave the hotspot with the roller during operation. The RE should check daily to make sure data are being collected and uploaded to the vendor cloud. If needed, the device should be turned off and back on to see if the data can be retrieved. If none of this works, the RE should contact the manufacturer’s technical support for troubleshooting. The operating instructions for the DirtMate device and hotspot were given through the instruction files and webinars and uploaded to the IC SharePoint site. Many projects had missing data from the DirtMate.
- *Missing or invalid data from DirtMate*: One of the challenges in collecting IC pass count data was setting up the DirtMate correctly and on the correct roller. In some cases, the DirtMate was mounted backward, and the output data was incorrect. Another issue was mounting the DirtMate on the wrong roller (e.g., finish roller). The RE should check with the operator to make sure the DirtMate is installed correctly.
- *Measurements of DirtMate:* Some projects did not provide the mounting measurements for the DirtMate. The setup of the DirtMate is vital for ensuring the data is valid.
- *FLIR time settings*: In some cases, the PMTP QA was not possible because the timeclocks between the PMTP and FLIR camera did not match. As previously described, the clocks on the PMTP unit and FLIR camera need to be synchronized before use and set to US Central time zone.
- *FLIR images*: In some cases, the thermal images were not appropriate for data QA, including incorrect offset and height (not centered with event marker object) and interference from paver, workers, grass, and surrounding objects. The instructions for taking images should be reviewed and followed precisely.
- *Complex Analysis Procedures*: The analysis for the data QA uses a combination of Veta analysis and Excel macro tools. The Veta analysis requires some knowledge of the filtering. Some judgment calls are required, making it difficult for REs and

inspectors to implement. The current procedure is considered complex. Until a QA tool is implemented in Veta, the current method is the best available tool.

- *Thermal Camera*: After evaluating both the FLIR E5 and FLIR E85 cameras, it was determined that a larger FOV was more important than the increased resolution. The GPS tagging is no longer critical because the analysis uses timestamps for data location rather than global position. Therefore, the E5 camera is recommended for the 2021 construction season.

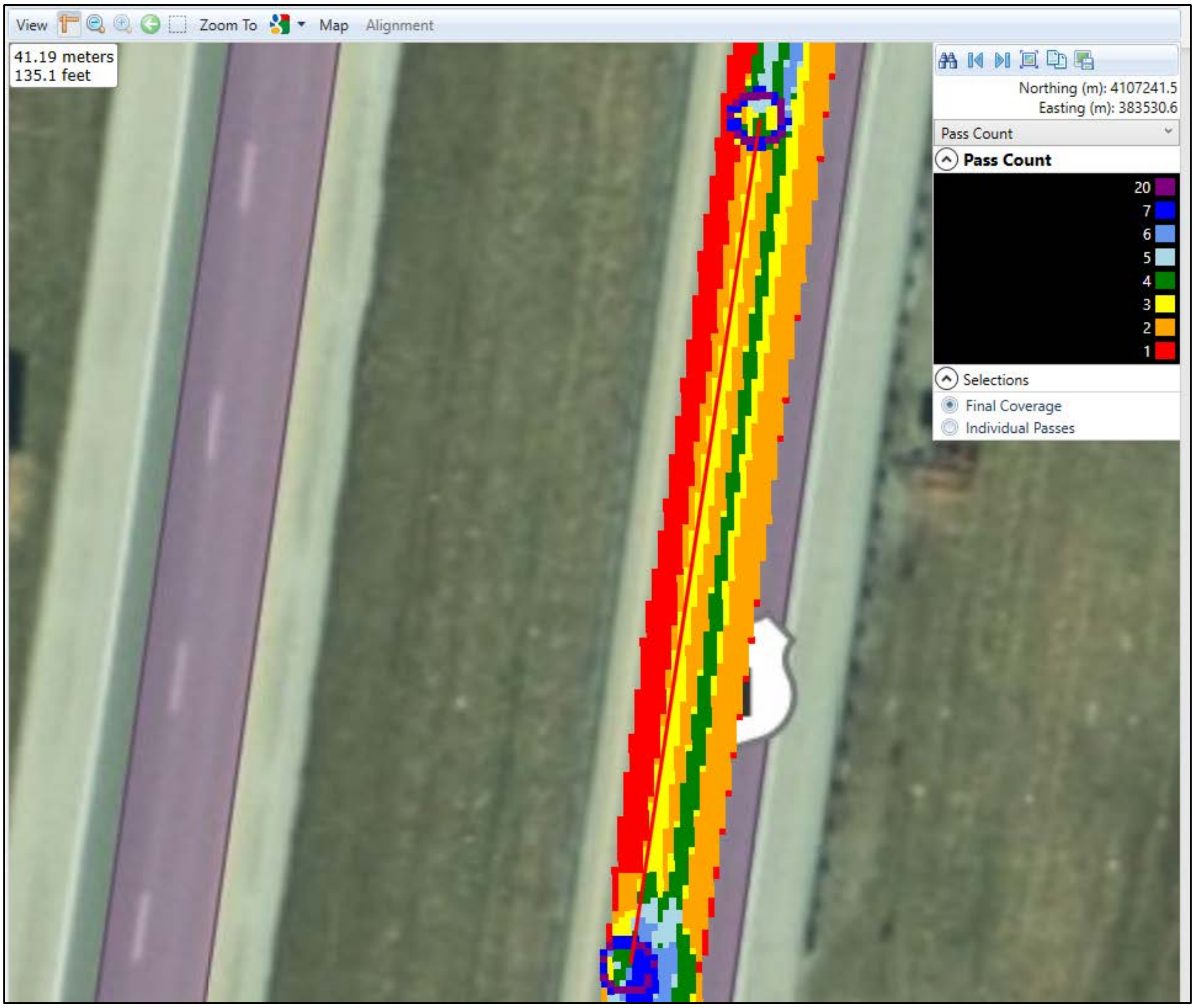

Figure 1. Screenshot. Image of DirtMate data halos.

3.4 SUMMARY

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

The purpose of the pilot studies was to determine the feasibility of the new QA procedures to be implemented successfully in 2021. Valuable lessons learned were summarized and used to modify the procedures and be highlighted in the 2021 training workshops.

The analysis procedures are complex. The Consultant produced training videos and step-by-step instructions for implementation. It is recommended that MoDOT continue with training efforts and provide technical support to ensure data QA processes are implemented successfully.

The long term goal of data QA is to implement a tool in Veta to automate the process. The Consultant is working with the FHWA, the Transportation Pooled Fund (TPF) Veta study, the National Road Research Alliance (NRRA), and the International Society for Intelligent Construction (ISIC) to study the feasibility of simplifying data QA.

CHAPTER 4 TASK 3-PILOT INNOVATION TECHNOLOGIES

4.1 INTRODUCTION

Under MoDOT's instructions, the Consultant proposed piloting innovative technologies, including:

- Efficient Boundary Measurements: Pilot new technologies for boundary measurements, include: (1) Paver-mounted GPS to obtain paving boundary, (2) Mobile LiDAR scanning on pavement surface to extract boundary, (3) Topcon measurements of the centerline of pavements to be used as the offset to the pavement edges to create the boundary.
- Dielectric constant Profiles Systems (DPS): Ground Penetrating RADAR (GPR)-based technologies can be piloted on selected projects to measure dielectric constant profiles, which can be calibrated against cores to predict asphalt in-place density or void ratio. These technologies can be used behind the finish roller(s). The DPS data can then be imported to Veta for analysis and compared with IC/PMTP data and field core data. The purpose of the comparison is to evaluate the effectiveness of various technologies.

4.2 DIELECTRIC CONSTANT PROFILES SYSTEMS

The FHWA Equipment Loan Program at the Mobile Asphalt Technology Center (MATC) (FHWA, 2020B) agreed to loan MoDOT a unit of the GSSI PaveScan Rolling Density Meter (RDM) 2.0 (GSSI, 2020) for field testing and evaluation during the 2021 construction season. The requirements to borrow the FHWA equipment are:

- Take good care of the equipment.
- Be willing to return it within a mutually agreed-upon time frame. If the equipment is needed for a more extended period, FHWA will do its best to accommodate the request; however, this is done on a case-by-case basis.
- Be willing to pay for shipping it back to FHWA or the next equipment loan requester in the queue.
- After the equipment loan has ended, please provide FHWA with feedback on the use of equipment (a paragraph or two submitted via email on your experience with the equipment would suffice).

MoDOT plans to mount an RDM 2.0 unit on a bumper of a pickup truck (Chevrolet 1500) instead of using the original cart-based system to improve mobility and safety. A training from GSSI will include YouTube videos and onsite training as well as a demonstration on sensor calibration, RDM data collection, and data analysis. The calibration methods for the RDM sensors will include:

- Overlapping Lines: Minnesota DOT has been using this method and has collected a substantial amount of data. GSSI is developing a software module specifically for this method.

- Repeat Line: Alaska DOT has been using this method to draw six lines on asphalt in their parking lot (labeled lined 1 – 6). The lines are 2 feet apart and about 10 feet long. They start on one side of the lines and collect data along the 10 feet. Then, they move over one line and collect data. With this method, the sensor on the left dielectric on line #2 should match the sensor in the center dielectric on line #2 and so-on.
- Verification Kit: GSSI is currently using this method for RDM 2.0 that uses an HDPE block to verify the dielectric from the sensors.

The RDM data is stored in the AASHTO MP 39-19 TDS format (AASHTO, 2019). Veta 6.1 beta will be used for data viewing and analysis.

4.3 SUMMARY

Due to the impact of COVID-19 and the unavailability of prototypes, the pilot innovative technologies task could not be implemented in 2020 and postponed to 2021.

CHAPTER 5 TASK 4-IC-PMTP PROJECT SUPPORTS

5.1 INTRODUCTION

The original work plan included onsite and remote technical support. Due to the impact of COVID-19, there was no on-site IC-PMTP project support in 2020. Instead, all support was provided remotely. The project supports are summarized in the following sections.

5.2 TASK 4-1: ONSITE SUPPORT

Due to the impact of COVID-19, there was no onsite IC-PMTP project support in 2020.

5.3 TASK 4-2: REMOTE TECHNICAL SUPPORT

Table 5 summarizes the projects that received remote technical support. The project contractor is identified using a random contractor code. Only MoDOT personnel have access to the contractor code. Remote technical support was provided on an as-needed basis. Projects received support for the following reasons:

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

Table 5. Summary of projects that received remote technical support.

Project Code	Contractor Code	Project Support Description
3	2	The contractor was using two different vendors for IC data collection. Veta only supports one vendor type. Assisted the contractor with specialized data analysis and management. The IC temperatures were not valid. The Consultant helped to troubleshoot faulty temperature measuring equipment. The contractor did not analyze the data per the protocols and was using a summary sheet that did not meet the project specifications. The RE and contractor were notified that the summary sheet did not meet project requirements.
21	10	The contractor was experiencing significant data loss for IC equipment. The Consultant helped to troubleshoot the cause of the data loss. The vendor IC equipment uses a cellular sim card to access the RTK correction. Any cellular provider can supply the sim card. The sim card being used did not have cellular coverage on the job site. However, other cellular providers did have cellular coverage in the area (including the cellular provider used for the PMTP equipment). The Consultant developed the GPS Obstruction and Data Loss methodology as previously described in section 2.2.2.3 to analyze projects with data loss.

Project Code	Contractor Code	Project Support Description
4	5	The contractor was using an old version of Veta and not following data management protocols. The contractor had issues analyzing multiple discontinuous sections with different production boundaries within the same daily segment. There was also confusion with the coordinate systems being used. The data was collected using GRS80-based coordinates, and the boundaries were collected using Missouri Central State Plane coordinates. The Consultant helped resolve all issues.
18	6	The contractor did not have access to SharePoint to upload data. The contractor requested assistance with data analysis. Several phone calls were scheduled to help with step by step data analysis.
7	1	The contractor requested assistance using alignment files for daily production boundaries. The Consultant assisted the contractor with Veta alignment file requirements.
11	4	The contractor requested assistance with analysis as they were getting lower than expected IC coverage results. The contractor applied incorrect data filters and used a data legend that did not correspond to the optimum pass. The Consultant assisted the contractor in resolving these issues.
23, 24	12	The contractor used an old summary sheet that did not consider the mean temperature at optimum pass (MTOP) requirements. The MTOP shall be above 180˚F. The contractor had several segments that did not meet MTOP. The RE was notified of the issue, and the contractor began using the correct summary sheet.
14	5	The contractor was having significant equipment issues. The equipment issues were carried over from 2019. The equipment vendor could not find any issues when the equipment was sent for repair over the winter. Erratic data caused issues with sublot generation, as illustrated in Figure 2. Veta does not know when erratic data occurs and will classify any sublot with data. This results in invalid segregation results. The Consultant notified the RE and contractor of the issues using invalid PMTP data and assisted the contractor with general Veta analysis questions.
16	9	The contractor was not available to attend the training session and was not using the correct version of Veta. The Consultant conducted a virtual meeting to help with step by step analysis in Veta 6.0. The contractor was still using MOBA PMTP reports. These are no longer accepted per the protocols and specifications. The Consultant assisted the contractor with PMTP analysis in Veta.
25	8	The contractor was not analyzing the IC and PMTP data in one project. The Consultant notified the contractor of the new protocols and assisted with the new analysis procedures using Veta 6.0.
13	11	The contractor did not upload any data to the intelligent construction SharePoint. Therefore, no data quality checks were made. The RE requested assistance with price adjustments. The Consultant assisted the RE and contractor to upload all data to the intelligent construction SharePoint site. The data had not been analyzed per the specifications. The boundary data had not been processed in a format compatible with Veta. The Consultant assisted the contractor and RE with protocols and data analysis, and evaluation.

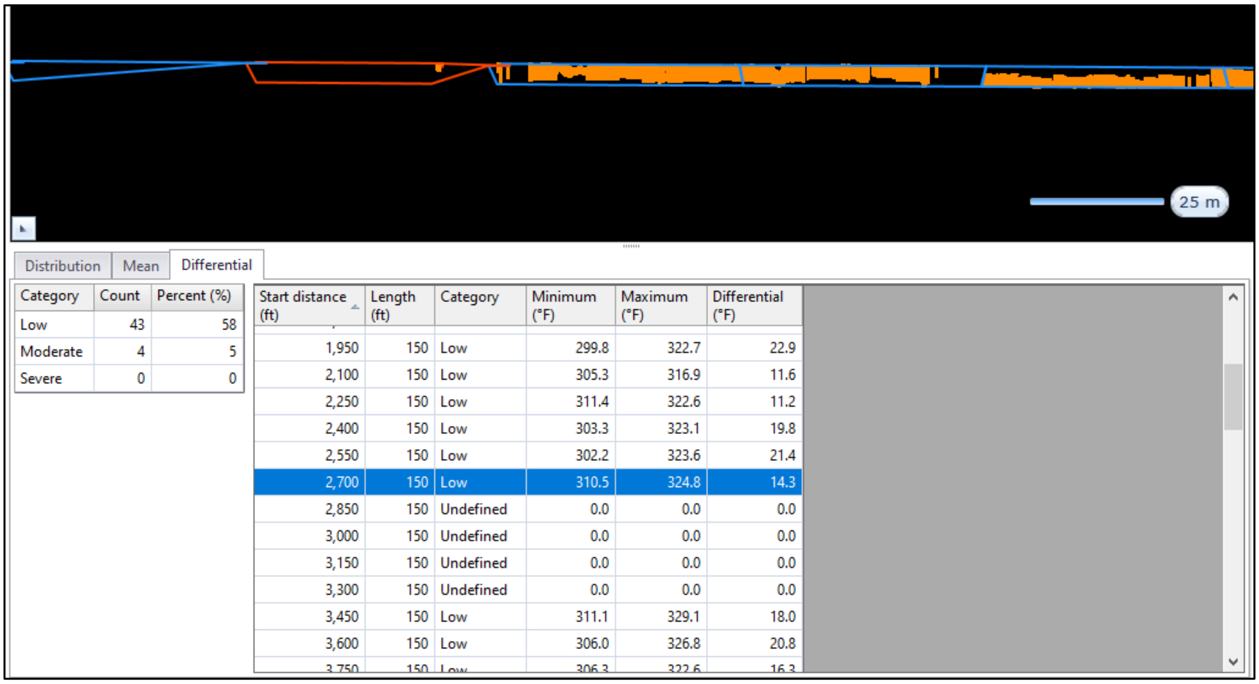

Figure 2. Illustration. Invalid sublot generation around erratic and missing PMTP data.

5.4 TASK 4-3: DATA QA CHECKS

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

- Data management checks including standard naming convention, file management, and missing or incomplete data.
- Data analysis checks including correct filtering, legend customization, and analysis setup. Data analysis procedures are further described in section 0
- 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 6. The reoccurring data quality issues are ranked as frequent, moderate, or infrequent. Table 6 helps to understand the most common data quality issues better. It may be beneficial to discuss the most common data quality issues in future training sessions to minimize them in future construction seasons.

Table 6. 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
The incorrect summary sheet was used.	Many contractors used older versions of the summary sheet. The summary sheet is periodically updated with new protocols and specifications. Some older versions of the summary sheet do not meet the current protocols. Some contractors developed their summary sheet, which did not meet the current protocols.	Frequent	It is recommended to emphasize the use of the most updated summary sheet. The Consultant will try to avoid making any changes to the summary sheet after training sessions are held. It is recommended that REs check the summary sheets being used to ensure the correct version is being used. Contractors should not use their own summary sheets.
Incorrect filters used.	The most common filtering issue was applying the IC boundary to the PMTP data. The PMTP data does not use RTK GPS. Therefore, the RTK boundary should not be applied to the PMTP data. Applying an RTK boundary to non-RTK data will result in inaccurate filtering of data. Other common filtering issues were missing data filters on the PMTP data and failure to select sublot start and endpoints manually.	Frequent	It is recommended to continue to emphasize the correct filtering procedures in future training sessions. 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. It is recommended that REs are trained to check for common mistakes to avoid them in future construction seasons.
Incorrect naming conventions and data file management.	Standard naming convention and file management were commonly incorrect.	Frequent	Data management is often not considered as critical during data collection. However, if data management protocols are not followed, it is easy to lose track of data, and analysis becomes more difficult and time-consuming. These protocols should continue to be emphasized in future training sessions. REs should be trained to check for proper data management.

Data Quality Issue	Description	Frequency of Occurrence (frequent, moderate, infrequent)	Recommendations
Missing data.	Missing data is commonly due to equipment malfunction. Different equipment malfunctions include loss of GPS signal, failure to record data, and failure to upload to vendor cloud storage.	Moderate	Procedures were developed to assist contractors with analyzing projects with missing data (reference section 2.2.2.3). There are provisions in the specifications that reasonably allow for data malfunction without penalty to the contractor as long as good faith efforts are made to fix the equipment issues. It is recommended that contractors continue to work with their vendors when equipment issues arise. It is anticipated that fewer equipment issues will occur as the technology becomes more widely used and more vendors (competition) enter the market.
Incorrect setup of equipment.	Data headers are visible in the Veta data files screen. Vendors should include data headers according to relative AASHTO standards. In some cases, the PMTP paving width was less than the actual paving width. Therefore, the full width of mat temperatures was not collected. Other common equipment issues included invalid IC machine name types. Some contractors used only one machine name for all rollers. This makes it impossible to filter by roller, which makes the proposed data QA procedures impossible to execute.	Moderate	Equipment setup varies by vendor. Contractors should work with their equipment vendors to ensure they understand how to set up the equipment settings correctly. Unique machine IDs for IC rollers should be emphasized in future training sessions so that data QA procedures (described in Chapter 3) can be executed.
Incorrect analysis setup.	Some contractors did not customize the pass count legend to match the optimum pass. This makes the report more challenging to review and understand. Some contractors also used incorrect analysis options.	Infrequent	To use the coverage pie charts efficiently, the contractors should customize the pass count legend to match the optimum pass. Proper analysis of data should continue to be emphasized in future training sessions. REs should be trained to check the reports for correct analysis setup.

Data Quality Issue	Description	Frequency of Occurrence (frequent, moderate, infrequent)	Recommendations
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 continue to perform quality checks on the contractor data. The correct transfer of report results to the summary should continue to be emphasized in future training sessions.
Analyzing PMTP and IC data separately.	Some contractors continued to analyze the data files in a separate project.	Infrequent	The analysis procedures changed significantly from Veta 5.2 and Veta 6.0 because now multiple data types can be analyzed in the same project. A learning curve is expected as the contractors learn the new procedures. It is anticipated that this will become less frequent in future construction seasons.

5.5 SUMMARY

Due to the impact of COVID-19, all IC-PMTP project support was conducted remotely in 2020. Remote support included assistance to REs and/or contractors during data analysis. Data quality checks were randomly performed on the data uploaded to the intelligent construction SharePoint.

All but one of the contractors sought technical support during project analysis. Increased need for technical support was anticipated due to the new features of Veta 6.0 and new intelligent construction protocols. A summary of the project support efforts was listed in Table 5. Due to the turnover of personnel, it is recommended that training sessions and technical support are continued. Technical support will continue under this project in the 2021 construction season.

The most common data quality issues were summarized in Table 6. These were ranked as frequent, moderate, or infrequent. These commonly occurring issues should continue to be emphasized in future training sessions so that they can be minimized in future construction seasons. This table should be used as a resource for REs to understand and watch for common mistakes during their data QA checks of contractor data.

CHAPTER 6 PROJECT DATA ANALYSIS AND RESULTS

6.1 PROJECT OVERVIEW

The projects that were completed during the 2020 construction season are shown in Table 7. Some projects show multiple job numbers. These projects were originally let using individual project numbers but were awarded to and completed by the same contractor. Table 7 includes the IC and PMTP equipment vendors used for each project. The contractor codes and corresponding contracting firm are summarized in Table 8. The project codes and corresponding contractor are summarized in Table 9. Table 8 and Table 9 have been removed from the public report.

There were three different IC vendors used during the 2020 season, including Topcon retrofit, Trimble retrofit, and Volvo original equipment manufacturer (OEM). Moba Pave-IR was the only PMTP vendor used.

Table 7. Summary of 2020 projects.

Project Code	Contractor Code	IC System	PMTP System
1	12	Trimble	Moba Pave-IR
2	7	Trimble	Moba Pave-IR
3	2	Trimble, Topcon	Moba Pave-IR
4	5	Trimble	Moba Pave-IR
5	7	No data	Moba Pave-IR
6	7	No data	Moba Pave-IR
7	1	Volvo	Moba Pave-IR
8	1	Volvo	Moba Pave-IR
9[a]	2	No data	No data
10	2	Topcon	Moba Pave-IR
11	4	Topcon	Moba Pave-IR
12[b]	5	Trimble	Moba Pave-IR
13	11	Volvo	Moba Pave-IR
14	5	Trimble	Moba Pave-IR
15	9	Volvo	Moba Pave-IR
16	9	Volvo	Moba Pave-IR
17[a]	9	No data	No data
18	6	Trimble	Moba Pave-IR
19[b]	10	Topcon	Moba Pave-IR
20[b]	4	Trimble	Moba Pave-IR
21[b]	10	Topcon	Moba Pave-IR
22[b]	4	Trimble	Moba Pave-IR
23[c]	12	Trimble	Moba Pave-IR
24[c]	12	Trimble	Moba Pave-IR
25	8	Volvo	Moba Pave-IR

[a] No data were submitted. Therefore, this project was not included in the final results.
[b] Projects were let separately but analyzed as one project.
[c] Projects were let as one project but analyzed separately.

Table 8. Contractor code (remove for public).

Contractors	Code
Capital Paving	1
Ideker	2
Chester Bross	3
APAC	4
Magruder	5
Blevins	6
Herzog	7
Pace	8
NB West	9
Leo Journagan	10
Krupp	11
ESS	12

Table 9. Project code (remove for public).

Project Number	Code	District	County	Route
J1I0914	1	NW	Harrison Daviess	35
J1I3016	2	NW	Clinton	35
J1I3018	3	NW	Clinton	35
J1P3165	4	NW	Caldwell	36
J1S3249	5	NW	Buchanan	169
J1S3257	6	NW	Buchanan	169
J3I3046	7	KC	Saline	70
J3P3111	8	KC	Johnson	50
J4I3119	9	KC	Jackson	470
J4P3215	10	KC	Clay	169
J5I3211	11	CD	Lacelede	44
J5P3121 J5P3128	12	CD	Cole	54
J6I3195	13	SL	St Charles	70
J6I3257	14	SL	St Louis	70
J6I3263	15	SL	St Louis	270
J6I3295	16	SL	Franklin	44
J6P3184	17	SL	Jefferson	141
J7I3083	18	SW	Barton	49
J7I3201 J8I3120	19	SW	Greene	44
J7P3265 J7P3272	20	SW	Webster	60
J7S3217 J7S3218 J7S3219	21	SW	Webster Douglas Greene	Z KK D
J8P0601B J8P0601C	22	SW	Greene	160

Project Number	Code	District	County	Route
J2P3175 SP095	23	NE	Shelby	36
J2P3175 SP048	24	NE	Shelby	36
J6P3185 J6P3186	25	SL	St. Charles	T

6.2 PROJECT ANALYSIS

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

6.2.1 Data Import and Legend Customization

The daily IC and PMTP data were imported to one project file using applicable coordinate systems. This was a new feature of Veta 6.0. The pass count legend was customized to reflect the optimum pass count established during the trial section.

6.2.2 Project Filters

The project filters were more complex than previous years due to the new feature of supporting multiple data types in one project. Table 10 summarizes the filters that were used to analyze the data.

Table 10. 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. Therefore, data may not fall within the boundary. Custom endpoints are used as the start and stop locations for sublots.
Operation Filter	Cold Edge and Ride Bracket	PMTP	Statistically removes cold edges of adjacent pavement or paver smoothing skis.

6.2.3 Spot Tests

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

6.2.4 Analysis

6.2.4.1 IC Setup

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

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

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

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

6.2.4.2 PMTP Setup

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

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

6.2.5 Reporting

PDF reports were generated for each system (IC and PMTP) and uploaded to SharePoint along with associated data (reference section 2.2.2.1 for more details). The following results were pulled from the reports and manually input to the supplemental excel summary sheet:

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

6.3 PROJECT RESULTS

This section includes a summary of project IC and PMTP results from the 2020 construction season and a summary of results from 2017 through 2020.

6.3.1 2020 Construction Season

The following sections include the results for the 2020 construction season. The data were assessed for meeting data management, IC, and PMTP protocols. All IC and PMTP results are based on the contractor submitted summary sheet. Some projects did not upload a summary sheet to the IC SharePoint site, as summarized in Table 11. Therefore, these project results are not included. Several contractors submitted the data to a different SharePoint site specific to their projects. *It should be emphasized in the 2021 training programs that the data needs to be uploaded to the IC SharePoint site.*

6.3.1.1 Data Management Results

The data management folder structure and the standard naming convention required per the protocols were previously summarized in Table 2 and Table 3, respectively. The data management protocols were revised for the 2020 season. Adjustment to the new protocols was anticipated. Some of the data files did not follow the naming convention or folder structure. While these management protocols may seem fastidious, they are essential for successful data management. Data organization will have a significant impact on the ability to find the files for analysis, QA checks, and future research or assessment. Failure to implement standard naming conventions and folder structures could lead to misplaced or lost data and cause a delay in analysis activities. *These practices should be emphasized in 2021 training programs.*

The data management protocols include contractor data submission and RE data submission. Table 11 and Table 12 summarize the data management assessment for contractors and REs, respectively. The results below assess whether the data was submitted to the IC SharePoint site. Due to the anticipated learning curve of new protocols, the assessment does not evaluate whether the data met the exact naming convention or folder structure. *However, it is recommended that these are evaluated in the 2021 construction season.*

The legend for the tables is described as follows:

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

Table 11. 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	12	N	Y	Y	N	N	Y	N	N
2	7	N	Y	Y	Y	Y	Y	Y	Y[a]
3	2	N	Y	Y	Y	Y	Y	N	N[b]
4	5	Y	Y	Y	Y	Y	Y	P	Y[a]
5	7	N	P	N	N	N	N	N	P[c]
6	7	N	P	N	N	N	N	N	P[c]
7	1	Y	Y	Y	Y	N	Y	Y	Y[a]
8	1	Y	Y	Y	Y	N	Y	Y	Y[a]
10	2	Y	Y	Y	Y	Y	Y	N	N[b]
11	4	Y	Y	Y	Y	P	Y	Y	Y
12	5	Y	N	Y	Y	Y	Y	P	Y[a]
13	11	N	Y	Y	P	N	Y	N	P[d]
14	5	Y	Y	Y	Y	Y	Y	P	Y
15	9	N	Y	Y	N	N	Y	N	N
16	9	N	Y	Y	Y	P	Y	Y	Y
18	6	Y	Y	Y	Y	P	Y	Y	Y
19	10	Y	Y	Y	Y	N	Y	Y	Y
20	4	Y	Y	Y	Y	N	Y	Y	Y
21	10	Y	Y	Y	Y	N	Y	Y	N
22	4	Y	Y	Y	Y	N	Y	Y	Y
23	12	Y	Y	Y	Y	N	P	Y	Y[a]
24	12	Y	Y	Y	Y	N	Y	Y	Y[a]
25	8	N	Y	Y	Y	N	Y	Y	Y

[a] Old version of summary sheet was used. This version of the summary does not consider the mean roller temperature at optimum pass (as previously described in section 2.2.3). Nevertheless, this project was included in the results summary.
[b] Contractor used their own summary sheet that does not comply to project specifications. Therefore, this project was not included in the final results.
[c] Summary sheet was not complete. Therefore, this project was not included in the final results.
[d] The IC results are incomplete, therefore only the PMTP results are included in the summary.

General observations from Table 11 include the following:

- Most contractors are submitting the required data to the IC SharePoint site. The most common missing data is the spot test data. Only a few contractors submit complete spot test data with coordinates and final density results. *This data is critical to performance correlation and will be emphasized in 2021 training programs.*
- Most contractors are submitting the raw IC and PMTP data. This may indicate that few contractors are taking advantage of direct download from the vendor cloud storage.

Table 12. RE data management results.

Project Code	Contractor Code	RE Checklist	RE QA[a]	RE Diary
1	12	N	N	N
2	7	N	P	N
3	2	N	P	N
4	5	N	N	N
5	7	N	N	N
6	7	N	N	N
7	1	N	P	N
8	1	N	N	N
10	2	N	N	N
11	4	N	P	N
12	5	N	Y	N
13	11	N	N	N
14	5	N	N	N
15	9	N	N	N
16	9	N	Y	N
18	6	Y	Y	Y
19	10	N	N	N
20	4	N	N	N
21	10	N	P	N
22	4	N	N	N
23	12	N	P	N
24	12	N	P	N
25	8	N	Y	N

General observations from Table 12 include the following:

- Only one project submitted complete RE data files.
- REs may be completing the checklist and diary but not uploading them to SharePoint. It is recommended that these files are uploaded to SharePoint to complete the database.

[a] The data QA procedures were only piloted in the 2020 construction season. Therefore, it was not expected to be completed for every project.

- REs were able to pilot the data QA protocols on several projects. More information on the data QA pilot projects is described in Chapter 3.

6.3.1.2 IC Results by Project

The IC data are evaluated according to 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. 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 classified as flagged. This does not affect price adjustments.
- 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 disincentive.

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

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

A summary of the 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.

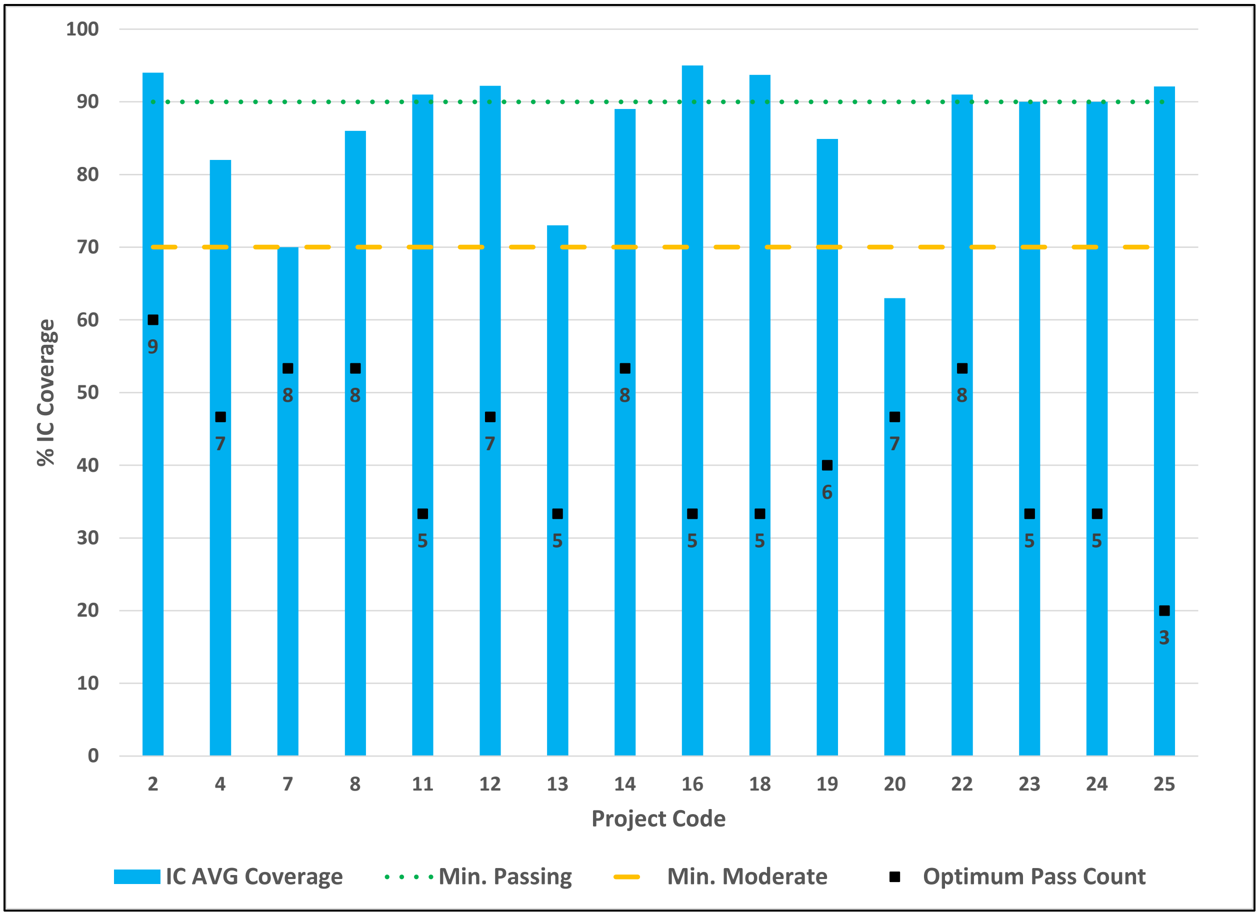

Figure 3. Chart. Average IC coverage per project and optimum pass counts.

General observations from Figure 3 include the following:

- Eight projects are above the 90 percent (passing) threshold, six projects between the 70 (moderate) and 90 percent thresholds, and two projects at or below the 70 percent threshold. The two projects below the moderate threshold are further investigated in the following section to determine why coverage was not met.
- Optimum pass counts range from three to nine. There is no clear trend between optimum pass count and IC coverage.

Low IC Coverage Investigation

Project codes 7 and 20 had average project IC coverage of less than 70 percent. According to the project specifications, IC coverage of less than 70 percent is considered deficient. Both of these projects experienced equipment malfunctions.

Based on the contractor summary sheet, project code 20 experienced ongoing issues on one of the rollers. Data was not collected for this roller. Based on the contractor's daily notes, the equipment was malfunctioning for over half of the project duration. *Good support from equipment vendors is critical for the success of IC implementation.*

Based on the contractor summary sheet, project code 7 experienced data loss or data incompatibility on three production days. These days were not reported and thus did not contribute to the overall average IC coverage. This is acceptable per the project specifications NJSP-18-08 section 9.5. Several production days, or segments, had roller coverage below 70 percent, with some segments as low as 20 percent. This is most likely due to equipment malfunction or data loss.

Further investigation into project code 7 resulted in missing data files in the Veta project. These files were present in the SharePoint Raw_IC_Data folder but not present in the Veta project. When these files were added to the Veta project, IC coverage went from 23 percent to 91 percent. This changes the segment classification from deficient to passing. The contractor was notified of the analysis issues. *QC and QA efforts of contractor data may reduce data analysis errors.*

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

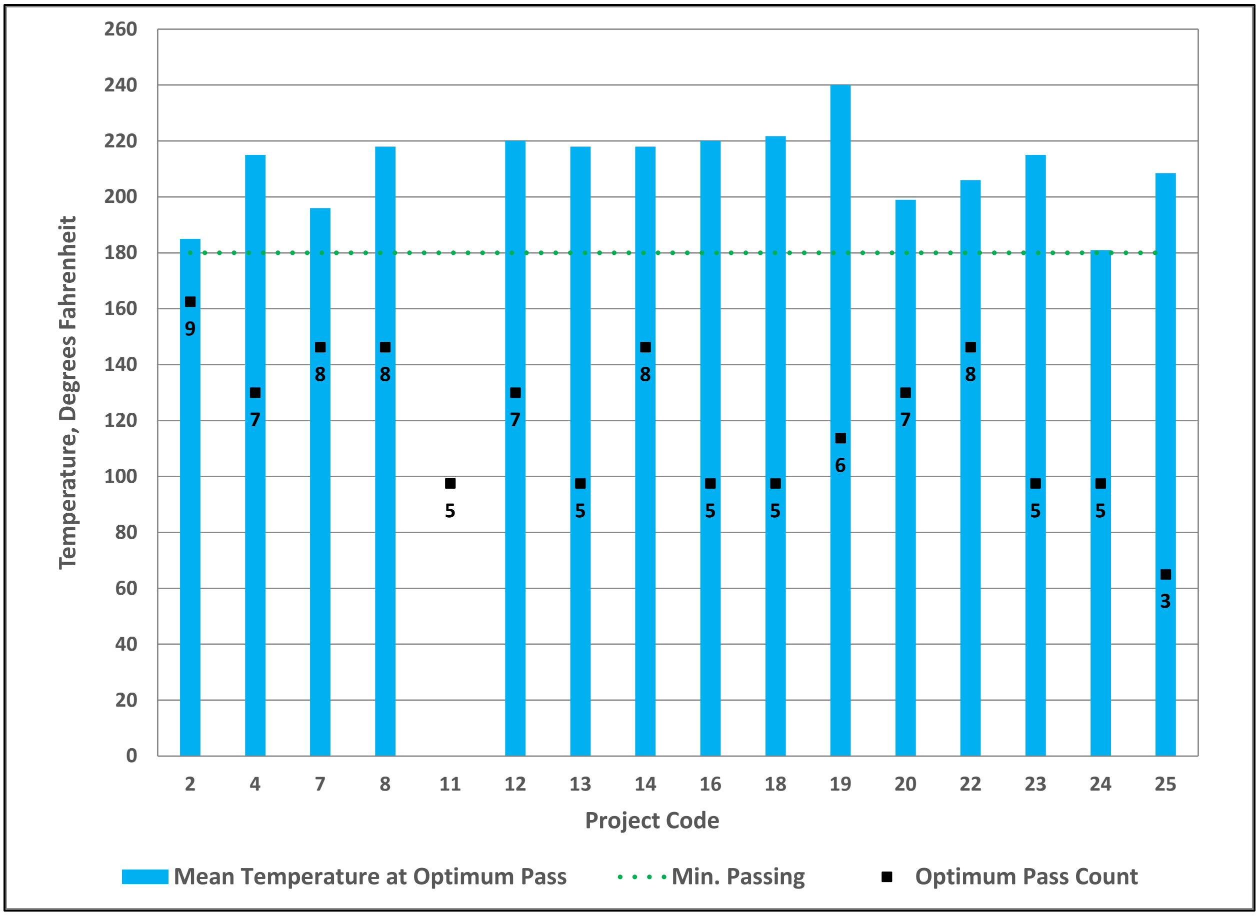

Figure 4. Chart. The average mean temperature at optimum pass count per project and optimum pass counts.

General observations from Figure 4 include the following:

- All projects have an overall average MTOP at or above 180˚F.
- One project (project code 11) did not report MTOP.
- There is no clear trend between optimum pass count and MTOP.

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.

Successful Case Study

Contractor code 12 analyzed their project as two separate sections (project code 23 and 24). These sections were on the same route, with a gap in production of only two days. No changes were made to the rolling pattern. The first section had an average MTOP of 181˚F, ranging from 158˚F to 214˚F. Almost half of the MTOPs were classified as deficient. The second section had an average MTOP of 214˚F, ranging from 198˚F to 238˚F. No segments were classified as deficient. *This is an example of successful practice and good use of IC data to improve the pavement quality by increasing compaction temperatures to meet the project specifications.*

6.3.1.3 IC Results by Contractor

A summary of the IC coverage (% of the optimum pass) is shown in Figure 5. The chart shows the average IC coverage for each contractor (average of results for all projects completed by the contractor).

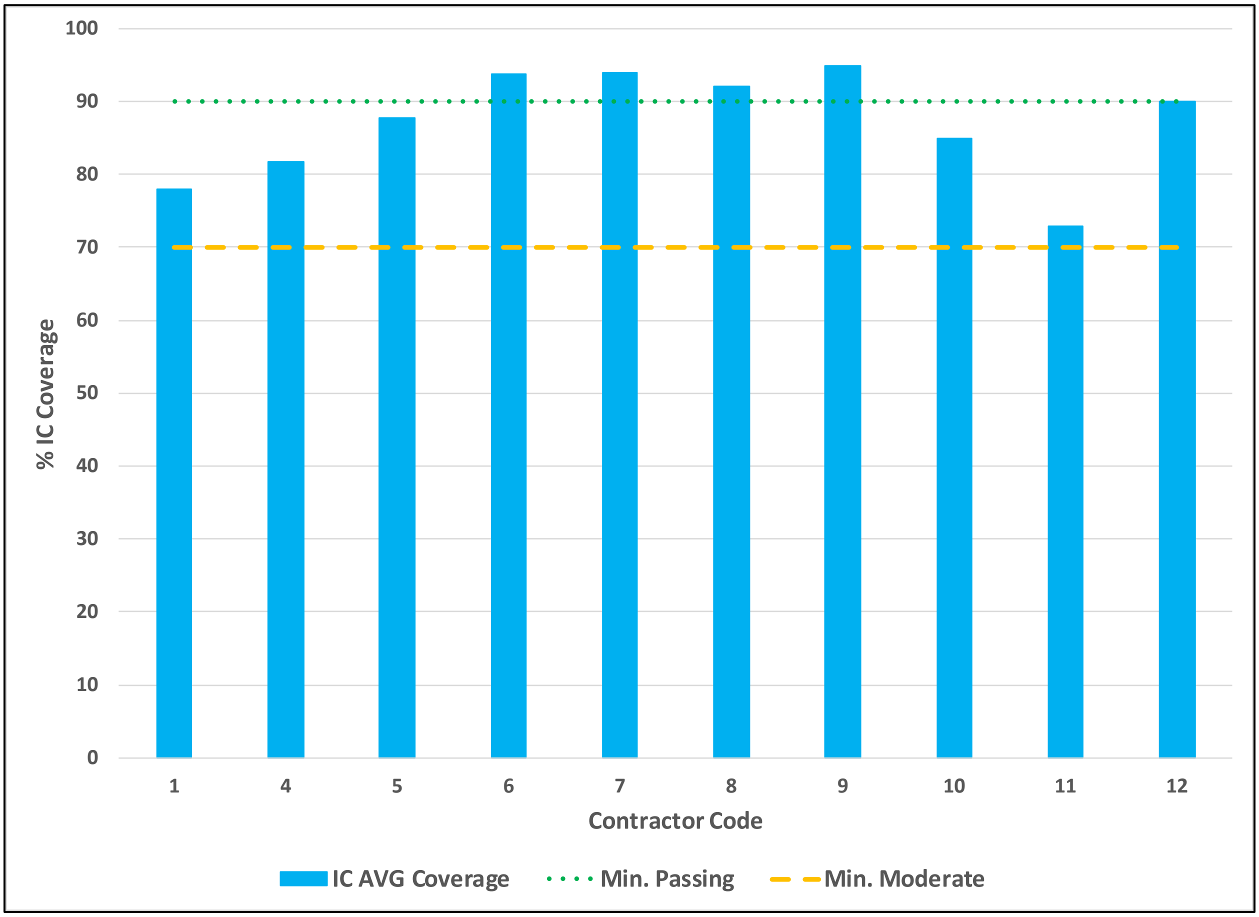

Figure 5. Chart. Average IC coverage per contractor.

General observations from Figure 5 include the following:

- All of the contractors had average IC coverage above the moderate threshold.
- Half of the contractors had average IC coverage results (average of all projects) at or above the passing threshold.

6.3.1.4 PMTP Results

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

- The work shall be completed per AASHTO PP80-17. A summary of the temperature differential (TD) specification is shown in Table 13.

- Low thermal segregation receives price incentives, moderate thermal segregation receives no price adjustment, and severe thermal segregation receives a price disincentive.

Table 13. AASHTO PP80-17 temperature differential specification and thermal segregation categories.

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

A summary of the PMTP results is shown in Figure 6. The chart shows the overall average thermal segregation category for each project.

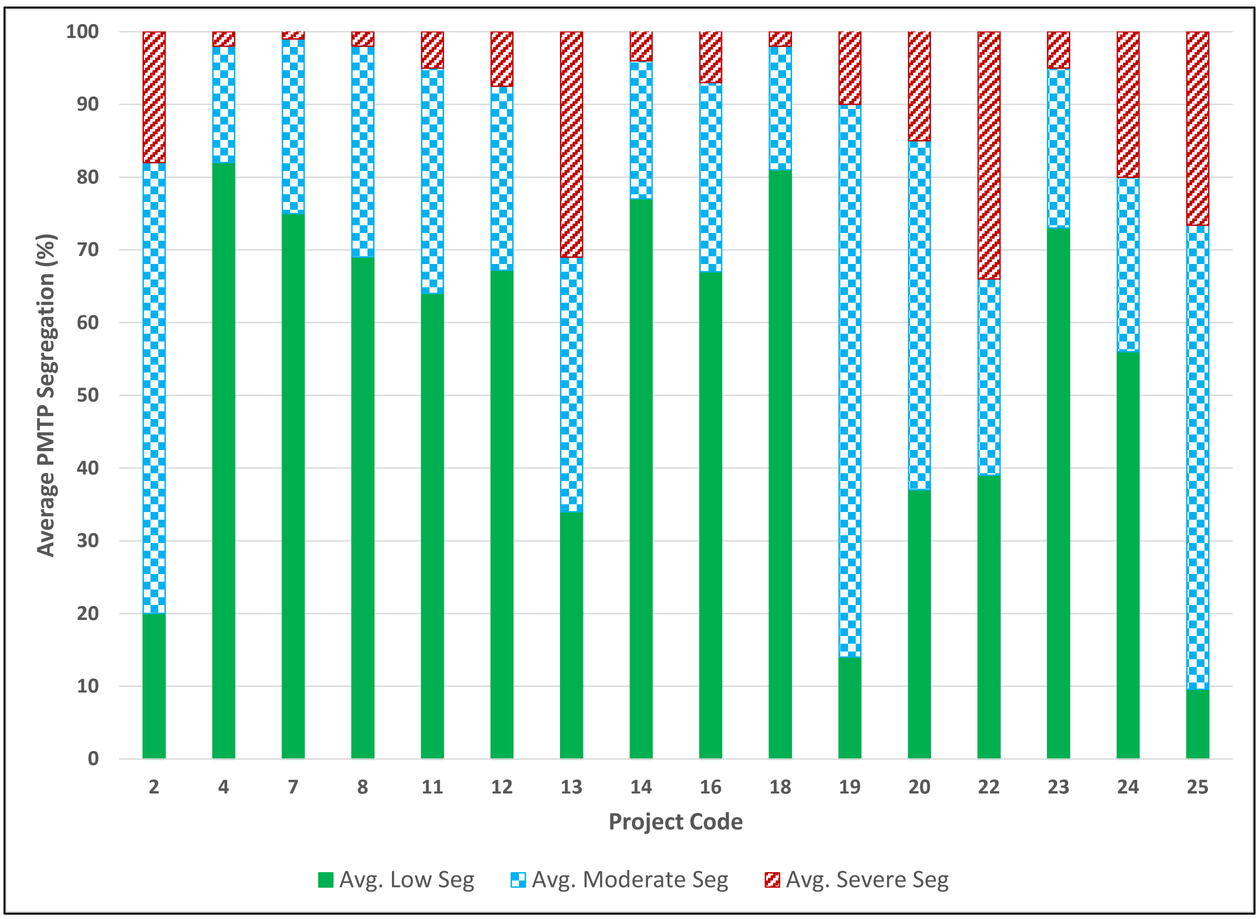

Figure 6. Chart. Average thermal segregation classification for each project.

General observations from Figure 6 include the following:

- Nine projects had less than 10 percent severe segregation.

- Four projects had between 10 and 20 percent segregation.
- Three projects had more than 20 percent severe segregation.
- Five jobs had over 70 percent low segregation.
- Three projects had less than 20 percent low segregation

A summary of each contractor's overall average thermal segregation category (average of results for all projects completed by the contractor) is shown in Figure 7.

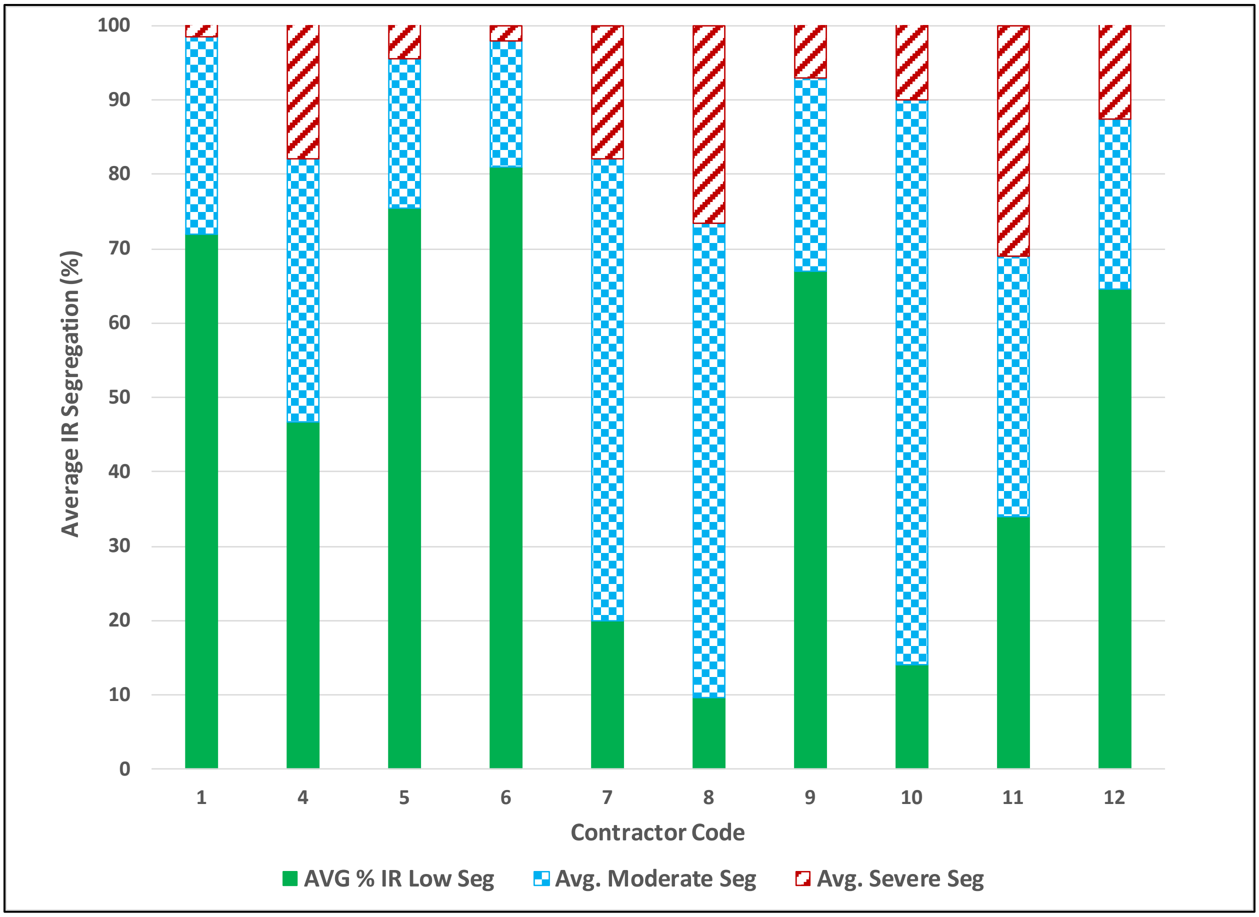

Figure 7. Chart. Average PMTP thermal segregation classification per contractor.

6.3.2 2017 Through 2020 Construction Seasons

Data from 2017 through 2020 were compiled so that general trends could be identified.

6.3.2.1 PMTP Data Trends

The average thermal segregation classifications were averaged across all projects during each construction season. The average PMTP segregation classifications are illustrated in Figure 8.

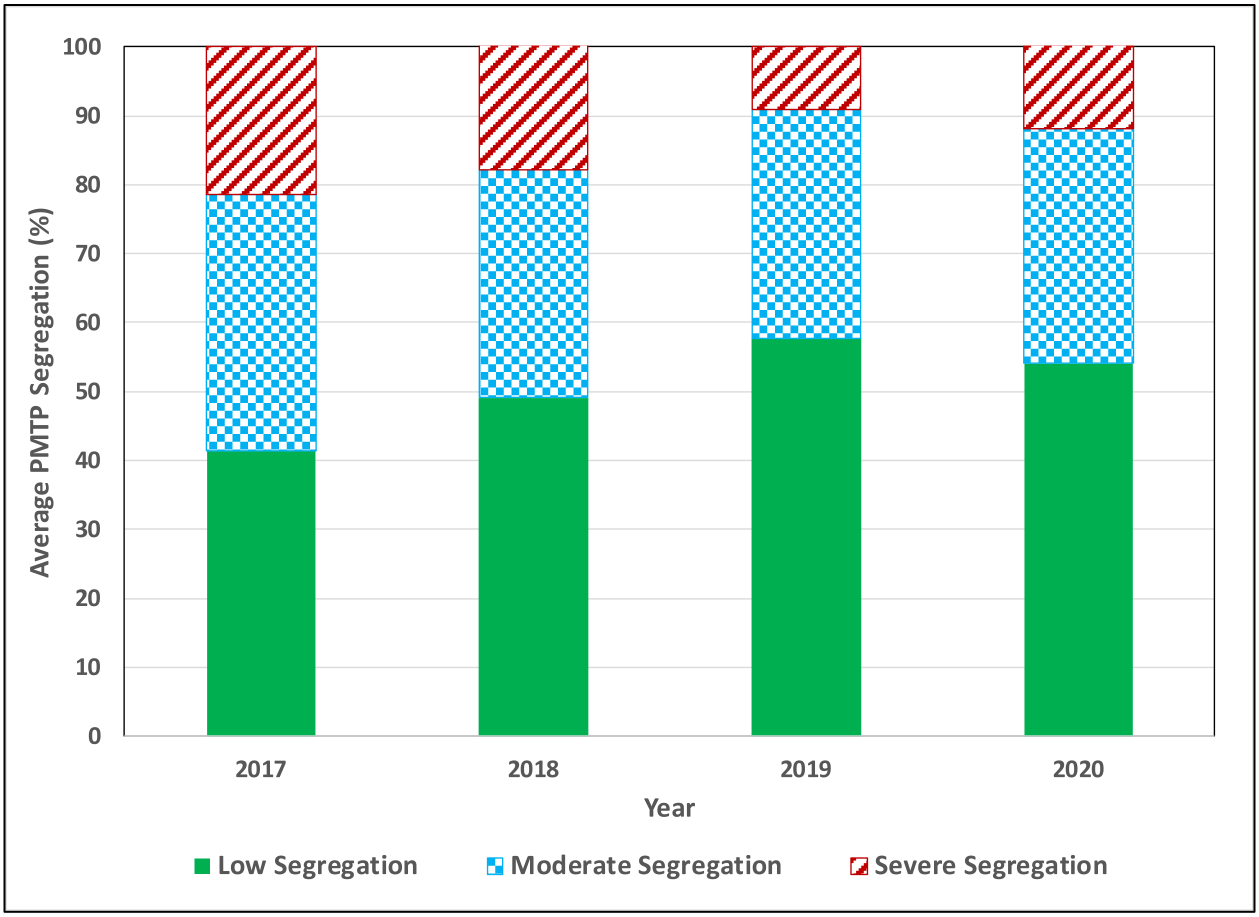

Figure 8. Chart. Average PMTP thermal segregation classification for all projects per construction season.

General observations from Figure 8 include the following:

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

6.3.2.2 IC Coverage Data Trends

The average IC percent coverage was averaged across all projects during each construction season. The average IC percent coverage trends are illustrated in Figure 9.

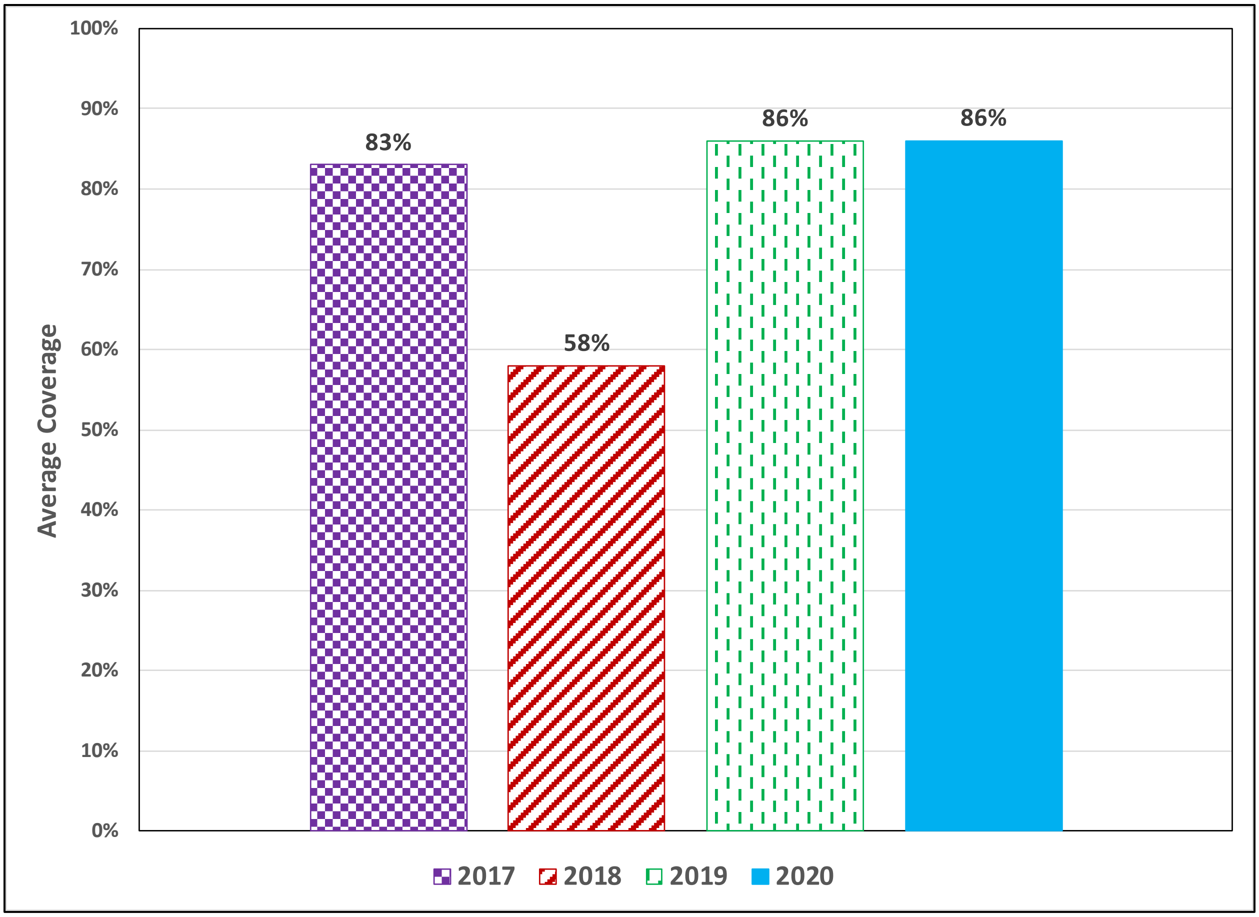

Figure 9. Chart. Average IC percent coverage for all projects per construction season.

General observations from Figure 9 include the following:

- The average IC percent coverage in 2017 was 83 percent. The average IC percent coverage in 2019 and 2020 was 86 percent. This shows a generally positive trend for IC percent coverage.
- The year 2018 shows an average percent coverage of 58%. This is attributed to the learning curve associated with the technology and specifications. Most projects had on-site support in 2017. The on-site support in 2018 was significantly less. Therefore, this was the first year that most contractors were using the technology without additional technical support. The consistently higher IC percent coverage in 2019 and 2020 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). This is illustrated in Figure 10.

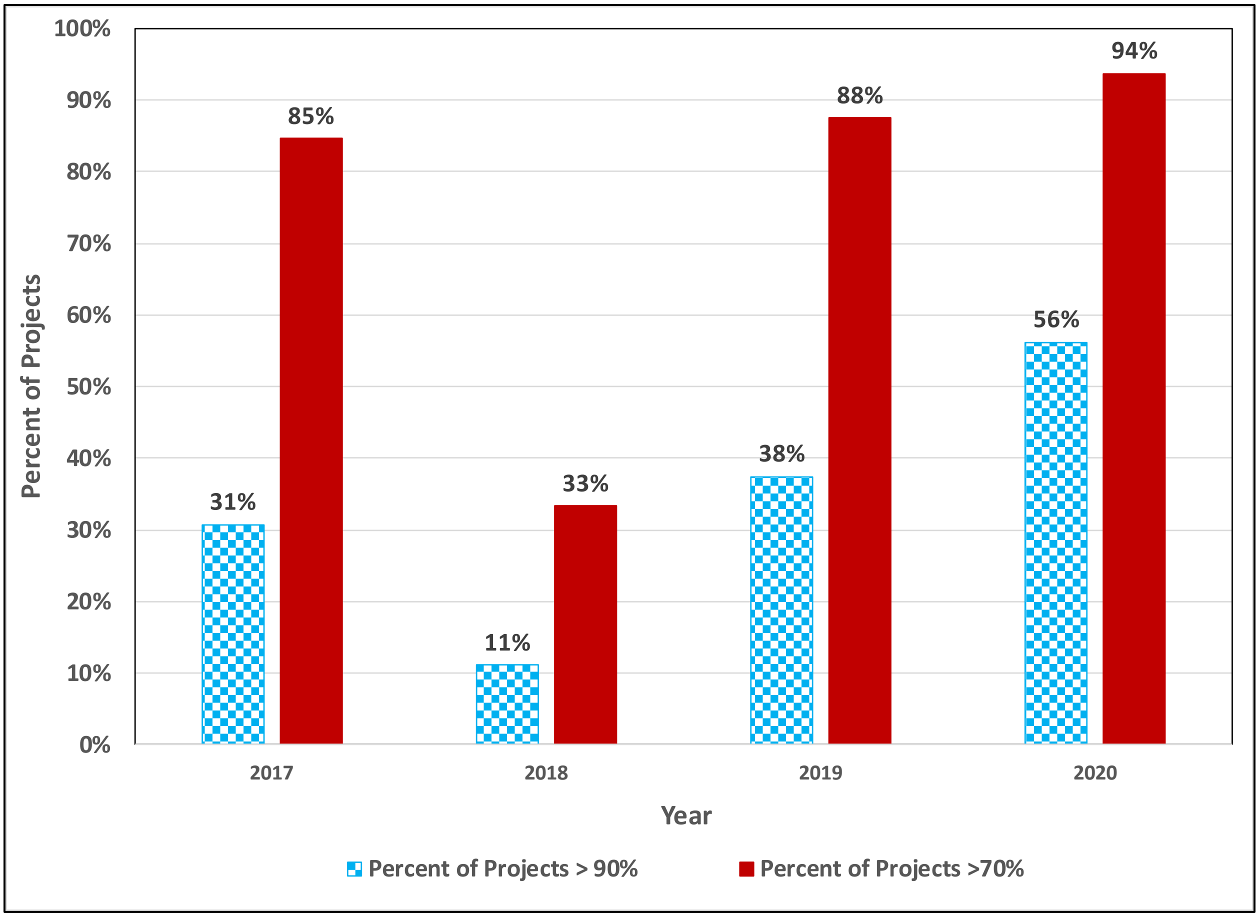

Figure 10. Chart. Percent of projects that meet the 70 percent and 90 percent thresholds per construction season.

General observations from Figure 10 include the following:

- The percent of projects that meet the 70 percent and 90 percent thresholds increase each year. The exception is 2018. This is attributed to the learning curve associated with the technology, as previously described in Figure 9.
- In 2020 over half of the projects met the 90 percent threshold and were eligible for price incentives based on IC coverage. Nearly all (94 percent) of projects met the 70 percent threshold.
- Consistent rolling patterns that meet the optimum pass specific to each project and mix is widely recognized as a critical quality control measure. These trends indicate an improvement of this metric by using IC.

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

6.4 SUMMARY

The strengths from the 2020 construction season are summarized as follows:

- There was a higher percentage of projects in 2020 that achieved the 70 percent and 90 percent IC coverage thresholds than any other year since implementation in 2017. This may indicate acceptance of technology by contractors, increased understanding, and successful implementation of IC.
- Thermal segregation classifications are similar to those of 2019. Since implementation in 2017, there are more low segregation classification and less severe segregation classifications. This may indicate acceptance of technology by contractors, increased understanding, and successful implementation of IC.
- In general, intelligent construction protocols are being followed by the contractors. Data management still shows some room for improvement but is improving year after year.

The lessons learned and areas for improvement based on the data analysis results of the 2020 construction season are summarized as follows:

- Many contractors are not including spot test data in Veta. As MoDOT continues to move towards fully implementing intelligent construction and reducing pavement coring, spot test data will become increasingly important. Emphasis on spot test data should be considered in future training sessions.
- Many contractors used an older version of the summary sheet. This may be because the latest version was released after the training session. This is understandable, and effort should be made to finalize all intelligent construction protocols and tools before training sessions are held.
- The contractors are struggling to report the correct percent of target ICMV. This is for informational purposes only and does not affect price adjustments. However, even the level I/II ICMV data can still be a valuable quality metric. Emphasis on ICMV data analysis and selection of a target value should be emphasized so that contractors can better understand and use ICMV data on their projects.
- Few REs submit their diaries and intelligent construction data checks to the intelligent construction SharePoint. This is not required per the specifications and does not indicate that the work is not being completed. However, failure to include it in the intelligent construction SharePoint makes the database incomplete. It is recommended that REs begin uploading their diaries and data checks to SharePoint for successful data management.

CHAPTER 7 TASK 5-PAVEMENT PERFORMANCE TRACKING

7.1 INTRODUCTION

This chapter includes the pavement performance tracking for selected field sites from the MoDOT IC-PMTP projects. The existing database and the additional field performance data collected during this project's timeline are used to study the relationship between the as-built IC-PMTP data and the actual pavement performance.

7.2 CORRELATING THE IC-PMTP BASED TEMPERATURE SEGREGATION DATA WITH LABORATORY PERFORMANCE TESTS

7.2.1 Case Study Description

An IC-PMTP project (job no. J1P3005) conducted by MoDOT in 2017 on US Route 24 in Chariton County, MO (Universal Transverse Mercator UTM zone 15N) was used as a case study. The project included the placement of a new 1.75-inch HMA surface, which overlaid the existing asphalt surface. The approximate length of the project was 13 miles.

The paving mixture was a MoDOT specified BP-1, a 0.5-inch nominal maximum aggregate size - 35 blow Marshall mix with PG 58-28 asphalt binder. The mix also consisted of 35 percent Recycled Asphalt Pavements (RAP) and 1 percent Recycled Asphalt Shingles (RAS), with a total effective binder replacement of 34 percent.

The paving operations for this project consisted of a total of 10 days. Days 1, 2, 4, and 5 were considered for this case study.

- Day 1 included a 1,500 feet trial section within the paving area. The paving equipment consisted of a Caterpillar AP1055F paver, a Caterpillar CB64 IC roller for breakdown compaction, and another Caterpillar double-drum roller for finish rolling operations.

- On day 2, a Roadtec SB-2500 Material Transfer Vehicle (MTV) was used to transfer material from the haul trucks to the paver. A MOBA Pave-IR PMTP was mounted on the paver. A Trimble GPS receiver was used for the IC roller, and a Trimble hand-held rover was used to verify the accuracy of GPS receivers, to measure the daily boundary points, and spot test locations.

7.2.2 IC-PMTP Data Analysis

The MOBA PAVE-IR raw data were downloaded and analyzed using Veta software.

Veta uses the AASHTO PP80-17 method to compute range values by taking the differences between the 98-percentile value and 1-percentile value of thermal profile data with a given 150 feet sublot. The data from 2 feet before and 8 feet after any paver stop are excluded from temperature differential computation as per AASHTO PP80-17 specification.

The classification of temperature differential is based on the range value: Low for temperature difference ≤ 25.0 ˚F; Moderate for 25.0 ˚F < temperature difference ≤ 50.0 ˚F; and Severe for temperature difference > 50.0 ˚F. The temperature differential results are summarized in Table 14.

Significant temperature segregation changes between day 1 and day 2 since an MTV was used on day 2. The minor differences between the MOBA PPM and Veta results were due to slight differences in computation methods. Days 1, 2, 4, and 5 were considered for this case study.

Table 14. Summary of thermal segregation analysis results using Veta.

Day	Date	Veta Low (Count)	Veta Low (%)	Veta Moderate (Count)	Veta Moderate (%)	Veta Severe (Count)	Veta Severe (%)
1	04/24/2017	0	0	1	1	77	99
2	04/25/2017	16	20	61	76	3	4
3	05/02/2017	0	0	18	18	82	82
4	05/05/2017	0	0	19	20	78	80
5	05/06/2017	0	0	25	24	78	76
6	05/08/2017	0	0	25	25	74	75
7	05/09/2017	0	0	70	60	47	40
8	05/15/2017	0	0	56	55	45	45
9	05/16/2017	0	0	39	47	44	53

One sublot was selected from each of the four paving days. In total, three sublots with severe temperature segregation (S1, S3, S4) and one sublot with moderate segregation (S2) were identified. Within each sublot, test sections were established according to the following criteria:

- Uniform (U): 20-30 feet in length with relatively high temperatures (in comparison to the rest of the sublot) and relatively low thermal segregation. These were labeled as S1-1, S2-1, S3-1, and S4-1.
- Nonuniform (NU): 20-30 feet in length with relatively low temperatures (in comparison to the rest of the sublot) and relatively high thermal segregation. These were labeled as S1-2, S2-2, S3-2, and S4-2.

The temperature differential (as previously described) and thermal segregation index (TSI) were then determined for each test section using Veta software. The TSI is a composite index that considers conventional standard deviation and transverse semi-variogram. This method considers the distance with respect to temperature variance, meaning lateral uniformity (streaking) can be identified. The classification of TSI classification is as follows: Low for temperature difference ≤ 30.0 ˚F; Moderate for 30.0 ˚F < temperature difference ≤ 70.0 ˚F; and Severe for temperature difference > 70.0 ˚F.

Within each test section, a total of eight cores (four cores for cyclic fatigue test and four cores for dynamic modulus test) were collected and tested in the laboratory. The outcomes of these laboratory tests were used to analyze HMA performance according to AASHTO TP-132-19 (AASHTO, 2019B) and TP-133-19 (AASHTO, 2019C). The data exported from the lab tests were entered into FlexMAT^{TM} (FHWA, 2020C) software to determine the dynamic modulus and damage characteristic curve coefficients and then into FlexPAVE™ to calculate the cyclic fatigue index parameter S_{app}. S_{app} accounts for the effects of a material's modulus and toughness on its fatigue resistance and is a measure of the amount of fatigue damage the material can tolerate under loading. Higher Sapp values indicate better fatigue resistance of the mixture. (FHWA 2019)

The segregation indices (temperature differential and TSI) calculated from PMTP measurements within each test section and the corresponding S_{app} results are shown in Table 15.

Table 15. The S_{app} and corresponding temperature differential and TSI for each test section.

Test Section	S_{app}	Temperature Differential (˚F)	TSI
S1-1 (U)	Not reported	20.9	33.5
S1-2 (NU)	13.14	70	100
S2-1 (U)	5.77	33.7	81.1
S2-2 (NU)	13.15	38.6	78.7
S3-1 (U)	6.02	29.4	100
S3-2 (NU)	7.26	78.3	100
S4-1 (U)	5.47	34.4	100
S4-2 (NU)	3.72	52.7	100

The U and NU S_{app} were averaged to provide an overall S_{app} for each sublot. The average S_{app} for each sublot and the corresponding overall temperature differential and TSI are summarized in Table 16.

Table 16. The average S_{app} and overall temperature differential and TSI for each sublot.

Sublot	Average S_{app}	Overall Temperature Differential (˚F)	Overall TSI
Sublot 1	13.14	69.3	66.2
Sublot 2	9.46	49.8	50.9
Sublot 3	6.64	70.5	100
Sublot 4	4.59	94.8	100

7.2.3 Temperature Segregation and Damage Capacity Correlation

Several different correlation scenarios were considered to see if there were any general trends between Sapp and the segregation indices. The scenarios that were considered are as follows:

- S_{app} for U test sections plotted against corresponding temperature differential and TSI.
- S_{app} for NU test sections plotted against corresponding temperature differential and TSI.
- S_{app} for all (U and NU) test sections plotted against corresponding temperature differential and TSI.
- Average S_{app} for each sublot plotted against the overall temperature differential and TSI.

The results for each correlation scenario are shown in Table 17.

Table 17. Correlation between S_{app} and temperature differential, and S_{app} and TSI.

Pavement Damage Parameter	Temperature Differential	TSI
S_{app} U	*y=-8.87x+83.53* (R^2=0.81)	*y=-2.40x+107.51* (R^2=0.00)
S_{app} NU	*y=-0.63x+65.72* (R^2=0.03)	*y=-1.26x+106.39* (R^2=0.30)
S_{app} All (U+NU)	*y=1.44x+36.91* (R^2=0.08)	*y=-0.88x+101.08* (R^2=0.11)
Average S_{app}	*y=-2.92x+95.80* (R^2=0.34)	*y=-5.04x+121.90* (R^2=0.57)

As seen in Table 17, in almost all cases (except between S_{app} all and temperature differential), the slope of the correlation line is negative. Therefore, S_{app} generally decreases with increasing TSI and temperature differential. This may indicate less fatigue resistance of the asphalt with increasing temperature segregation.

The data shows a high correlation between S_{app} U and temperature differential and a low correlation between S_{app} NU and temperature differential. This trend is the opposite when considering S_{app} and TSI, although the correlation is generally low. There is not enough data or high correlation in any scenario to further describe or justify any trends. It is important to note that other critical variables, including compaction efforts, have not been considered in this correlation study.

7.3 IC-BASED DENSITY MODEL

7.3.1 Density Model Description

Chang et al. (2014) developed a model to estimate the HMA density at different times and locations based on IC measurement values. Extensive field measurement (in-place density) and laboratory data collection, data analysis, and IC measurements are required to use this model. This model was developed using field data from across the country. The multivariate nonlinear model is described in Figure 11:

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

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 11. Equation. The multivariate nonlinear model used to estimate density using IC data.

7.3.2 Data Collection and Analysis

The data has not been provided at this time. The analysis will be performed after the complete data set is provided by MoDOT

7.3.3 Results of IC-Based Density Prediction

The results will be included in the 2021 project report (pending the receipt of data).

7.4 SUMMARY

The PMTP temperature segregation index (TSI) and the cyclic fatigue index parameter S_{app} were calculated for different sublots. A comparison between laboratory test results and in-situ parameters was conducted. There is not enough data to identify the correlation between the data with the limited data available.

Once a sufficient amount of data is provided by MoDOT, a nonlinear model will be used to estimate the HMA density at different times and locations based on IC measurement values. The 2021 report will include the findings of this study.

CHAPTER 8 TASK 6 FEEDBACK MEETING AND EXECUTIVE BRIEFING

8.1 SUMMARY

As directed by MoDOT, the 2020 annual feedback meeting and Executive briefing were canceled due to concerns of COVID-19 and reduced work hours of MoDOT staff. The contents of this report will serve as the feedback for the 2020 construction season.

CHAPTER 9 CONCLUSIONS AND RECOMMENDATIONS

9.1 LESSONS LEARNED AND RECOMMENDATIONS

The lessons learned during each of the described tasks are summarized below. More details regarding the lessons learned can be found in the relevant chapters.

9.1.1 Task 1 - Training Program

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

The data QA procedures are complex and require engineering judgment and a basic understanding of Veta and IC-PMTP project analysis. Most REs have not had to perform any analysis in Veta before the data QA procedures, and there was a learning curve. Therefore it is recommended that more training workshops for data QA are held before the 2021 construction season.

9.1.2 Task 2 - IC PMTP Data QA

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

Based on the evaluation of two different FLIR thermal camera models, the E5 is recommended for the 2021 construction season.

The pilot studies for data QA were useful in identifying common issues. The most common issues related to data QA and a plan for minimizing these issues are summarized in section 3.3.

Table 18. Summary of common issues related to data QA procedures.

Common Issues	Recommended Resolution
IC Pass count – Contractor not setting up IC equipment correctly using unique machine IDs. Therefore, the machine that has the DirtMate cannot be isolated from the other rollers for comparison.	Highlight this issue during training workshops and check-in at the initial project start-up that the data can be filtered by Machine ID.
IC Pass count – DirtMate data "halos" have a false pass count that is significantly higher than the IC data pass count.	Highlight this issue during training workshops and include it in the data QA procedures. Until the DirtMate manufacturer (Propeller) can resolve the problem, REs should avoid the data "halos" during analysis.
IC Pass count – There were missing or invalid data. There were many issues with the hotspot's successful setup, and many projects had missing DirtMate data. Many projects did not include the measurements regarding DirtMate setup on the roller. Therefore, proper setup could not be verified.	Highlight this issue during training workshops. Have Propellor troubleshoot any issues with the hotspot to make sure the issue is not equipment related. Request that REs upload the DirtMate setup measurements to the IC SharePoint to verify the proper setup.
PMTP Temperature – Wrong time on the FLIR camera, or different times between FLIR camera or PMTP equipment.	Highlight this issue during training workshops. The timestamps must match to implement the data QA procedures.
PMTP Temperature – Invalid images. The images must be taken exactly according to the directions for the data QA to be valid.	Highlight this issue during training workshops. The procedures may seem tedious, but they are necessary.
Complex analysis procedures.	Continue training REs and project engineers on the procedures and provide technical support for data QA implementation.

9.1.3 Task 3 – Pilot Innovation Technologies

No pilot innovation technologies took place in 2020. MoDOT plans to mount a loaned RDM 2.0 unit on a pickup truck's bumper (Chevrolet 1500). Lessons learned will be included in the 2021 report.

9.1.4 Task 4 – IC-PMTP Project Supports

Due to the impact of COVID-19, all IC-PMTP project support was conducted remotely in 2020. Remote support included assistance to REs and/or contractors during data analysis. Data quality checks were randomly performed on the data uploaded to the intelligent construction SharePoint.

All but one of the contractors sought technical support during project analysis. Increased need for technical support was anticipated due to the new features of Veta 6.0 and new intelligent construction protocols. The remote technical support was generally successful, and contractors were able to resolve and correct most issues related to data collection and analysis.

The main issues for each project were summarized in Table 6. The most common issues that should be highlighted in future training workshops are summarized as follows:

- Ensure contractors use the most recent summary sheet and follow the most recent protocols. Some contractors continue to use old procedures and protocols from past seasons.
- Ensure contractors are using the IC SharePoint site and not the other general project SharePoint site.
- If there are equipment issues, ensure that the data loss procedures are followed as described in section 2.2.2.4. Ensure that erratic or invalid data does not get analyzed. This may result in invalid results that falsely affect price adjustments.
- Ensure the correct filters are being applied to the data during Veta analysis. Make sure that the data is transferred correctly to the summary sheet.
- Ensure that the data management and file naming convention are followed. This may seem tedious and unnecessary. However, the proper naming convention is critical for the successful implementation of the excel macro tools developed for data QA. The proper naming convention is a data quality successful practice that ensures the intelligent construction database is organized and useful. If the standard naming convention is not followed, data loss and/or unusable data become more common.

9.1.5 Project Analysis and Results

The strengths from the 2020 construction season are summarized as follows:

- There was a higher percentage of projects in 2020 that achieved the 70 percent and 90 percent IC coverage thresholds than any other year since implementation in 2017. This may indicate acceptance of technology by contractors, increased understanding, and successful implementation of IC.
- Thermal segregation classifications are similar to those of 2019. Since implementation in 2017, there are more low segregation classification and less severe segregation classifications. This may indicate acceptance of technology by contractors, increased understanding, and successful implementation of IC.
- In general, intelligent construction protocols are being followed by the contractors. Data management still shows some room for improvement but is improving year after year.

The lessons learned and areas for improvement based on the data analysis results of the 2020 construction season are summarized as follows:

- Many contractors are not including spot test data in Veta. As MoDOT continues to move towards fully implementing intelligent construction and reducing pavement coring, spot test data (nuclear density results) may become increasingly important. Spot test data is also necessary to further the pavement performance study described in Chapter 7. Emphasis on spot test data should be considered in future training sessions.
- The contractors are struggling to report the correct percent of target ICMV. This is for informational purposes only and does not affect price adjustments. However, even the level I/II ICMV data can still be a valuable quality metric. Emphasis on ICMV data

analysis and selection of a target value should be emphasized so that contractors can better understand and use ICMV data on their projects.

- Few REs submit their diaries and intelligent construction data checks to the intelligent construction SharePoint. This is not required per the specifications and does not indicate that the work is not being completed. However, failure to include it in the intelligent construction SharePoint makes the database incomplete. It is recommended that REs begin uploading their diaries and data checks to SharePoint for successful data management.

9.1.6 Task 5 – Pavement Performance Tracking

The temperature segregation index (TSI) and the cyclic fatigue index parameter Sapp were calculated for different sublots, and a comparison between laboratory test results and in-situ parameters was conducted. The established correlation needs improvement after collecting additional data. Once a sufficient amount of data is available, a nonlinear model will be used to estimate the HMA density at different times and locations based on IC measurement values.

9.2 SUMMARY

There were many new procedures implemented in 2020. Significant changes include a new version and changes to analysis software and new data QA procedures. Learning curves were expected with these changes. The learning curve was steepened with the effects of COVID-19 and the lack of onsite support. Despite these challenges, the overall outcome of 2020 was successful. There were many valuable lessons learned associated with new and complex data QA procedures. The Consultant and MoDOT leadership will focus on the common issues encountered in 2020 during the 2021 season.

The implementation of data QA is critical to the success of MoDOT's goal of full IC-PMTP implementation. This will continue to be a key focus in 2021. Training and technical support will be critical for successful implementation.

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

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