Accelerated Innovation Deployment (AID) Demonstration Project:

Intelligent Compaction and Infrared Scanning Projects

Final Report
February 2018

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INTRODUCTION

ACCELERATED INNOVATION DEPLOYMENT (AID) DEMONSTRATION GRANTS

The Accelerated Innovation Deployment (AID) program is one aspect of the multi-faceted Technology and Innovation Deployment Program (TIDP) approach, which provides funding and other resources to offset the risk of trying an innovation. The AID Demonstration funds are available for any project eligible for assistance under title 23, United States Code. Projects eligible for funding shall include proven innovative practices or technologies such as those included in the EDC initiative. Innovations may include infrastructure and non-infrastructure strategies or activities, which the award recipient intends to implement and adopt as a significant improvement from their conventional practice.

The Federal Highway Administration (FHWA) Accelerated Innovation Deployment (AID) Demonstration grant program, which is administered through the FHWA Center for Accelerating Innovation (CAI), provides incentive funding and other resources for eligible entities to offset the risk of trying an innovation and to accelerate the implementation and adoption of that innovation in highway transportation.

Projects deemed eligible for funding included proven innovative practices or technologies, including infrastructure and non-infrastructure strategies or activities, which the applicant or subrecipient intends to implement and adopt as a significant improvement from their conventional practice. The AID Demonstration funds were available for any project eligible for assistance under title 23, United States Code.

Entities eligible to apply included State departments of transportation (DOT), Federal Land Management Agencies, and tribal governments as well as metropolitan planning organizations (MPOs) and local governments which applied through the State DOT as subrecipients.

REPORT SCOPE AND ORGANIZATION

This report documents the Missouri Department of Transportation (MoDOT) demonstration grant award for field demonstration projects using intelligent compaction (IC) and infrared scanning (IR) (also called paver-mounted thermal profiles PMTP in the AASHTO PP80 specification). IC is an EDC 2 innovation. IR is a FHWA Strategic Highway Research Program 2 (SHRP2) technology. The report presents details relevant to the employed project innovation(s), the overarching TIDP goals, performance metrics measurement and analysis, lessons learned, and the status of activities related to adoption of intelligent compaction and paver-mounted thermal profiles as conventional practice by MoDOT.

PROJECT OVERVIEW

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The Missouri Department of Transportation (MoDOT) was awarded a grant from the FHWA Accelerated Innovation Deployment (AID) program in 2016. MoDOT provided the required matching funding to support this Intelligent Compaction (IC) and Infrared Scanning (IR) Field Projects with Consulting Support in 2017. The term “IC” is defined in the AASHTO PP81-17 terminology. The term “IR” is equivalent to the AASHTO PP80-17 terminology for Paver-Mounted Thermal Profiles (PMTP).

The consulting support provided by the Transtec Group (Consultant) includes the development of MoDOT IC-IR protocols and training materials, conducting IC-IR training, on-site technical support to IC-IR field projects, and analysis and reports of IC-IR field data.

The first MoDOT IC-IR contract (No. TR201706) was funded by the AID grant and matching funds, included support for ten (10) field projects. The second MoDOT IC-IR contract (No. TR201802) was funded by MoDOT to add support tasks for three additional IC-IR field projects. Therefore, a total of thirteen (13) IC-IR field projects were performed under these two contracts.

The main goal of this project is to demonstrate the usage of IC, IR, and the Veta software to improve construction quality control (QC) and efficiency to make pavements last longer and to reduce maintenance cost.

LESSONS LEARNED

Through this project, the MoDOT gained valuable insights with regard to the innovative intelligent compaction (IC) and infrared scanning (IR) used. The following were some of the lessons learned:

- The MoDOT IC-IR projects in 2017 can be considered a success in terms of building up experiences for both MoDOT personnel and contractors.
- The IC-IR project protocol proved to be mostly effective for planning and conducting field projects. The IC-IR data management is a key component of the Protocol to ensure consistent data naming convention and submission. The MoDOT SharePoint is very useful to share data files, especially when the file sizes are too large as email attachments.
- The IR implementation has shown as a real-time indicator of any temperature segregation. In turn, the IR data and analysis reports can be used to fine tune paving process accordingly, such as making use of MTV and adjustment of truck fleet and paving speeds.
- There are issues with IR regarding the DMI/data sampling issues of a vendor’s system and analysis issues with a vendor’s software. These issues can be resolved with better training and use of the standard software, Veta, for analysis.

- The IC implementation has been mostly utilized to maximize roller coverage with some exceptions. The latter can be resolved by planning the construction operations based on project location and alignment, lift thickness to be constructed, type of materials, and availability of equipment and resources, along with proper training.
- There were issues with IC roller calibration that requires better vendor's training to overcome.
- The GPS boundary measurements were mostly successful with occasional issues that require sorting, inspection, and correction.
- The IC-IR data management is still tedious, especially when IC or IR data need to be exported/transferred manually. There were occasional human errors that caused incorrect file naming convention, etc. Better training with the Protocol and additional experiences will resolve these issues.
- There was still a lack of submission of check lists, forms, and paving records to the SharePoint site.
- Most of core data were not submitted to the SharePoint.

MoDOT also conducted a very successful "Industry Feedback" meeting to share "Lessons Learned" and to receive industry feedback to improved future IC-IR projects. Further details are described in this report.

PROJECT DETAILS

BACKGROUND

The project involved 13 IC-IR field projects and related planning, training, data analysis and report. The locations for the MoDOT IC-IR field projects and workshops are shown in Figure 1.

Figure 1: MoDOT IC-IR Project and Workshop Locations.

PROJECT DESCRIPTION

This project included five (5) main tasks.

- Task 1 – Kick Off Meeting
- Task 2 – IC-IR Data Management Protocol
- Task 3 – IC-IR Training Courses
- Task 4 – IC-IR Field Project Supports
- Task 5 – IC-IR Specifications

Task 1 – Kick-Off Meeting

The Consultant conducted a kick-off meeting with MoDOT. The purpose was to discuss the Work Plan for any updates or modifications, if needed. Deliverables included the meeting minutes and updated work plan within two weeks of notice to proceed of this project.

Task 2 – IC-IR Data Management Protocol

The Consultant developed IC-IR Data Management Protocol to include the following elements:

- File folder structure (daily data folders, raw data, exported data, rover boundary files, Veta files, spot tests files, correlation analysis files)
- File and Veta filter group naming convention (lot info: route type, route number, material, layer, lane offsets, direction; daily operation: date, lot name, lot number, machines)
- GPS and IR sensors validation records
- Daily operation records (paving section-direction and lanes, layer information, paver information, breakdown/intermediate/finish rollers, boundary rover data, associated spot tests, associated spot tests)

Deliverables include the IC-IR Data Management Protocol document.

Task 3 – IC-IR Training Courses

Task 3-1: Development of IC-IR Training Course Materials

The Consultant developed one-day instructor-led training materials for IC-IR. The training materials include the following:

- Technical background of IC and IR
- IC and IR measurements and analysis
- Positioning systems
- MoDOT IC-IR Data Management Protocol
- Case Studies and hands-on exercises with Veta and MOBA PaveManager Software

Deliverables include the IC-IR Training presentation materials in MS PowerPoint formats, handout materials in PDF format, and case study files in Veta project files.

Task 3-2: Conduct IC-IR Training Courses

The Consultant conducted one-day instructor-led IC-IR training courses for personnel from the seven (7) MoDOT District Offices. All contractors' Quality Control (QC) managers and technicians that are involved in the 13 AID IC and IR projects were trained during these workshops. Based on the training facilities, computers, and trainee locations, the dates and locations were designated by the MoDOT project manager to facilitate the delivery of the training courses closer to the corresponding paving dates.

One of the key components of the training courses was to train MoDOT staff and contractors how to take advantage of IC and IR technologies for their own QC and Quality Assurance (QA) benefits. The training stressed on trouble shooting in the field to ensure adequate IC-IR operations and data collection.

Task 4 – IC-IR Project Support

The Consultants provided technical support for 13 IC-IR projects according to the following sub-tasks for each project. Further information regarding these field projects are described in a later chapter in this report.

Task 4-1: Planning for IC-IR Data Management

The Contractor provided ad hoc planning meeting for each field project, generally during the IC-IR training workshop one to several weeks prior to the paving. The email correspondence includes MoDOT IC-IR project manager, inspector, and contractors. The MoDOT IC-IR data management protocol and check list were reviewed by all parties.

Task 4-2: Field Support

The Contractor provided field support for each field project. The Contractor provided onsite technical support during the first few days of each paving project. The key was to ensure proper IC-IR operations and data reviews for the first few days of paving.

Task 4-3: IC-IR Data Analysis

The Contractor conducted IC-IR data analysis for each field project. The analysis includes data observations, statistics analysis and correlation analysis to indicate any issues and evaluate the quality levels with field operations.

Task 4-4: IC-IR Project Reports

The Contractor produced a concise report for each field project. The reports focused the benefits and lessons learn on IC-IR technologies. The reports served as case studies to facilitate the marketing of the IC-IR technologies within Missouri. Deliverables included field support for all IC-IR projects, and completed data analysis and project reports.

Task 5 – IC-IR Specifications

Drawing on experiences from the IC-IR field projects, the Contractor provided recommendations for modifications to the MoDOT IC and IR specifications. The modification reflected the practicality of field operations and local needs of MoDOT.

Schedule of IC-IR field Projects

The schedule for the MoDOT IC-IR field projects is listed in Table 1.

Table 1. MoDOT IC-IR Project Schedule

No.	Job No.	District	County	Route	Start Date	End Date	Paving Days
1	J5P3117	CD	Morgan	52	5/9/2017	7/13/2017	19
2	J4I3111	KC	Clay	29	8/18/2017	9/16/2017	7
3	J3I3042	KC	Lafayette	70	8/14/2017	9/13/2017	18
4	J2P3099	NE	Macon	36	5/8/2017	5/17/2017	7
5	J2P3100	NE	Macon	36	5/25/2017	6/21/2017	12
6	J2P3051	NE	Randolph	24	10/21/2016	11/3/2016	8
7	J1P3005	NW	Chariton	24	4/24/2017	5/16/2017	9
8	J9P3161	SE	Texas	17	9/28/2017	10/19/2017	11
9	J6S3123	SL	Jefferson	61	5/31/2017	6/9/2017	9
10	J7I3072	SW	McDonald	49	6/5/2017	7/6/2017	13
11	J1S3028	NW	Daviess	69	6/29/2017	7/7/2017	5
12	J5P3170	CD	Cooper	5	9/8/2017	9/19/2017	10
13	J9P3296	SE	Texas	17	7/5/2017	8/18/2017	16

The IR and IC systems used for each of the MoDOT IC-IR field projects is listed in Table 2.

Table 2. MoDOT IC-IR Project Systems Used

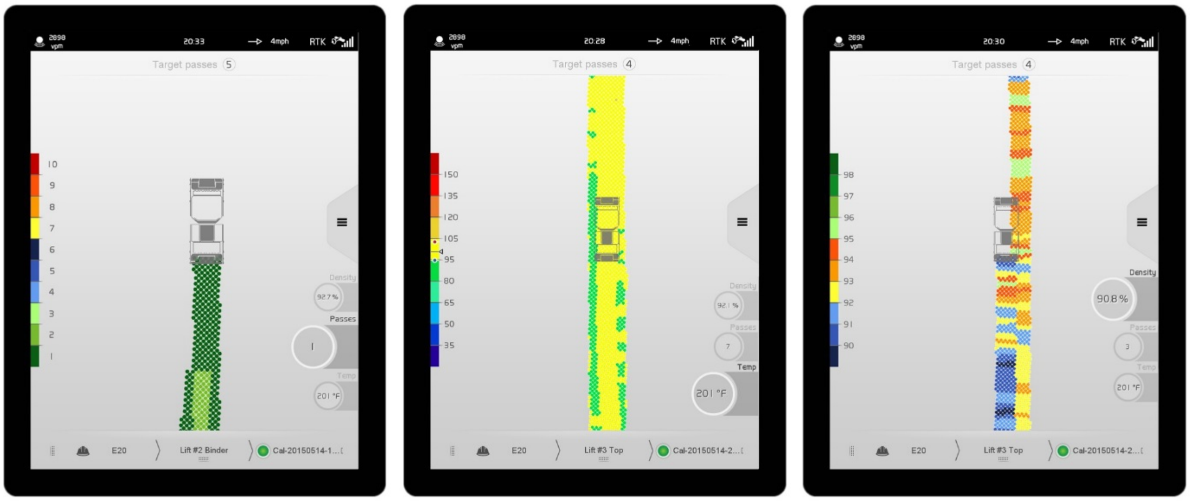
No.	Job No.	District	County	Route	IR System	IC System
1	J5P3117	CD	Morgan	52	MOBA-PAVEIR	TOPCON
2	J4I3111	KC	Clay	29	MOBA-PAVEIR	Trimble
3	J3I3042	KC	Lafayette	70	MOBA-PAVEIR	Volvo
4	J2P3099	NE	Macon	36	MOBA-PAVEIR	Volvo
5	J2P3100	NE	Macon	36	MOBA-PAVEIR	Volvo
6	J2P3051	NE	Randolph	24	MOBA-PAVEIR	Trimble
7	J1P3005	NW	Chariton	24	MOBA-PAVEIR	Trimble
8	J9P3161	SE	Texas	17	MOBA-PAVEIR	TOPCON
9	J6S3123	SL	Jefferson	61	MOBA-PAVEIR	Caterpillar
10	J7I3072	SW	McDonald	49	MOBA-PAVEIR	Trimble
11	J1S3028	NW	Daviess	69	MOBA-PAVEIR	Trimble
12	J5P3170	CD	Cooper	5	MOBA-PAVEIR	TOPCON
13	J9P3296	SE	Texas	17	MOBA-PAVEIR	Volvo

INNOVATIVE TECHNOLOGIES

The following is a comprehensive description of the main innovative technologies used for this project: IC, IR, and Veta software.

IC Technologies

Intelligent compaction is an equipment-based technology to improve quality control of compaction. IC vibratory rollers are equipped with a high precision global positioning system (GPS), infrared temperature sensors, an accelerometer-based measurement system, and an onboard tablet computer for real time display of color-coded maps (e.g., passes, temperature, Intelligent Compaction Measurement Values, ICMV, etc. as shown in Figure 2). GPS is used interchangeably with Global Navigation Satellite System (GNSS) in this report. IC can be used to improve compaction control for various pavement materials including granular and clayey soils, subbase materials, and asphalt materials. The accelerometer-based measurement system, ICMV, is a core IC technology that was invented in the early 80’s and is still evolving today.



Courtesy of Volvo

Figure 2. Example of IC Color-coded Displays for Roller Passes, Asphalt Temperatures, and ICMV.

IC systems are available in two forms: Original Engineering Manufacture (OEM, Figure 3) and after-market IC retrofit (Figure 4). The OEM is directly from roller vendor's factory. The IC retrofit can be mounted on selected models of rollers.

Figure 3. Examples of OEM Double-Drum IC Rollers.

Figure 4. An Example of IC Retrofit Systems.

Intelligent Compaction Measurement Value is a generic term for an accelerometer-based measurement system instrumented on vibratory rollers as a key component of intelligent compaction systems. ICMV is based on the acceleration signals that represent the rebound force from the compacted materials to the roller drums. ICMV comes in different forms of metrics with various levels of correlation to compacted material's mechanical and physical properties, such as stiffness, modulus, and density (Figure 5).

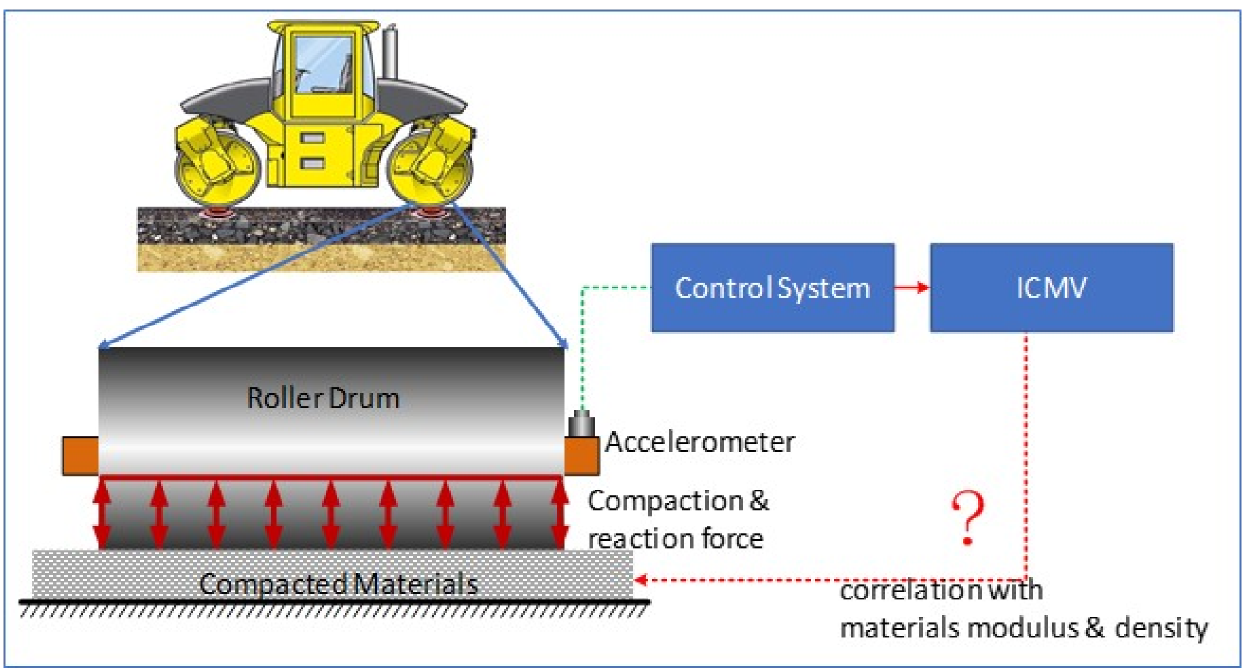


Figure 5. Method of Measuring and Calculating ICMV.

A recent FHWA IC Technical Brief provides a comprehensive description of ICMV and a classification system based on its correlation with in-situ spot tests, whether valid when drum-materials decouple, and whether it can be used to produce layer-specific mechanical properties. Table 3 and Table 4 summarize key information from this Tech Brief.

Table 3. Summary of ICMV Model and Methods (FHWA ICMV Tech Brief).

Model	Methods	Mechanistic /Empirical	Dynamic/Static
A	Reactive Models	Empirical	NA
B	Continuous Roller and Half-space Layered System	Mechanistic	Dynamic/Static
C	Lump Model - Drum and Spring-Dashpot Coupled system	Mechanistic	Dynamic
D	Dynamic Impact Model for Decoupled Drum and Compacted Layer System	Mechanistic	Dynamic
E	Artificial Intelligence Method	Mechanistic	Dynamic data

Table 4. Classification of ICMV Levels (FHWA ICMV Tech Brief).

Level	Model	Measurement Values	Correlation[1]	Decouple[2]	Layer specific[3]
1	A1, A2 Empirical	Harmonic ratio	Weak or Poor	No	No
2	A3 Energy	Energy index	Weak or Poor	NA[4]	No
3	B + C Discrete vibration, continuous static	Stiffness, resistance force, modulus	Good	No	Difficult
4	D Hybrid	Resistance force, Modulus	Good	Yes	Yes
5	D + E Continuous dynamic	Density, Modulus	Excellent	Yes	Yes

Notes:

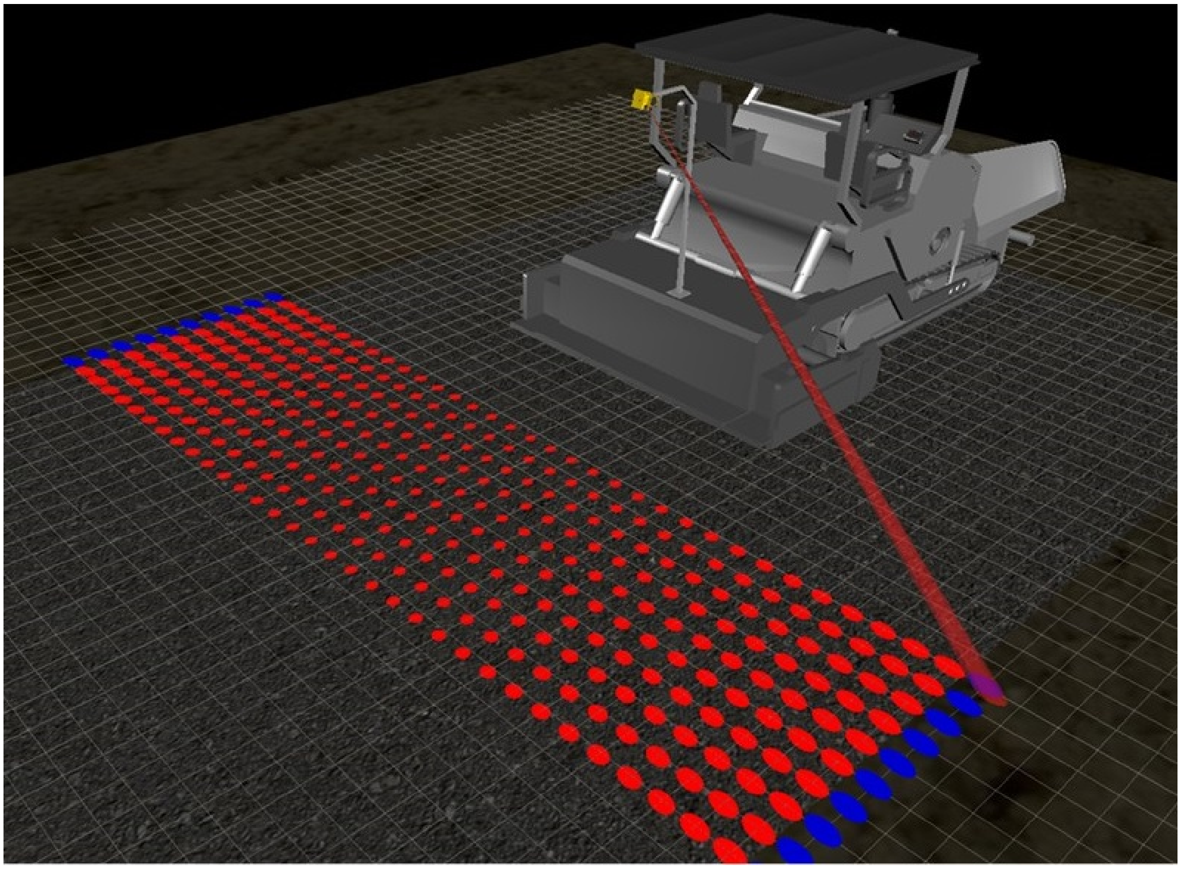
1. Correlation with mechanical and physical properties of various compacted materials.
2. Valid measurement when drum and compacted materials are decoupled (loss of contact).
3. Allow layer-specific measurements of compacted materials mechanical and physical properties.
4. Model A3 functions in static rolling.

The ICMVs used for the MoDOT field projects included: Compaction Meter Value (CMV), Compaction Control Value (CCV), and Estimated Density Value (EDV). The first two were considered a Level 1 solution, while the third is not classified due to lack of third-party field validation test data.

The IC systems used for the 13 MoDOT field projects included: OEM Caterpillar system, OEM Volvo System, Trimble IC retrofit system, and TOPCON IC retrofit system. Wireless transmitting of IC data to the vendors' cloud was available for all of these systems except Volvo. The Caterpillar and Trimble systems use VisionLink, while the TOPCON system uses SITELINK3D. The cloud solution can prevent data loss and make future "direct import of data from the cloud to Veta" feature possible. The limitation of using wireless data transmission is cellular signal coverage in remote project locations. Machine-to-machine communication was not available for the IC systems used under this project.

IR Technologies

The IR or PMTP systems make use of infrared scanners or thermal imaging techniques to measure asphalt mat temperatures right behind the paver (Figure 6). The IR system is equipped with GPS and a DMI to track the positions of thermal profiles and paver speeds (Figure 7). The IR system used for the 13 field projects was the MOBA PAVE-IR system. Wireless transmitting IR data to the vendors' cloud was available for the MOBA PAVE-IR system.



Courtesy of MOBA

Figure 6. An Illustration of an IR System.

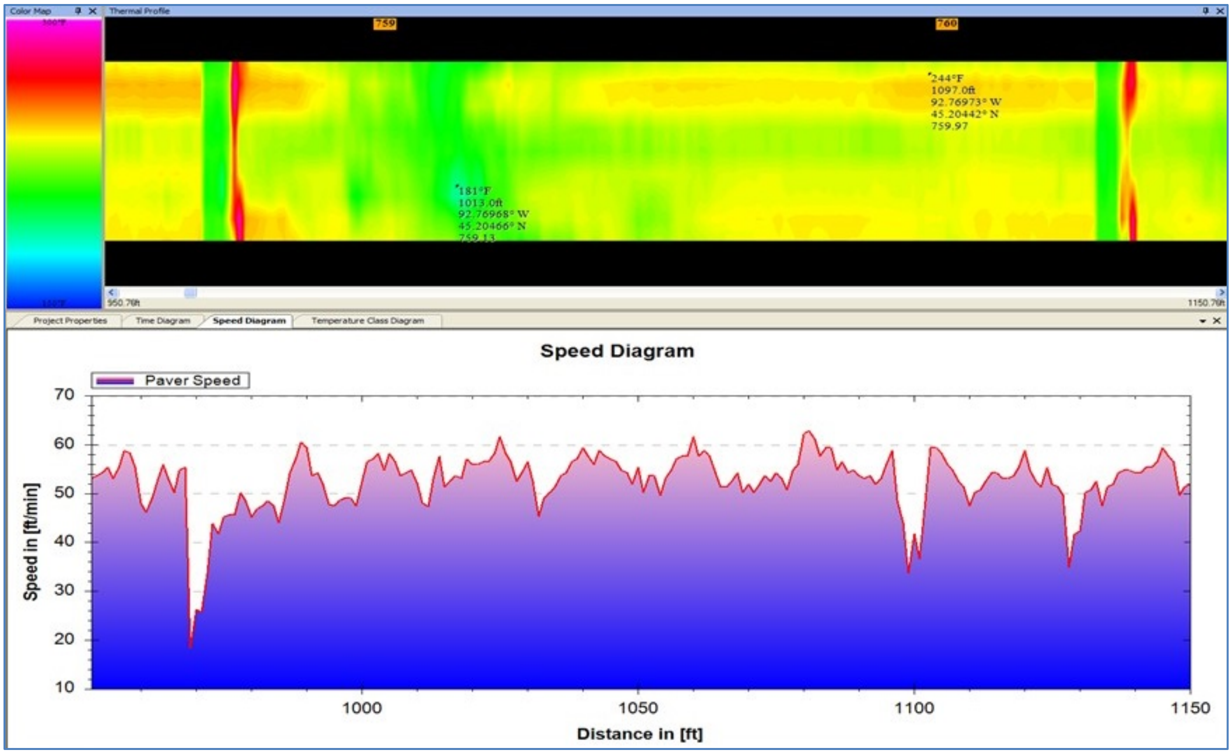


Figure 7. An Example of IR Display of Thermal Profiles and Paver-Speed.

Veta Software

Veta is a public-domain standardized software for IC and IR analysis. It is required in the AASHTO PP81-17 specifications and most State Highway Agency (SHA) IC specifications. The Consultant developed and is continuously enhancing Veta with the funding from the Transportation Pooled Fund study, “TPF-5(334) Enhancement to the Intelligent Construction Data Management System (Veta) and Implementation”.

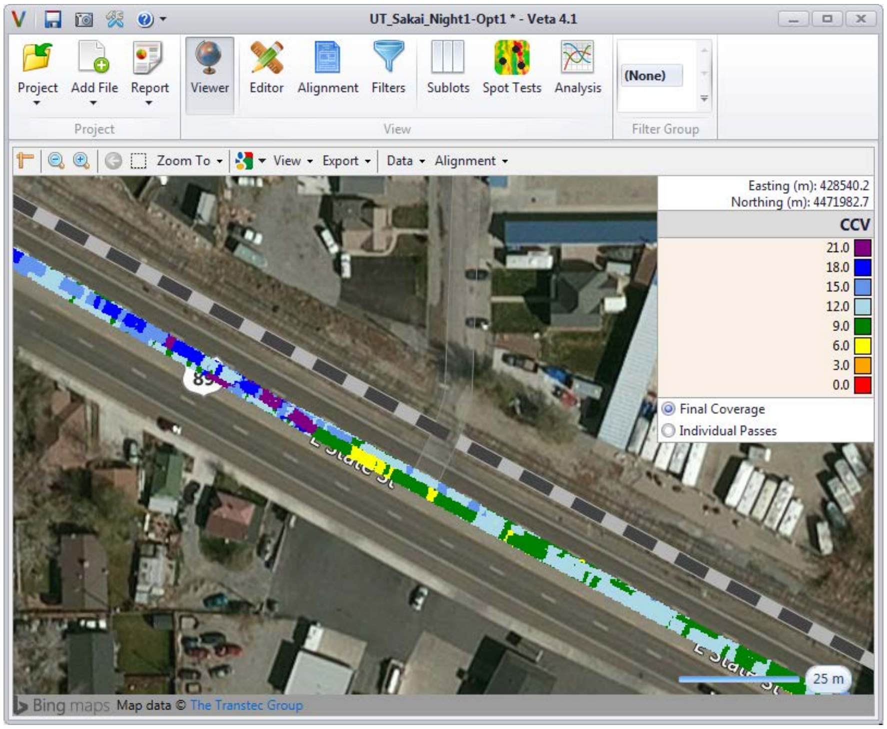


Figure 8. AASHTO Standard Software Veta for Intelligent Construction Data Management.

Veta can import data from various IC machines and MOBA PAVE-IR thermal bars and scanners to perform editing, data layering, point testing, and analysis (Figure 9). IC data are collected as raw ungridded data as one point across the drum. The raw IC data are then gridded typically in 1 ft. X 1 ft. cells to better track detailed positions of roller coverage (Figure 10). The “all-passes” IC data include all IC data through the entire compaction process. The final coverage is the final product or the “bird’s-eye view” of the IC data layers (Figure 11). Veta now imports all-passes data and produce final coverage data. Veta displays compaction information in easy-to-read formats, including graphs and maps (Figure 12). Veta was used for all IC and IR analysis under this project.

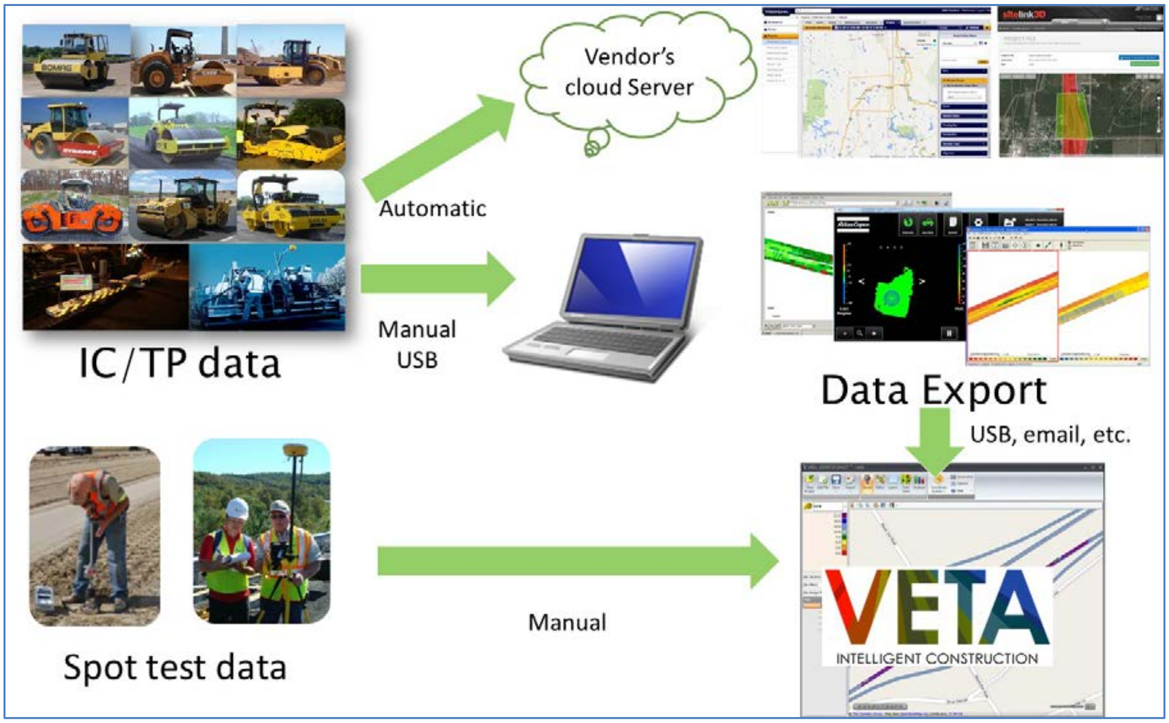


Figure 9. IC and IR Data Flow to Veta.

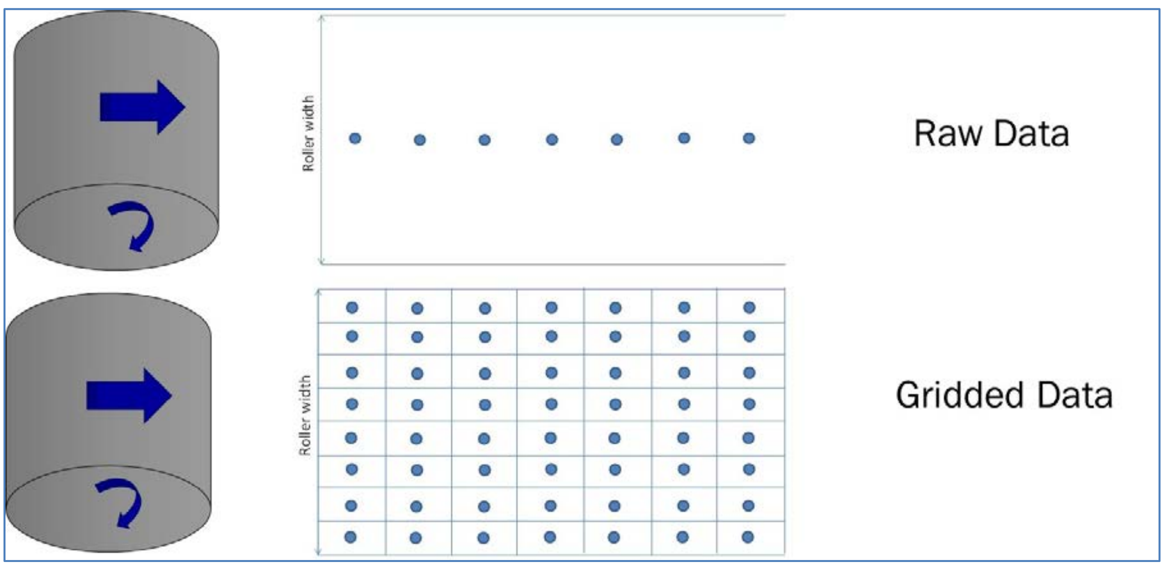


Figure 10. IC Raw and Gridded data.

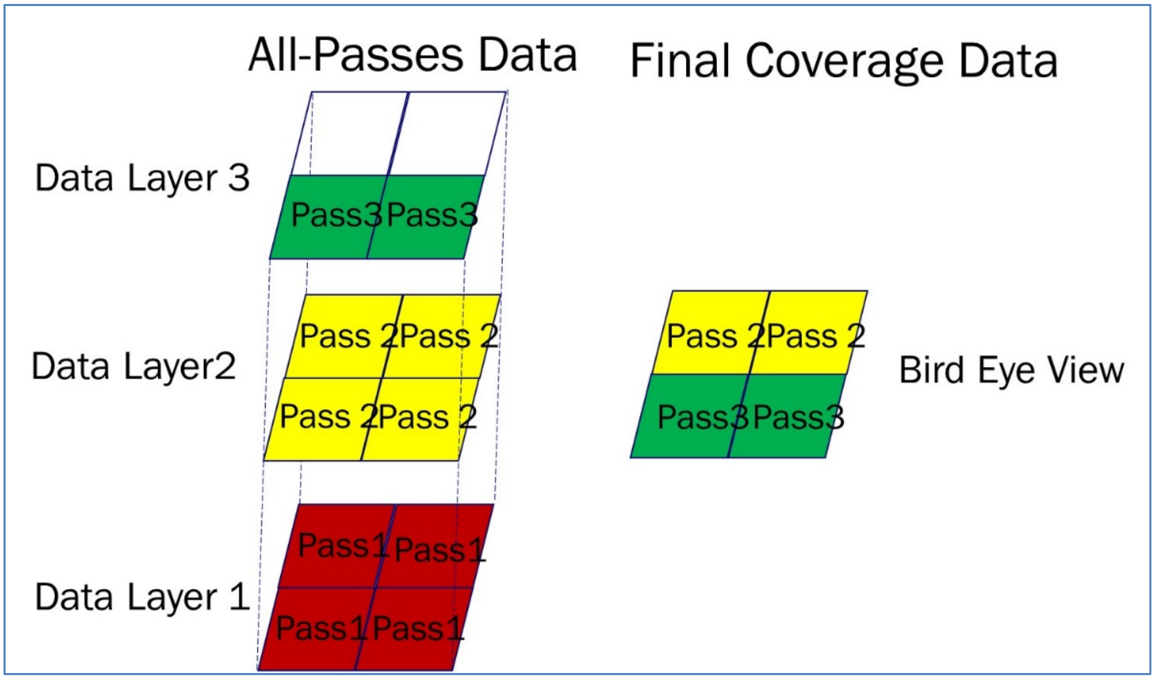


Figure 11. IC All-Passes Data and Final Coverage data.

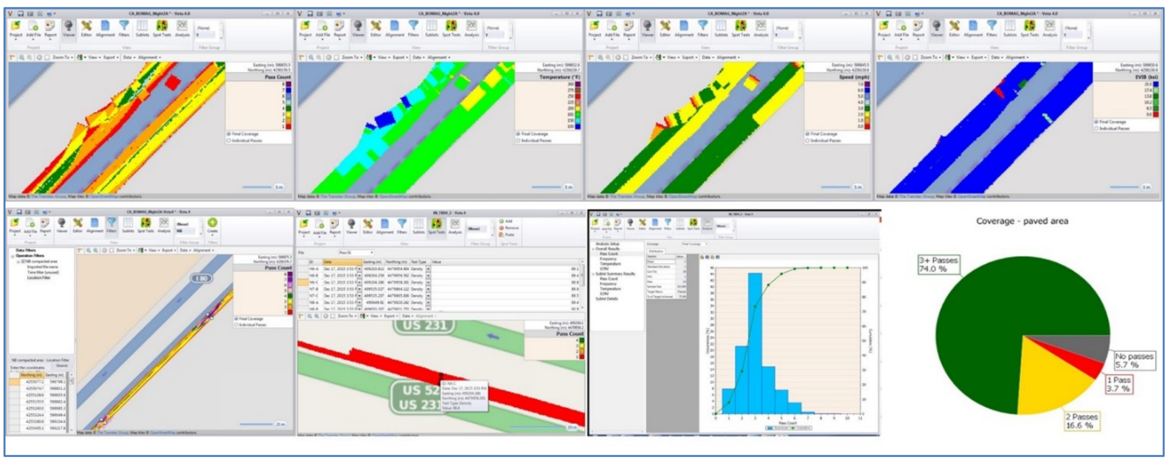


Figure 12. Screenshots of Veta Displays and Analysis.

DATA COLLECTION AND ANALYSIS

Performance measures consistent with the project goals were jointly established for this project by MoDOT and FHWA to qualify, not to quantify, the effectiveness of the innovation to inform the AID Demonstration program in working toward best practices, programmatic performance measures, and future decision-making guidelines

Data was collected to determine the impact of using IC-IR on improve asphalt pavement construction quality and demonstrate the ability to:

- Identify potential temperature segregation with IR
- Achieve consistent compaction with IC

This section discusses how the MoDOT established baseline criteria, monitored and recorded data during the implementation of the innovation, and analyzed and assessed the results for each of the performance measures related to these focus areas with IR and IC data analysis.

IR DATA ANALYSIS

The IR data was analyzed using the MOBA PaveProj Program (PPM) reports as per the MoDOT IR specification. Veta (version 4.1) analysis reports were generated for informational purposes. Veta uses the AASHTO PP 80-17 method to compute the "Range" values by taking the differences between the 98.5-percentile value and 1-percentile value of thermal profile data with a given 150 ft. sublot. The areas of any paver stop, 2 ft. before and 8 ft. after, were excluded from temperature differential computation as per AASHTO PP 80-17 specification (Figure 13). MOBA indicates that the intention of this exclusion is to capture temperature segregation during "normal paving operation".

The remaining data are used to calculate the Range value, 98.5th percentile – 1th percentile (Figure 14). The classification of temperature segregation is based on the Range value as follows: Low (Range ≤ 25.0 °F); Moderate (25.0 °F < Range ≤ 50.0 °F); and Severe (Range > 50.0 °F), as shown in Figure 15. The temperature segregation based on the above analysis method does not consider the effects of paver stops.

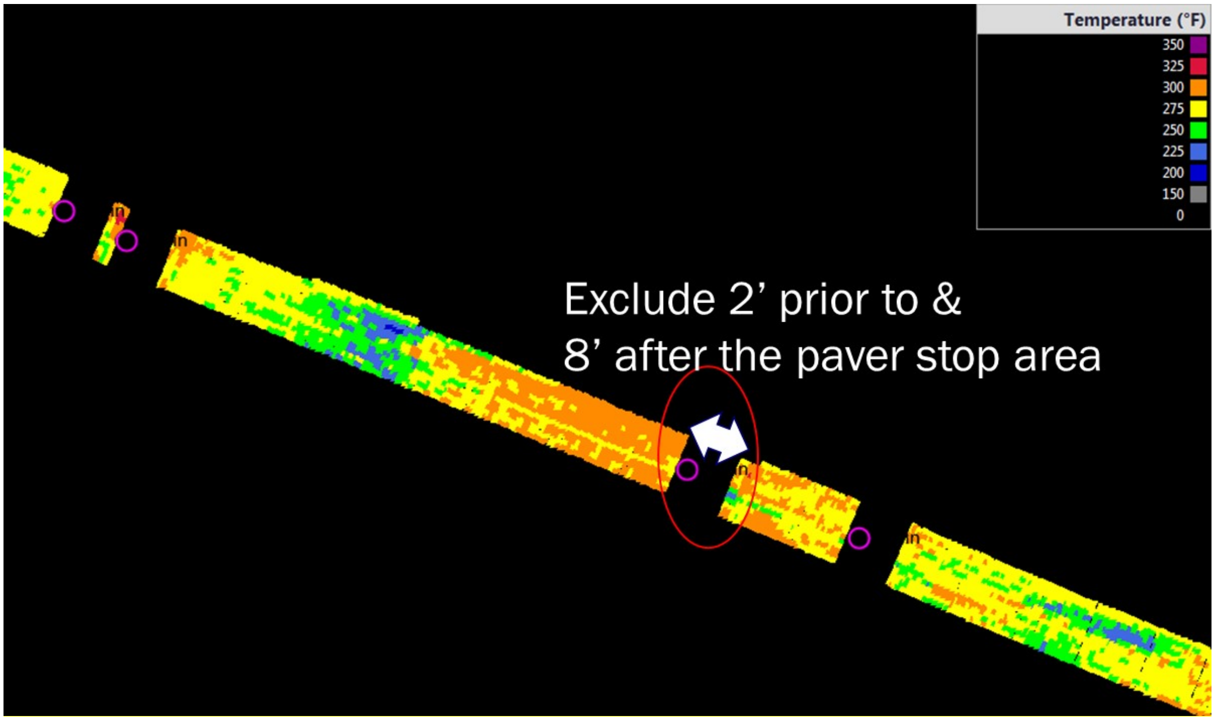


Figure 13: AASHTO PP80 IR Analysis Method: 10' exclusion around a paver stop location

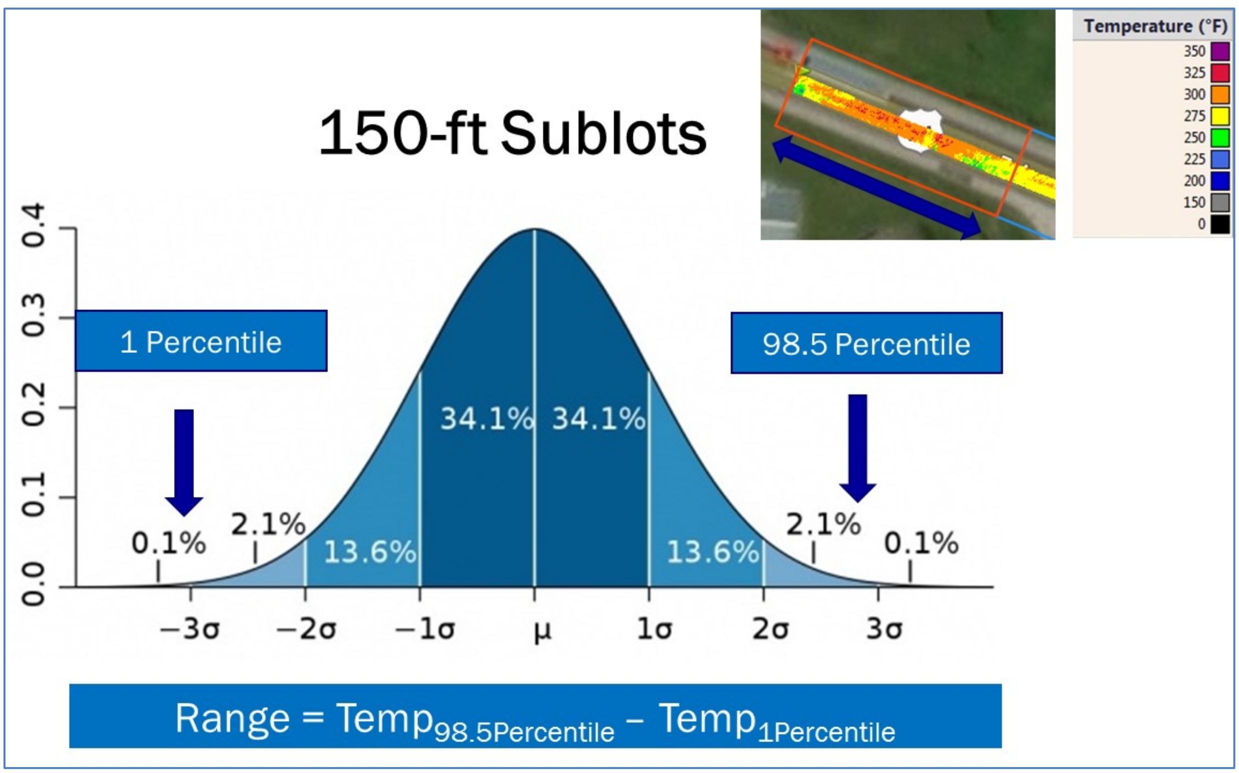


Figure 14: AASHTO PP80 IR Analysis Method: Computation of "Range" value

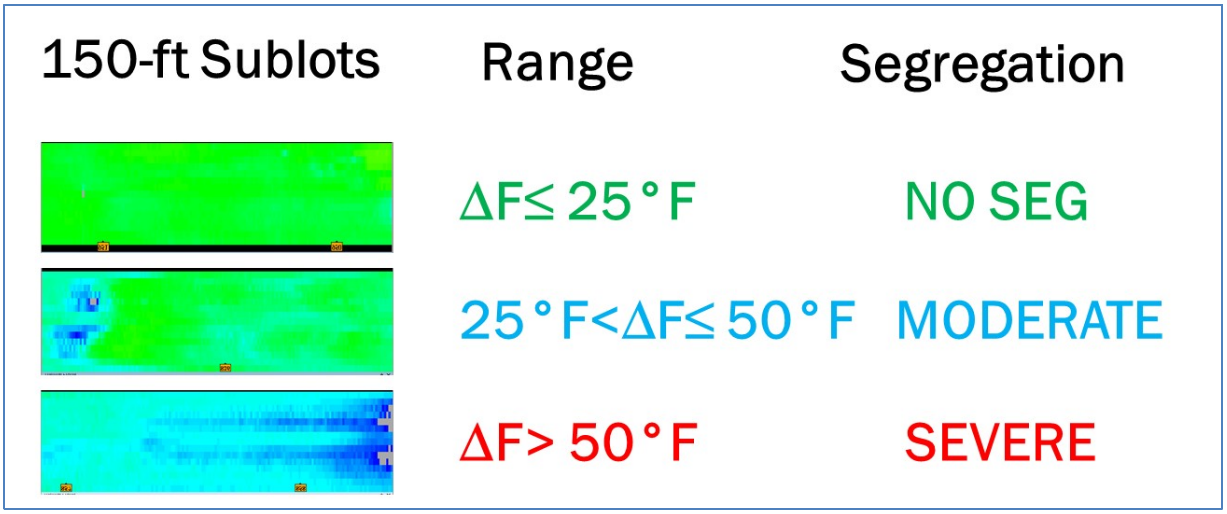


Figure 15: AASHTO PP80 IR Analysis Method: Segregation categories

An example of IR data analysis from the August 14, 2017 data from J3I3042 RT 70 is shown in Figure 16. The MOBA PAVE-IR data were downloaded from eRoutes, and the corresponding MOBA PPM screenshot shown below. Note that there is erroneous time/speed data around 4,000 ft.

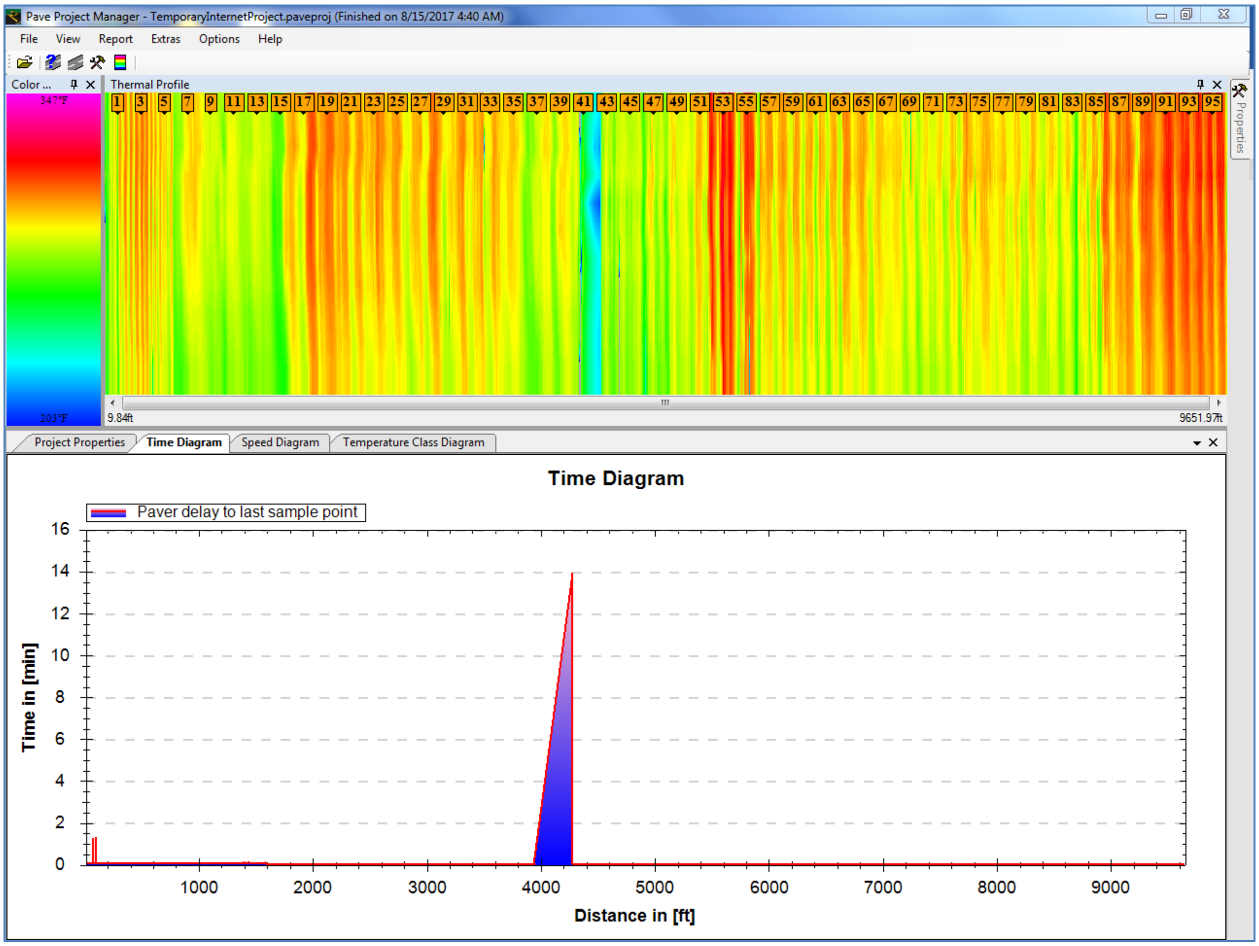


Figure 16: Example of MOBA PPM IR Analysis Screens.

The MOBA PPM report indicates 57% no segregation, 38% moderate segregation, and 5% severe segregation (Figure 17). The MOBA PPM report is the data source used to determine incentive/disincentive according to the IR Job Special Provision (JSP).

Thermal Profile Results Summary				
Number of Profiles	Moderate 25.0°F < differential <= 50.0°F		Severe differential > 50.0°F	
65	Number	Percent	Number	Percent
	25	38	3	5

Figure 17: Example of MOBA PPM IR Analysis Report of Temperature Segregation.

The MOBA raw data were imported to Veta, and Figure 18 shows the Veta Viewer screen of IR data plot on a satellite base map for the project.

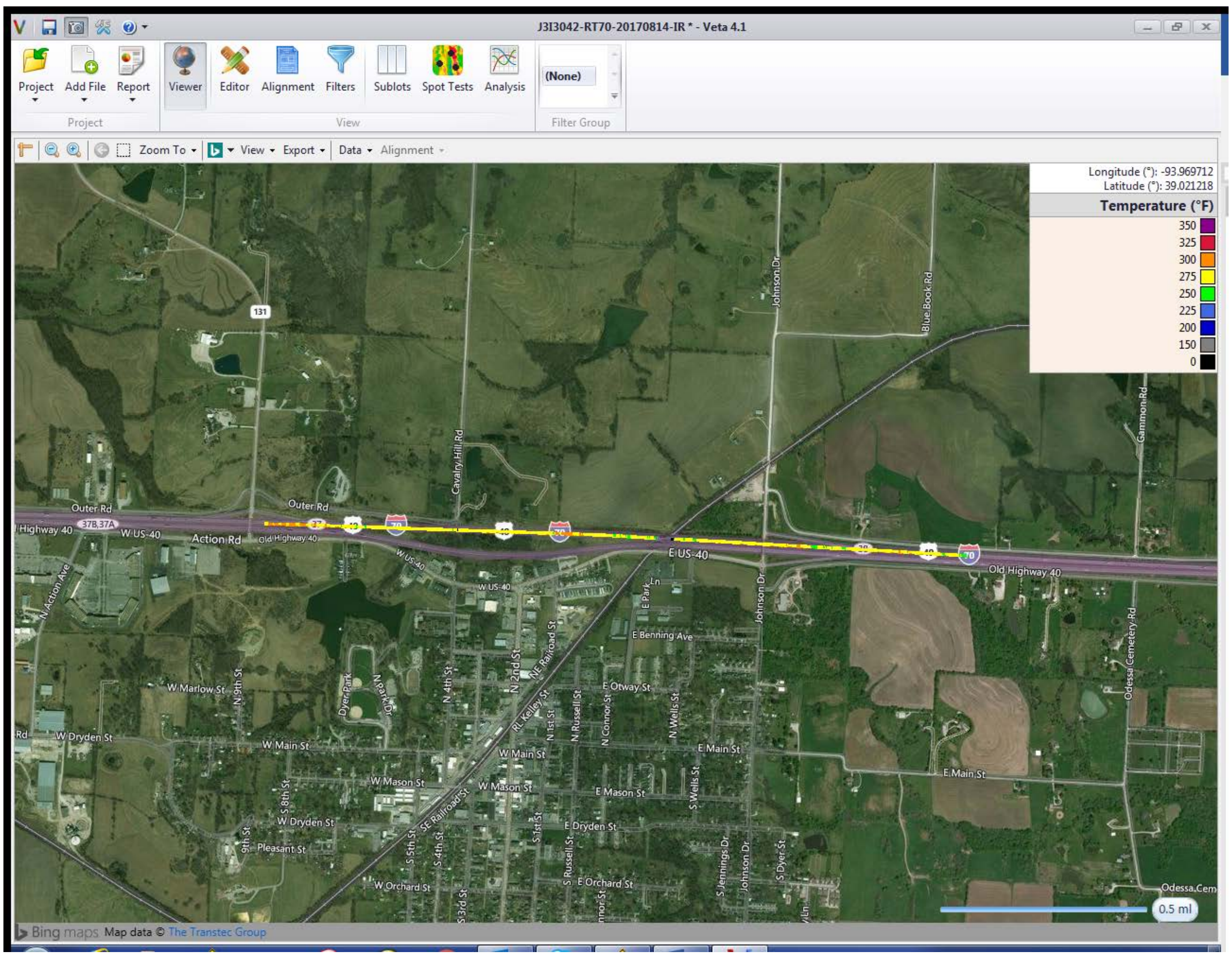


Figure 18: Example of Veta Viewer screen of IR data plots (J3I3042, RT70).

A Veta filter group is created to use Data Filters to exclude temperatures under 180°F and an Operation Filter/Cold Edge filter to exclude any cold temperatures from adjacent existing pavement/shoulder surfaces (Figure 19). Note that the IR data uploaded to VETA was for research purposes and was not used to evaluate incentive/disincentive.

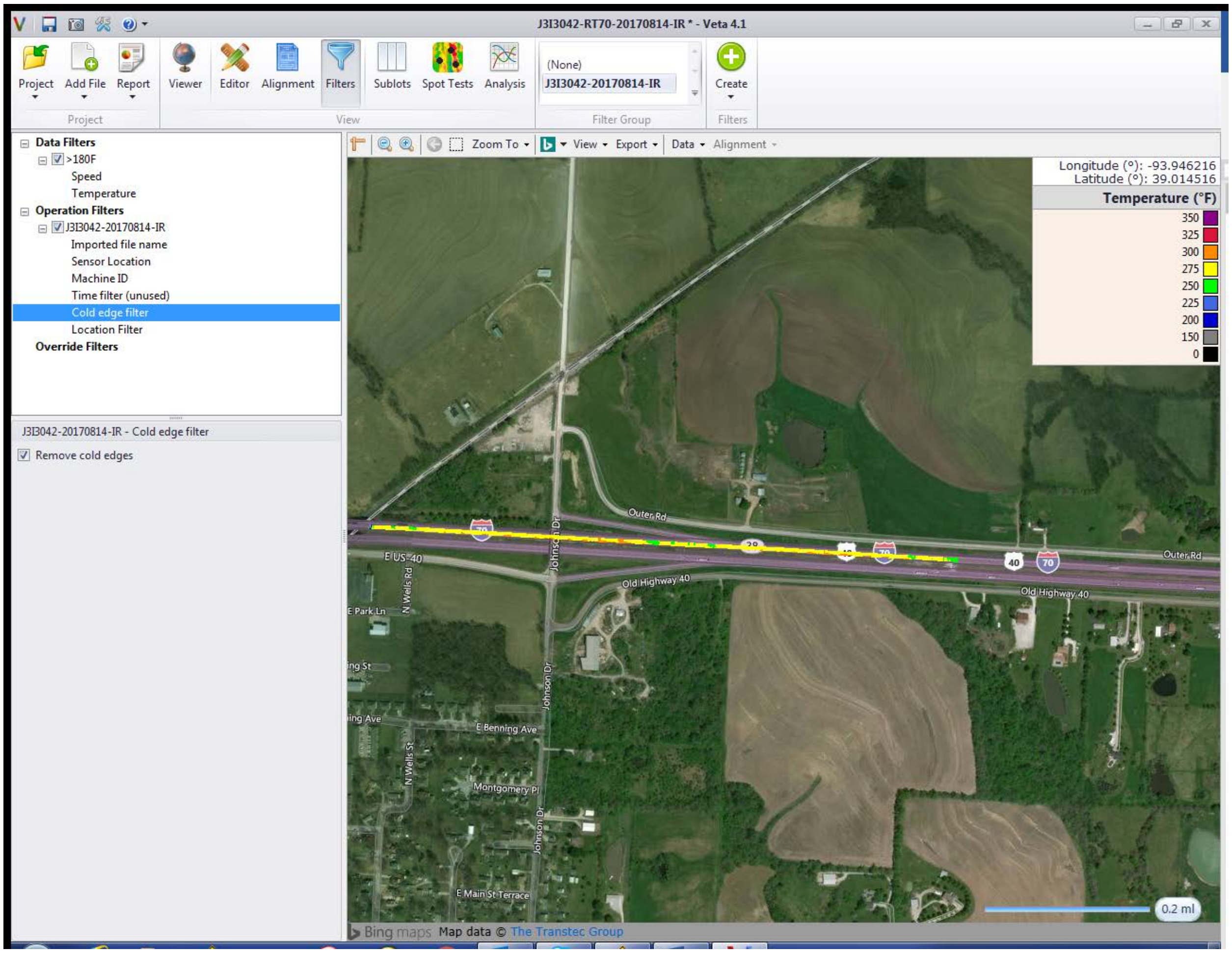


Figure 19: Example of Veta Filter screen (J3I3042, RT70).

Further, 150-ft sublots were created for analysis (Figure 20).

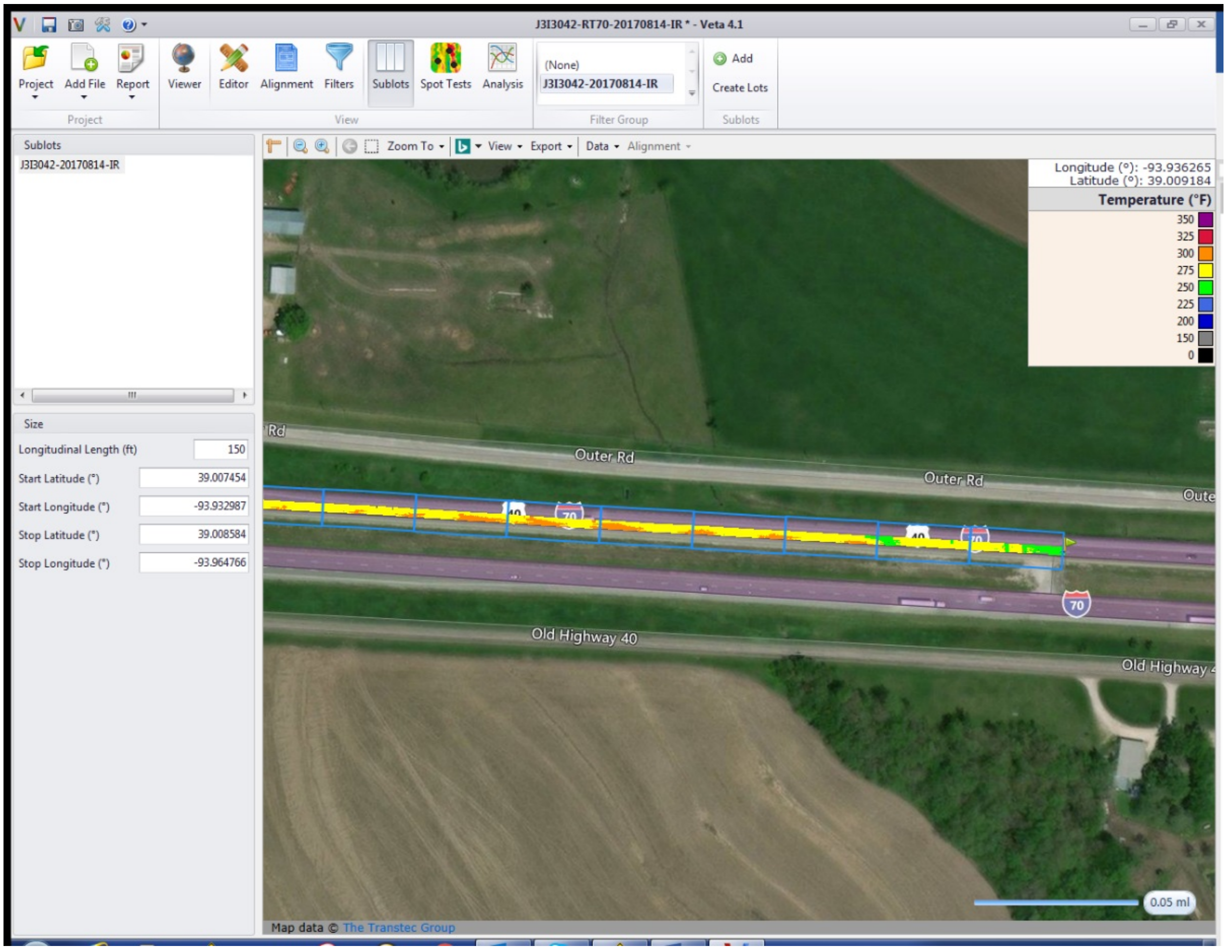


Figure 20: Example of a Veta Sublot screen (J3I3042, RT70).

Note the data gap at a bridge in the screenshot in Figure 21. The data gap is due to the fact that there was no HMA placed on the bridge, and since the temperature of the surface was below the threshold of 80^oC, the data was filtered out by the MOBA. However, it is recommended that the MOBA system be left "ON" while the paver mobilizes across a bridge (or similar situation) as the distance data is continued to be collected and is used in data analysis.

Figure 21: Example of a Veta Sublot screen for IR data analysis (J3I3042, RT70).

A typical Veta analysis setup for this set of IR data is shown in Figure 22.

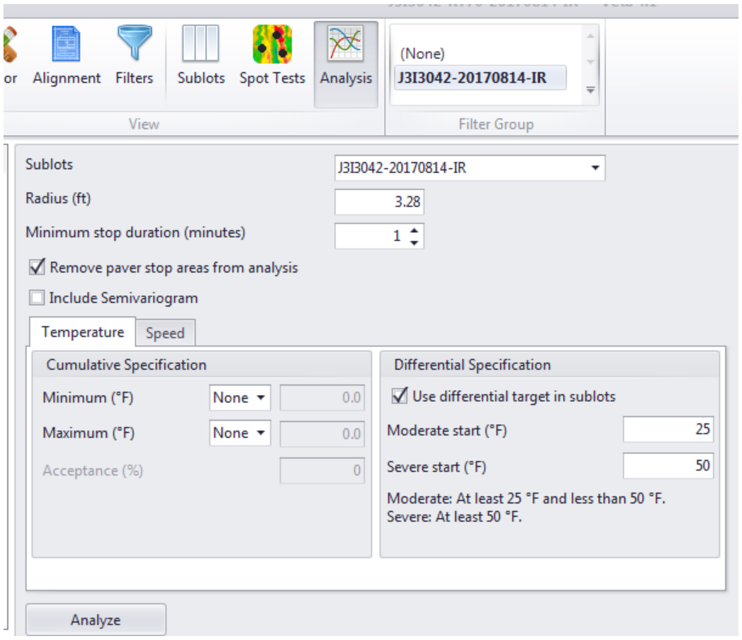


Figure 22: Example of a Veta Analysis setup for IR data analysis (J3I3042, RT70).

A typical Veta thermal profile, time diagram, and paver speed plot are shown in Figure 23. The vertical black bar in the thermal profile, along with the time diagram plot and the paver speed, indicates a paver stop for approximately 14 minutes at an approximate distance of 3,800 ft. from beginning of the paving operation.

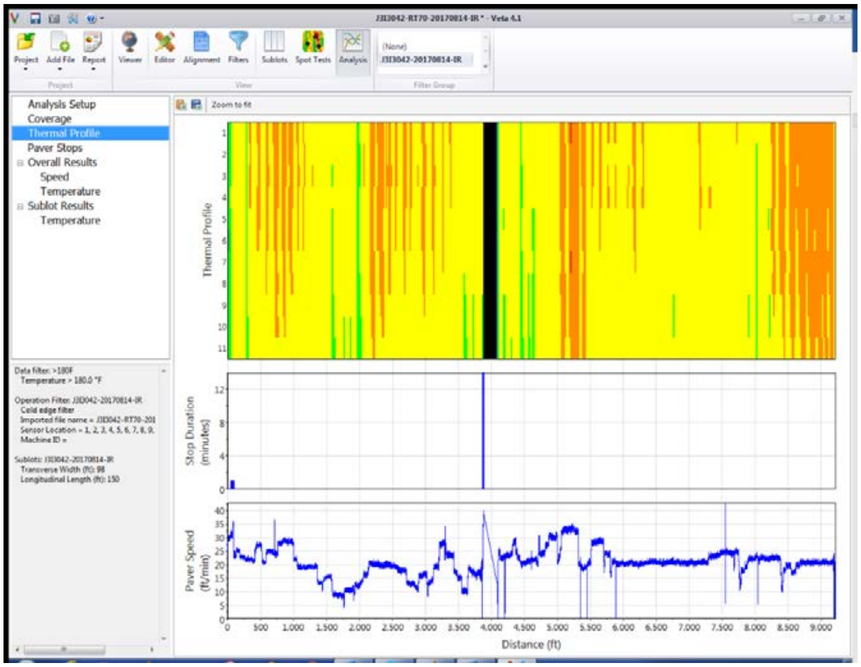


Figure 23: Example of a Veta IR data analysis results (J3I3042, RT70).

The Paver Stop map (Figure 24) plots a pink circle indicating paver stop locations, and text indicating stop duration in minutes.

Figure 24: Example of a Veta Paver Stop plot (J3I3042, RT70).

A sample Veta temperature differential report is shown in Figure 25. The reported length is 9,038 ft. (approximately 600 ft. different from the MOBA reported length).

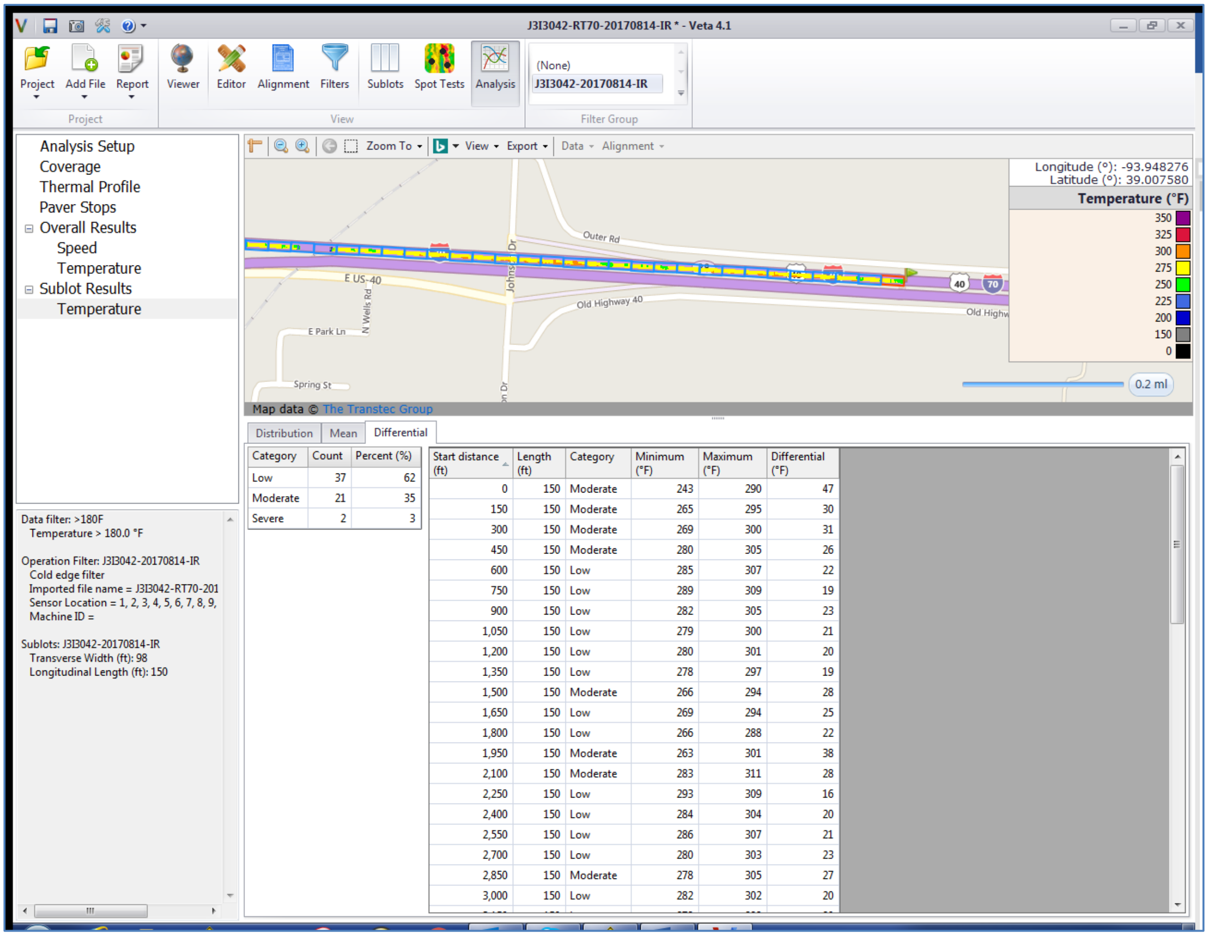


Figure 25: Example of a Veta IR Temperature Differential report (J3I3042, RT70).

IC DATA ANALYSIS

Roller Passes

The IC coverage analysis was based on the optimum pass count. The rolling pattern should depend on the asphalt mix and decision by the RE and the contractor. The optimum pass count is determined by the trial section. That may consist of vibratory passes, static passes, or a combination of both. The "Roller Coverage" for each day of paving was classified according to the percentage of paved area which met or exceeded the optimum number of rolling passes based on the MoDOT Specification shown in Table 5.

Table 5. MoDOT IC Coverage Classification.

Classification	% Coverage
Passing	Coverage ≥ 90
Moderate	$70 \leq$ Coverage < 90
Deficient	Coverage < 70

ICMV

The target ICMV can be determined based on the correlation between the ICMV data and acceptance spot tests from the trial section (Figure 26). The requirements for the acceptable correlation between ICMV and acceptance spot tests is R< 0.7 or $R^2 < 0.5$, based on most of the international IC specifications.

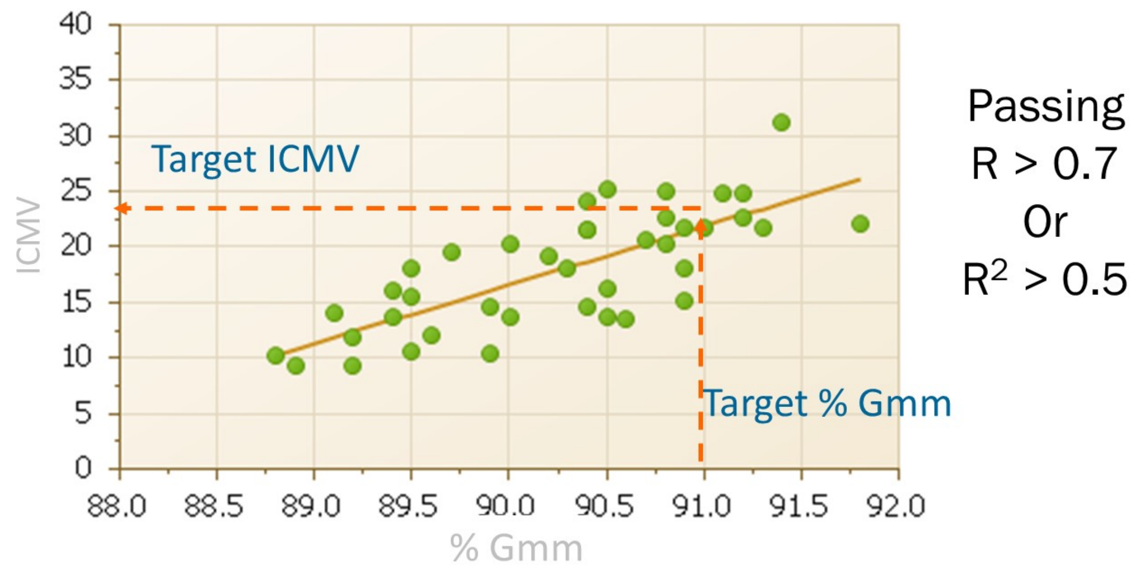
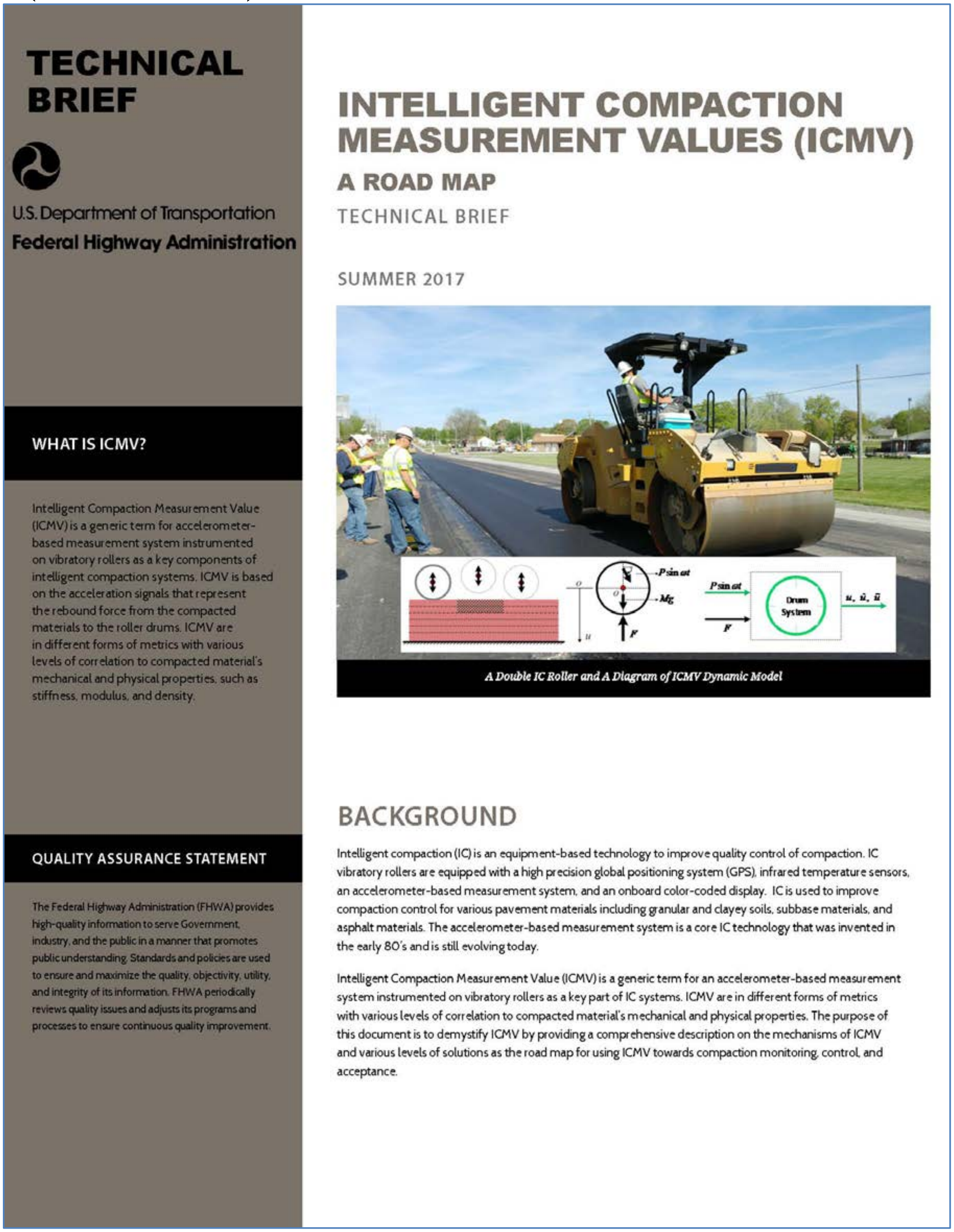


Figure 26: Target ICMV determined by Correlation between ICMV and Acceptance Spot Tests from Trial Section Data.

Note that ICMV and acceptance spot tests are often fundamentally different mechanisms and not all ICMV methods are equal. The FHWA ICMV Tech Brief provides additional details on this issue (FHWA-HIF-17-046).



TECHNICAL BRIEF

U.S. Department of Transportation
Federal Highway Administration

WHAT IS ICMV?

Intelligent Compaction Measurement Value (ICMV) is a generic term for accelerometer-based measurement system instrumented on vibratory rollers as a key components of intelligent compaction systems. ICMV is based on the acceleration signals that represent the rebound force from the compacted materials to the roller drums. ICMV are in different forms of metrics with various levels of correlation to compacted material's mechanical and physical properties, such as stiffness, modulus, and density.

QUALITY ASSURANCE STATEMENT

The Federal Highway Administration (FHWA) provides high-quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

INTELLIGENT COMPACTION MEASUREMENT VALUES (ICMV)

A ROAD MAP

TECHNICAL BRIEF

SUMMER 2017

A Double IC Roller and A Diagram of ICMV Dynamic Model

BACKGROUND

Intelligent compaction (IC) is an equipment-based technology to improve quality control of compaction. IC vibratory rollers are equipped with a high precision global positioning system (GPS), infrared temperature sensors, an accelerometer-based measurement system, and an onboard color-coded display. IC is used to improve compaction control for various pavement materials including granular and clayey soils, subbase materials, and asphalt materials. The accelerometer-based measurement system is a core IC technology that was invented in the early 80's and is still evolving today.

Intelligent Compaction Measurement Value (ICMV) is a generic term for an accelerometer-based measurement system instrumented on vibratory rollers as a key part of IC systems. ICMV are in different forms of metrics with various levels of correlation to compacted material's mechanical and physical properties. The purpose of this document is to demystify ICMV by providing a comprehensive description on the mechanisms of ICMV and various levels of solutions as the road map for using ICMV towards compaction monitoring, control, and acceptance.

Figure 27: FHWA ICMV Tech Brief (FHWA-HIF-17-046).

Since ICMV is measured only with vibratory passes, the projects that use only static passes or mix of vibratory/static passes did not have sufficient ICMV data for further analysis. When vibratory passes are used but without companion acceptance spot tests, the target ICMV and optimal passes can be determined based on the ICMV compaction curve where the increment of ICMV with each subsequent pass is less than 5% (Figure 28).

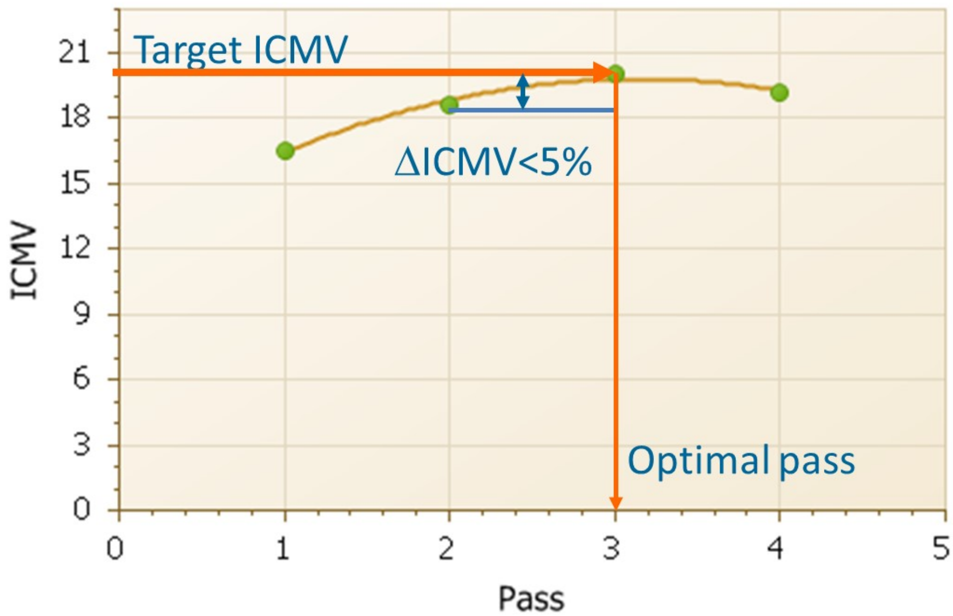


Figure 28: Target ICMV determined by an ICMV Compaction Curve when Acceptance Spot Tests from Trial Section Data are Not Available.

The target ICMV coverage was based on MoDOT IC specification, as shown in Table 6.

Table 6. MoDOT Target ICMV Coverage Classification.

Classification	**% > Target ICMV**
Not Flagged	Coverage ≥ 70
Flagged	Coverage < 70

Mat Temperature

Based on MoDOT Specification Section 403.15 (Figure 29), during vibratory compaction, the internal asphalt mat temperature requirement should be > 225 °F for non-warm mix or > 200°F for warm mix paving. Consideration is given to the fact that the IC roller collects surface temperatures while the intent of this specification is for internal temperatures.

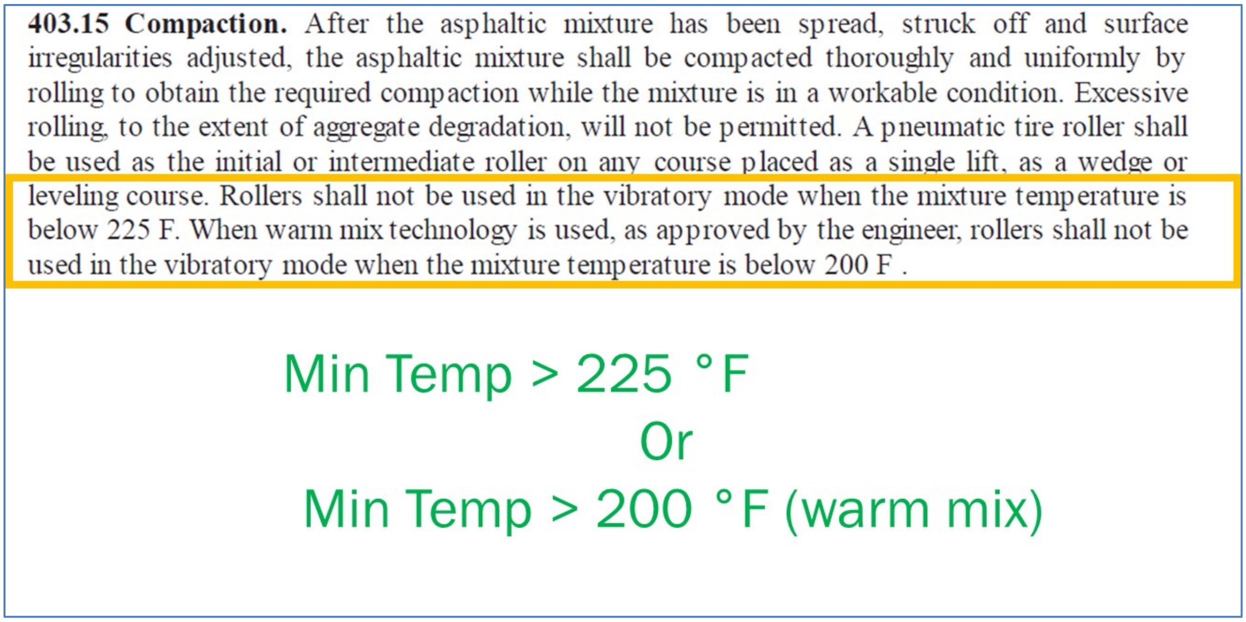

403.15 Compaction. After the asphaltic mixture has been spread, struck off and surface irregularities adjusted, the asphaltic mixture shall be compacted thoroughly and uniformly by rolling to obtain the required compaction while the mixture is in a workable condition. Excessive rolling, to the extent of aggregate degradation, will not be permitted. A pneumatic tire roller shall be used as the initial or intermediate roller on any course placed as a single lift, as a wedge or leveling course. Rollers shall not be used in the vibratory mode when the mixture temperature is below 225 F. When warm mix technology is used, as approved by the engineer, rollers shall not be used in the vibratory mode when the mixture temperature is below 200 F .

Figure 29: MODOT Requirement for Mat Temperatures during vibratory compaction.

The Veta analysis for the temperature requirement makes use of a data filter for vibratory passes only and an analysis setup for the target temperature coverage (Figure 30). While as demonstrated in Figure 30, the capability exists with Veta to exclude vibratory passes under a given temperature. However, due to the differences between roller surface temperature measurements and internal temperatures, these passes were not excluded for the pilot projects.

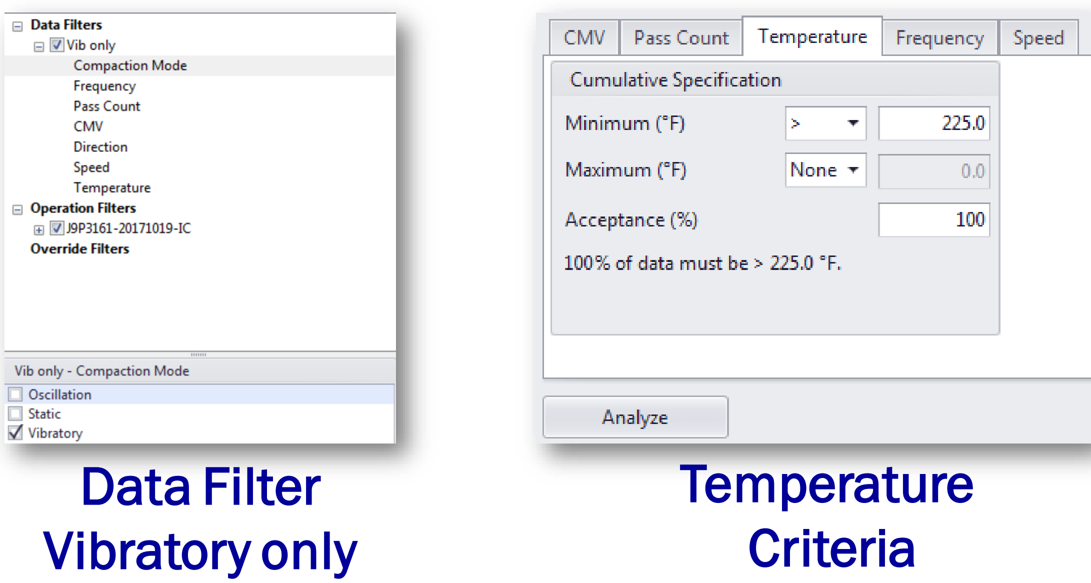


Figure 30: Veta Data Filter and Analysis Setup for MODOT Requirement for Mat Temperatures during vibratory compaction.

ANALYSIS EXAMPLE

An example of a complete IC analysis is presented below from the J1P3005 RT 24 project on 4/24/2017.

Trial Section – 4/24/2017

- Section: The initial 1,500 ft. of the paved area (Figure 31).
- A nuclear density gauge was used to perform spot tests of density. Readings were taken at exactly the same spots after each pass.
- Optimum Rolling Pattern

The compaction curve is shown in Figure 32. The rolling pattern for the breakdown IC roller is four passes, including three vibratory passes and one static pass. The roller was set to operate at high frequency and low amplitude.

Figure 31: Trial Section Tests on 4/24/2017 (J1P3005 RT 24).

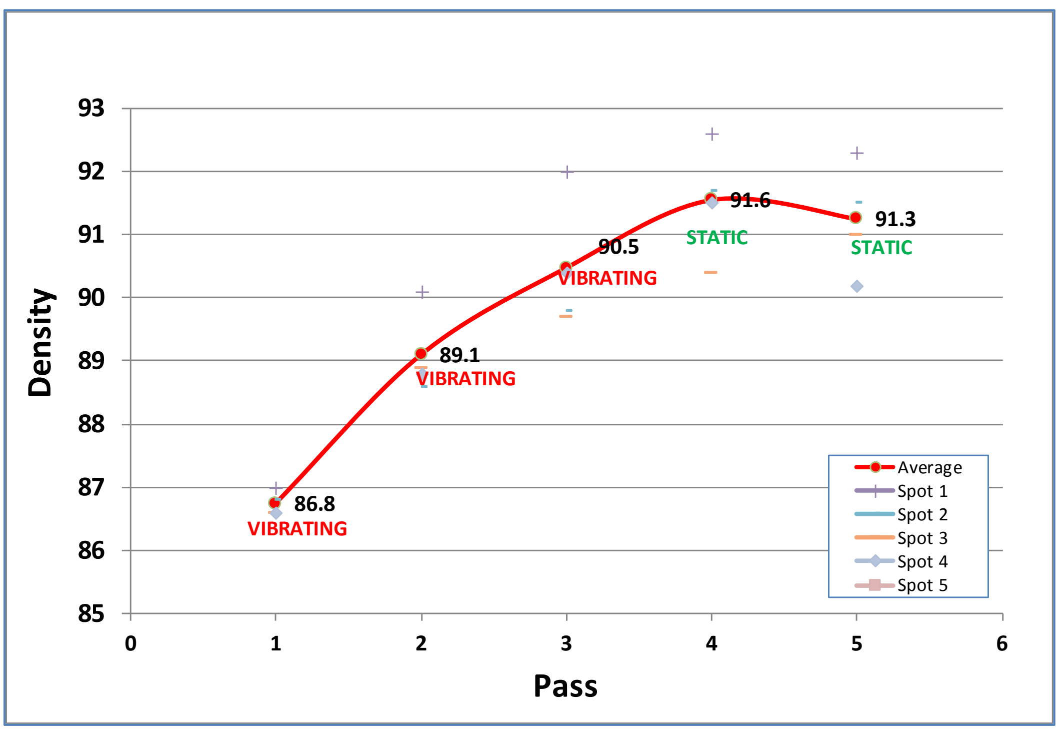


Figure 32: Compaction Curve from the Trial Section on 4/24/2017 (J1P3005 RT 24).

The VisionLink IC data file was imported to Veta for analysis. Figure 33 shows the pass count map.

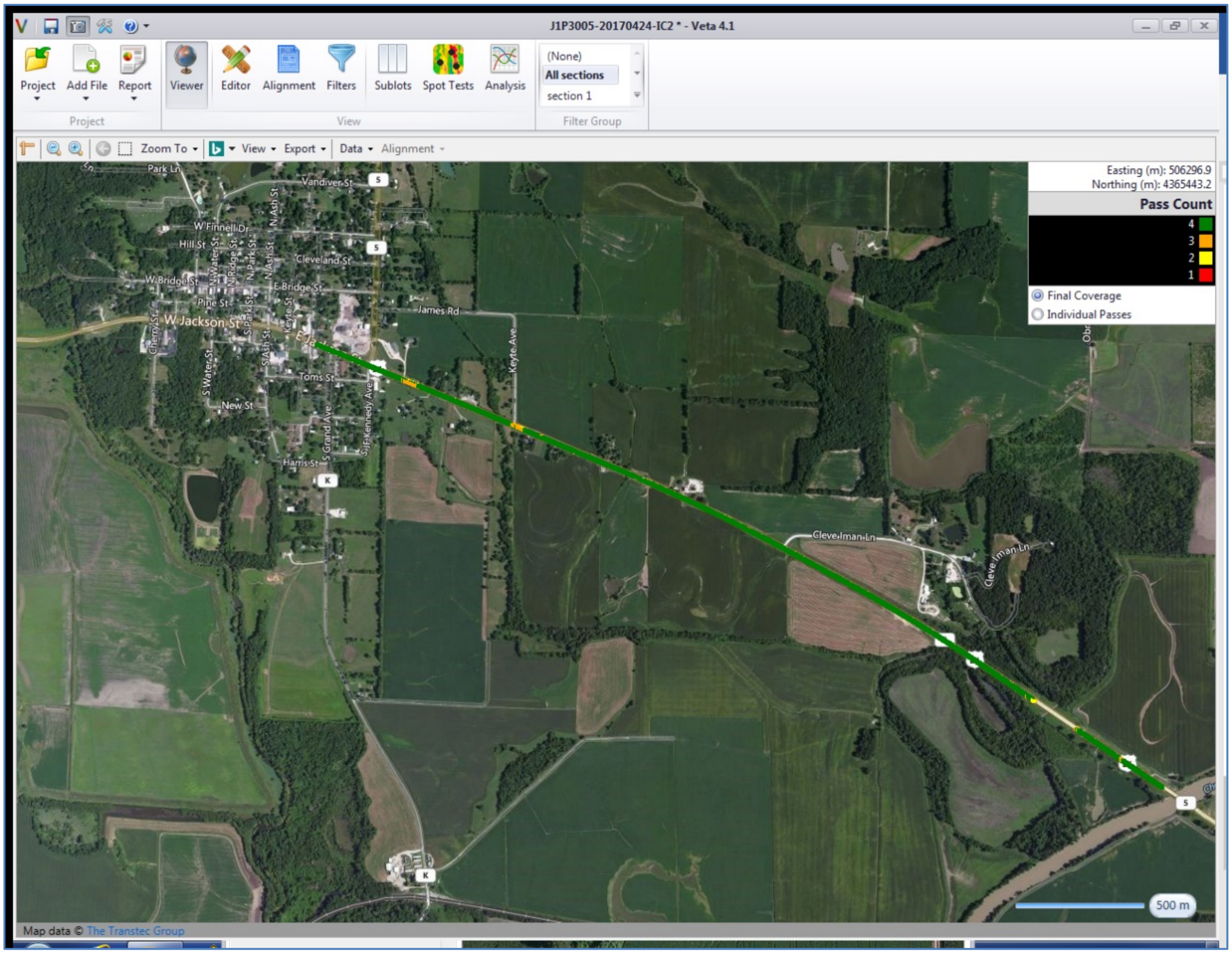


Figure 33: An Example Veta Analysis Screen showing Pass Count map (J1P3005 RT 24).

Two filter groups were created, or Section 1 and Section 2 (Figure 34). A third filter group was created by combining both sections.

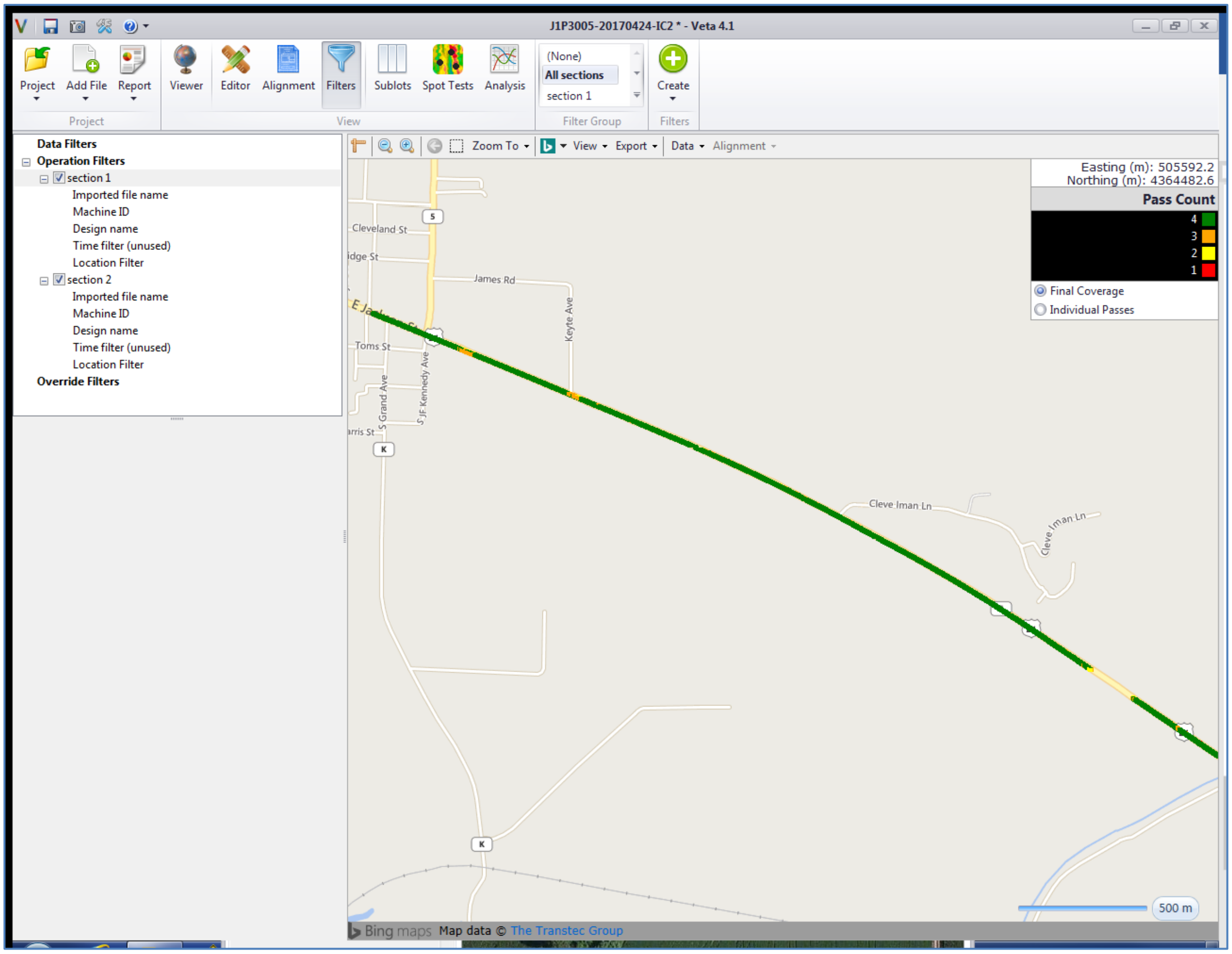


Figure 34: An Example Veta Analysis Screen showing Filter Groups (J1P3005 RT 24).

Spot test data of core density were imported to Veta's Spot Test Screen (Figure 35). The four core density tests correspond to the second set of four test locations within the trial section.

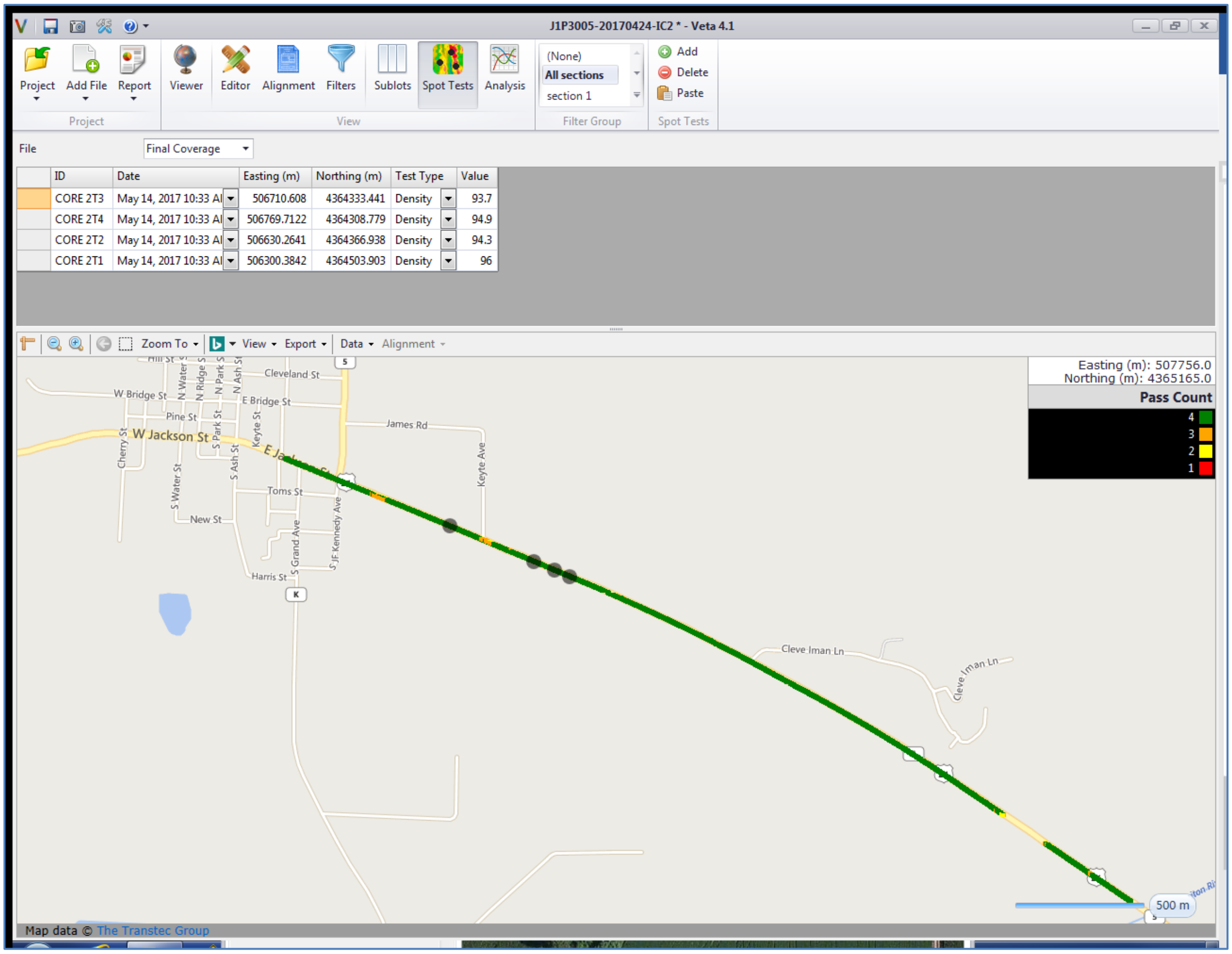


Figure 35: An Example Veta Analysis Screen showing spot tests (J1P3005 RT 24).

The first round of the IC analysis is used to inspect the correlation analysis between CMV and core density (Figure 36). Since the R^2 is 0.62, it is valid to use the linear correlation to calculate the target CMV based on 92% G_{mm} for the core density data. The resulting target CMV is 10.68.

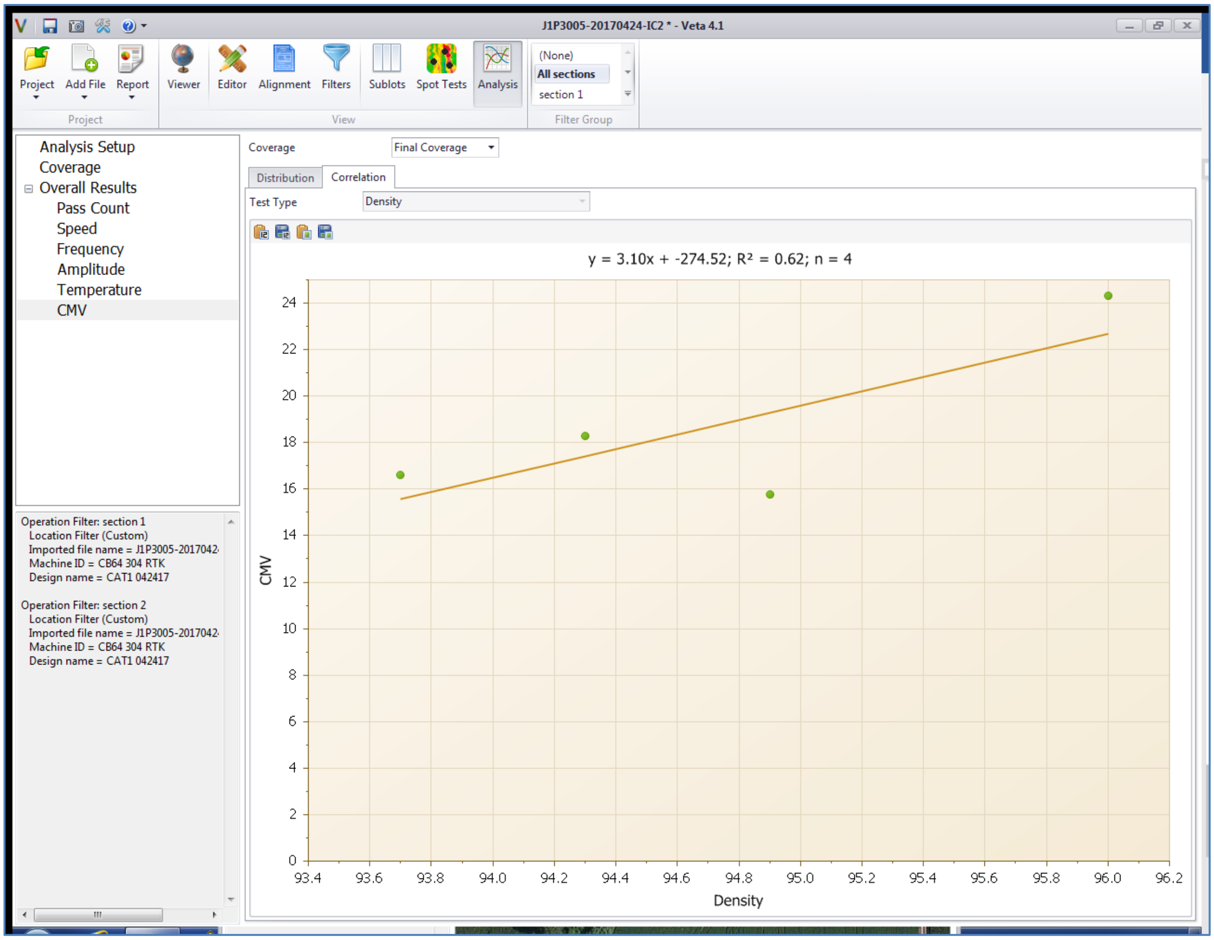


Figure 36: An Example Veta Analysis Screen showing correlation tests between ICMV and spot tests (J1P3005 RT 24).

The roller coverage for the target passes (four) is 95% (Figure 37), which passes the 90% requirement criteria. The ICMV coverage for the target ICMV is 92% (Figure 38), which passes the 70% criteria (i.e., not flagged).

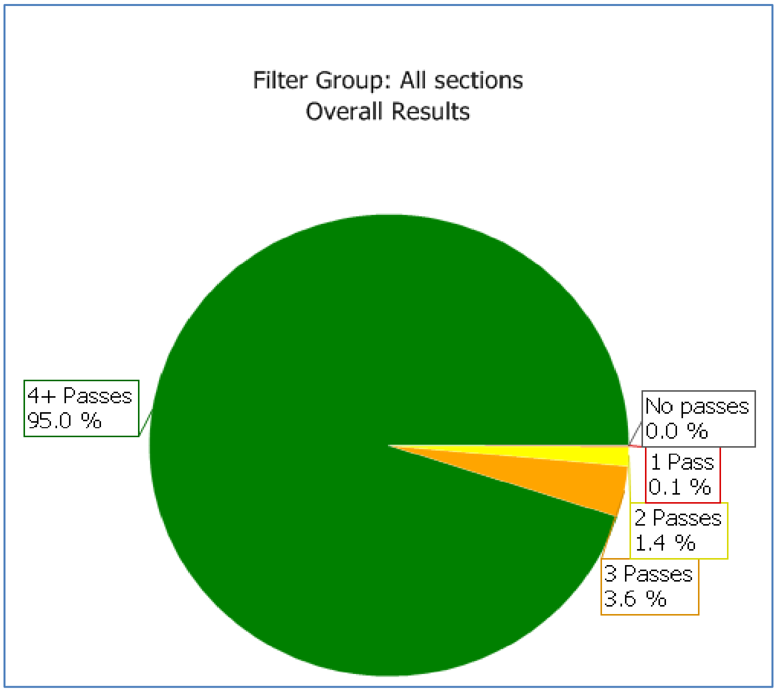


Figure 37: An Example Veta Analysis Screen showing the Roller Coverage report (J1P3005 RT 24).

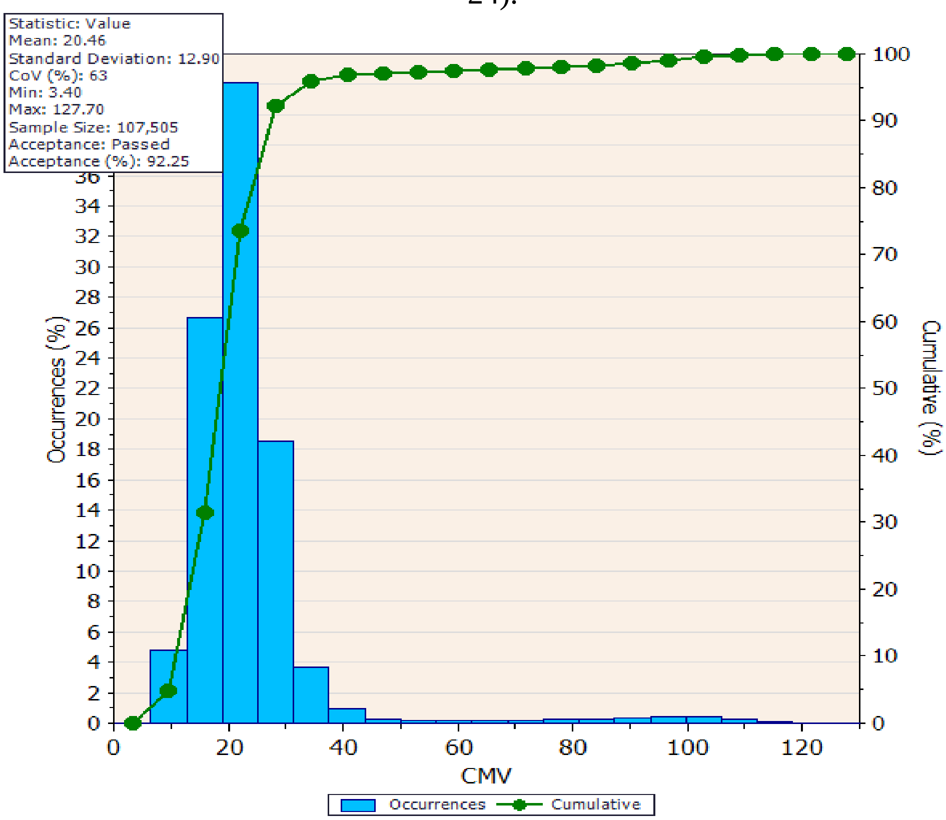


Figure 38: An Example Veta Analysis Screen showing the ICMV Coverage report (J1P3005 RT 24).

Another filter group is created for vibratory passes only. The temperature requirement was set to the specification criteria of 225°F. The coverage for vibratory passes at or above the target temperature is 51% (Figure 39), which fails the criteria of 100% (based on the MoDOT specification requirements).

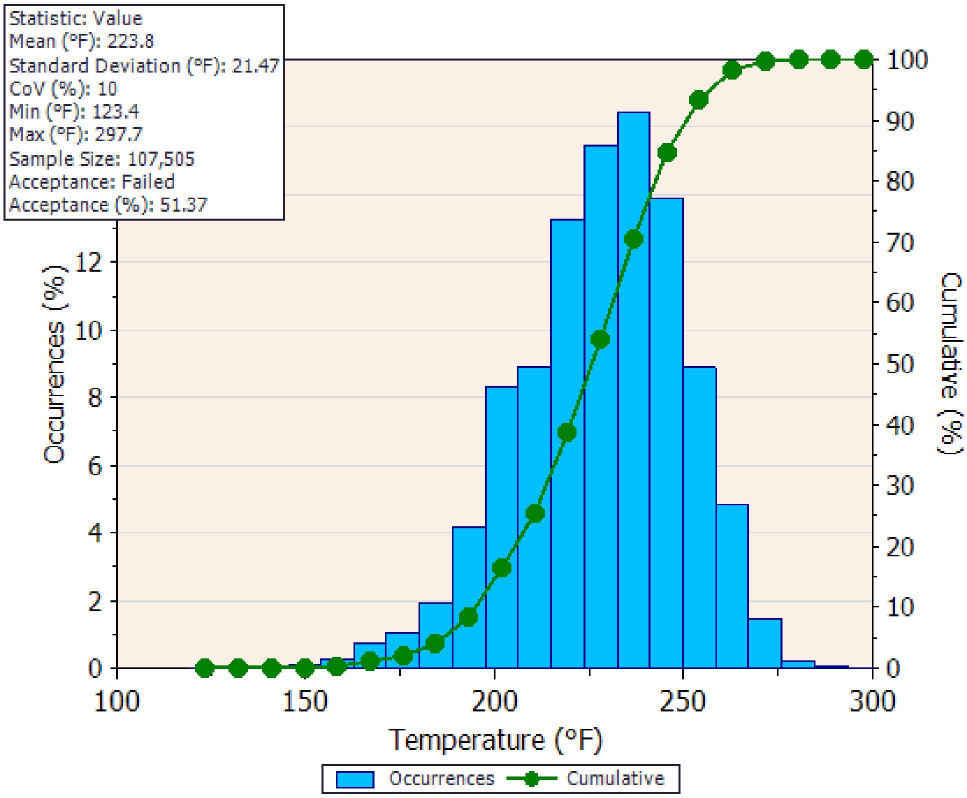


Figure 39: An Example Veta Analysis Screen showing the Mat Temperature report (J1P3005 RT 24).

SUMMARY OF RESULTS

In terms of mean values of temperature segregation for all projects, there were projects (No. 6, 7, 12, and 13) that had significant severe temperature segregation, projects (No. 1, 2, 3, 4, 5) which showed only limited severe segregation, and projects (No. 8, 9, 10, 11) which had moderate temperature segregation. Figure 40 shows a comparison of overall average temperature segregation by project.

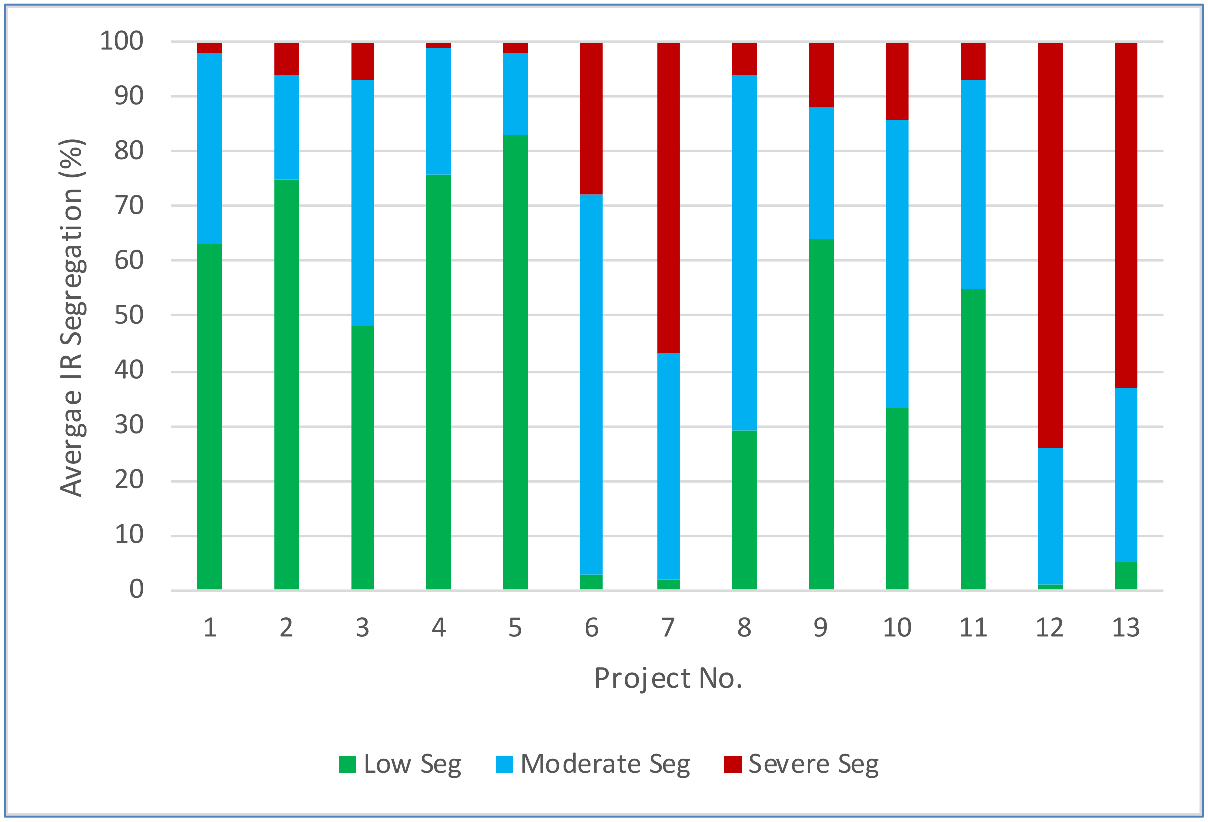


Figure 40: Comparison of IR Segregation for all projects.

In terms of mean values of temperature segregation for those projects by the same contractors, there were contractors (No. 1 and 8) whose projects showed significant severe temperature segregation, contractors (No. 2, 3, 4) whose projects exhibited excellent uniform temperature with only limited severe segregation, and contractors (No. 4, 5, 6, 7) whose projects fell in between the above. Figure 41 shows a comparison of overall temperature segregation by contractor.

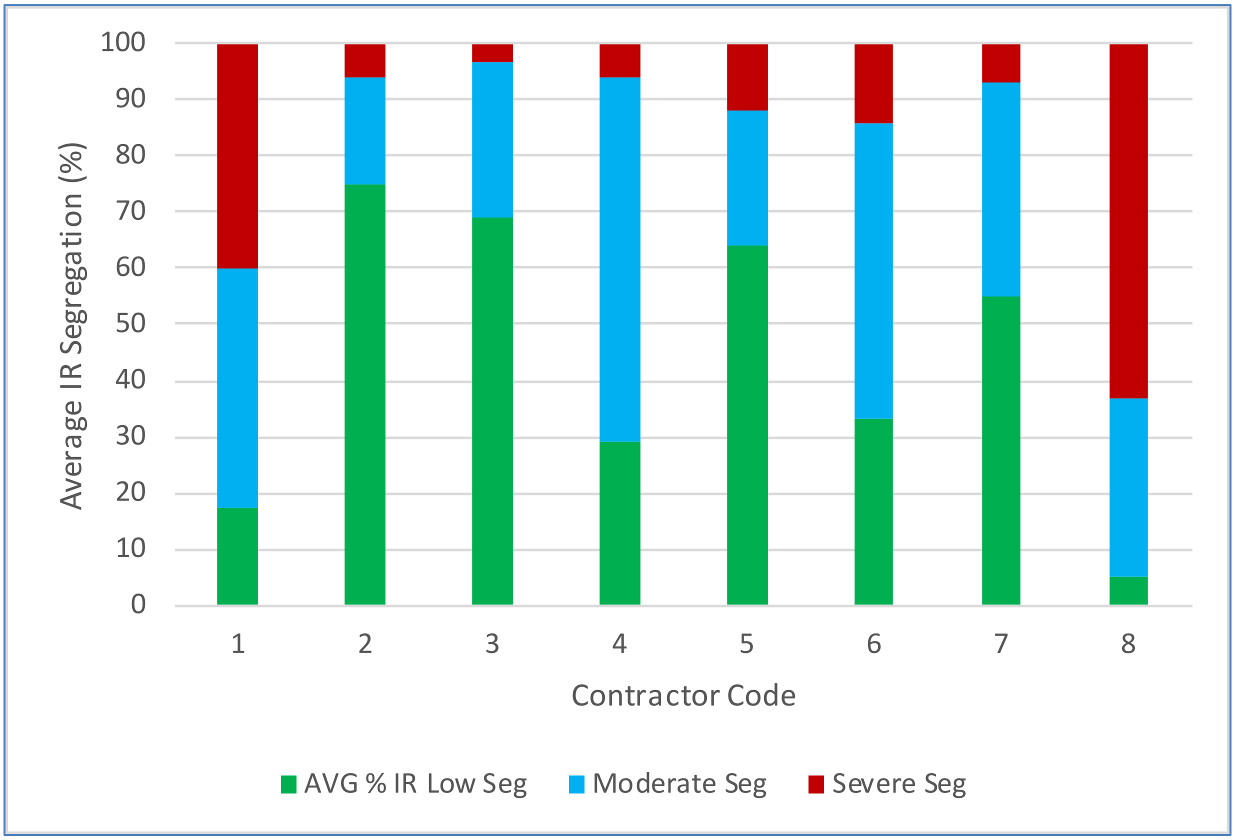


Figure 41: Comparison of IR Segregation for projects by coded contractors.

In terms of mean values of target pass coverage for all projects, there were projects (No. 6 and 9) that did not meet the 70% minimum coverage requirements (i.e., deficient), there were projects (No. 7, 8, 10, and 13) that met the 90% excellent coverage (i.e., passed), and there were projects (No. 1, 2, 3, 4, 5, 11, and 12) which fell in between the above. Figure 42 provides an overall summary of IC coverage for all projects.

Figure 42: Comparison of IC Coverage for all projects.

In terms of mean values of target pass coverage for those projects by the same contractors, there were contractors (No. 5) whose projects did not the 70% minimum coverage requirements (i.e., deficient), there were contractors (No. 4, 6, and 8) whose projects met the 90% excellent coverage (i.e., passing), and there were contractors (No. 1, 3, and 7) in between the above (i.e., moderate).

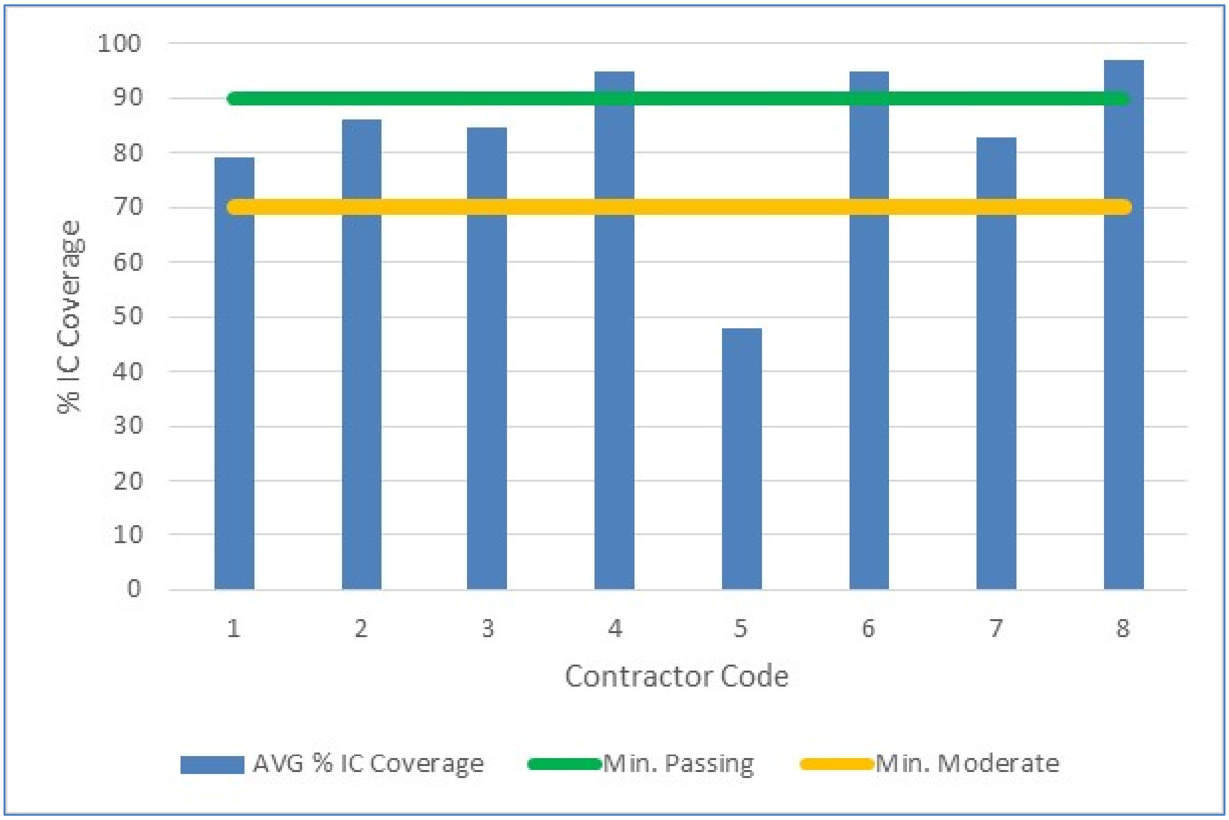


Figure 43: Comparison of IC Coverage for projects by coded contractors.

PROJECT EVALUATION

The field projects were evaluated on various aspects as follow.

GPS Verification

- GPS verification is crucial to ensure GPS measurements from the IC system and hand-held rover are consistent.
- GPS verification and record keeping has not always be done by contractors though it was required in the Protocol.
- The actual field operation of GPS verification is straightforward and not time consuming. It should be a natural part of the daily setup.

GPS and Cellular Signal Coverage

- GPS and cellular signal coverage would affect the GPS accuracy and reception.
- GPS coverage can be affected by many factors such as nearby tree lines. This issue cannot be avoided.
- Cellular coverage has been an issue at remote areas. Without adequate cellular coverage, GPS VRS would be affected and wireless transmission from machines to the cloud will be limited or not functioning. The former cannot be corrected. The latter can be overcome by “pushing” the data to the cloud once the cellular reception is good or via internet connection where available.
- There were instances when the GPS base station’s battery drained, causing GPS outage.
- It is recommended to include a clause in the IC specification regarding GPS and cellular signal coverage for project selection and qualification.

Functioning of IC Equipment and System

- There were limited IC systems used for these projects: Caterpillar/Trimble/SITECH, TOPCON, and Volvo.
- Most of IC equipment and system were functioning except for some occasions (e.g., setting telematic for machines to collect data and transmit data). Data loss happens on those occasions.
- The actual issues were normally human errors instead of equipment.
- There were also instances where ICMV data were missing when compaction was in vibratory mode. There was also the opposite issue when collecting ICMV data even though they were in static mode.
- There were still issues regarding lack of technical training and support from vendors’ dealers.
- It is recommended to include a clause in the IC specification regarding data collection and submission that tied to pay items (e.g., percent of data collected/submitted).

Functioning of IR Equipment and System

- There was only one IR system used for these projects (i.e., MOBA). However, the technical support varied depending on the dealers used. Some contractors have access to onsite technical support provided by a consultant, but others have to call MOBA directly for assistance.

- The main issue of IR systems is that the DMI calibration was not always performed correctly (i.e., rolling radius setting was incorrect).
- Incorrect DMI caused incorrectly reported distance and incorrect number of sublots by the MOBA PPM software. However, the Veta report was not affected due to the use of GPS records instead of DMI. The Veta display of IR thermal profiles was affected due to the incorrect sampling intervals of IR data (e.g., 3 ft. instead of 1 ft.) caused by incorrected rolling radius (e.g., 5 in. instead of 16 in.).
- There were still issues regarding lack of technical training and support from vendors' dealers.
- The current requirement for GPS precision for IR system is still too poor, making it difficult to combine with other data such as IC data and alignment files. It is expected higher precision GPS will be used in future IR systems.

Paving Boundary Measurements

- The paving boundary measurements are crucial for roller coverage analysis.
- The current paving boundary measurements with hand-held rovers are tedious and labor-intensive with some reports 300 plus measurements for a given paving day.
- Most of paving boundary data were collected correctly, but required sorting, inspection, and sometimes correction for human errors (e.g., incorrect measurement values, IDs, sections). The sorting would reply on proper IDs convention for each paving edges (e.g., center line, edges) and ascending order (e.g., in the direction of increasing milepost or paving direction).
- The unit of coordinates was sometimes not compatible with the IC data. Therefore, sometimes errors occur when using improper unit conversion factors (e.g., US survey feet to meters).
- It is recommended to consider producing alignment files using design files or LiDAR survey files to reduce the manual paving boundary measurements.

IC Data Collection and Submission

- When IC systems are functioning, IC data are generally collected properly.
- Due to differences in IC systems, contractors need to learn how to use and calibrate IC system as well as handle data storage/transmission correctly.
- For example, using Volvo EDV IC system, the calibration requires an involved process that requires detailed training and practice. Contractors also need to understand the limitation of the IC calibration regarding compacted layer thickness and required vibratory roller passes.
- Some IC systems (e.g., Trimble/Caterpillar, TOPCON) allow wireless data transmission as long as the telematic is setup properly with adequate cellular signals.
- Some IC systems (e.g., Volvo) require manual data handling using USB drives transferring data from the onboard display unit. Care should always be taken during those processes, especially when multiple files were produced for a given paving operation. This is one of the weak links.

- Another hurdle is to learn vendors' software systems (e.g., Trimble VisionLink, TOPCON SiteLink3D) to filter, extract, and export data for a specific date, lift of construction, paved lane, direction, and roller(s).
- The above exported files are generally very large due to the gridding results (i.e., populating raw recorded data, one point across a drum, to 1 ft. X 1 ft. grids), at 100 to 200 MB per roller. The size would challenge data transmission for areas with slow internet connection.
- It is anticipated that most of the above issues can be resolved by upcoming feature in Veta 5, which will provide a direct data import from the cloud to Veta.
- It is recommended to include a clause in the IC specification regarding data collection and submission that tied to pay items (e.g., % of data collected/submitted).

IR Data Collection and Submission

- The only IR system used in these project (i.e., MOBA PAVE-IR) transmits data to the cloud (e.g., eRoutes).
- The wireless data transmission mostly works except for remote areas with poor cellular coverage.
- The current issues of eRoutes display of available data and the date stamp are the challenges for IR data management. The latter often causes roll over data, especially when new IR files were not started for paving in different lanes, directions, and lifts.
- The use of low accuracy GPS also make IR data impossible to separate when paving in adjacent lanes. It cannot use with the alignment files for coverage and other analyses.
- It is anticipated that most of the above issues can be resolved by upcoming feature in Veta 5, which will provide a direct data import from the cloud to Veta.
- It is recommended to include a clause in the IR specification regarding data processing using Veta instead of vendors' software.
- It is recommended to include a clause in the IR specification regarding data collection and submission that tied to pay items (e.g., % of data collected/submitted).

Other Data Collection and Submission (trial sections and core data)

- Trial section data were mostly recorded for these projects.
- However, measurements of asphalt densities with nuclear density gauges are still challenging to complete after each roller pass at selected locations with the last 400-ft of a 1000-ft trial section.
- The gauge was intended to measure density for two-inch lifts (vs. the actual 1.75-inch lift thickness). Troxler has published a Tech Brief regarding thin lift nuclear density gauge without the influence from the underlying layers materials (https://aggrebind.com/wp-content/uploads/2012/12/Troxler-Testing.pdf) In each case where spot readings were taken, efforts were made to consistently record density measurements with the nuclear density gauge at exactly the same spots. The effect of this data collection occurring repeatedly at the same locations provided the benefit of reducing the influence of gauge settings and underlying conditions.

- Most contractors use the first paving day's trial section data to determine target passes and vibration/static for the remaining of paving days.
- Core data and the associated GPS coordinates are often missing and miss-matched.

Completion of Check list

- Contractor's check list is rarely completed.
- RE's check list and diary are often missing.
- The daily paving records were only provided by several contractors.
- It is recommended to include a clause in the IC/IR specifications regarding submission of required forms as a portion of the required reports.

Utilization of Full Capabilities of IC and IR Systems

- Based on the roller coverage reports, most contractors' roller operators have paid a lot of attention to achieve required roller passes.
- From some of the IC reports, it is evident that some contractors have learned to meet the coverage quickly as projects progress with regarding to the carefully measured boundary points.
- The IR reports are not always taken advantage of by contractors to fine tune their paving operations. (e.g., reduce paver stops)
- The thermal segregation is mainly influenced by the use or lack of use of material transfer device (MTV) as shown in the IR analysis reports.

IC-IR Training Workshops

- The IC-IR training workshop materials were designed to be practical and hands-on to equip contractors and REs for conducting the actual field projects.
- Although the IC-IR training workshops were scheduled to be close to the start dates of paving, some contractors still need significant assistance from the Consultant for conducting field operation properly and subsequent data collection/reduction/submission/Veta data analysis. It may be due to lack of experience in contractors in IC-IR technologies.
- A few contractors have learned well and kept proper records and file collection/submission.
- It is expected the contractors will do better once they have more experienced in IC and IR.
- With regarding to Veta analysis, the contractors and RE still need assistance from the Consultant for Veta data analysis. As the project progressed, the contractors appeared to be more confident managing and analyzing the IC and IR data.
- There will be major new release of Veta in 2018 that includes many enhancements (e.g., direct download of IC-IR data from manufacturers' cloud, automated filter group generation, etc.). Refresher and training in using those new features are recommended for MoDOT staff, contractors, and IC-IR dealership.

IC-IR Data Completion

- Trial section data is required in the MoDOT IC specification to determine target rolling pattern. Most projects have included trial section data and the companion compaction curves except for limited projects that was conducted in 2016 and that was using the Volvo EDV system.
- The IR data were collected properly due to the use of wireless data transmission with some exception that data need to be manually downloaded due to lack of cellular coverage.
- The IC data were collected properly with mostly wireless data transmission and, in the case of the Volvo system, manual data transfer from the onboard display unit. There was exception for IC data loss due to incorrect setup for telematic and other human errors.
- The GPS data for paving boundary were mostly collected correctly with some exception that requires sorting, data inspection, and correction.
- The GPS data for core locations are normally available. However, most core data were not submitted.
- Table 7 Summarizes the IC-IR Data Completion for the 13 field projects.

Table 7. Completion of IC-IR Data Collection.

Project No.	**Job No.**	**District**	**County**	**Route**	**Trial Section Data**	**IR Data**	**IC Data**	**GPS Data**	**Core Data**	**Analysis Complete**	**Report Complete**
1	J5P3117	CD	Morgan	52	Y	Y	Y	Y	N	Y	Y
2	J4I3111	KC	Clay	29	Y	Y	Y	Y	Y	Y	Y
3	J3I3042	KC	Lafayette	70	Y	Y	Y	Y	N	Y	Y
4	J2P3099	NE	Macon	36	N	Y	Y	Y	N	Y	Y
5	J2P3100	NE	Macon	36	N	Y	Y	Y	N	Y	Y
6	J2P3051	NE	Randolph	24	N	Y	Y	Y	Y	Y	Y
7	J1P3005	NW	Chariton	24	Y	Y	Y	Y	Y	Y	Y
8	J9P3161	SE	Texas	17	Y	Y	Y	Y	N	Y	Y
9	J6S3123	SL	Jefferson	61	Y	Y	P	Y	N	Y	Y
10	J7I3072	SW	McDonald	49	Y	Y	Y	Y	N	Y	Y
11	J1S3028	NW	Daviess	69	Y	Y	Y	Y	Y	Y	Y
12	J5P3170	CD	Cooper	5	Y	Y	Y	Y	N	Y	Y

Legend: Y- Yes N- No P- Partial

IC-IR Check List and Form Completion

- The contractors' check lists were mostly not submitted.
- There are limited number of contractors who submitted paving record forms.
- Those contractors who submitted the paving records have also performed MOBA PPM and Veta analysis. There were two contractors performed the analysis but did not submit paving record forms.
- The RE's check lists were mostly not submitted.
- The RE's diaries were mostly not submitted.
- Table 8 Summarizes the completion of IC-IR check lists and forms for the 13 field projects.

Table 8. Completion of IC-IR Check Lists and Forms.

Project No.	**Contractor Code**	**Job No.**	**District**	**County**	**Route**	**Contractor Check List**	**Paving Record Forms**	**Contractor Analysis**	**RE check List**	**RE Diary**
1	1	J5P3117	CD	Morgan	52	N	Y	Y	Y	N
2	2	J4I3111	KC	Clay	29	P	P	Y	Y	Y
3	3	J3I3042	KC	Lafayette	70	N	N	N	N	N
4	3	J2P3099	NE	Macon	36	N	N	N	N	Y
5	3	J2P3100	NE	Macon	36	N	N	N	N	Y
6	1	J2P3051	NE	Randolph	24	N	N	N	N	P
7	1	J1P3005	NW	Chariton	24	N	N	N	N	Y
8	4	J9P3161	SE	Texas	17	P	Y	Y	Y	N
9	5	J6S3123	SL	Jefferson	61	N	N	N	N	N
10	6	J7I3072	SW	McDonald	49	N	Y	Y	N	N
11	7	J1S3028	NW	Daviess	69	N	N	Y	N	N
12	1	J5P3170	CD	Cooper	5	N	Y	Y	N	N
13	8	J9P3296	SE	Texas	17	N	N	Y	Y	N

Legend: Y- Yes N- No P- Partial

RECOMMENDATIONS AND IMPLEMENTATION

This project has been a great opportunity for MoDOT personnel and local paving contractors to learn the innovative technologies, IC and IR, via hands-on training workshops, field projects, and IC-IR data management and analysis. The goal is to explore the full capacity of the IC and IR technology to improve QC and QA for asphalt paving projects. Until then, there are lessons learned and recommendations for the improvements for future IC-IR implementation as described as follows.

CONCLUSIONS

From the above IC-IR project data analysis and specification reviews, the following conclusions can be made:

- The MoDOT IC-IR projects in 2017 can be considered a success in terms of building up experiences for both MoDOT personnel and contractors.
- The IC-IR project protocol proved to be mostly effective for planning and conducting field projects. The IC-IR data management is a key component of the Protocol to ensure consistent data naming convention and submission. The MoDOT SharePoint is very useful to share data files, especially when the file sizes are too large as email attachments.
- The IR implementation has shown as a real-time indicator of any temperature segregation. In turn, the IR data and analysis reports can be used to fine tune paving process accordingly, such as making use of MTV and adjustment of truck fleet and paving speeds.
- There are issues with IR regarding the DMI/data sampling issues of a vendor's system and analysis issues with a vendor's software. These issues can be resolved with better training and use of the standard software, Veta, for analysis.
- The IC implementation has been mostly utilized to maximize roller coverage with some exceptions. The latter can be resolved by selecting adequate roller operators and better training.
- There were issues with IC roller calibration that requires better vendor's training to overcome.
- The GPS boundary measurements were mostly successful with occasional issues that require sorting, inspection, and correction.
- The IC-IR data management is still tedious, especially when IC or IR data need to be exported/transferred manually. There were occasional human errors that cause incorrect file naming convention, etc. Better training with the Protocol and additional experiences will resolve these issues.
- There was still a lack of submission of check lists, forms, and paving records to the SharePoint site.
- Most of core data were not submitted to the SharePoint.

RECOMMENDATIONS

The following are recommendation to move the IC-IR implementation forward at MoDOT:

- Utilizing standards, such as Veta, for IR data analysis and reporting would resolve several issues identified at 2017 projects.
- It is recommended to reduce the GPS boundary measurement efforts by utilizing alignment files generated either by design software or LiDAR measurements.
- Fine tuning the IC and IR specification may help resolve several issues that occurred at the 2017 projects, as recommended in the IC-IR specification review section. Detailed report requirements are crucial as recommended in the specification review section.
- It is also recommended to encourage healthy competition for the IC-IR industry to allow all technology solutions. It can be regulated by the performance requirements in the IC-IR specifications.
- IC-IR project selection criteria may include sizes (lane miles), GPS coverage, and cellular coverage.
- Conducting research to determine the criteria for mean asphalt surface (vs. internal) temperature requirements for vibratory passes.
- IC-IR training and technical support is still an essential element for a successful field project, due to contractors' lack of experiences and support from vendors. It should also be noted that IC-IR systems and Veta software are evolving. It is recommended to conduct annual MoDOT IC-IR and Veta training to qualify IC-IR quality control technicians and to issue annual (or bi-annual) certificates.
- Within available limits, increasing unit cost for IC-IR incentive/disincentive pay schedule may encourage industry's fully utilization of IC-IR technologies.
- Indicating long term plans for MoDOT IC-IR implementation will encourage industry investment in equipment, trained personnel, etc. It is recommended to target 100% implementation of IC-IR by 2020.

STATUS OF IMPLEMENTATION AND ADOPTION

Since the completion of MoDOT IC-IR projects the MoDOT has undertaken the following activities to implement IC-IR into our standard operating procedures as a significant improvement from our traditional practice for similar type projects:

- MoDOT also conducted a very successful "Industry Feedback" meeting on December 12, 2017, to share "Lessons Learned" and to receive industry feedback to improved future IC-IR projects.
- The MODOT IC-IR project team presented the summary of the 2017 IC-IR project to the MoDOT Chief Engineer on December 14, 2017 and received positive feedbacks from the executive levels.
- MoDOT has planned 14+ IC-IR Projects in 2018 as shown in Figure 44.

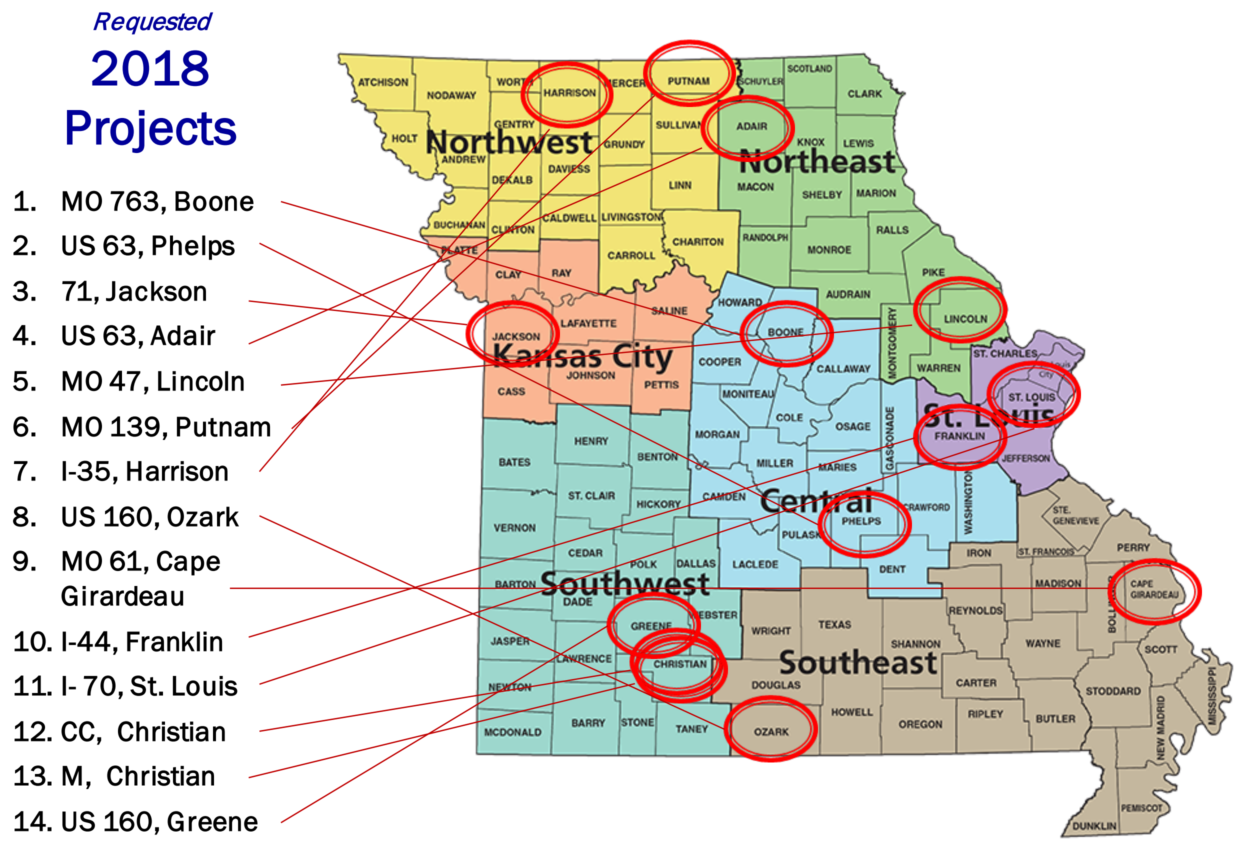


Figure 44: Planned MoDOT IC-IR Projects in 2018.

MoDOT's plan for full adoption of IC-IR is within five years following the similar path of 2017/2018 projects.

APPENDICIES

TECHNOLOGY TRANSFER

USER SATISFACTION SURVEY

REFERENCES

TECHNOLOGY TRANSFER

During this project, the Consultant had developed IC-IR workshop materials and conducted seven lecturer-led workshops for the paving contractors, resident engineers, inspectors, and equipment suppliers of the 13 field projects.

TRAINING MATERIALS

The Consultant developed IC-IR training materials in a package that includes:

- Workshop agenda
- Workshop trainers' information
- Veta software and support
- Workshop slides
- Instructions for hands-on sample files

The workshop agenda is shown in Figure 45, below. The IC-IR workshop handout documents include all the elements mentioned above.

Workshop Agenda

Objectives

- To familiarize attendees with the intelligent compaction (IC), infrared (IR) thermal profiling and Veta software.
- To review the State Specifications, and protocol.
- To inform attendees of the advantages, limitations, and troubleshooting IC and IR data.
- To provide an interactive and hands-on approach throughout the workshop.

Agenda

AM

08:00 am	Session 1 – IC-IR Setup and Data Collection
08:45 am	Hands-on Exercises
10:00 am	Break
10:15 am	Session 2 – Data Analysis with Veta
10:45 am	Hands-on Exercises
11:45 am	Break (Lunch)

PM

01:15 pm	Session 3 – Trouble Shootings
01:45 pm	Hands-on Exercises
02:45 pm	Break
03:00 pm	Hands-on Exercises
04:00 pm	Adjourn

Figure 45: MoDOT IC-IR Training Workshop Agenda.

TRAINING WORKSHOPS

The training workshops (Table 9, Figure 46) were scheduled to be as close as possible to the start of paving of the field projects. The final one (7th workshop) will target all contractors in MO.

Table 9. MoDOT IC-IR Training Workshop Schedule.

No.	Date	Location
1	3/29/17	Jefferson City
2	4/6/17	Springfield
3	5/15/17	St. Louis
4	5/18/17	Willow Spring
5	6/15/17	St. Joseph
6	8/3/2017	Clay County
7	3/14/2018	Jefferson City

Figure 46: Photos from the MoDOT IC-IR Training Workshops.

USER SATISFACTION FEEDBACK

MoDOT has conducted an "Industry Feedback" meeting on December 12, 2017 at the MoDOT office in Jefferson City, MO. The purpose is to provide the IC-IR project analysis results by the Consultant and solicit feedbacks from the contractors and IC-IR vendors. So that, both MoDOT and contractors can improve IC-IR implementation at projects in the future. The meeting was very successful. The feedbacks and discussion are summarized as follow:

Material Transfer Vehicle (MTV) Usage Issues

- Temperature segregation is tied to pavement performance and MTV is proven beneficial to reduce temperature segregation.
- There were safety concerns on using MTV on narrow roads, with personnel walking along MTV.
- As for truck traffic, contractors may try moving full-lane closure at low volume roads.
- There were also maneuver issues of MTV at curves and super-elevation sections.
- There was claimed limited benefits of using small size MTV. However, there was no solid data for the poof.

IC-IR Project Selection and Data Loss Clause

- The criteria for IC-IR project selection should consider: GPS coverage, cellular coverage, tree lines/canopy, and at least once a day for cellular connection/data transmission.
- It is recommended to include a verbiage in IC-IR specification to determine data loss caused due to non-human errors.
- There were also Q&A to handle data loss.

Trial Section

- Contractors requested flexibility of conducting trial sections.
- There were concerns of waiting time for nuclear density gauge (NDG) measurements between roller passes.
- The intent of trial section is to produce optimum rolling patterns to match the rolling patterns of production areas.
- There are cases when rolling patterns need to be adjusted through the production paving process if mix and condition changes.

Temperature requirements

- 190°F is considered as minimum of mean asphalt surface temperature for vibratory. Passes.

Paving Boundary Measurements

- The paving boundary measurements using rover is tedious and expensive.
- LiDAR is still not proven successfully to scan pavement surfaces and produce paving boundary files.

Overall, the paving contractors were very satisfied with the results from the 2017 IC-IR projects and looking forward to the 2018 IC-IR project opportunities. As a result, MoDOT was planning for more than 14 IC-IR projects in 2018.

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