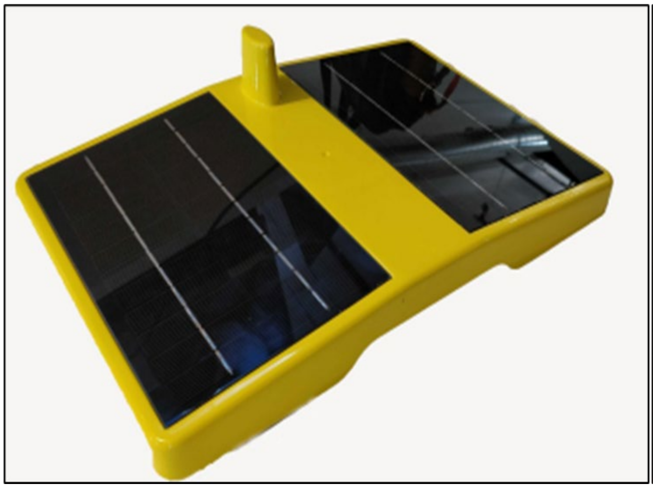
Implementation of Data Quality Assurance (QA) for Innovative Technologies at MoDOT



November 2022
Final Report

Project number TR202124
MoDOT Research Report number cmr 22-012

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. cmr 22-012	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Implementation of Data Quality Assurance (QA) for Innovative Technologies at MoDOT		**5. Report Date** September 2022 Published: November 2022 **6. Performing Organization Code**
7. Author(s) Dr. George Chang, P.E. (https://orcid.org/0000-0002-4945-8827), Amanda Gilliland, P.E., and Dr. Abbas TaghaviGhalesari, P.E. (https://orcid.org/0000-0001-9872-3706)		**8. Performing Organization Report No.**
9. Performing Organization Name and Address The Transtec Group, Inc. 6111 Balcones Drive Austin, TX 78731		**10. Work Unit No.** **11. Contract or Grant No.** MoDOT project # TR202124
12. Sponsoring Agency Name and Address Missouri Department of Transportation (SPR-B) Construction and Materials Division PO Box 270 Jefferson City, MO 65102		**13. Type of Report and Period Covered** Final Report (April 2021-November 2022) **14. Sponsoring Agency Code**

15. Supplementary Notes

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

16. Abstract

Intelligent construction technologies (ICTs) combine modern science and innovative construction technologies. The goal of ICT is to improve the quality of construction, save costs, and improve safety. The ICTs described in this report include intelligent compaction (IC), paver-mounted thermal profiler (PMTP) equipment, and dielectric profiling systems (DPS). IC and PMTP systems are mounted on contractor paving equipment. Therefore, the data generated by these systems is collected by the contractor. DPS systems can be owned and operated by the agency or contractor.

Meeting the Code of Federal Regulations (CFRs) for construction acceptance using ICT is a national issue but a worthwhile endeavor to ensure the ICT produces quality data for construction acceptance decisions. MoDOT is among the leading DOTs working towards satisfying the requirements to implement ICT. This project's main objective is to advance MoDOT's efforts to obtain data QA solutions for ICT.

17. Key Words Intelligent construction technologies; Intelligent compaction; Paver-mounted profiles; Dielectric profile systems; Data quality assurance	**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified.	**20. Security Classif. (of this page)** Unclassified.	**21. No. of Pages** 66	**22. Price** NA

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

MoDOT Project No. TR202124

IMPLEMENTATION OF DATA QUALITY ASSURANCE (QA) FOR INNOVATIVE TECHNOLOGIES AT MODOT

FINAL REPORT

Submitted to:

Missouri Department of Transportation

1617 Missouri Blvd.

Jefferson City, MO 65102

September 2022

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ACKNOWLEDGEMENTS

The authors graciously thank MoDOT for funding intelligent construction technology (ICT) projects since 2017 and as a national leader for ICT's data quality assurance (QA). The authors would also express gratitude towards the National Road Research Alliance (NRRA) and the International Society for Intelligent Construction - North American (ISIC-NA) Chapter for advancing ICT technologies to meet federal regulations.

EXECUTIVE SUMMARY

Intelligent construction technologies (ICTs) combine modern science and innovative construction technologies. The goal of ICT is to improve the quality of construction, save costs, and improve safety. The ICTs described in this report include intelligent compaction (IC), paver-mounted thermal profiler (PMTP) equipment, and dielectric profiling systems (DPS). IC and PMTP systems are mounted on contractor paving equipment. Therefore, the data generated by these systems is collected by the contractor.

The Title 23 US Code of Federal Regulations Section 637 Subpart B (CFR) includes construction quality assurance (QA) program requirements. 23 CFR 637.207 allows the use of contractor data as an acceptance tool, provided the DOT has verified the data. The CFR requirements were written for conventional spot testing. Conventional spot tests involve onsite sampling and laboratory testing of sampled materials. The conventional sampling of material (e.g., coring) differs from the data collection and analysis methods used in ICT (e.g., using non-contact sensors). ICT data is often collected for the entire project area rather than limited spot sampling. Therefore, the conventional validation and verification methods of sampling and testing do not apply to ICT data. Therefore, new QA procedures need to be developed to meet the CFR requirements for ICT data.

This report describes ICT data QA procedures piloted at MoDOT. The report includes the procedures, training materials, training programs, field support, and partial results of the QA program. The final results of the ICT data QA program will be included in the IC-PMTP field support final report.

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LIST OF ABBREVIATIONS

CCV:	Compaction Control Value (Sakai, TOPCON)
CFR:	Code of Federal Regulation
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:	Mobile Asphalt Technology Center
MTOP:	Mean Temperature at Optimum Pass
MTV:	Material Transfer Vehicle
NDG:	Nuclear Density Gauge
NRRA:	National Road Research Alliance
OEM:	Original Engineering/Equipment Manufacturer

PDH: Professional Development Hour

PMTPS: Paver-Mounted Thermal Profile Systems

PPK: Post-Processed Kinematic

PPM: PaveProj Program (MOBA)

QA: Quality Assurance

QC: Quality Control

RAP: Recycled Asphalt Pavements

RAS: Recycled Asphalt Shingles

RDM: Rolling Density Meter

RE: Resident Engineer

RTK: Real-time Kinematic Positioning System

SOW: Scope of Work

TPF: Transportation Pooled Fund

TSI: Thermal Segregation Index

UTM: Universal Transverse Mercator

LIST OF CFR TERMS

Acceptance program: All factors that comprise the State transportation department's (STD) determination of the quality of the product as specified in the contract requirements. These factors include verification sampling, testing, and inspection, including quality control sampling and testing results.

Independent assurance program: Activities that are an unbiased and independent evaluation of all the sampling and testing procedures used in the acceptance program. Test procedures used in the acceptance program which are performed in the STD's central laboratory, would not be covered by an independent assurance program.

Proficiency samples: Homogeneous samples that are distributed and tested by two or more laboratories. The test results are compared to ensure that the laboratories obtain the same results.

Qualified laboratories: Laboratories that are defined by appropriate programs established by each STD. As a minimum, the qualification program shall include provisions for checking test equipment, and the laboratory shall keep records of calibration checks.

Qualified sampling and testing personnel: Personnel capable as defined by appropriate programs established by each STD.

Quality assurance: All those planned and systematic actions necessary to provide confidence that a product or service will satisfy given requirements for quality.

Quality control: All contractor/vendor operational techniques and activities that are performed or conducted to fulfill the contract requirements.

Random sample: A sample drawn from a lot in which each increment in the lot has an equal probability of being chosen.

Vendor: A supplier of project-produced material that is not the contractor.

Verification sampling and testing: Sampling and testing were performed to validate the quality of the product.

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Intelligent construction technologies (ICTs) combine modern science and innovative construction technologies. The goal of ICT is to improve the quality of construction, save costs, and improve safety. The ICTs described in this report include intelligent compaction (IC), paver-mounted thermal profiler (PMTP) equipment, and dielectric profiling systems (DPS). IC and PMTP systems are mounted on contractor paving equipment. Therefore, the data generated by these systems is collected by the contractor. DPS systems can be owned and operated by the agency or contractor.

ICT can be used to improve construction quality. ICT has generally been developed and considered a quality control (QC) tool in the past. However, several barriers may deter some contractors from implementing ICT. These barriers include initial costs, lack of training and knowledge, and unique labor needs. Some state departments of transportation (DOTs) have tried to accelerate full implementation by requiring ICT in construction specifications. Some DOTs have incentivized ICT requirements by using ICT as acceptance tools with price adjustments. Therefore, the contractor data is used as part of the acceptance decision. The Title 23 US Code of Federal Regulations Section 637 Subpart B (CFR) includes construction quality assurance (QA) program requirements. 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.
>
> If the quality control sampling and testing results are used in the acceptance program, the state department of transportation (DOT) shall establish a dispute resolution system. The dispute resolution system shall address discrepancies between verification sampling and testing and quality control sampling and testing.

In summary, the CFR allows contractor data as an acceptance tool, provided the DOT has verified the data. Supplementary requirements found in 23 CFR 637.205 are as follows:

> 23 CFR 637.205(d): Verification sampling and testing. The verification sampling and testing are to be performed by qualified testing personnel employed by the State Transportation Department (STD) or its designated agent, excluding the contractor and vendor.

In summary, the verification samples must be separate from the QC samples. The sampling and testing must be performed by testing personnel employed by the DOT, not the contractor. Furthermore, according to the CFR 637.205(e):

> 23 CFR 637.205(e): Random samples. All samples used for quality control and verification sampling, and testing shall be random samples.

Random sampling is a sample drawn from a lot in which each increment in the lot has an equal probability of being chosen. The statistical aspect of random samplings, such as sample sizes, lot/population, statistical inference, normal distribution, risk types, buyer/seller and contractor/agency risk, Operation Characteristic (OC), Expected Payment (EP) curves, etc., are well-documented (FHWA 2003).

Also, the related CFR terms and definitions are under the List of CFR Terms before Chapter 1, including Acceptance Program, Independent Assurance Program, Proficiency Samples, Qualified Laboratories, Qualified Sampling, and Testing Personnel, Quality Assurance, Quality Control, Random Sample, Vendor, and Verification Sampling and Testing.

The above CFR requirements were written in 1994 for conventional spot testing, typical for acceptance testing. Conventional spot tests involve onsite sampling and laboratory testing of sampled materials. The conventional sampling of material (e.g., destructive coring) differs from the data collection and analysis methods used in ICT (e.g., non-destructive testing or non-contact sensors). ICT data is often collected for the entire project area rather than limited spot sampling. Therefore, the conventional validation and verification methods of sampling and testing do not apply to ICT data. Therefore, new QA procedures need to be developed to meet the CFR requirements for ICT data.

1.2 PROJECT TASKS AND OBJECTIVES

Meeting the CFR for construction acceptance using ICT is a national issue but a worthwhile endeavor to ensure the ICT produces quality data for construction acceptance decisions. MoDOT is among the leading DOTs working towards satisfying the QA requirements to implement ICT. This project's main objective is to advance MoDOT's efforts to find data QA solutions for ICT. This project includes the following seven tasks:

- Task 1 – Kick-Off Meeting.
- Task 2 – Review QA Programs.
- Task 3 – Develop New and Improve QA Program Materials.
- Task 4 – Develop QA Training Resources.
- Task 5 – Conduct QA Training.
- Task 6 – Conduct Field Trials of the New and Improved QA Programs.
- Task 7 – Final Report.

1.3 REPORT OBJECTIVES AND ORGANIZATION

This document is the deliverable of Task 7 of this project – Final Report. Each of the subsequent chapters corresponds to one of the project tasks. This report aims to summarize the improved data QA program, the field trials' results, and recommendations for implementing the lessons learned in future data QA efforts.

1.4 TRAINING MATERIALS

The new or improved training materials developed under this project can be found on the MoDOT IC-PMTP SharePoint site located at:

https://partner.modot.mo.gov/sites/cm/IntellComp/SitePages/Home.aspx.

The different materials are organized using a document located on the SharePoint homepage titled "DocHelper SharePoint Navigator." This document is further described in Chapter 4.

CHAPTER 2 TASK 2 – REVIEW OF QA PROGRAMS

2.1 INTRODUCTION

Under Task 2, the Research Team reviewed existing ICT data quality assurance (QA) programs and the Title 23 United States Code of Federal Regulations Section 637 Subpart B (CFR) requirements for state departments of transportation (DOTs) data QA programs. The goals of the Task 2 report were as follows:

- Describe conventional spot testing QA programs and summarize critical differences that may not apply to ICT data.
- Evaluate existing ICT data QA programs and parallel efforts by other DOTs and agencies.
- Summarize the IC and PMTP data QA pilot project efforts completed by MoDOT in the 2020 construction season, including successes and lessons learned.
- Anticipate data QA issues related to the *implementation of DPS.*

Complete findings from Task 2 can be found in the Task 2 report – Review of Existing Intelligent Construction Technologies QA Efforts. The key findings that address the goals of the Task 2 efforts are summarized in the following sections.

2.2 CONVENTIONAL SPOT TESTING QA PROGRAMS

The FHWA requirements for construction materials QA are detailed in the CFR. The regulations require each DOT develops and maintains an FHWA-approved Quality Assurance Program (QAP) for materials used in federal-aid highway construction projects on the National Highway System (NHS).

There are six core hierarchical elements of a QAP (Dvorak 2019), including:

- Agency acceptance.
- Contractor quality control (QC).
- Independent assurance (IA) sampling and testing.
- Personnel qualification and certification.
- Laboratory accreditation and qualification.
- Materials testing dispute resolution.

The CFR was last updated on June 29, 1995. The significant changes to the 1995 version of the CFR included guidelines for using contractor QC data in agency acceptance programs. Before the 1995 revision, the CFR was written assuming that the state would perform all the sampling and testing, which was the traditional approach (Federal Register 1995). With the downsizing of many DOTs in the 1990s, inspection and testing personnel positions were reduced significantly, and many technicians were removed from the contractors' materials plants. Although DOTs often took it upon themselves to control most production and construction aspects, staff reductions made it more important to assign QC where it rightfully belonged (to the contractor) so the DOT could focus on acceptance testing and inspection. Many DOTs found ways to include contractor test results in the acceptance decision (FHWA 2004).

The FHWA studied the ramifications of using contractor-performed sampling and testing in a 1993 report titled "Limits of Use of Contractor Performed Sampling and Testing." One of the report's recommendations was that contractor results could be used in acceptance programs, provided that adequate checks and balances are in place to protect public investment. (Federal Register 1995). The CFR requires that the DOT verify contractor data used for acceptance. The verification sampling and testing must be performed on independent samples obtained by the state or designated agent to verify the quality of the material. In other words, verification shall not be performed on split samples. When comparing contractor and agency data, statistical analysis procedures must be used to evaluate the mean and the variance. The American Association of State Highway and Transportation Officials (AASHTO) and FHWA recommend using F-test and t-test to compare the variances and means, respectively (TRR 2019).

If contractor results are used for acceptance, the DOT must implement a written *dispute resolution* plan to address the situation when the verification sample results do not match the contractor results. The dispute resolution requirements are flexible, as long as a written procedure covers the inevitable situation where two sets of data conflict (TRR 2019).

State verification of contractor data differs from the *Independent Assurance (IA)* sampling and testing. The need for IA programs dates back to the early 1960s when a Congressional investigation uncovered improper testing and fraud in federally funded highway projects. The fraud was investigated by splitting material samples and testing the splits using separate personnel and equipment. The results of each split were compared. This process was later rewritten as the IA program (FHWA 2011). The requirement for an IA program remains in place regardless of whether contractor or state data is used for acceptance. The IA program evaluates the qualifications of testing personnel and equipment. The IA program must use different personnel and equipment from what is used for acceptance testing (acceptance data may be state-tested data or contractor QC with state verification data). DOTs have flexibility in designing the IA program. The testing equipment can be verified by one or more of the following: calibration checks, split samples, or proficiency samples. The testing personnel can be evaluated using observations, split samples, or proficiency samples.

The CFR does not specify frequencies for IA evaluation. DOTs must specify evaluation schedules and frequencies in their QAPs on a project or system level and by a unit of production or time. Typically, DOTs use 10 percent of the acceptance testing frequency when using the project approach. DOTs typically aim to check 90 percent of active testers (FHWA 2011). Some states also use a hybrid approach, where different state regions or areas use different approaches (TRR 2019).

The CFR requires qualified laboratories and personnel to perform sampling and testing in the acceptance decision. Technician certification can be performed by one of the following:

- National certification, such as the American Concrete Institute (ACI) or AASHTO.
- Regional Technical Training/Certification Organizations, such as:
  - WAQTC - Western Alliance for Quality Transportation Construction

  - M-TRAC - North Central Multi-Regional Training and Certification Program
  - NETTCP - Northeast Transportation Training and Certification Program
  - SETFTTQ - Southeast Task Force for Technician Training/Qualification
  - MARTCP - Mid-Atlantic Region Technician Certification Program
- State certification programs.

All testing for acceptance and IA must be performed in an AASHTO *accredited laboratory* (or another FHWA-approved accreditation program). If contractor results are used for acceptance, their laboratory must be AASHTO accredited.

This project mainly aims to find suitable equipment and procedures for contractor data verification. Other elements like IA and dispute resolution should be considered in future research projects.

2.3 CONSIDERATIONS FOR ICT DATA QAP

ICT as a QC tool has been widely researched and is a successful practice. ICT is revolutionary to the asphalt paving industry. For the first time, it allows the contractors and DOTs to measure real-time material properties during paving, track progress visually, record measured data and machine settings digitally, and report everything from the field, all while using technically advanced equipment (Chang et al., 2014).

However, at this level of implementation, DOTs rely on the contractor to reap the full benefit of ICT. In this scenario, the contractor's focus may still be on the spot test data used for acceptance. Therefore, ICT may be purchased and installed but not adequately implemented. A few leading DOTs, including MoDOT, are moving towards fully implementing ICT for acceptance tools. The benefits of transitioning from conventional spot test acceptance to ICT acceptance are as follows:

- Complete coverage data instead of limited spot test data that may not reflect the entire project.
- Improved safety with coring crews removed from the roadway.
- Shorter traffic closures with no need to keep roads closed for coring crews.
- A complete electronic paving history of data that can be used to promote and ensure successful paving practices and develop digital as-builts.

At this time, FHWA does not approve Federal-aid funds for pay adjustment without DOT verification of ICT data since payment would be based on contractor equipment and data (Dvorak 2018). Therefore, it is essential to provide successful ICT QAP processes that meet the regulations and minimize risks to Federal-aid projects. Some of the significant differences between ICT data and conventional spot test data are as follows:

- ICT data provides full-coverage data as opposed to spot test results. Spot tests are samples from a small area (e.g., a six-inch diameter core) but are used to represent a much larger area (e.g., a 500-ton sublot). According to Ohio DOT, their current asphalt acceptance sampling rate of 10 cores per day only covered 0.004 percent of the sample area (FHWA 2021). ICT provides data for the entire sublot area; therefore, the spot tests and ICT data sets differ.

- ICT data produce large data sets that are managed differently than conventional acceptance testing. For example, data management protocols such as standard naming conventions and folder organization are essential to ensure data quality. Therefore, data management is critical for ICT data implementation.
- Most ICT data is collected in real-time during construction. Therefore, the data cannot be recollected after construction. The exception is DPS data which can be collected after construction. Differences in moisture and other variables may compare to data collected during construction and after conduction is invalid. Real-time data collection makes dispute resolution requirements complex since data can't be re-collected after construction.
- The CFR refers specifically to sampling and testing performed by laboratory personnel. ICT data is not processed in a laboratory compared to conventional loose mix asphalt samples or cores, and ICT requires processing and analysis in computer software programs. The skillset required to analyze and understand data differs from the typical laboratory or field technician, and therefore, they require different skillsets and training. Therefore, the certification processes for ICT data technicians are different from materials testing technicians.
- Most ICT systems are mounted on contractor equipment (pavers, rollers), and DOTs cannot purchase the companion equipment (pavers, rollers) to duplicate test results. On the other hand, conventional testing uses DOT laboratory equipment corresponding to equipment used in contractor labs (e.g., asphalt content ignition furnaces to check AC content) which simplifies verification efforts.
- Statistical analysis methods for spot test data versus full coverage data may differ. For conventional spot testing, FHWA recommends the F-test and t-test for verification testing because they have more power to detect actual differences. The F-test provides a method for comparing two data sets' variances (standard deviation squared), and the t-test assesses differences in means. Directly comparing one department spot test to one or more contractor spot tests is ineffective due to the high variability with individual spot test values. However, full coverage data does not have the same level of variability as spot tests; therefore, other evaluations may be more appropriate.

2.4 2020-2021 DATA QA EFFORTS AT MODOT

MoDOT's experience dates back to the IC-PMTP implementation projects beginning in 2017 and continuing today. These efforts are summarized in annual MoDOT reports (Chang et al., 2017, 2019, 2020). MoDOT has seen quality improvements on numerous field projects due to ICT implementation.

Based on the success of the IC-PMTP implementation projects, MoDOT is working towards the full implementation of ICT for acceptance in place of conventional spot testing. Therefore, MoDOT is one of the leading DOTs trying to implement ICT QA to meet CFR requirements and receive Federal-aid for IC-PMTP projects. MoDOT is a member of TPF-5(466) and works parallel with the road map efforts of the pooled fund. MoDOT is one of the first DOTs to pilot verification of contractor measurements for IC and PMTP data.

MoDOT is also a member of TPF-5(443) and piloted DPS data collection equipment during the 2021 construction season. Data QA devices to verify DPS equipment have not been developed or piloted at this time. Also, MoDOT has not purchased DPS equipment. If MoDOT decides to purchase DPS equipment, the calibration and certification efforts of TPF-5(466) can be considered for implementation.

The 2020 and 2021 data QA efforts are detailed in the annual IC-PMTP reports (Chang et al., 2020 and 2021). These reports include step-by-step instructions on collecting and comparing the QA data. The lessons learned from the 2020 and 2021 seasons are summarized below.

2.4.1 2020 Data QA Lessons Learned

Lessons learned from the 2020 data QA pilot studies include the following:

2.4.1.1 IC Data QA

IC pass count analysis fails: There were a few issues encountered during the pilot studies, including:

- The contractor did not set up the machine ID correctly. Therefore, the roller with 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.

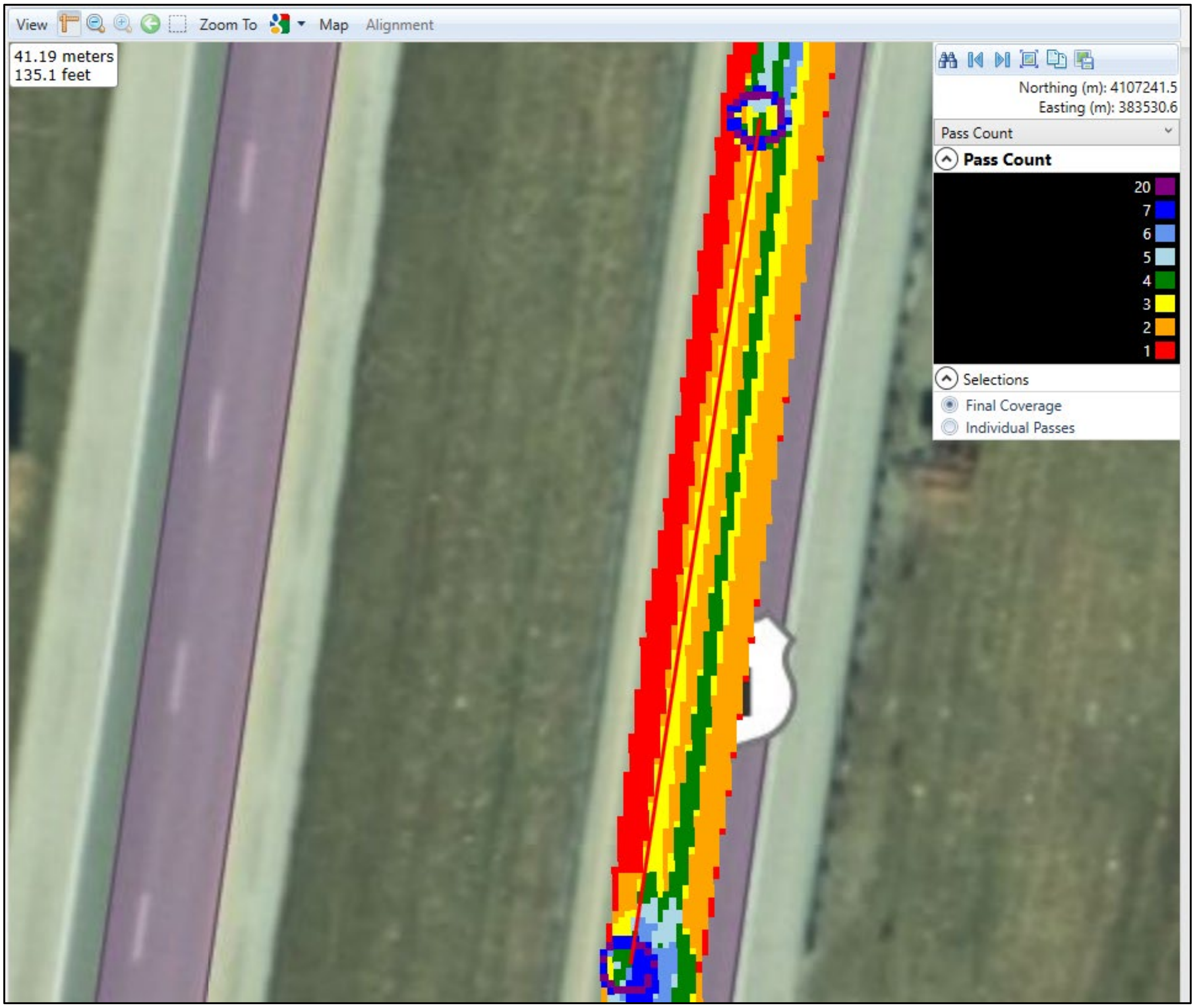


Figure 1. Screenshot. Image of Dirtmate data halos (purple circles).

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 ensure 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 (the network light is fast blinking). It is recommended to leave the hotspot with the roller during operation. The RE should check daily to ensure data are 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 MoDOT IC-PMTP 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. Sometimes, 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 ensure the Dirtmate is installed correctly.

Measurements of Dirtmate: Some projects did not provide the mounting measurements for the Dirtmate. The setup of the Dirtmate and corresponding mounting measurements is required to generate the file correctly.

2.4.1.2 PMTP Data QA

FLIR time settings: In some cases, the PMTP QA was impossible because the time clocks between the PMTP and FLIR camera did not match. As previously described, the PMTP unit and FLIR camera clocks must 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 filtering knowledge, and 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 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.

2.4.2 2021 Data QA Lessons Learned

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

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

Additionally, in 2021 MoDOT IC-PMTP staff were restructured, and the new Field Office team did not have the past years of IC-PMTP knowledge and experience. The restructuring of staff and COVID-19-related challenges made it difficult to pilot the data QA protocols, and therefore, there was limited data QA performed in 2021.

The biggest lesson in 2021 was that more training was needed to implement the data QA procedures. During the 2021 end-of-year feedback meeting, it was decided that the project staff should be responsible solely for data collection and that the Field Office and Transtec would assist with the analysis procedures. Therefore, by emphasizing data collection, data quality could hopefully be improved.

CHAPTER 3 TASK 3 – DEVELOPMENT AND IMPROVEMENT OF QA PROGRAM MATERIALS

This chapter summarizes Task 3 of this project, including the field data QA operation procedure improvements. It includes onsite calibration and verification of measurements, operation of the data QA devices, and data analysis procedures aiming to meet the CFR code.

3.1 IC DATA QA

The IC data QA methods used in the 2021 MoDOT construction season were summarized in Chapter 2. The issues observed in the data collected using the data QA device (Dirtmate) made it necessary to improve the device and analysis process. The issues and improvements made to address the issues are described in the following sections.

3.1.1 QA Equipment

3.1.1.1 2021 Construction Season

The components of the IC data QA equipment used in the 2021 construction season include (Figure 2):

- Dirtmate: A PPK/RTK GPS rover is mounted on the top of an active IC roller using magnets or brackets to collect real-time GPS data that can be offset to the center of the front drum (see Figure 2). User inputs determine the offset and drum footprint during file generation. Therefore, placement of the Dirtmate and recorded measurements are critical.
- Wi-Fi hotspot: A hotspot device was used to connect the Dirtmate to the network to upload the data in a Wi-Fi range (see Figure 3).

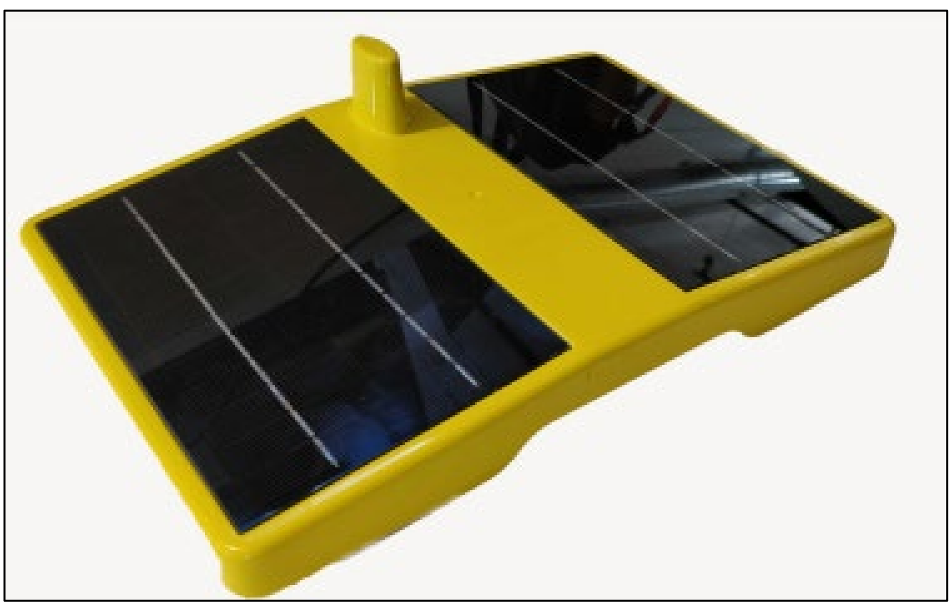


Figure 2. Image. Dirtmate Gen 2 was used in the 2021 construction season.

Figure 3. Photograph. Wi-Fi hotspot used in 2021 construction season.

Further information on Dirtmate and Wi-Fi hotspots used in the 2021 construction season can be found in MoDOT (2021) report.

However, there are issues with the Dirtmate system during the 2021 construction season. Based on the feedback meeting at the end of the 2021 construction season, MoDOT personnel struggled with using Wi-Fi hotspots due to loss of connection and short Wi-Fi range, which resulted in losing Dirtmate data. Due to the lack of internet connection in several project sites, all or parts of the data collected using Dirtmate were not correctly uploaded to the network. An example of missing GPS data is shown in Figure 5 and Figure 4. The corresponding contractor data (Figure 5) shows a pass count of seven compared to Dirtmate's four. The data loss is validated by looking at the data available on the propeller site, as shown in Figure 6. This issue was attributed to the Wi-Fi hotspot's network connection loss.

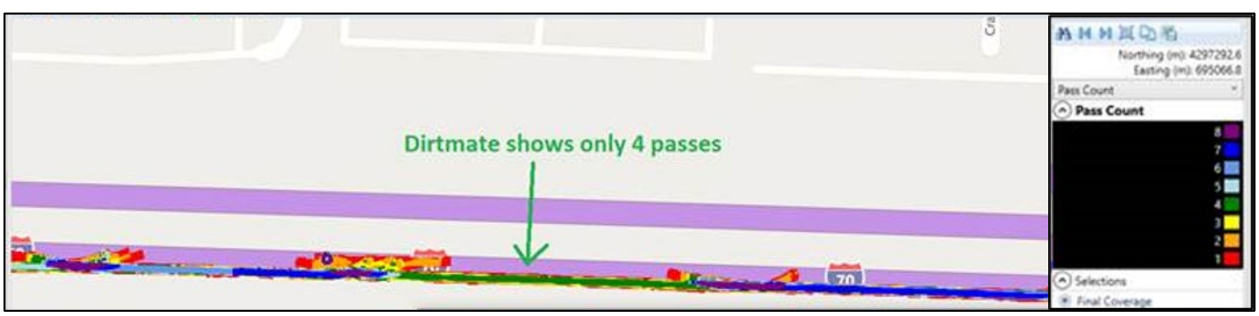


Figure 4. Screenshot. Example of Dirtmate data with missing pass count data.

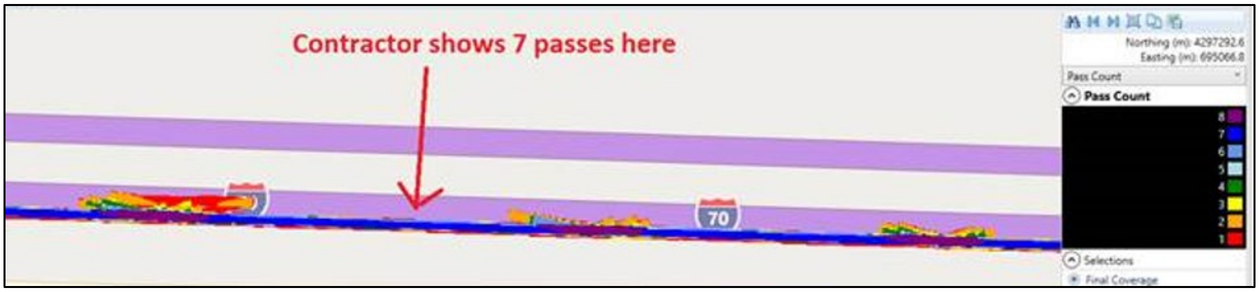


Figure 5. Screenshot. Contractor data corresponding to the Dirtmate data in Figure 4.

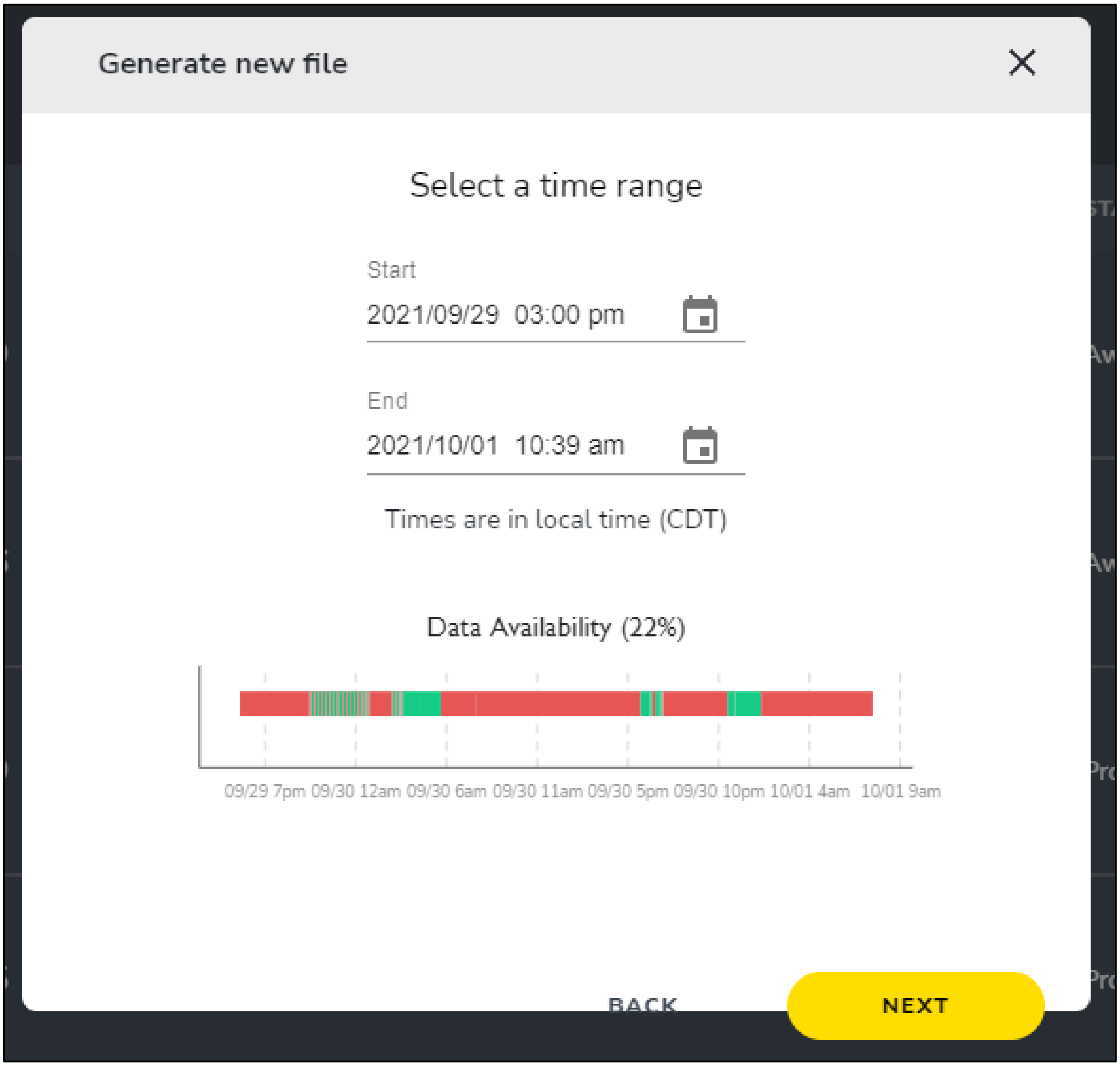


Figure 6. Screenshot. Example of missing data during file generation.

3.1.1.2 2022 Construction Season

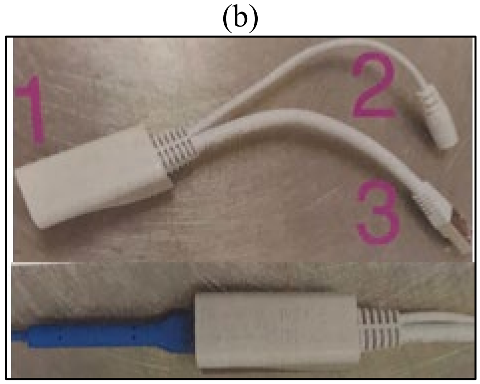
MoDOT requested Propeller make Dirtmate improvements in the 2022 construction season to address the missing data issue in 2021. The improvements included the purchase of Generation 3 (GEN 3) Dirtmates and replacing the hotspot with a Daily Use Gateway (DUG). The improvements to the GEN 3 Dirtmate from the previous GEN 2 Dirtmate models include:

- A refined solar panel that improves charging for long-term or night paving processes.
- Better quality data.
- Wi-Fi range.
- Higher memory capacity.
- Longer battery life.

The DUG enables continuous data upload or temporary setup for data upload, while the Wi-Fi hotspot used in 2021 used batch data upload. Batched uploading could have attributed to data loss in 2021. The components of a DUG system include a gateway hub, an antenna, a battery, Ethernet and AC charging cables, a foam-padded case, and a tripod (Figure 7). MoDOT personnel elected to replace the tripod with a magnetic stand so that the DUG could be mounted on the back of a truck (Figure 8). MoDOT also facilitated the equipment installation by pre-assembling the DUG, which can be transported in a padded case to the project site.

(a)

(b)



(c)

Figure 7. Photographs. Components of Daily Use Gateway (DUG) (a) Gateway and antenna (b) Gateway battery (c) Connection cables

Figure 8. Photograph. An assembled Daily Use Gateway (DUG).

3.1.2 QA Data Collection

Different options exist to turn the Dirtmate on and off in the field as follows:

- The contractor can turn the Dirtmate on and off manually.
- The Dirtmate can be turned on and off using a scheduled program set by Propeller.
- The Dirtmate can be left on indefinitely, but special attention is needed to ensure the battery is sufficiently charged.

The DUG operation should be verified daily. To test the DUG, ensure the DUG and its battery are charged and that the cables are connected correctly. The wider cap on the DUG should be removed to connect the ethernet power cable. Note that the power light on DUG does not show any activity while the Dirtmate is charging unless the Dirtmate is also on, in which case the DUG power light displays a fast blink. Like cell phones, signal strength bars on the DUG show the area's coverage. Further details can be found in the quick reference guide described in section 4.2.2.

For data transfer, the assembled DUG should be placed within a half-mile distance and with a clear line of sight to the roller with Dirtmate. The time required to transfer the data for one day's worth of production to Propeller's cloud storage is approximately 30 minutes. The Dirtmate can store at least 24 hours of operation if fully charged. When a Dirtmate is discharged, it takes approximately 4.5 hours to charge using the solar panels. Each Dirtmate includes a wall charger that can be used if needed.

The QA data file generation requires the project information, the specific roller that was instrumented, the measurements of the offsets from the mounted Dirtmate location to the center of the roller's front drum, drum dimensions, Dirtmate ID, and the date and time. The offset measurements and drum size project the GPS into a drum-sized footprint (like the IC projections). Once the Dirtmate data file is generated in Propeller's web portal, it takes a few minutes to a few hours for Propeller to process the data.

The Dirtmate data file is filtered and compared to the contractor IC data, as described in the following section.

3.1.3 QA Data Analysis

3.1.3.1 Veta Analysis and Exporting Pass Count Results

The first step of the IC QA analysis is to import IC and Dirtmate to Veta to perform pass-count statistical analysis and export the results to text files.

The raw Dirtmate data are ungridded positioning data in the AASHTO M 39 standard format with the *.tds file extension. During the import process, Veta processes the raw Dirtmate data to final coverage, gridded data. The concept of gridding the data is illustrated in Figure 9.

A Veta filter group needs to be created to extract a random data section with a time filter. Care is needed to avoid the areas with known issues, such as those described in section 6.2. After analyzing the filtered gridded Dirtmate data, the final coverage's pass count statistic report needs to be exported to a text file using Veta's report feature. Further details are documented in the step-by-step instructions found on the MoDOT IC-PMTP SharePoint site.

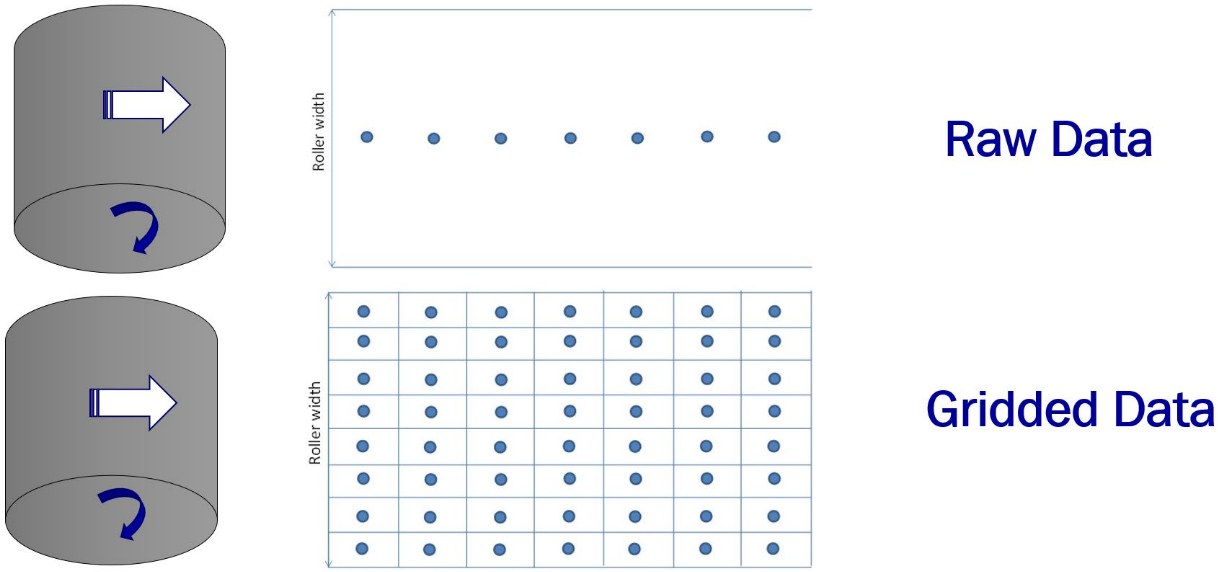


Figure 9. Graphic. Example of raw ungridded and gridded data.

IC vendors may submit gridded or ungridded data. Therefore, the gridding technique and grid spacing, or size, used by IC vendors may differ from the Dirtmate data, and the pass counts calculated over the same compacted area could be slightly different. More research is needed to determine how much grid size affects coverage data.

The corresponding IC data from the roller that the specific Dirtmate was mounted needs to be imported to Veta and filtered to match the Dirtmate data. Note that the time filter must exactly match the one in the Dirtmate analysis.

3.1.3.2 Excel Macro Analysis for Comparing the Pass Count Results

The Research Team developed an Excel macro tool to perform the final QA analysis. This stop-gap solution will be used until an automated analysis feature in Veta is implemented.

The IC QA analysis tool compares the mean, standard deviation, coefficient of variation, and variance of the number of passes from the two pieces of equipment. Besides the slight change due to different gridding, both IC roller's GPS and Dirtmate are expected to generate the same data sets in a specific time window.

The Excel macro tool imports the exported Dirtmate and IC pass count statistics text files (mean, standard deviation, coefficient of variation, variance, minimum, maximum, and sample sizes). Threshold values were used to determine pass or fail for the differences in the mean (0%), standard deviation (5%), coefficient of variation (10%), and variance (15%). Those thresholds were established based on the first few IC QA projects in 2021. However, the Research Team continues calibrating these thresholds as more IC data are analyzed. The QA will fail if one or more of the thresholds are exceeded. The Excel macro also includes a feature to print a PDF report of the QA results.

There was a minor change in the Excel macro to export the results to a clipboard and paste them to the summary spreadsheet for all QA results. The latter is to track all IC QA results and perform statistical analysis of pass or fail, as described in section 6.4.

3.2 PMTP DATA QA

The PMTP data QA methods used in the 2021 construction season were summarized in Chapter 2. The issues observed in the data collected using the data QA device (FLIR camera) made it necessary to improve the data collection and analysis process. The issues and improvements made to address the issues are described in the following sections.

3.2.1 QA Equipment

3.2.1.1 2021 Construction Season

FLIR E5-XT thermal cameras were used to collect QA data. The FLIR E5-XT has the following characteristics:

- Resolution of 160 × 120 pixels.
- Sensitivity of 0.27 °F.
- Range of -4 ˚F to 752 ˚F.
- Field of view of 45˚ × 34˚.

Event markers (1-foot by 1-foot) were specified but not supplied, which caused some issues since project staff struggled to find a suitable object. The event markers were placed directly behind the paver so the contractor's PMTP equipment could scan it. The same event marker was photographed using the FLIR camera, which facilitated the comparison of surrounding temperatures (since the event marker could be used to align the data sets). However, it was observed that the event marker's size might be too small to be identified visually in Veta for the PMTP data. PMTP data is not gridded but corresponds to vendor-specific "sensor" spacing. Vendor's sensor spacing is generally around 1-foot but varies, and some vendors use sensor spacing as small as 10 inches.

3.2.1.2 2021 Construction Season

The same FLIR E5-XT thermal cameras were used to capture thermal images for PMTP data QA in the 2022 construction season.

The event marker was provided to project staff in 2022. These event markers were enlarged to be 2 feet by 2 feet in the 2022 construction season to address the event marker's issue in 2021, and a handle was added to facilitate the safe pickup of the event marker (see Figure 10).

Figure 10. Photograph. A 2-foot by 2-foot event marker was used in the 2022 construction season.

3.2.2 QA Data Collection

The FLIR's time zone setting should be set to US Central time zone. The PMTP unit and FLIR camera clocks need to be synchronized before use.

During the field measurements, the FLIR thermal images need to be taken with an event marker placed at the near edge of the paved area. The FLIR camera's position should be 5 feet in height and 6 feet offset from the near edge of the paved area. The FLIR camera's FOV should cover the entire paved width and small portions of the adjacent shoulder or lanes. Further details are documented in the step-by-step instructions and quick reference guide in Appendices A and B, respectively.

The QA data collection method was slightly changed from the one in 2021. The scenarios for the FLIR camera's positions were simplified relative to the operator and paving direction. The scenarios in 2021 considered paving direction (north, south, east, or west) and FOV direction, creating eight scenarios. The scenario was simplified in 2022 to include whether the paver was moving towards the right or left of the FOV of the camera, as shown in Figure 11 and Figure 12.

All FLIR files are named according to the standard naming convention as follows:

- **Scenario R**: Paving to the Right Direction (ProjectCode-YYYYMMDD-**R**-N.jpg), N: sequential number of shots (1, 2, or 3).
- **Scenario L**: Paving to the Left Direction (ProjectCode-YYYYMMDD-**L**-N.jpg), N: sequential number of shots (1, 2, or 3).

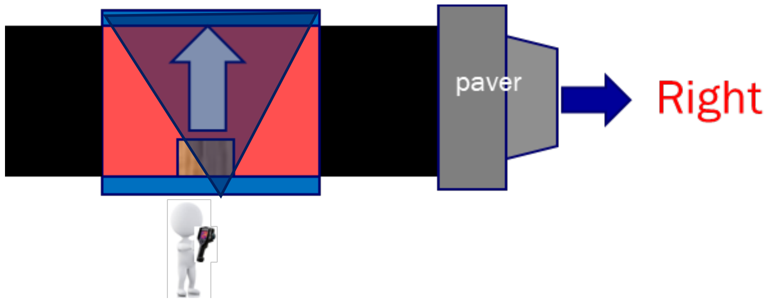


Figure 11. Illustration. Scenario R indicates the paver was moving to the right.

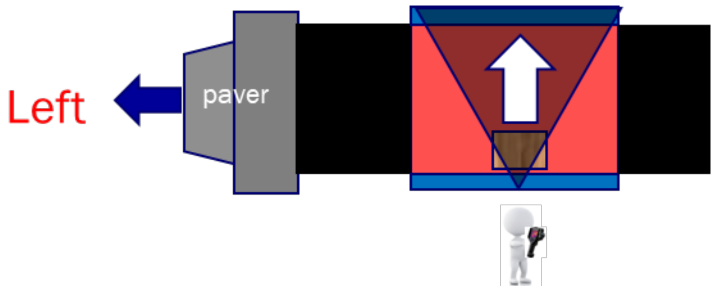


Figure 12. Illustration. Scenario L indicates the paver was moving to the left.

Common issues in data collection are summarized in section 4.2.8.

3.2.3 QA Data Analysis

3.2.3.1 Veta Analysis to Filter and Export PMTP Data

The first step of the PMTP QA analysis is to import the raw PMTP data to a Veta project filter and filter/export the PMTP data to match the FLIR thermal image location. The process of filtering PMTP data in Veta has not changed since 2021, as described in the step-by-step instructions on the MoDOT IC-PMTP SharePoint site.

The FLIR camera's time stamp must be synchronized to the PMTP timestamps and can be adjusted with one-minute accuracy (see Figure 13).

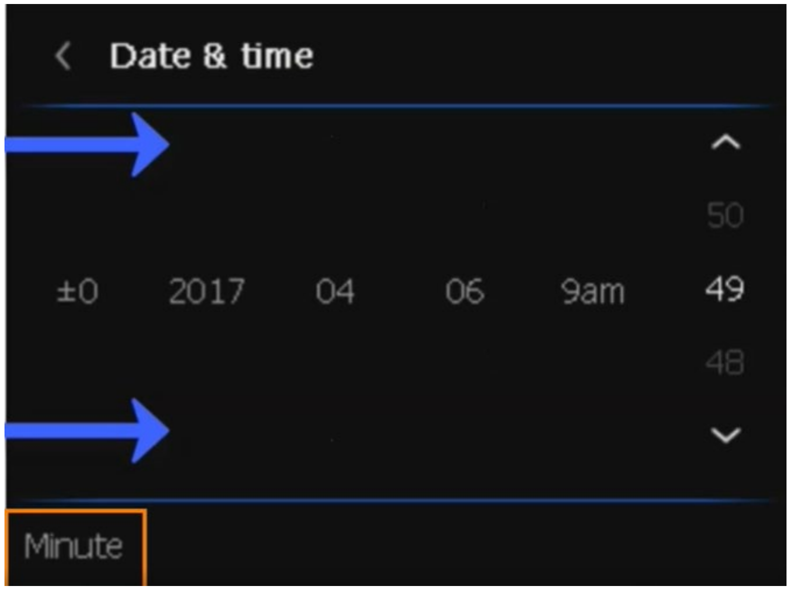


Figure 13. Screenshot. FLIR camera date and time setting.

The minimum length of the filtered PMTP was 100 feet in 2021 to allow Veta's cold-edge filter to function. A cold-edge filter function was added to the Excel macro tool in 2022, so the minimum length of the PMTP data could be reduced. Reducing the length requirement provides additional flexibility for the data filtering options. Shorter lengths may be required when there are many additional cold spots present, as further described in section 6.3.3.5.

3.2.3.2 Excel Macro Analysis for Comparing Filtered FLIR Thermal Camera and PMTP Data

The research developed an Excel macro tool to import the thermal images and filtered PMTP data from Veta to perform QA analysis.

Many changes were made to the Excel macro tool in 2022 to improve the QA analysis, including:

- Five quantile results were added (5, 25, 50, 75, and 95 percentiles) to compare the data distribution. It is recommended that percentile thresholds are evaluated for appropriateness in the future after all data comparisons are complete. Justification for using percentiles to assess PMTP and FLIR camera differences is included in section 3.2.4.
- The FLIR camera positioning scenario codes were reduced from eight to two cases (see the above data collection section). This change reduces the FLIR data file naming errors that may fail the QA analysis.
- The color legends of FLIR and PMTP heat maps were changed to match Veta's default PMTP color legend.
- The PMTP cold-edge filtering function was added to be consistent with FLIR data's cold-edge filtering. It would also allow a shorter pavement length for the filtered PMTP data.
- If the temperature unit is ˚C in the filtered PMTP data, the data were converted to ˚F.

- The heat maps that use conditional formatting were replaced with exported images from the original heat maps to improve run time.
- A progress bar was added to monitor the run time for the FLIR data import, heat map generation, cold-edge filtering, and export of the heat map to an image.
- The event marker identification code was improved to handle the event maker data that spans into multiple cells and that multiple cold spots (possibly from people walking under the camera) exist in the filtered PMTP data. Note that any cold spots near the actual event marker may be mistaken as an event marker. Therefore, data with many close cold spots should be evaluated cautiously.
- An export result function was added to copy the results to the clipboard to paste them into a summary file for further statistical analysis.

3.2.4 Statistical Evaluation Methods for PMTP Data

Unlike IC and Dirtmate data, which are similar data files and sample sizes, PMTP and FLIR data have significantly different sample sizes. Therefore, using statistics such as mean temperature and COV may not be adequate for comparison purposes. This section includes considerations for comparing PMTP and FLIR datasets. Different statistical comparison methods are currently being piloted for the 2022 season.

3.2.4.1 Uncertainty in Data

Any measurement will have some uncertainty associated with it, no matter the precision of the measuring tool. The uncertainty in data consists of systematic error and random error. The careful methodology can reduce uncertainty by correcting for systematic errors and minimizing random errors.

Systematic errors in the PMTP and FLIR measurements include:

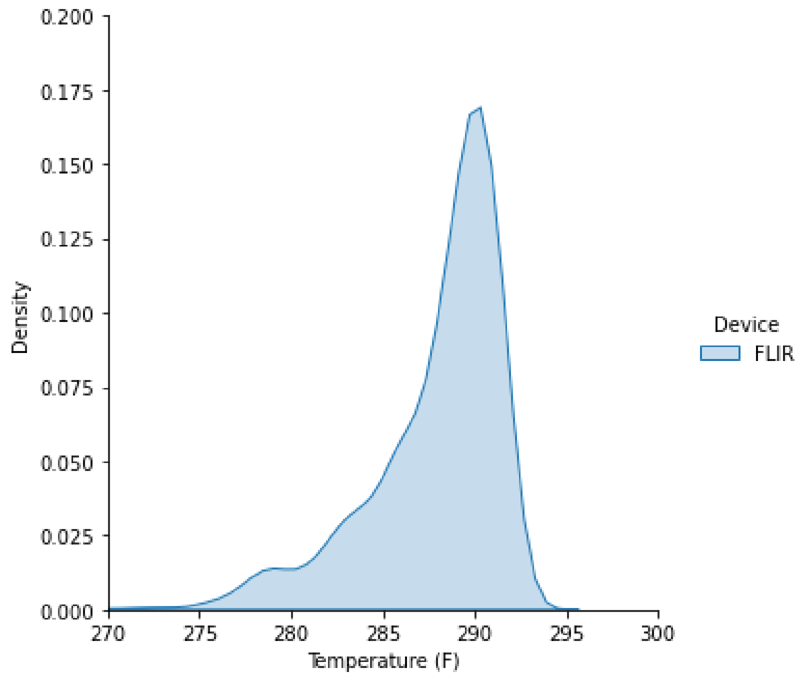
- Instrumental: The thermal measurement device may not be calibrated. Other accuracy limitations of the equipment fall in this category. Protocols should be developed to ensure equipment is routinely calibrated per national standard procedures.
- Environmental: The temperature of the asphalt mat can change if taking the FLIR image is delayed for several seconds. Since the devices only measure surface temperatures, this is exacerbated by the climate (e.g., wind, temperature).
- Observational: The inspector (inadvertently) does not set up the date and time of the FLIR camera correctly.
- Theoretical: The test designed for data QA has some limitations. For example, the effect of perspective on temperature measurement is not exactly considered. The instrumental error of low accuracy in reading temperature at farther distances may add to this error. Other theoretical issues include the different grid/pixel sizes of measurements. The number of measurements using the FLIR camera is a thousand times more than PMTP data within the same pavement area. The temperature in PMTP is averaged over the large grids of approximately 1 foot by 1 foot which is much less accurate than FLIR measurements. The discrepancy in sample size causes other issues in comparing the data described in the following section.

3.2.4.2 Data Distribution

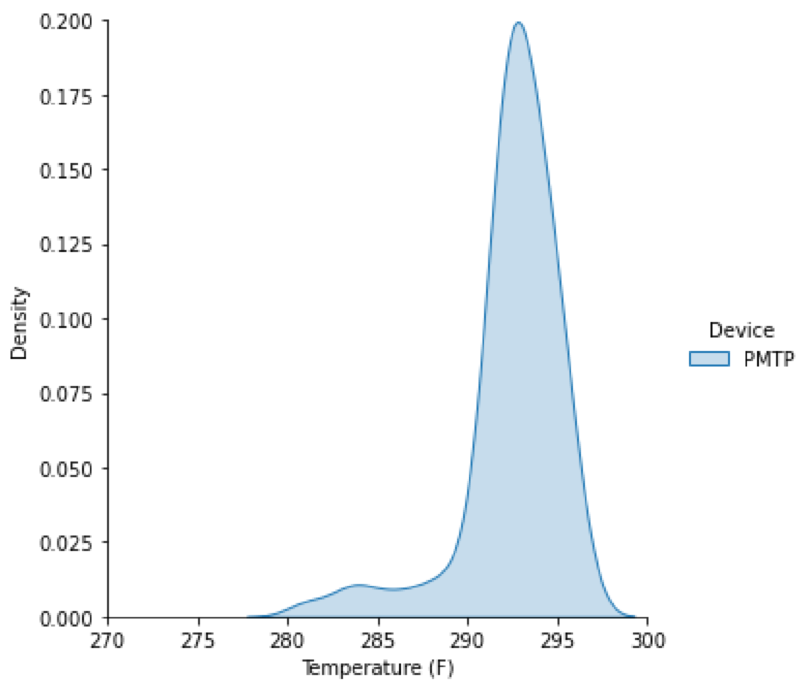
One of the recommendations this season was to change the passing criteria from comparing the mean values of PMTP and FLIR (to be within ±5%) to evaluate the data distribution. The precision of PMTP measurements could be identified using nonparametric descriptive statistics, i.e., there is no assumption about the underlying distribution of the data. For this purpose, the quantile results were added to the output table of the thermal QA tool. The quantiles reported include the 5th percentile, 25th percentile, 50th percentile, 75th percentile, and 95th percentile, which are calculated simply from the recorded data. Therefore, the percentile bounds can be set instead of a threshold on the mean value error. Using percentiles is advantageous, especially when the data distribution is skewed or there are extreme values where the mean value is not a good representation of data.

The Research Team also investigated other statistical tests to compare the FLIR and PMTP data distribution from one thermal data QA tool example. One- or two-tail t-tests with unequal variances (Welch's t-test) were used to test the hypothesis that two populations have equal means. As opposed to the paired t-test that needs the same size sample and has other assumptions, this test works for samples of different sizes. Z-test compares the mean values of two data sets when their variances are known. These tests failed because the p-values obtained for this example were too low (p-value less than 0.05), i.e., the two populations have statistically significantly different mean values. The two-sample Kolmogorov-Smirnov (KS) test is a nonparametric test of the equality of continuous one-dimensional probability distributions that can be used to compare a sample with a reference probability distribution or two samples against each other. This test was run using a Matlab function. The null hypothesis of the two samples being from the same distribution was rejected. Therefore, for several reasons, such as different data gridding, different sample size, and different viewpoint, the two data sets of FLIR and PMTP data cannot be compared using the common statistical tests.

Another tool to compare the distribution of FLIR and PMTP data is to look at the distribution or histogram plots. An example of comparing the distribution of FLIR and PMTP data extracted after filtering in the PMTP data QA tool is shown in Figure 14. As seen, the data distribution from the two thermal equipment is similar. The extreme values (5th and 95th percentiles) and the median (50th percentile) also seem close.



(a)



(b)

Figure 14. Charts. An example of a comparison of (a) the distribution of FLIR data and (b) the distribution of PMTP data extracted after filtering in the PMTP data QA tool.

Final recommendations for statistical comparison methods and thresholds will be evaluated at the end of the 2022 season. It is recommended that these are reported in the annual 2022 IC-PMTP support report.

3.3 DPS DATA QA

In 2021 MoDOT Field Office staff piloted DPS equipment on five IC-PMTP projects. The DPS equipment was rented from the FHWA Equipment Loan Program at the Mobile Asphalt Technology Center (MATC). The DPS equipment was returned at the end of the season.

MoDOT has not elected to purchase DPS equipment at this time. Therefore, detailed QA procedures were not developed. Since the Research Team members are in the DPS technical working group (TWG) for TPF-5(443), the Research Team members are familiar with TPF-5(443)'s research on the DPS certification and verification for acceptance decision-making.

According to their website, TPF-5(443) aims to establish a research consortium focused on the following:

- Further advancing and improving the system based on the experience and needs of participants so that the system can effectively and efficiently support their Quality Assurance Programs.
- Support communication.
- Provide training and technical assistance, including support for specification development and agency implementation strategies.
- Conduct technology promotion and marketing for the system. Specific tasks within this multi-year program will be developed with the consortium participants.

The pooled fund began in 2020. Typically, pooled funds have a 5-year cycle. One of the ongoing projects is to publish equipment certification protocols that meet CFR requirements. Recent relative updates include a new calibration method (using fiberglass material) for checking the consistency of the DPS sensors for field testing has been tested in a controlled MnROAD environment and on routine project data collection. Comparison with previously specified methods of repeat line and swerve testing show that the new method is a viable alternative. The dielectric constant of fiberglass more closely reflects the range of values of asphalt pavement compared to the traditional HDPE blocks.

If MoDOT elects to use DPS equipment, it is recommended that they review the TPF-5(443) recommendations for suitability in their program.

3.4 RANDOM SAMPLING

23 CFR code part 637 requires that all samples used for quality control and verification sampling and testing be random. A random sample is a sample drawn from a lot in which each increment in the lot has an equal probability of being chosen. A sample chosen randomly is meant to be an unbiased representation of the total population. Random sampling can be implemented using random generator tools (such as the one in excel) to select a time of day to take the FLIR image. Such tools can also select dates and times to filter and compare Dirtmate and IC data. Such protocols should be implemented after the data verification processes are finalized.

3.5 SUMMARY

The following changes were made to IC and PMTP data QA in the 2022 construction season:

Propeller's solution to past data loss issues was to use Dirtmate GEN 3 equipment instead of the older generations used in previous construction seasons. The solar panels charging efficiency and battery life of the new generations are improved.

The data transmission device was changed from a Wi-Fi hotspot to Daily Use Gateway (DUG) for IC data QA. The DUG continuously transfers data to the cloud faster than the hotspots when connected to a cellular network. Therefore, the data loss in this season was significantly reduced.

Some data issues remain. Data halos still exist in Dirtmate data. Speed filters are a temporary solution for filtering data halos while Propeller's research and development team finds a solution.

For PMTP data QA, the device used to take a thermal image, FLIR E5-XT, was not changed from the previous season. A larger 2-foot by 2-foot event marker was used this season since the 1-foot by 1-foot event marker could not be well identified because of the grid size of PMTP data.

For PMTP data QA, the data QA macro tool was updated with several improvements on raw and filtered data visualization, data processing, and reporting. One of the outputs is the quantile results that facilitate comparing FLIR and PMTP data distribution. The Research Team continues to streamline the PMTP data QA tool.

CHAPTER 4 TASK 4 – DEVELOPMENT OF QA TRAINING RESOURCES

4.1 INTRODUCTION

Based on some of the feedback at industry meetings in 2021, more training for data QA procedures was a common request. The following sections summarize the training resources that were developed under this project. Some of the below training resources were developed under the ongoing Consultant Support for Intelligent Compaction and Paver-Mounted Thermal Profiling Projects in 2022-2023. However, they are summarized here since they affect data QA efforts.

A significant improvement to the IC-PMTP SharePoint site in 2022 was the development of the IC-PMTP DocHelper SharePoint Navigator document. This document helps organize all of the training resources on SharePoint, as summarized in section 4.2.7.

4.2 RESOURCES

4.2.1 Step-by-Step Instructions

The step-by-step instructions for data QA were written in 2020. There are separate instruction files for IC and PMTP data QA procedures. Minor changes were made to the instructions based on the changes described in 0. The instructions include the complete data QA process, including data collection and comparison. The step-by-step instructions are located on the MoDOT IC-PMTP SharePoint site.

4.2.2 Quick Reference Guides

The step-by-step instructions are thorough instructions for collecting QA data and comparing it against contractor data. However, the amount of content may have overwhelmed project inspectors. Based on the 2021 IC-PMTP feedback meeting, MoDOT staff decided that the project staff would only be responsible for data collection during the 2022 season. Therefore, quick reference guides were created that focused on data collection. These guides, one for IC data QA and one for PMTP data QA, summarize the data collection into a few steps, are only a few pages long, graphic-heavy, and are as simple as possible. The quick reference guides were posted to MoDOT's IC-PMTP SharePoint and the intelligentconstruction.com website and can be viewed at https://www.intelligentconstruction.com/flir-quick-reference/. Quick reference guides were also printed, laminated, and given to each project with the DUG and FLIR equipment.

4.2.3 QR Codes to Access Online Dirtmate and FLIR Quick References Guides

QR code stickers were printed for the IC pass count and PMTP temperature QA data collection. The stickers were placed on FLIR cameras and the DUG to facilitate easy access to training materials in the field. The QR codes link to the intelligentconstruction.com website, where the quick reference guides and FLIR data collection training video are posted. The QR code stickers are shown in Figure 15 and Figure 16. Sheets for printing the stickers were provided to MoDOT.

Figure 15. Graphic. Dirtmate Guide QR code sticker

Figure 16. Graphic. FLIR Guide QR code sticker.

4.2.4 Training Videos

Several training videos were made to facilitate training. These videos are described in the following sections.

4.2.4.1 FLIR Image Training Video

This training video was made in 2022 to demonstrate the proper collection of a FLIR image for PMTP data QA. The video includes the steps from the quick reference guide but includes actual footage of the collection of FLIR images. A link to the video is included on MoDOT's IC-PMTP SharePoint site, and the video is posted on the intelligentconstruction.com website. The video can be viewed at https://www.intelligentconstruction.com/flir-quick-reference/.

4.2.4.2 Dirtmate File Generation Video

This training video was made by Propeller in 2022 to demonstrate how to generate a Dirtmate data file. The video includes all the required steps to input the roller measurements to generate a data file, and it includes directions on importing the file into Veta. A link to the video is included on MoDOT's IC-PMTP SharePoint site. MoDOT Field Office and the Research Team are performing file generation and analysis in the 2022 season.

4.2.4.3 Step-by-Step Instruction Videos

Step-by-step instruction videos were created that showed the entire IC and PMTP data analysis procedure. These were used in the 2020 and 2021 construction seasons, and these videos were not updated to reflect the changes made for the 2022 season. Because the MoDOT Field Office and the Research Team are performing the analysis in the 2022 season, updating these videos was not a priority. These videos should be updated after the lessons learned from this project are fully implemented, and the data QA procedures are finalized.

4.2.5 Training Programs

During the IC-PMTP feedback meeting in 2021, additional training for data QA was requested. The MoDOT Field Office and the Research Team used just-in-time training (JITT) sessions to help with data QA. JITT was planned immediately before projects began or at the start of a project to help with data QA data collection and verification of contractor projects and results. JITT was offered for contractors and MoDOT staff.

During the IC-PMTP feedback meeting in 2021, a train-the-trainers (TTT) program was requested to help get the Field Office staff familiar with the IC-PMTP program and data QA procedures.

The JITT and TTT are described in further detail in Chapter 5.

4.2.6 Inspector Review Guide

Reviewing contractor submittals for completeness and accuracy is essential to data QA. Most of this project's efforts aimed to improve data verification procedures. However, emphasis was also placed on reviewing contractor projects, reports, and results. During one of the first JITT training sessions, MoDOT inspectors requested a review guide to help them navigate and verify the contractor data, analysis, reporting, and final summary sheet. A step-by-step guide was created with screenshots and an example project to show inspectors what to look for in contractor submittals. The inspector review guide can be viewed online on MoDOT's IC-PMTP SharePoint site.

4.2.7 SharePoint DocHelper Navigator Tool

During the IC-PMTP feedback meeting in 2021, several complaints were made about the difficulty of navigating the IC-PMTP SharePoint site. The training resources, construction forms, data submission guides, and other resources were lumped in one folder, and it wasn't easy to sort through all the files to find a specific one. Therefore, the Research Team created an IC-PMTP Document Helper SharePoint Navigator tool. The tool includes six categories for sorting the materials as follows:

- Construction Forms
- Data Submission
- Data Loss Issues
- Download or Update Veta

- Data QA
- Training

Each category is a “button” that links users to associated resources (such as those summarized in this chapter). Each resource is a hyperlink that users can click to download the material. The SharePoint DocHelper Navigator Tool can be found online on the MoDOT IC-PMTP SharePoint site.

4.2.8 Troubleshooting FLIR Photos

Despite all the training efforts for taking FLIR photos, many issues with FLIR photos were still occurring. A guide for troubleshooting FLIR photos was created to highlight such issues. These issues included the following:

- Capturing the rollers and pavers in the images (which create false cold spots).
- Not capturing cold edges on both sides of the fresh asphalt.
- Capturing excessive grass and weeds in the images (which create false cold spots).
- Placing the event marker where contractor equipment is not scanning. There were two common scenarios:
    - Placing the event maker after the contractor's equipment scanned the fresh asphalt.
    - Placing the event marker on a paved shoulder (not required for PMTP data collection) beyond the contractor’s equipment field of view (FOV).

Such issues were also included in the FLIR Image Training Video discussed in section 4.2.4.1. A copy of the troubleshooting document can be found online on the MoDOT IC-PMTP SharePoint site.

4.3 SUMMARY

During the 2022 IC-PMTP feedback meeting, projects staff, contractors, and industry attendees should be asked to provide feedback on the training materials to see which materials were most effective (e.g., in-person JITT training sessions, detailed step-by-step guides, quick reference guides, or videos preferred). These training resources should be updated for future construction seasons to reflect current procedures.

CHAPTER 5 TASK 5 – CONDUCTING QA TRAINING

5.1 INTRODUCTION

During the IC-PMTP feedback meeting in 2021, additional training for data QA was requested. The MoDOT Field Office and the Research Team used JITT and TTT sessions to help with data QA. Thorough data QA training was intentionally not included in the annual training workshops to avoid overloading workshop attendees with too much information. The following sections include the JITT and TTT training efforts specific to data QA during the 2022 construction season.

5.2 JITT PROGRAM

5.2.1 Training Agenda

The JITT sessions were tailored to specific district attendees, so the exact content varies. An example training agenda for a JITT session is shown in Figure 17. Note that the JITT in Figure 17 includes contractor training procedures as well. This report will only focus on the data QA portion of the training.

5.2.2 JITT Locations and Dates

The JITT locations, facilities, dates, and attendees are summarized in Table 1.

Table 1. Summary of JITT.

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

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

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

OBJECTIVES

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

*TRAINING AGENDA**

AM (Contractors and MoDOT)

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

PM (MoDOT only)

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

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

CONTACTS

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

REFERENCES

IC-PMTP Document Helper SharePoint Navigator

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

Figure 17. Screenshot. Example JITT agenda.

5.2.3 Summary of JITT Data QA Training

The JITT data QA training was hands-on and focused on QA data collection and verification of contractor submittals. The training sessions are summarized below.

5.2.3.1 IC Pass Count QA Data Collection Training

The DUG and Dirtmate were displayed and passed around so all attendees could see the equipment. The DUG was set up in the classroom (Figure 18) so attendees could see how the equipment was put together and used. Protocols for using the DUG (as described in 0) were summarized.

Figure 18. Photograph. Setting up the DUG during JITT.

5.2.3.2 PMTP Temperature Data Collection Training

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

5.2.3.3 Checking Contractor Submittals

During the session on checking contractor submittals, the inspector's review guide (described in section 4.2.6) was shown, and an example set of data was used to go through the process. Key inputs that generate price incentives, such as project length and IC and PMTP results, were emphasized.

5.2.4 Feedback from JITT Programs

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

5.2.4.1 Updating PMTP Protocols

The PMTP specification references an old PMTP protocol using an infrared temperature gun. MoDOT Field Office staff requested that this gets updated with the next specification revision to include the FLIR thermal camera procedure. It is recommended that this is updated under the IC-PMTP support project before the 2023 season.

5.2.4.2 Updating the Summary Sheet

The summary sheet references the old PMTP protocol using an infrared temperature gun. The summary sheet was revised to reference the FLIR thermal camera procedure.

5.2.4.3 Inspector's Guide to Contractor Submittals

During the Elwood, KS JITT, MoDOT personnel requested a quick reference guide for reviewing contractor submittals. A guide was created as described in section 4.2.6.

5.3 TTT PROGRAM

5.3.1 Training Agenda

The TTT was held on March 16, 2022. The training agenda for the TTT is shown in Figure 19. The attendees included MoDOT Field Office staff.

Statewide IC-PMTP Veta
TRAIN-THE-TRAINERS WORKSHOP

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

OBJECTIVES

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

*WORKSHOP AGENDA**

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

10:10 am Break

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

12:00 pm Adjourn

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

Handouts

Please download the following handouts before the workshops

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

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

Figure 19. Screenshot. Train-the-Trainers workshop agenda.

5.3.2 Summary of TTT Data QA Training

A representative from Propeller was onsite to support the new Dirtmate and DUG equipment. The Dirtmate Gen 3 device was mounted on a rental car to facilitate practice data collection (Figure 20). During the TTT, the Research Team and Field Office staff thoroughly covered data collection and analysis procedures.

Figure 20. Photograph. A Dirtmate Gen 3 is mounted on a rental car with the new DUG nearby to send data to the cloud.

Practice data files were generated for the Dirtmate. However, correction data was not received in time to view the data during training. After the training, when the data was available, there were issues with erratic “Shooting star” data. The issues are further described in section 6.2.3.5.

5.4 SUMMARY

The JITT and TTT were new training programs that aimed to provide more specific training tailored to the District Office or Field Office needs than annual workshops. This training emphasized data QA data collection (JITT) and analysis (TTT). These seemed to be valuable additions to MoDOT’s IC-PMTP program. Breaking the data QA training into smaller sessions made the material easier to understand and limited the content participants needed to digest. It is recommended that such training programs are continued in future construction seasons.

CHAPTER 6 TASK 6 CONDUCTING FIELD TRIALS OF IMPROVED QA PROGRAM

6.1 INTRODUCTION

This chapter summarizes the field trials of the improved QA program. The field trials include remote and onsite support. The significant lessons learned, completed procedure modifications, and recommended future improvements are described in the following sections.

As previously mentioned, project staff were responsible for data collection, and Field Office staff and the Research Team were responsible for data comparison. Projects are ongoing for the 2022 season, so the field trials summarized here are for projects that started before August 1, 2022.

6.2 IC DATA QA

6.2.1 Data Collection

6.2.1.1 Mounting the Dirtmate

Because the placement of the Dirtmate and associated measurements are critical to the validity of a data file, a Field Office team member typically installs the Dirtmate at the start of a project. The Dirtmate location offsets from the center of the front drum; the front drum dimensions, machine identification, project number, and location are recorded in a spreadsheet.

This spreadsheet was uploaded to the IC-PMTP SharePoint after making new entries so that the Research Team could access it. These measurements are required each time a Dirtmate data file is generated.

6.2.1.2 Transferring the Data

According to the information given by Propeller at the TTT, the Dirtmate can conservatively hold 2-3 days' worth of data on its local hard drive. The DUG is used to push the data from the Dirtmate to Propeller's online storage system. The DUG takes (conservatively) thirty minutes to push a day's worth of data to the cloud. The project staff is asked to hook up the DUG daily to push the data from the previous day of paving.

At this time, there is no way to check to see if the data is done uploading while onsite. Propeller is working on a phone application (app) to offer this service in the future. Until then, inspectors are asked to follow the rule-of-thumb instructions described in section 3.1.2 (line of sight of the roller for 30 minutes).

The DUG feedback from the project staff is as follows:

- It is generally easy to meet the rule-of-thumb requirements to push the data.
- Most inspectors try to get the DUG set up at the roller staging area before paving. The roller is not moving, so maintaining the line of sight is easy.
- Some projects have had data loss. It is difficult to diagnose data loss since it could be for any of the following reasons:

  - Dirtmate is not turned on. Some projects elected to use on and off features controlled by Propeller (e.g., turn on at 6:00 am and off at 8:00 pm). Other projects are turning the Dirtmate off manually or leaving it on indefinitely.
  - Dirtmate is not in the line of sight of the DUG. Staying in line-of-sight may be difficult for wooded or hilly areas.
  - DUG is too far from Dirtmate. Per Propeller, the DUG should be within a half mile of the Dirtmate.
  - DUG is not turned on, caused by issues with the setup of the DUG.
  - DUG has no cellular service, which is required to push the data.
  - Dirtmate malfunctioned during data collection or had GPS issues during data collection.
- Several incidents have occurred where the DUG falls off the inspector's vehicle. The inspectors have reported trying to drive slowly intentionally to keep up with the roller and having the DUG fall off or forgetting about the DUG. So far, no known damage has occurred.
- Most inspectors would like the ability to see when data has been uploaded. When Propeller's app becomes available, it is recommended to use it.

6.2.2 Data Comparison

MoDOT Field Office staff and the Research Team generate Dirtmate daily production files on Propeller's website. The following inputs are required to generate a file:

- Date and time of production.
- Roller footprint (width and diameter).
- Offsets from the center of the front roller to the center of the Dirtmate (the center of Dirtmate is designated on the equipment with a small divot).

Once files are generated, the comparison is performed using Veta and the Excel Macro. Step-by-step instructions for the complete process can be found on the MoDOT IC-PMTP SharePoint site.

After completing several data comparisons, it appeared that the DUG significantly improved the data transfer and reduced the amount of missing data. Further details on the results of the analyses are provided in the following sections.

6.2.3 Data or Procedure Findings

This section includes known issues found during data analysis. These issues should be resolved with the equipment vendors (IC and Dirtmate).

6.2.3.1 Low GPS Tolerance

Some contractors used the coarse GPS tolerance setting during the IC data collection. This setting allows the IC system to collect inaccurate data (4-5 ft) when the RTK mode (1/2") is not available. Therefore, the Research Team contacted the contractors to correct the tolerance as the fine setting measurement to collect the IC data in RTK to meet the requirements of the MoDOT

IC specification. However, feedback from the contractor was that RTK GPS was unavailable in the area. Any example of the contractor data collected using "coarse" GPS versus the Dirtmate data is shown in Figure 21 and Figure 22, respectively. The contractor data appears to be missing data and is "spotty" in areas. Currently, issues with GPS tolerances have only been observed in contractor IC data.

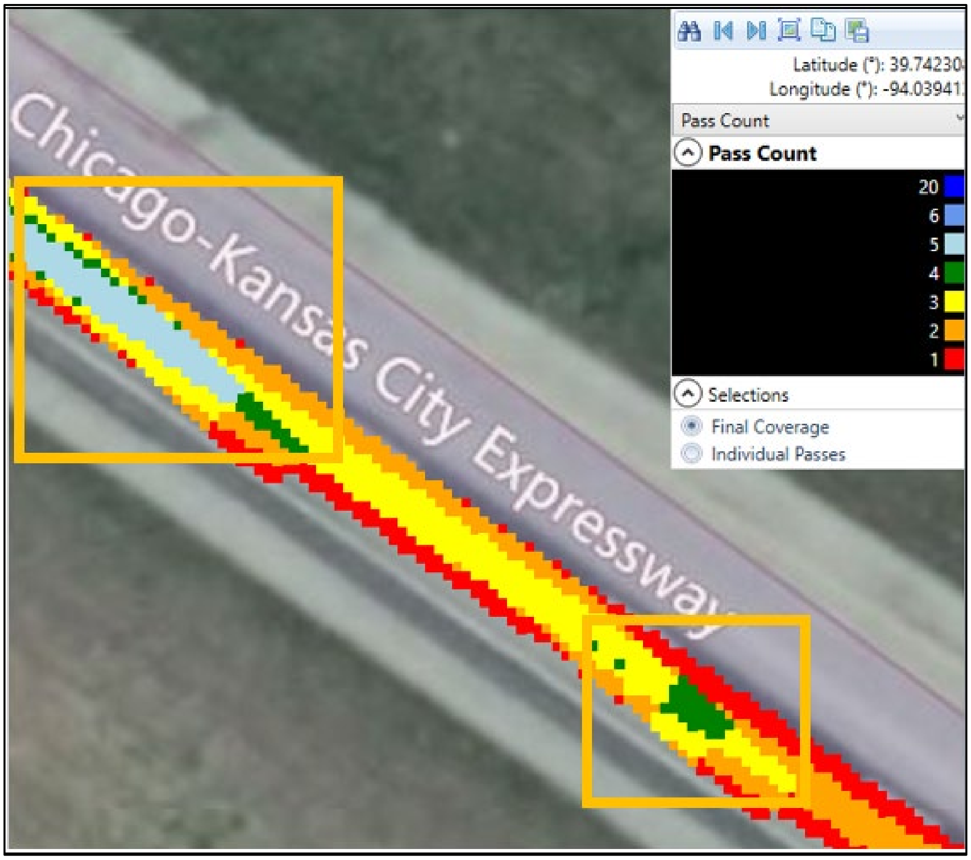


Figure 21. Screenshot. Contractor data was collected using a "coarse" GPS setting.

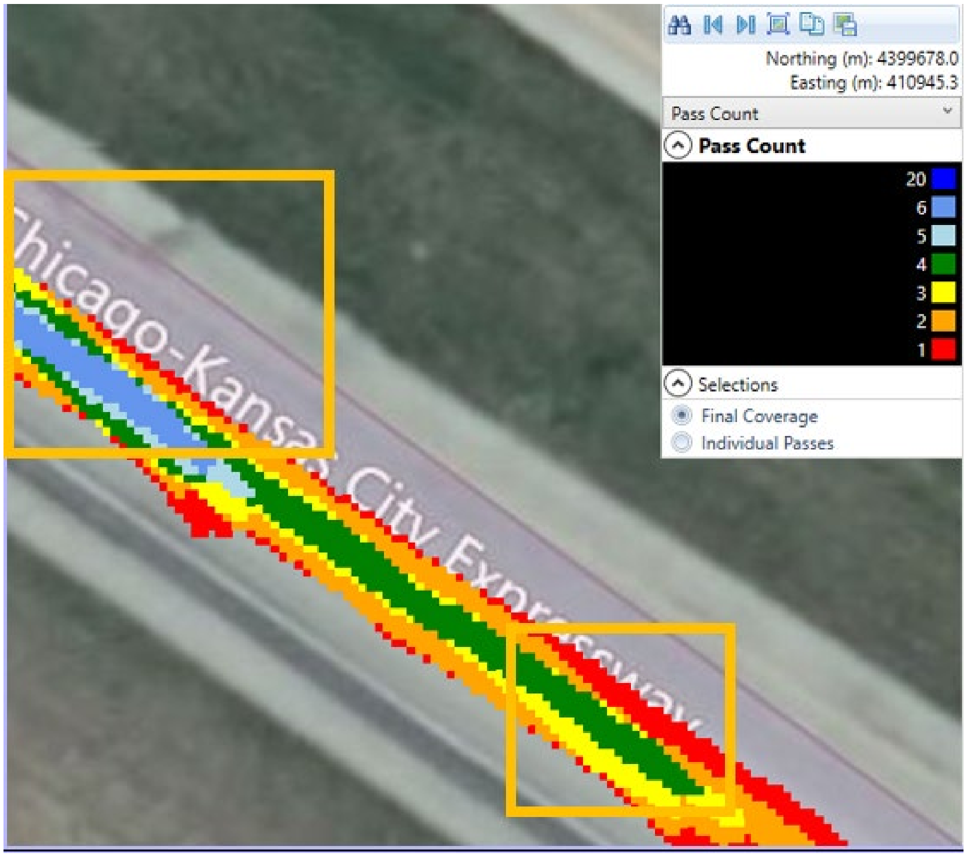


Figure 22. Screenshot. Corresponding (Figure 21) Dirtmate data

6.2.3.2 Missing Unique Roller Identification

Some IC vendors do not allow unique roller identifications in the Veta output files. The data files need unique identifiers to isolate the roller with the Dirtmate for data comparison. The vendors were notified of the issue. The feedback from the vendors was that they plan to update the data file output in the future and will include an option to name the rollers.

Most vendors allow unique roller names. However, it is the responsibility of the contractor to update or modify them. Despite training efforts, some contractors do not use meaningful naming conventions, and it is difficult to isolate the correct roller. In such instances, a “trial and error” approach is needed to find the roller that matches the Dirtmate data. Training efforts and IC protocols should continue to enforce unique roller names.

6.2.3.3 Pass Count Lagging Data

All IC vendors consider speed when collecting location data. As the rollers slow down, less data is collected, and Dirtmate collects data at the same rate regardless of speed. Therefore, at slow speeds, significantly more data is collected with the Dirtmate compared to the contractor IC. This discrepancy is problematic since Veta uses a time rule when calculating coverage, in which 1.5 seconds must pass before a new location is incremented. This rule works well for IC data since the collection frequency slows as the speed of the roller slows. This rule does not work well for Dirtmate data since speed is not considered in data collection. The differences are evident in data comparisons where the rollers are observed slowing (for example, before changing directions). When changing directions, rollers slow and turn to avoid tearing the asphalt. They may roll off the fresh asphalt onto adjacent asphalt during the turn, creating a "tail." "Tails" should have two pass counts since the roller rolls off and back on the mat. In the Dirtmate data, only one pass count is observed in the "tails" due to the time-rule lag. Such an example is observed in Figure 23 (IC data) and Figure 24 (Dirtmate data).

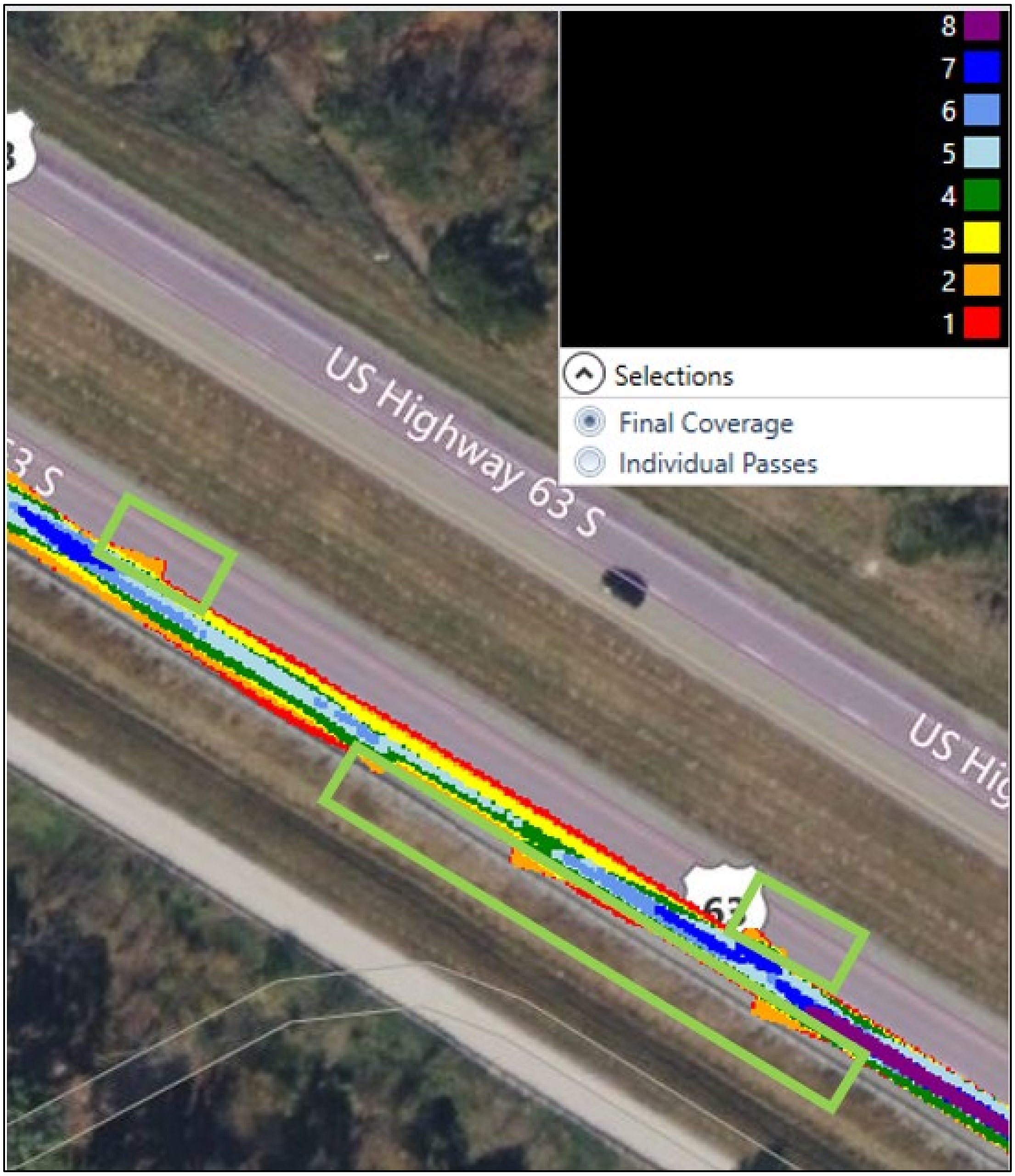


Figure 23. Screenshot. IC data "tails" show two pass counts.

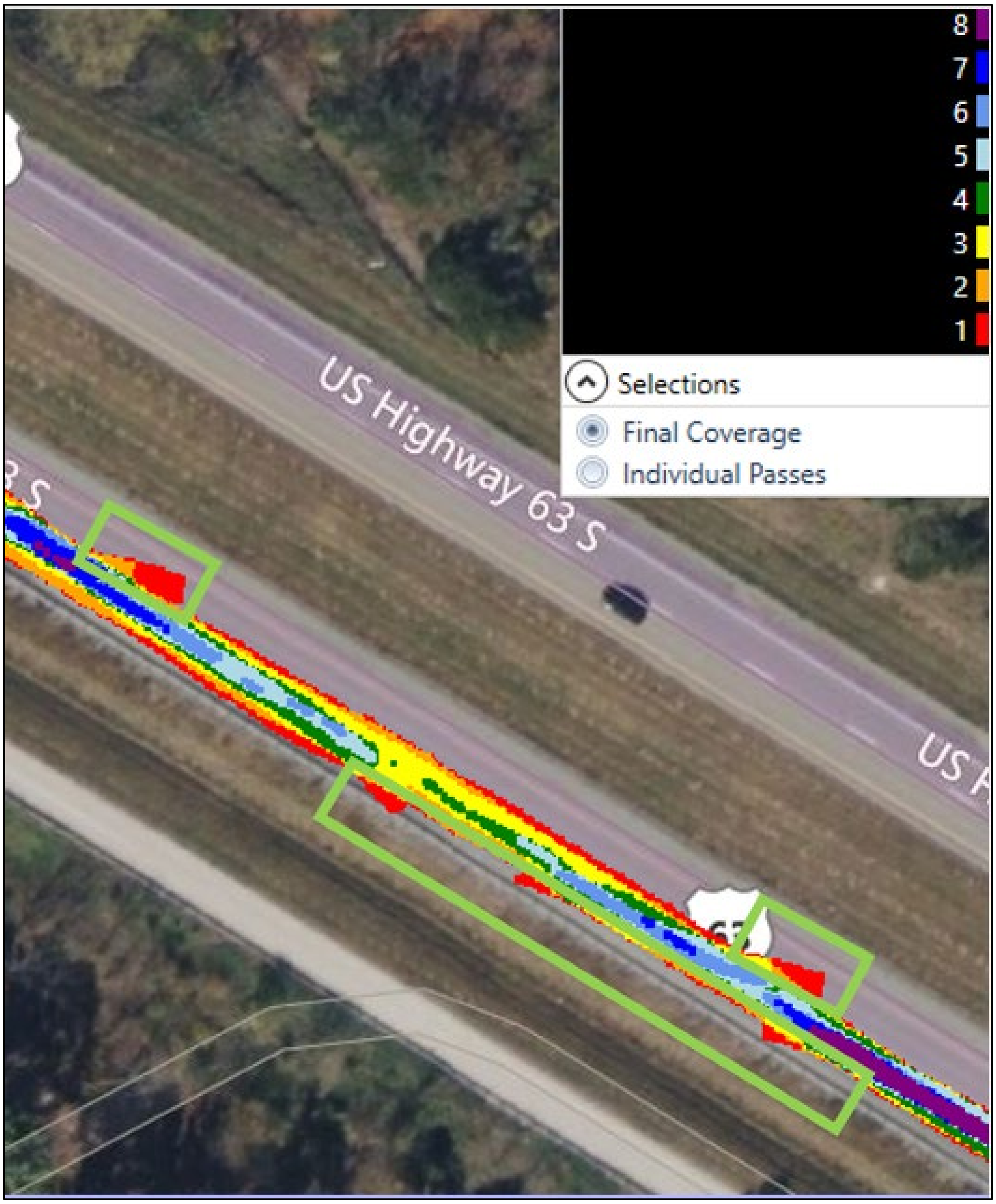


Figure 24. Screenshot. Dirtmate data "tails" show only one pass count.

6.2.3.4 Data Halos

Data halos were described in section 2.4.1 and shown in Figure 1. Data halos continued to be an issue in 2022. Such halos are caused when equipment continues to calculate data when the roller is not moving. IC rollers have created algorithms to address this issue, but Dirtmate has not. Speed filters can be used in Veta to remove the data with very slow speed information, which appears to help remove the data halos. However, such filters must be applied to both data sets (IC and Dirtmate) during the comparison process.

Another solution is to avoid data halos in the comparison. However, having to avoid the halos makes random sampling difficult.

6.2.3.5 Erratic Data or "Shooting Star" Data

Despite the significant improvements using the Gen 3 Dirtmate and the DUG, there are still missing and erratic data. "Shooting star" data refers to an extra pass count in a straight line and outward. This issue was observed in the data collected during the training in the MoDOT parking lot and was brought to Propeller's attention. This issue was repeated several times during the construction season. An example of shooting star data is shown in Figure 25. Missing data typically accompany shooting star data, and the analysis cannot be performed.

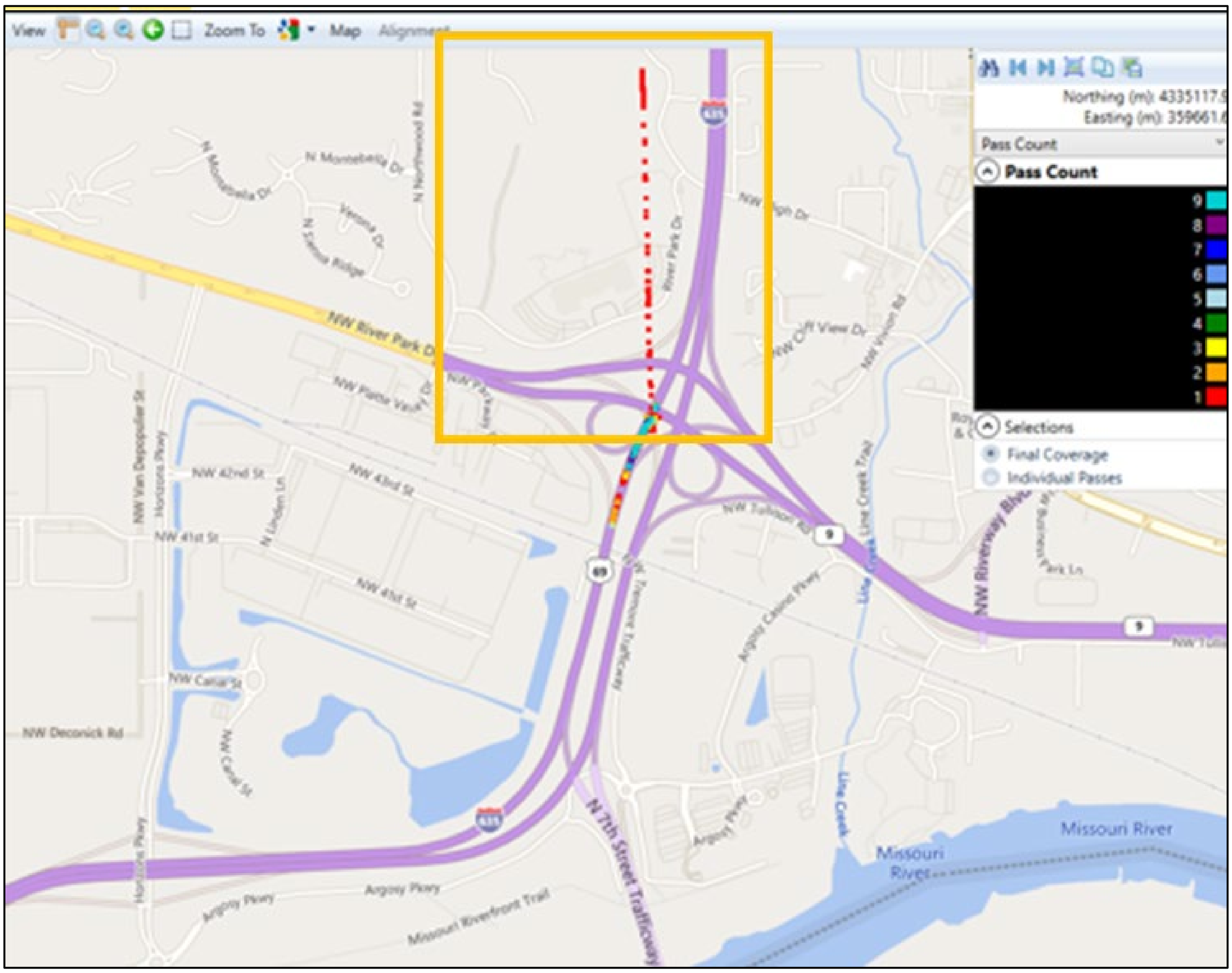


Figure 25. Screenshot. "Shooting star" data was observed in Dirtmate data.

6.2.3.6 Missing Data

Although the number of projects with missing data significantly reduced this year due to the use of DUG, there are still some projects where the data could not be extracted. Possible reasons for missing data were described in section 6.2.1.2.

6.3 PMTP DATA QA

6.3.1 Data Collection

Several issues occurred during FLIR photo collection, as described in section 4.2.8. A troubleshooting FLIR images guide was developed and distributed to MoDOT project staff. A copy of the guide can be found online on the MoDOT IC-PMTP SharePoint site.

Another recurring issue was related to time stamps. Similar to the 2020 pilot studies, some project staff failed to synchronize the FLIR camera timestamp to the contractor equipment. The importance of this step is included in the FLIR quick reference guide and FLIR data collection training video.

The project staff is responsible for taking a valid FLIR image, renaming it according to the standard naming convention, and uploading it to SharePoint.

6.3.2 Data Comparison

After data collection, the Research Team or MoDOT Field Office downloads the FLIR image and contractor PMTP from SharePoint and performs the analysis using Veta and the excel Macro. Several changes were made to the excel Macro to improve the comparison process, as described in section 3.2.3.2.

6.3.3 Data or Procedure Findings

This section includes known issues found during data analysis.

6.3.3.1 Missing Contractor Data

In some cases, there were GPS issues, and the contractor's PMTP data was missing in the location where the FLIR image was taken. In such instances, the comparison cannot be completed.

6.3.3.2 Erratic Contractor Data

The contractor PMTP data was erratic in some cases, as illustrated in Figure 26. In many instances of erratic data, the event marker was not visible in the data. Comparisons were not completed on erratic data.

Figure 26. Screenshot. Example of erratic data.

6.3.3.3 Missing Event Marker in Contractor Data

In some cases, the event marker was not visible in the contractor data. Missing event markers are likely caused by the invalid placement of the event marker. Invalid placement includes placing after the contractor equipment scanned the area or placing it outside the PMTP FOV (e.g., on a shoulder that does not require PMTP data collection).

6.3.3.4 Invalid FLIR Image

Several common issues with FLIR images were observed, as described in section 4.2.8. These were addressed in the Troubleshooting FLIR Photos Guide, which can be found online on the MoDOT IC-PMTP SharePoint site.

6.3.3.5 Too Many Cold Spots in Contractor Data

Some data sets had many random cold spots surrounding the event marker (Figure 27). The excel macro thresholds were revised (reference section 3.2.3.2) to identify the event marker. Despite these improvements, in some cases, it is impossible to identify the correct cold spot without manual intervention. Currently, the excel macro algorithms do not allow such intervention. Since the FLIR timestamp can only be set to the nearest minute, excluding all cold spots surrounding the actual event marker is impossible. In cases with many cold spots, the comparison was not completed.

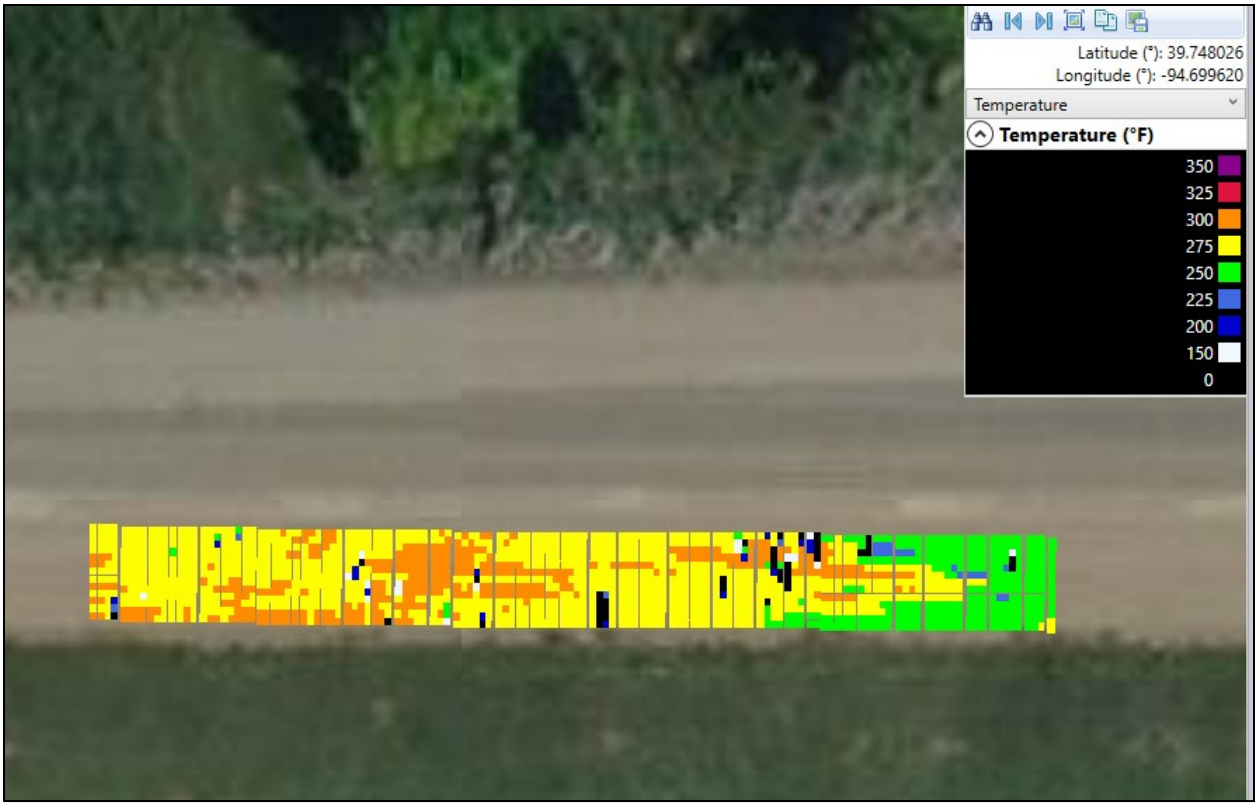


Figure 27. Screenshot. Example of data with many cold spots.

6.4 SUMMARY

The field trials for data QA are ongoing. The Field Office and Research Team continue comparing the IC and verification data. The comparison results are exported to a summary sheet where the data can easily be evaluated for trends. The summary sheet is easily filtered and will facilitate calibration and justification of the comparison thresholds. It is recommended that the final results of the field trials are included in the IC-PMTP annual report.

The issues observed to date have been sent to all contractors, vendors, and MoDOT staff (as applicable) for troubleshooting. It is recommended that the resolutions for these issues are included in the IC-PMTP annual report.

CHAPTER 7 SUMMARY

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

- Upgrading Dirtmate and hotspot equipment. Propeller's solution to past data loss issues was to use Dirtmate GEN 3 equipment instead of the older generations used in previous construction seasons. The solar panels charging efficiency and battery life of the new generations are improved.
- The data transmission device was changed from a Wi-Fi hotspot to Daily Use Gateway (DUG) for IC data QA. The DUG continuously transfers data to the cloud faster than the hotspots when connected to a cellular network. Therefore, the data loss in this season was significantly reduced.
- Some data issues remain. Data halos still exist in Dirtmate data. Speed filters are a temporary solution for filtering data halos while Propeller's research and development team find a solution.
- For PMTP data QA, the device used to take a thermal image, FLIR E5-XT, was not changed from the previous season. A 2-foot by 2-foot event marker was used this season since the 1-foot by 1-foot event marker could not be well identified because of the grid size of PMTP data.
- For PMTP data QA, the data QA macro tool was updated with several improvements on raw and filtered data visualization, data processing, and reporting. One of the outputs is the quantile results that facilitate comparing FLIR and PMTP data distribution. The Research Team continues to streamline the PMTP data QA tool.

Training materials were updated. Training materials included the original, step-by-step instructions developed in 2020 (updated for 2022). New training materials included quick reference guides and QR code stickers that lead to the quick reference guides. Quick reference guides were also printed and laminated and provided to project staff. Training videos and troubleshooting guides were created for PMTP FLIR image taking. All the training materials were uploaded to the IC-PMTP SharePoint, and an interactive DocHelper Navigator interactive document was created to help MoDOT and contracting staff navigate the site and content. It is recommended that during the 2022 IC-PMTP feedback meeting, project staff, contractors, and industry attendees should be asked to provide feedback on the training materials to see which materials were most effective (e.g., are in-person JITT training sessions, detailed step-by-step guides, quick reference guides, or videos preferred).

JITT and TTT were new training programs that aimed to provide more specific training tailored to the District Office or Field Office needs than annual workshops. This training emphasized data QA data collection (JITT) and analysis (TTT). These seemed to be valuable additions to MoDOT's IC-PMTP program. Breaking the data QA training into smaller sessions made the material easier to understand and limited the content participants needed to digest. It is recommended that such training programs are continued in future construction seasons.

The field trials for the new IC and PMTP data QA procedures are ongoing. The Field Office and Research Team continue comparing the IC and verification data. The comparison results are exported to a summary sheet where the data can easily be evaluated for trends. The summary sheet is quickly filtered and will facilitate calibration and justification of the comparison thresholds. The issues observed to date have been sent to all contractors, vendors, and MoDOT staff (as applicable) for troubleshooting. It is recommended that the resolutions for these issues and the final data QA results from 2022 are included in the IC-PMTP annual report.

MoDOT elected not to purchase DPS equipment at this time. Therefore, detailed QA procedures were not developed. However, the Research Team members are in the DPS technical working group (TWG) for TPF-5(443). They are familiar with its research on certification and verification efforts for DPS equipment used for acceptance decision-making. If MoDOT elects to use DPS equipment in the future, it is recommended that they review the TPF-5(443) recommendations for suitability in their program.

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