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Intelligent Compaction and Infrared Scanning
Field Projects with Consulting Support

Final Report

Submitted to

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By

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16. Abstract 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 funds to support this Intelligent Compaction (IC) and Infrared Scanning (IR) Field Projects with Consulting Support in 2017. The consulting support was provided by the Transtec Group (Consultant) and includes the development MoDOT IC-IR Protocol and training materials, conducting IC-IR training, on-site technical support to IC-IR field projects, data analysis, and reports of IC-IR field data. The original IC-IR project included 10 field projects. Additional MoDOT funding was later added to support three additional IC-IR projects, making a total of 13 field projects. This document is the final report summarizing the two combined projects including field test results, lessons-learned and recommendations.			
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Acknowledgement

The authors graciously thank the FHWA Accelerated Innovation Deployment (AID) program and MoDOT for funding these IC and IR projects. The authors would also express gratitude towards those IC and IR vendors, dealers, and contractors for their assistance and cooperation during the field projects and subsequent data collection and analysis.

Disclaimer

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

Acronyms and Symbols

AID : Accelerated Innovation Deployment, one FHWA's programs to support innovative highway technologies
CCV : Compaction Control Value, a type of ICMV manufactured by Sakai
CMV : Compaction Meter Value, a type of ICMV manufactured by German's Volkel, used by Caterpillar, Trimble, Dynapac, and Volvo
DMI : Distance Measurement Instrument
EDV: Estimated Density Value, a type of ICMV manufactured by Volvo
GNSS: Global Navigation Satellite System
GPS: Global Positioning System
IC : Intelligent Compaction
ICMV: Intelligent Compaction Measurement Values, a generic term for various solutions from the industry
IR: Infrared Scanning
OEM : Original Engineering Manufacture
PMTP : Paver-Mounted Thermal Profiles
PPM: PaveProj Program, MOBA's software program for the PAVE-IR thermal profile system
QA : Quality Assurance
QC : Quality Control
RE: Resident Engineers

Introduction

Project Scope

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. TR2176) was funded by the AID grant and matching funds, included support for ten (10) field projects. The second MoDOT IC-IR contract (No. TR20182) 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.

This report provides a summary of the two combined projects, including field test results, lessons-learned and recommendations. In additional to this final report, other reports produced under these projects include:

- MoDOT IC-IR Protocol: guidelines to plan and conduct IC-IR project
- MoDOT IC-IR workshop handouts: handout materials for workshop participants
- Individual MODOT IC-IR field project reports: 13 reports for the field projects

Structure of this Report

This report includes the following chapters:

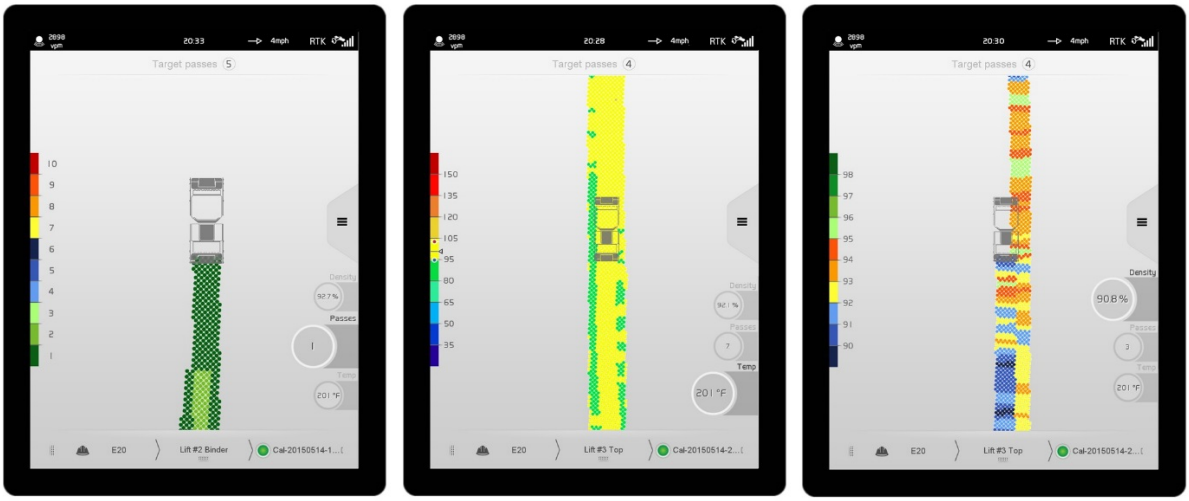
1. Introduction
2. Innovative Technologies: Description of the IC and IR technologies and the Veta software.
3. IC-IR Protocol: The Protocol for planning, conducting IC-IR field projects, and data management.
4. IC-IR Training: Training materials and workshops on IC and IR.
5. IC-IR Field Projects: Description of IC-IR project information and paving schedule.
6. Data Analysis and Results: Description of analysis methods, summary of results, and project evaluation.
7. IC-IR Specification Reviews: Reviews and comments on MODOT IC and IR specifications.
8. Conclusions and Recommendations: Conclusions of this study and recommendation for IC-IR future implementation.

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 1). 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 1. 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 2) and after-market IC retrofit (Figure 3). The OEM is directly from roller vendor's factory. The IC retrofit can be mounted on selected models of rollers.

Figure 2. Examples of OEM Double-Drum IC Rollers.

Figure 3. An Example of IC Retrofit Systems.

Intelligent Compaction Measurement Value (ICMV) 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 4).

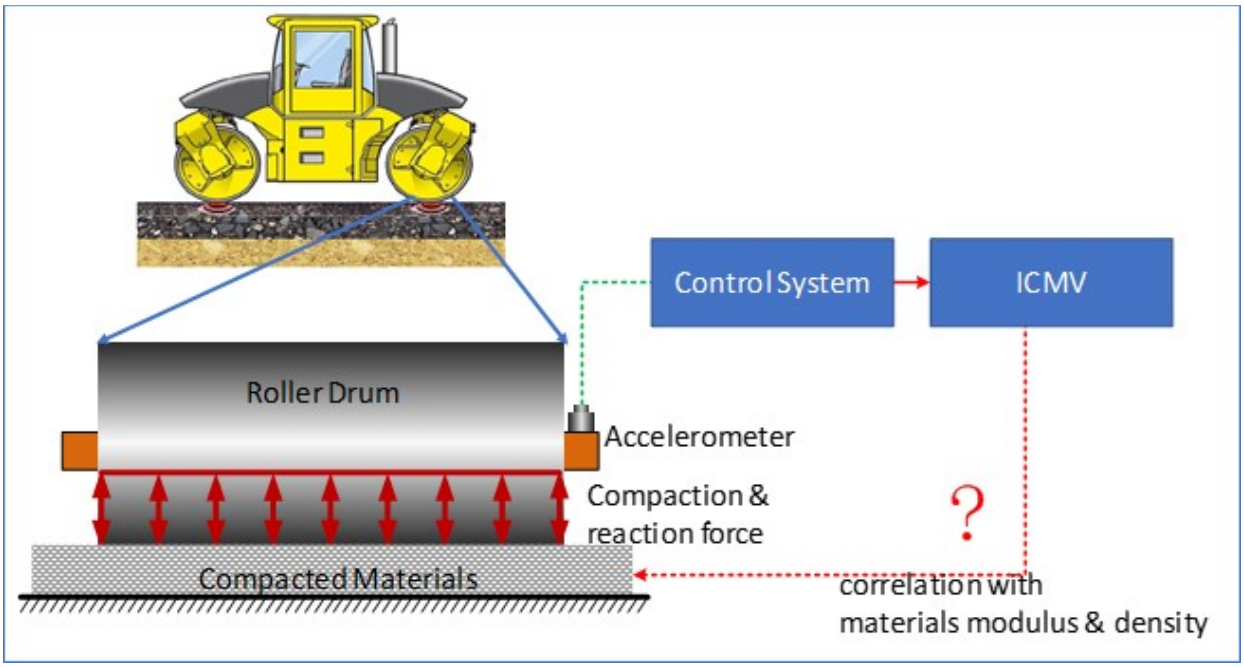


Figure 4. Method of Measuring and Calculating ICMV.

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 1 and Table 2 summarize key information from this Tech Brief.

Table 1. Summary of ICMV Model and Methods (FHWA ICMV Tech Brief).

Model	Description	Mechanistic/ Empirical	Dynamic/Static
A	Empirical Reactive Models	Empirical	N/A
B	Continuum Roller and Half-Space Layered System	Mechanistic	Dynamic/Static
C	Discrete Drum and Spring-Dashpot Coupled System	Mechanistic	Dynamic
D	Dynamic Impact Model for Decoupled Drum and Layer System	Mechanistic	Dynamic
E	Artificial Intellience Method	Mechanistic	Dynamic

Table 2. 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

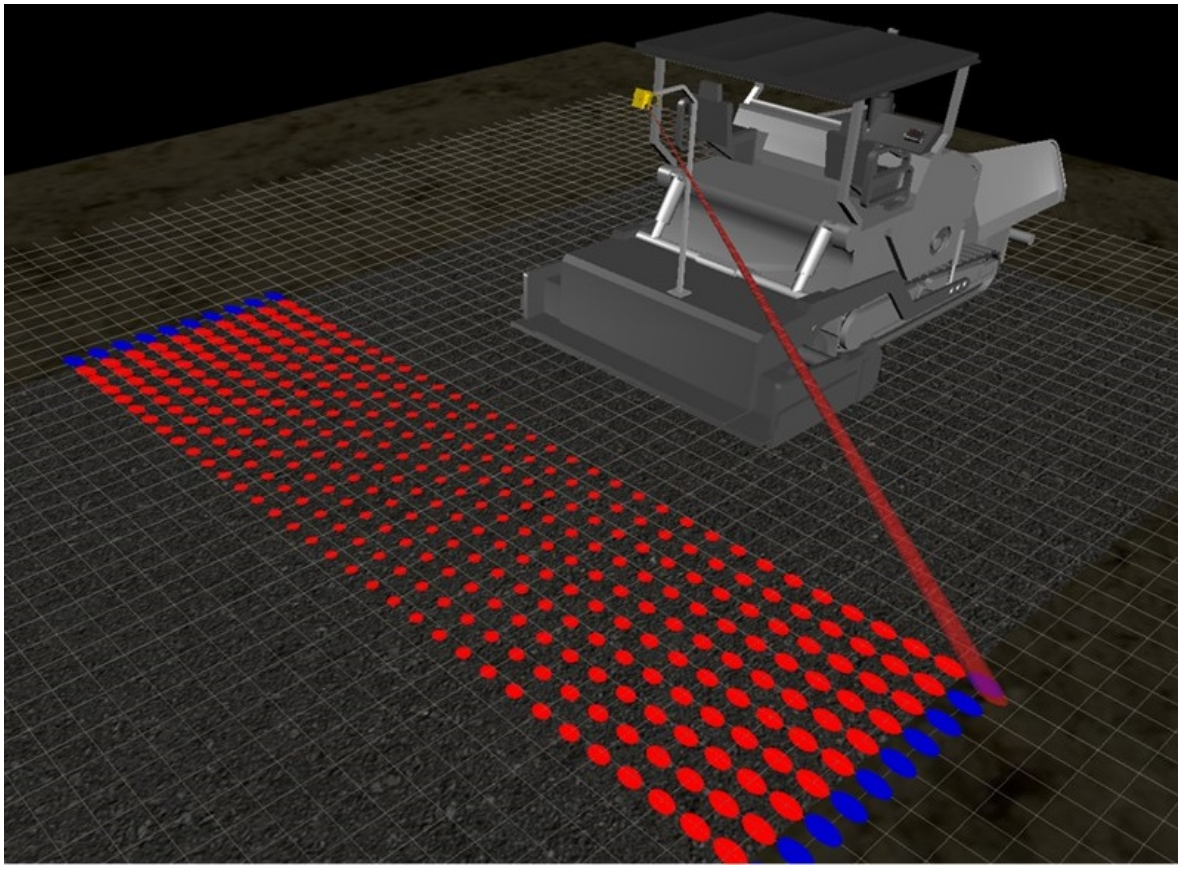
1. Correlation with mechanical and physical properties of various compacted materials.
2. Valid measurement when drum and compacted materials are decoupled.
3. Allows layer-specific measurements of compacted material's mechanical and physical properties.
4. Model A3 functions in static rolling.

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 5). The IR system is equipped with GPS and a DMI to track the positions of thermal profiles and paver speeds (Figure 6). 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 5. An Illustration of an IR System.

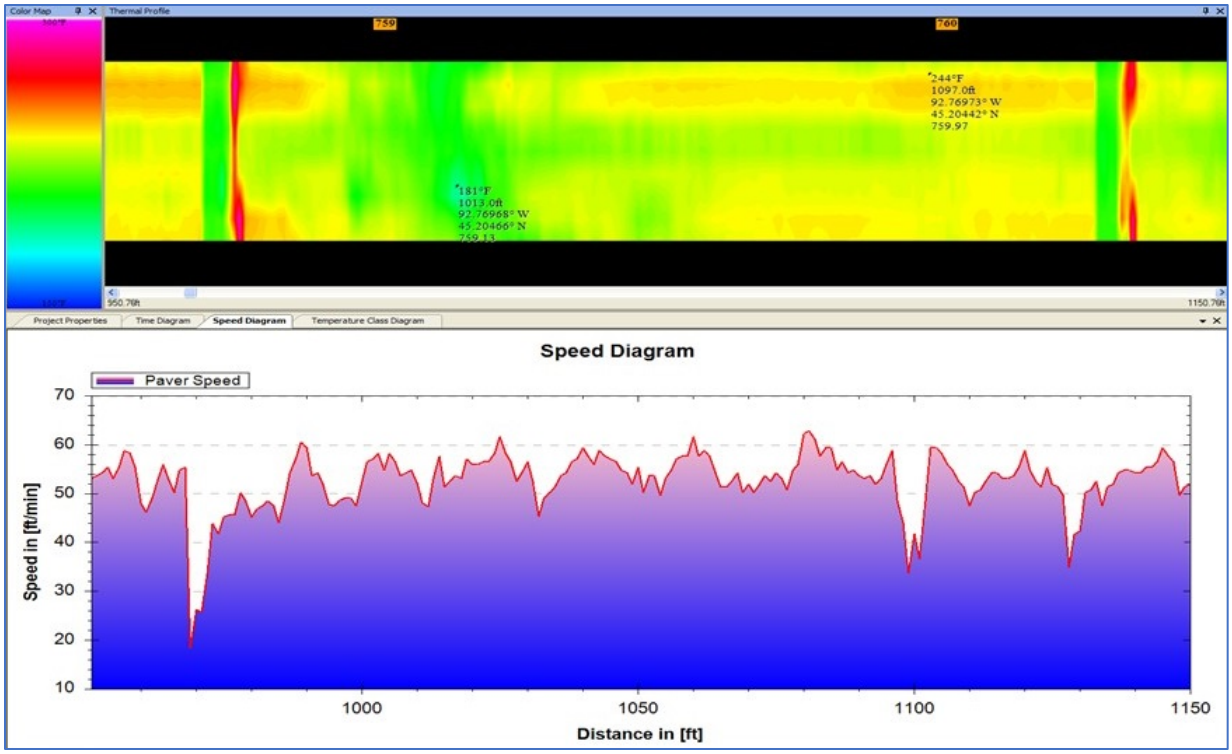
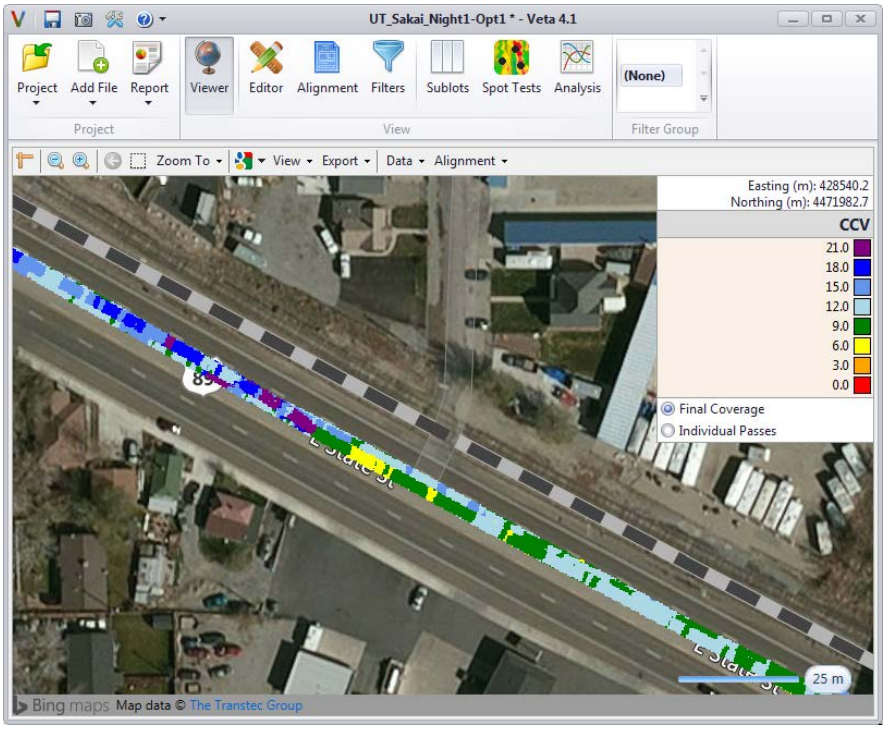


Figure 6. An Example of IR Display of Thermal Profiles and Paver-Speed.

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".



AASHTO

VETA
INTELLIGENT CONSTRUCTION

Figure 7. 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 8). 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 9). 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 10). 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 11). Veta was used for all IC and IR analysis under this project.

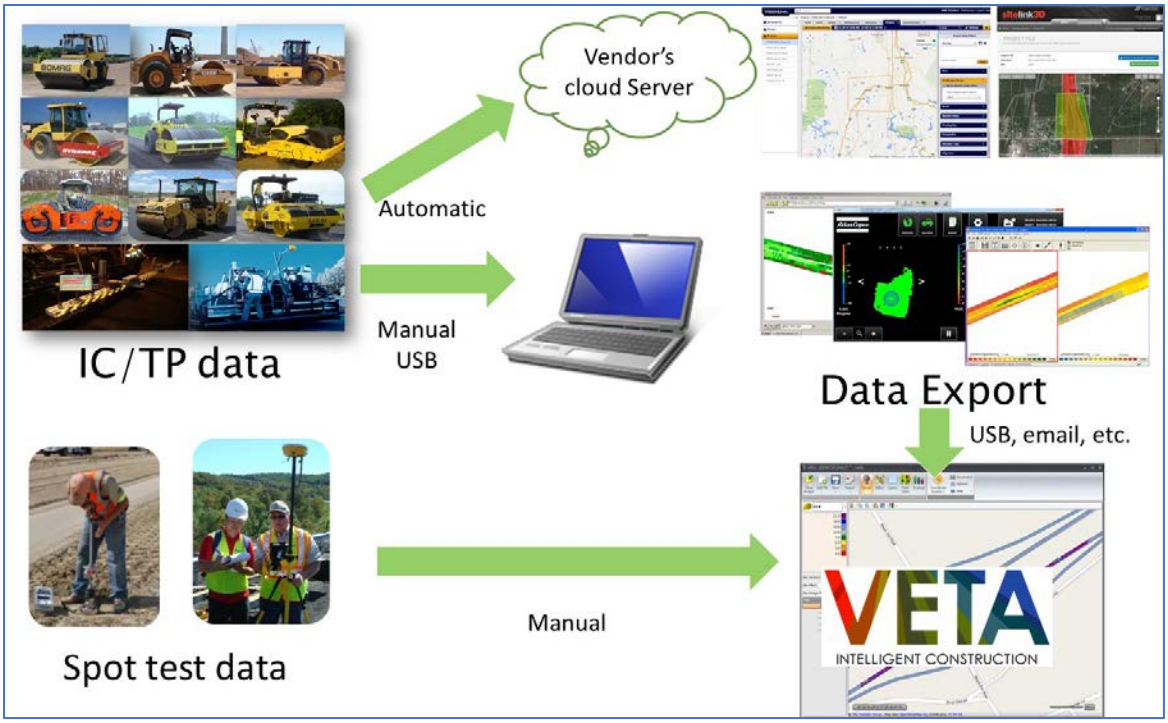


Figure 8. IC and IR Data Flow to Veta.

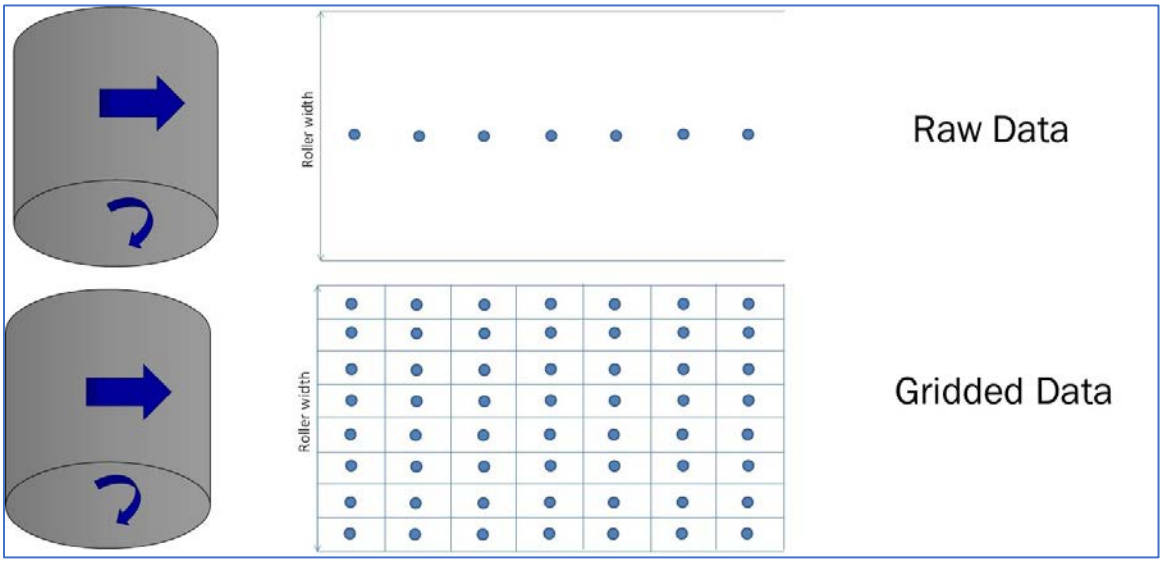


Figure 9. IC Raw and Gridded data.

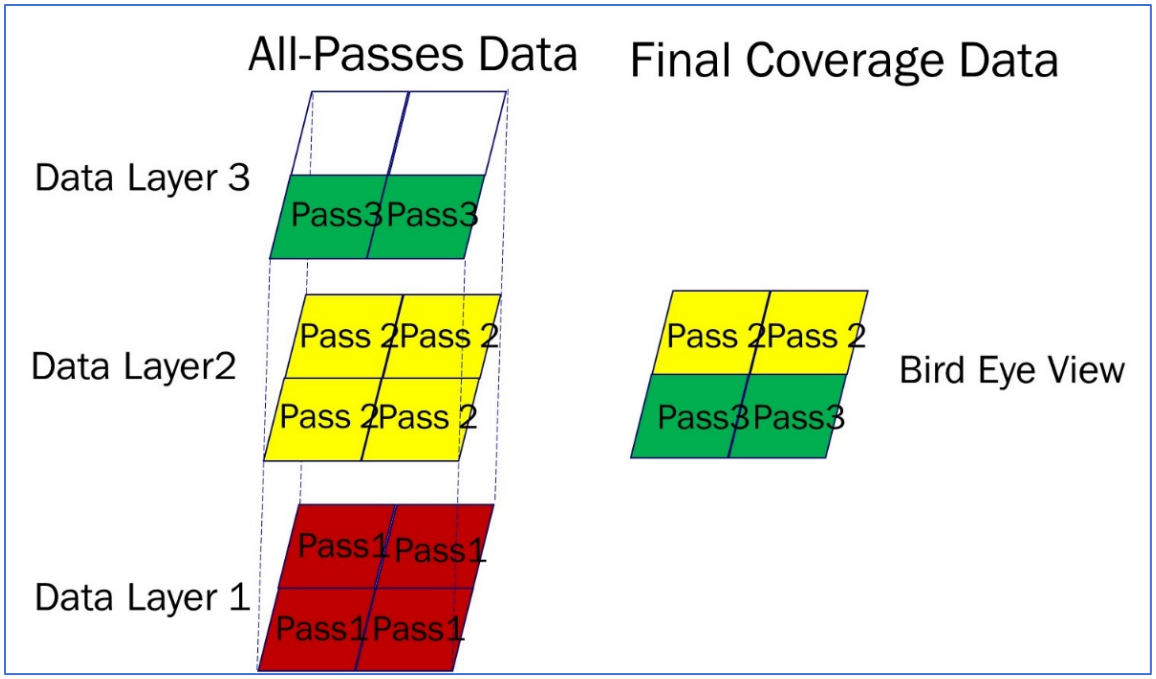


Figure 10. IC All-Passes Data and Final Coverage data.

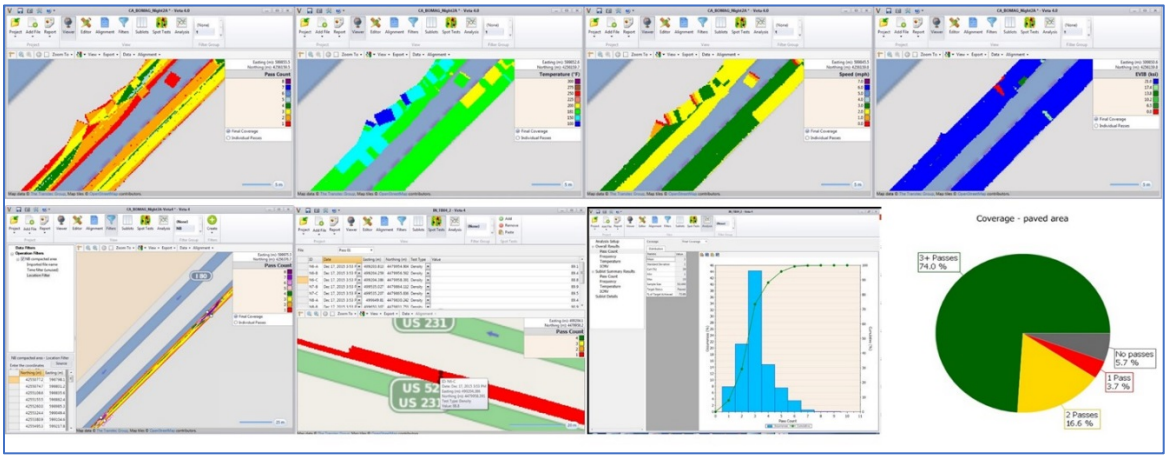


Figure 11. Screenshots of Veta Displays and Analysis.

Work Plan

The work plan for 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

The timeline and deliverable schedule for all tasks are summarized below in Table 3.

Table 3. Timeline and Deliverable Schedule.

	2017											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tasks	3	4	5	6	7	8	9	10	11	12	13	
Task 1 – Kick Off Meeting	XO											
Task 2 – IC-IR Data Management Protocol	X	XXXX	OO									
Task 3-1: Development of Training Materials	X	XXXX	OO									
Task 3-2: Conduct Training Courses			XXX	XXXX								
Task 4-1: Planning for IC-IR Data Management												
Task 4-2: Field Supports												
Task 4-3: IC-IR Data Analysis												
Task 4-4: IC-IR Project Report												
Task 5 – IC-IR Specifications										XXXX	OOOO	XX
Quarterly Report			X			X			X			X
Final Report									XXXX	XXXX	OOOO	XX

X Contractor's effort
O MoDOT reviews
Schedule for project field support will depend on the paving schedule.

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.

IC-IR Protocol

Summary of IC-IR Protocol Elements

The MODOT IC-IR Protocol (Figure 12) is a stand-alone document that includes the protocol to manage intelligent compaction and infrared scanning data for the IC-IR field projects. The goal is to ensure IC, IR, and associated data and derivative files are properly collected, stored, and managed.

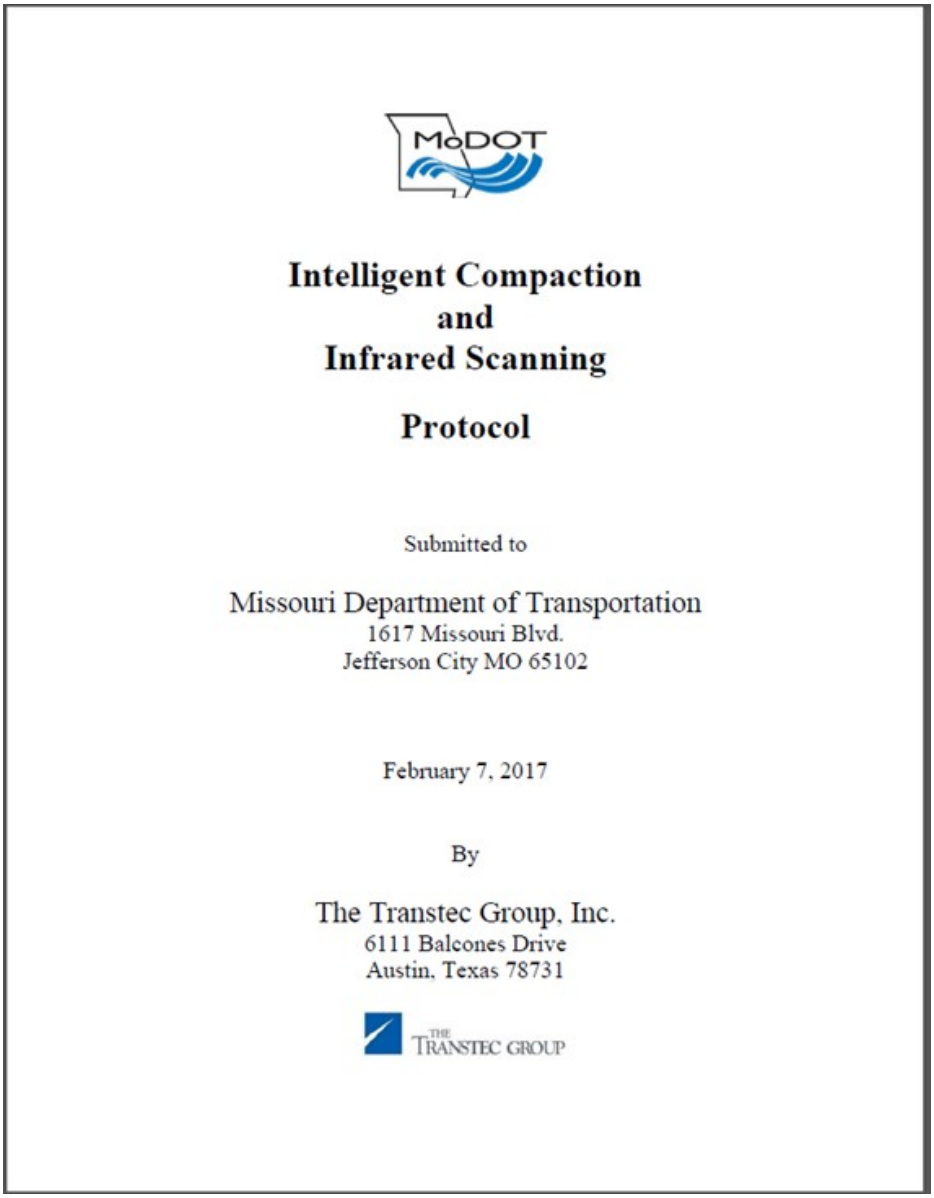


Figure 12: MoDOT IC-IR Project Protocol.

The elements of the MODOT IC-IR Protocol include:

1. Project Planning
    - Pre-paving Meeting
    - Responsibility of Each Party
    - Daily Debriefing

    - Communication Methods
2. Data File Sharing
    - MoDOT SharePoint
    - Data Folder Structure
    - Data Types
    - Data File Naming Convention
3. Pre-Paving Setup and Checks
    - IC System Setup and Checks
    - IR Scanner System Setup and Checks
4. Paving Operation Records and Data
    - Project Information
    - Daily Paving Record
    - Summary of Paving Activities and Machine Settings
    - Summary of IR and IC Analysis Results
    - Data Management
        - IC Data Management
        - GPS Daily Production Boundary Managements
        - IR Data Management
        - Data Files Inventory

Key elements of the MODOT IC-IR Protocol are described below. Further details can be found in the actual MODOT IC-IR Protocol document.

Check Lists and Forms

The Protocol includes check lists and standard forms to facilitate project and data management for the contractors, and resident engineers (REs).

Contractor's Check List

Route	
Job No.	
Date	
Contractor	

	Yes	No
Conduct IC GPS verification..		
Conduct IR scanner DMI calibration.		
Construct a trial section.		
Record and export IC data.		
Record and export daily production boundaries.		
Record IR scanner data.		
Record spot test data.		
Create a Veta project file for IC data.		
Produce MOBA IR Segment Report.		
Fill daily paving record form.		
Transmit all files to MoDOT SharePoint.		

Notes

Figure 13: Contractor's Daily Check List.

Route:		**Job No.**			
IC System:					
IR System:					
GNSS Ref:					
Date:					
Start time:		**Start Milepost:**		**Length (ft):**	0
Stop Time:		**Stop Milepost:**		**HMA (tons):**	

GPS Verification

	Nothing (m)	Easting (m)	Diff. (mm)	< 30mm?
IC GPS				Y
Rover				Y

Trial Section

Opt Passes	
Patterns	

Paving

Direction	Lane	Lift	Width (ft)	Thickness (")

Compaction

Position	Roller	Passes	Static/Vib	Amp (mm)	Freq (vpm)
Breakdown					
Intermediate					
Finishing					

Notes

Submitted:

Figure 14: Contractor's Daily Paving Record Form.

RE's Daily Check List

Route	
Job No.	
Date	
RE	

	Yes	No
Record daily field diaries.		
Review IC Veta Project file submitted by contractor.		
Review IR segment report submitted by contractor.		
Transmit daily diaries to MoDOT SharePoint.		

Notes

Figure 15: Daily Check List for REs.

File Naming Convention

The standard data file convention (Table 4) was recommended to facilitate data file management. The recommended file naming convention for the root name in this protocol is:

[job no]-[date]-[data Type].[extension]

Where:

[job no] **:** MoDOT field project job number (e.g., 2P3051) in 6 alpha-numeric characters.
[date] : paving date in YYYMMDD.
[data type] **:** data type in 3 characters (see definition in Table 4.)
[extension] **:** data file extension.

Table 4: Data File Naming Convention

Data Type	Data File Names	Examples
Daily Trial Section data	**[job no]-[date]-TRL.xlsx**	2P3051-20161021-TRL.xlsx
Daily GPS verification	**[job no]-[date]-GPS.PDF**	2P3051-20161021-GPS.PDF
IC Raw Data	**[job no]-[date]-ICD.[extension]** [extension]: • BOMAG exported IC files (*.csva) • Caterpillar/Trimble/Volvo exported IC files (*.csv) • Dynapac exported IC files (*.txt) • Hamm exported IC data files (*.vexp) • Sakai/TOPCON exported IC files (*.pln)	2P3051-20161021-ICD.CSV
IR Raw Data	**[job no]-[date]-IRD.paveproj**	2P3051-20161021-IRD.paveproj
IR MOBA Report	**[job no]-[date]-IRR.PDF**	2P3051-20161021-IRR.PDF
Daily Production Boundary Data	**[job no]-[date]-BND.xlsx**	2P3051-20161021-BND.xlsx
Daily Spot Test Data	**[job no]-[date]-SPT.xlsx**	2P3051-20161021-SPT.xlsx
Daily IC Veta Project File	**[job no]-[date]-IC.vetaproj**	2P3051-20161021-ICD.vetaproj
Daily IR Veta Project File	**[job no]-[date]-IR.vetaproj**	2P3051-20161021-IRD.vetaproj

Notes:

- If there are multiple operations in a day (e.g., different lifts or paving directions), tag sequential number at the end of the filename, e.g., 2P3051-20161021-ICD1.xlsx, 2P3051-20161021-ICD2.xlsx.
- When a Veta project file includes multiple days of data from a given project, a simple

naming convention will be used, such as: 2P3051-ICD.vetaproj, 2P3051-IRD.vetaproj.

- If MoDOT elects to use alignment files from design, the naming convention can be: **[job no]-[date]-ALN.kmz**.

MoDOT SharePoint

The MoDOT SharePoint has been essential for all parties to share data files for the field projects. Each project was assigned with a project folder (Figure 16).

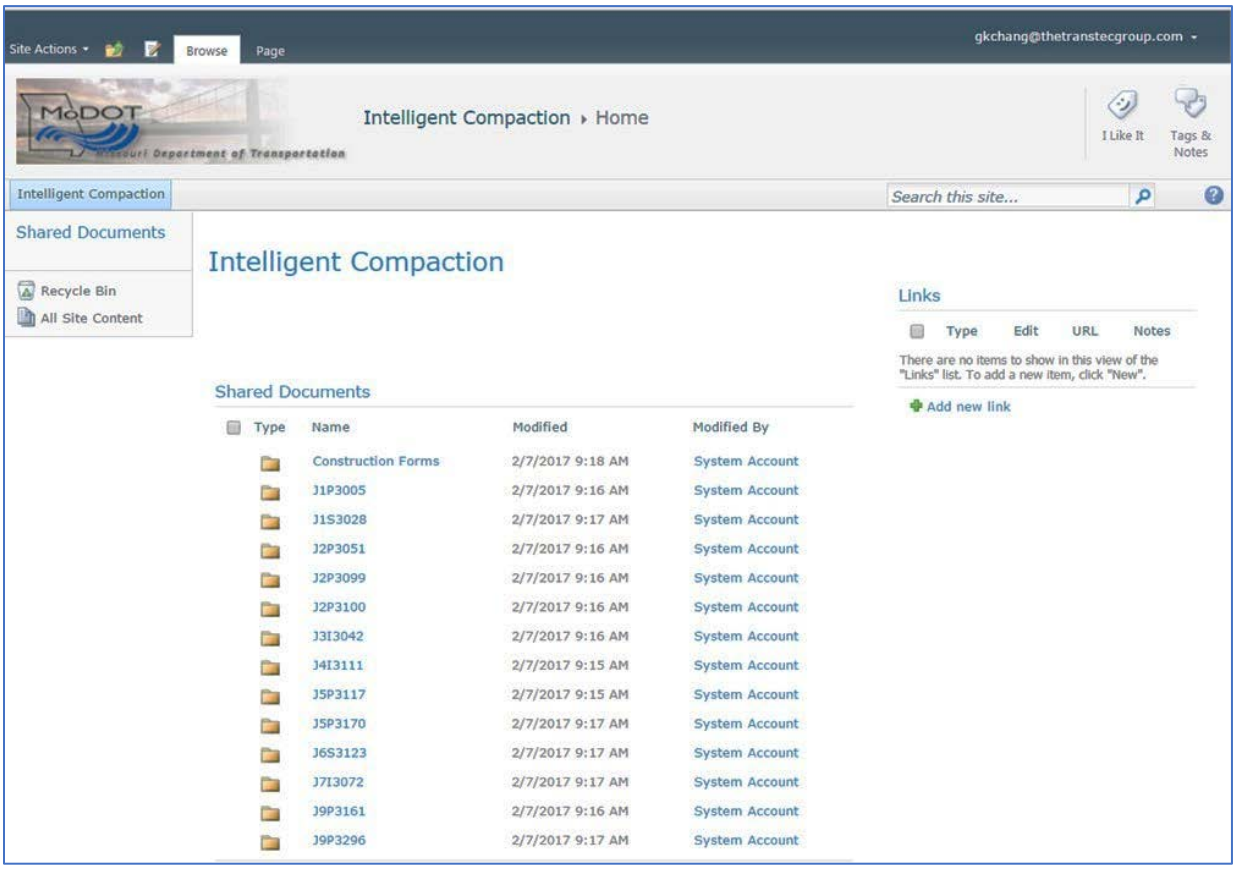


Figure 16: MoDOT SharePoint IC-IR Project Folders.

Each field project folder will have the subfolders to store specific types of data (Figure 17):

Analysis files (analysis spreadsheet files)
GPSdata (GPS validation files and daily production boundary spreadsheet files)
IC data (raw IC data files and notes)
IRData (raw IR data files and IR PDF report files)
Notes_Reports (notes and report files)
PhotoVideos (field photo and video files)
SpotTest (spot test data spreadsheet files)
Veta (Veta project and report files)

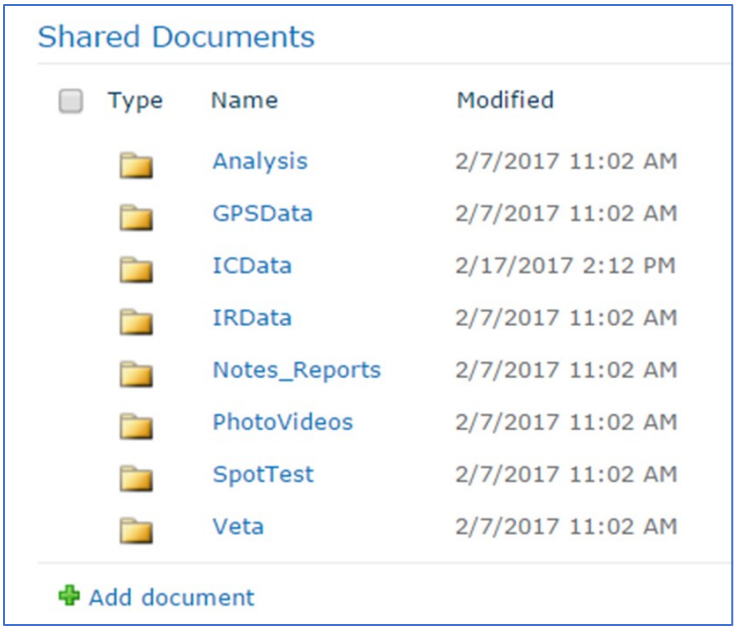


Figure 17: MoDOT SharePoint IC-IR Project Sub-Folders.

Contactors were required to transmit the following data to the respected sub-folders:

- Contractor's daily check list form,
- Daily paving record form,
- IC data,
- IR PDF reports,
- GPS paving boundary,
- Spot test data (core or nuke), and
- Photos (if any).

REs were required to transmit the following data to the respected sub-folders

- RE's daily check list form,
- Daily diaries,
- Photos (if any)

The Consultant managed all data files in all sub-folders. All essential IC-IR documents (e.g., check lists, standard forms, protocol, workshop handouts, trial section spreadsheet, etc.) were also uploaded to the SharePoint folders.

IC-IR Training

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 18, 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 18: MoDOT IC-IR Training Workshop Agenda.

Training Workshops

The training workshops (Table 5, Figure 19) were scheduled to be as close as possible to the start of paving of the field projects.

Table 5. MoDOT IC-IR Training Workshop Schedule.

No.	Date	Location	Targeted Contractors
1	3/29/17	Jefferson City	Chester/Capital
2	4/6/17	Springfield	Blevins/APAC
3	5/15/17	St. Louis	Magruder
4	5/18/17	Willow Spring	Pace/APAC
5	6/15/17	St. Joseph	Herzog
6	8/3/2017	Clay County	Ideker/Capital
7	3/14/2018	Jefferson City	All contractors

Figure 19: Photos from the MoDOT IC-IR Training Workshops.

IC-IR Field Projects

Project Descriptions

The schedule for the MoDOT IC-IR field projects is listed in Table 6.

Table 6. 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	9/22/2017	19
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	5/17/2017	10
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 7.

Table 7. 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

The contractor codes (1 to 8) are used for this report for protection of privacy and confidentiality.

The locations for the MoDOT IC-IR field projects and workshops are shown in Figure 20.

Figure 20: MoDOT IC-IR Project and Workshop Locations.

Data Analysis and Results

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 21). 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 22). 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 23. The temperature segregation based on the above analysis method does not consider the effects of paver stops.

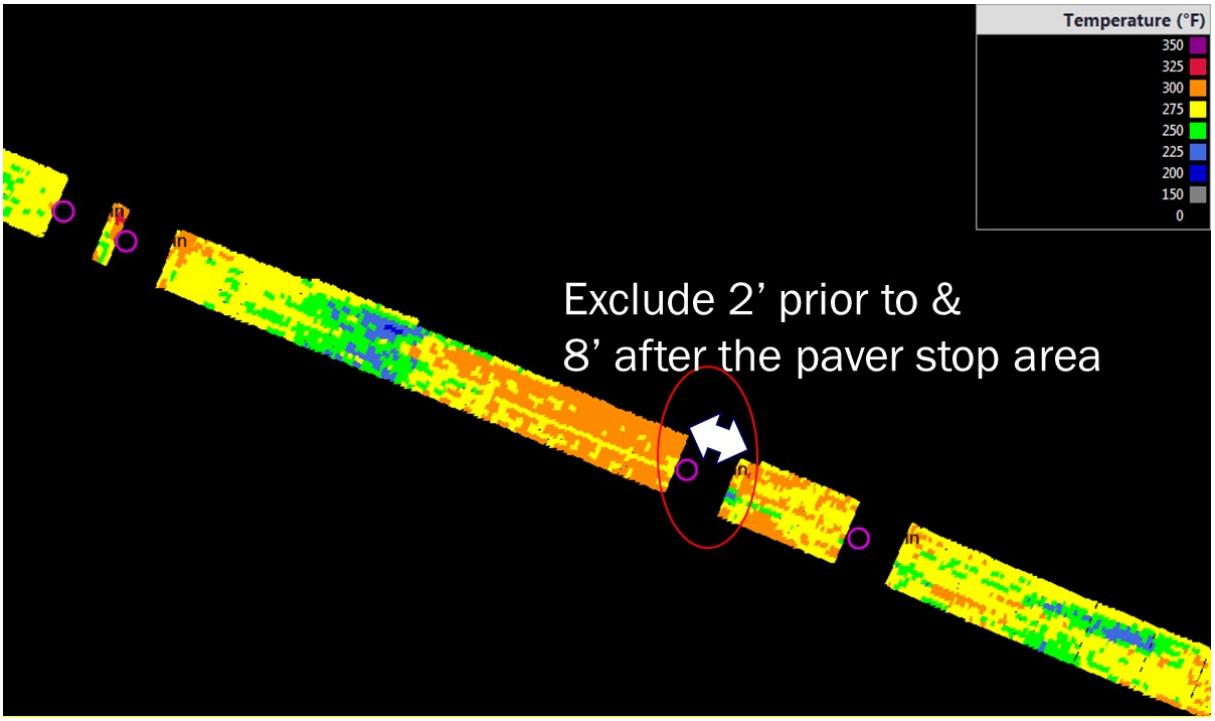


Figure 21: AASHTO PP80 IR Analysis Method: 10' exclusion around a paver stop location

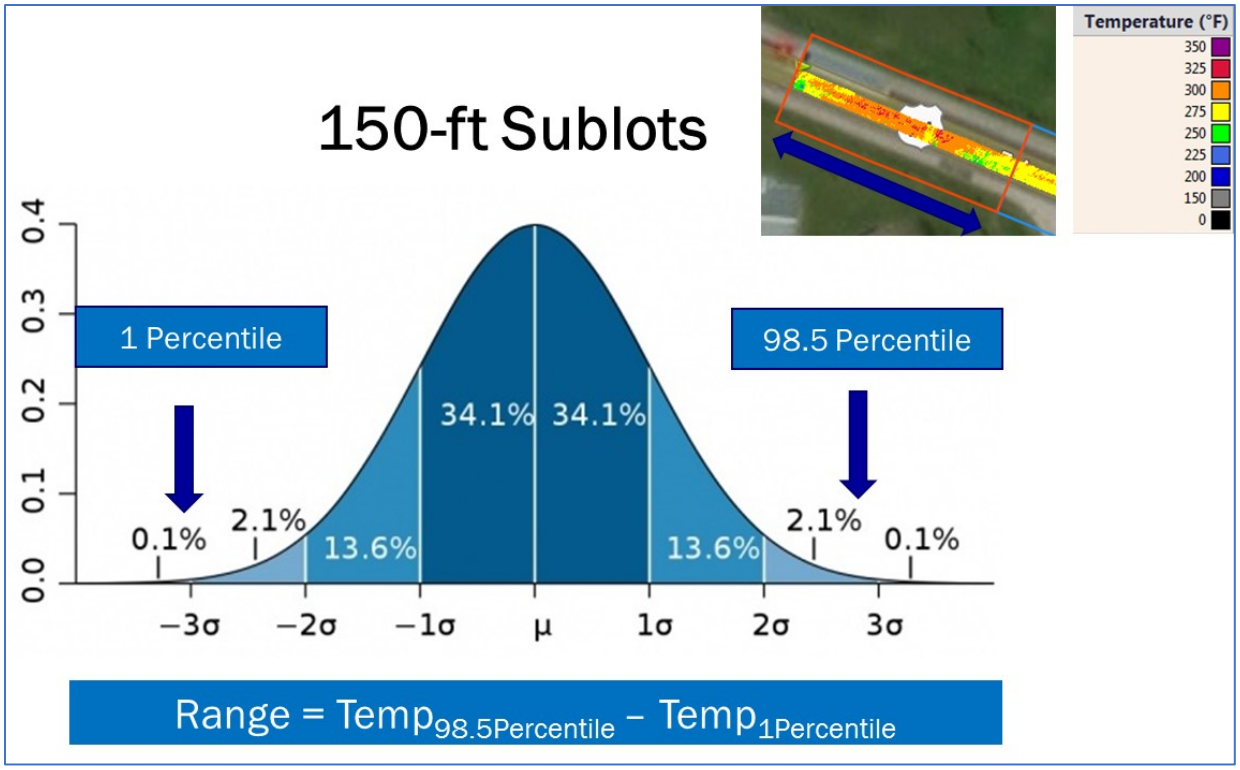


Figure 22: AASHTO PP80 IR Analysis Method: Computation of "Range" value

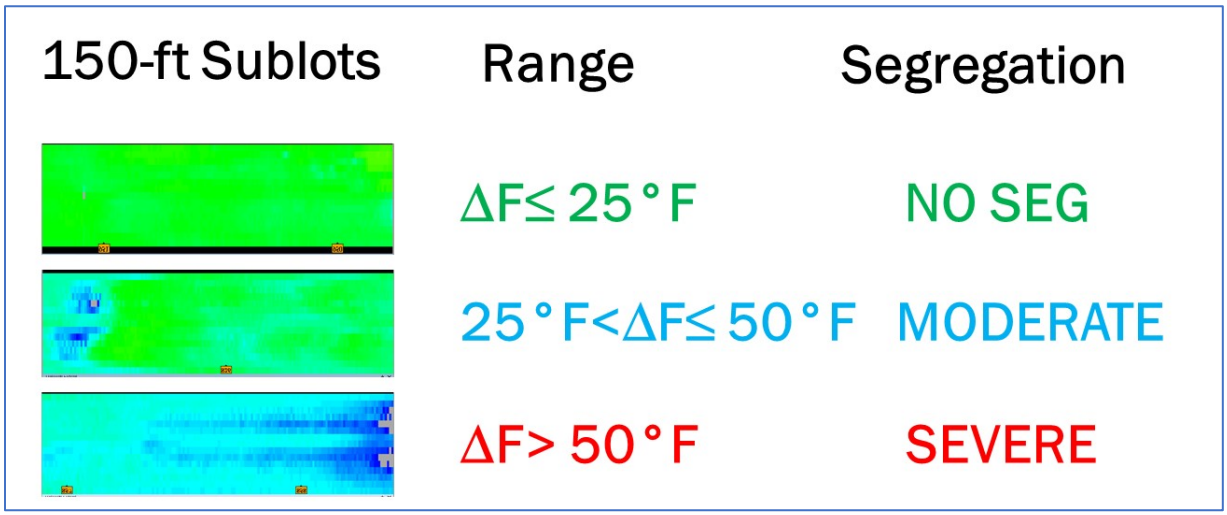


Figure 23: AASHTO PP80 IR Analysis Method: Segregation categories

An example of IR data analysis from the August 14, 2017 data from J3I3042 RT 70 is shown in Figure 24. 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.

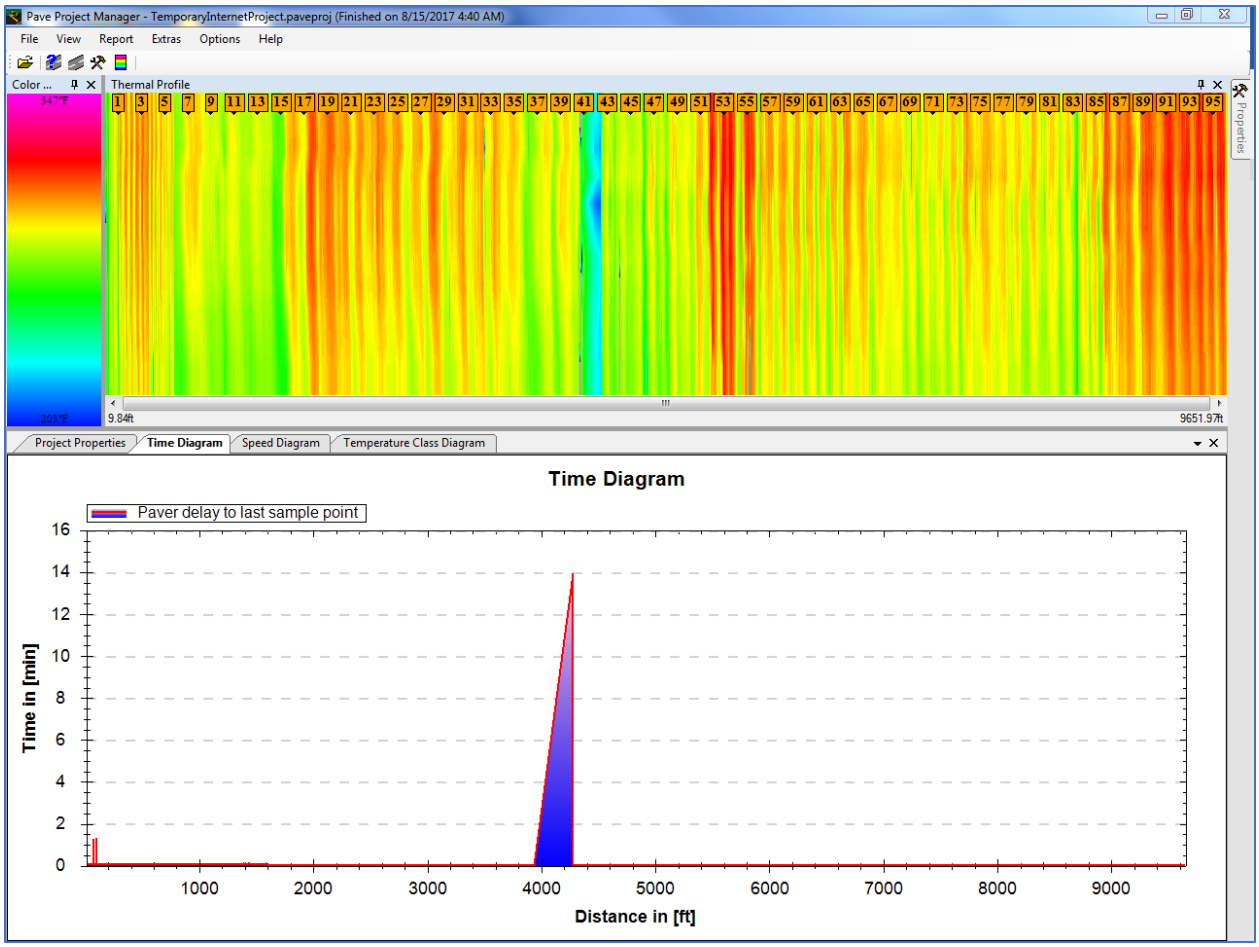


Figure 24: Example of MOBA PPM IR Analysis Screens.

The MOBA PPM report indicates 57% no segregation, 38% moderate segregation, and 5% severe segregation (Table 8). The MOBA PPM report is the data source used to determine incentive/disincentive according to the IR Job Special Provision (JSP).

Table 8. Example of MOBA PPM IR Analysis Report of Temperature Segregation.

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

The MOBA raw data were imported to Veta, and Figure 25 shows the Veta Viewer screen of IR data plot on a satellite base map for the project.

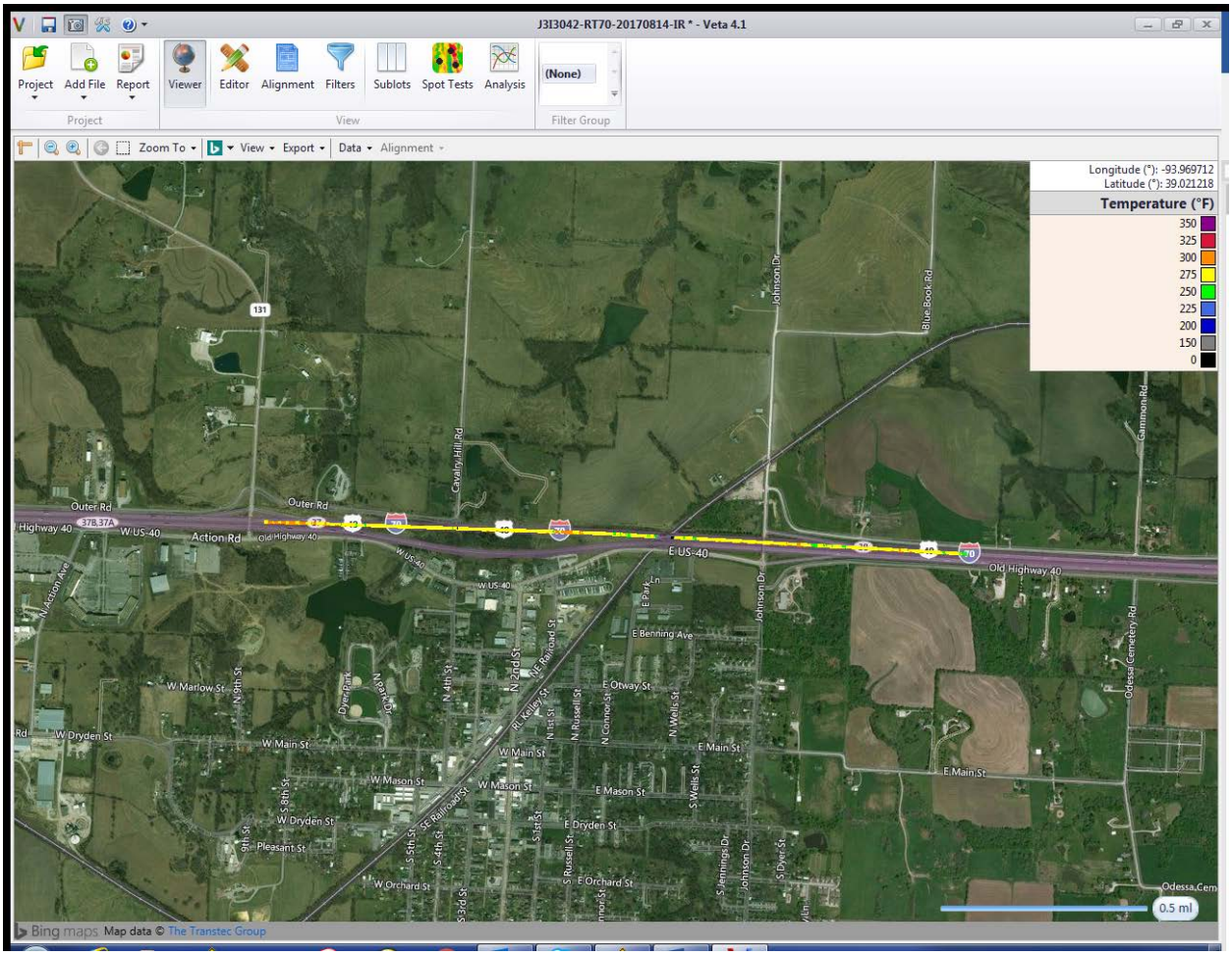


Figure 25: Example of Veta Viewer screen of IR data plots (J3I3042, RT70).

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 26). Note that the IR data uploaded to VETA was for research purposes and was not used to evaluate incentive/disincentive.

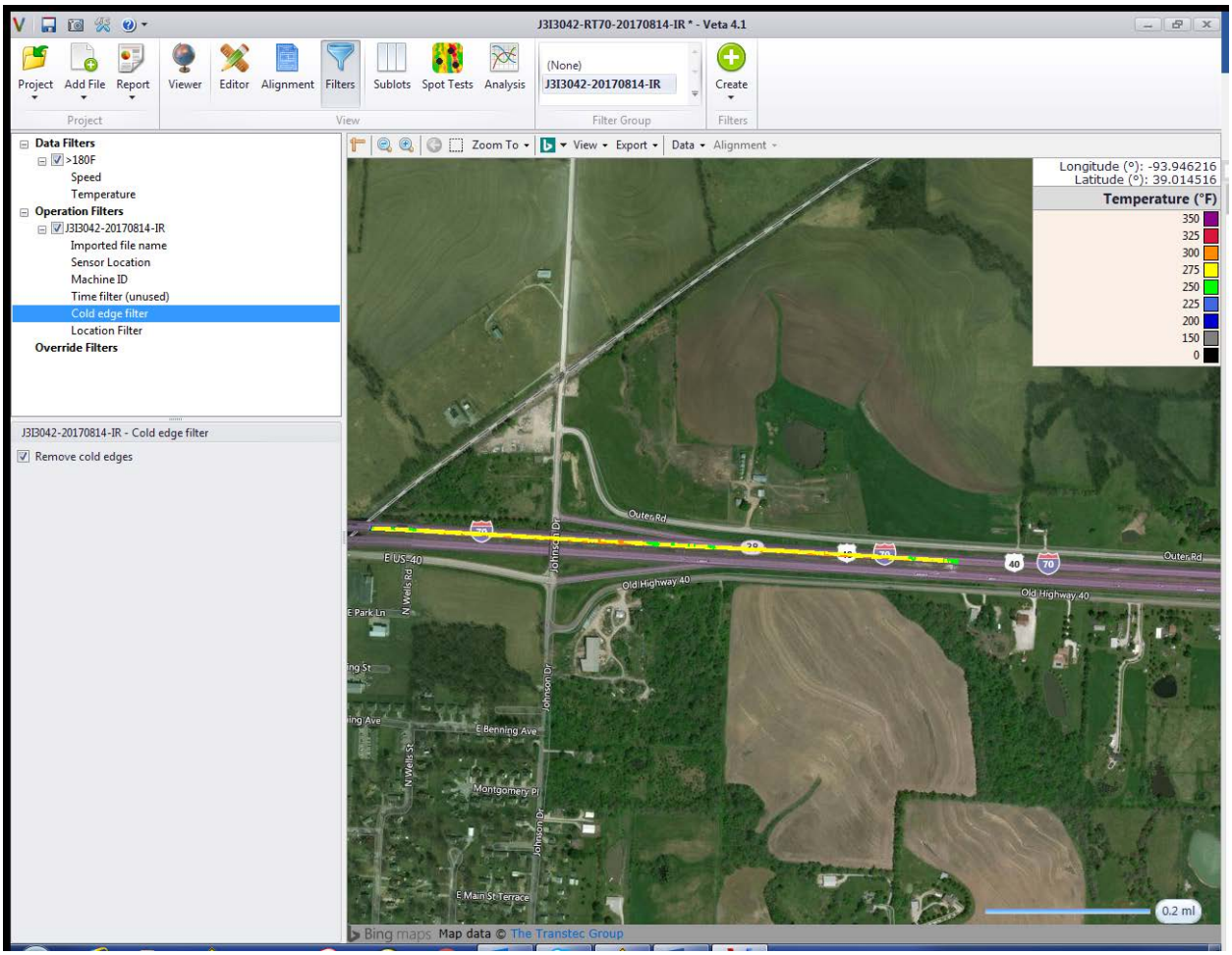


Figure 26: Example of Veta Filter screen (J3I3042, RT70).

Further, 150-ft sublots were created for analysis (Figure 27).

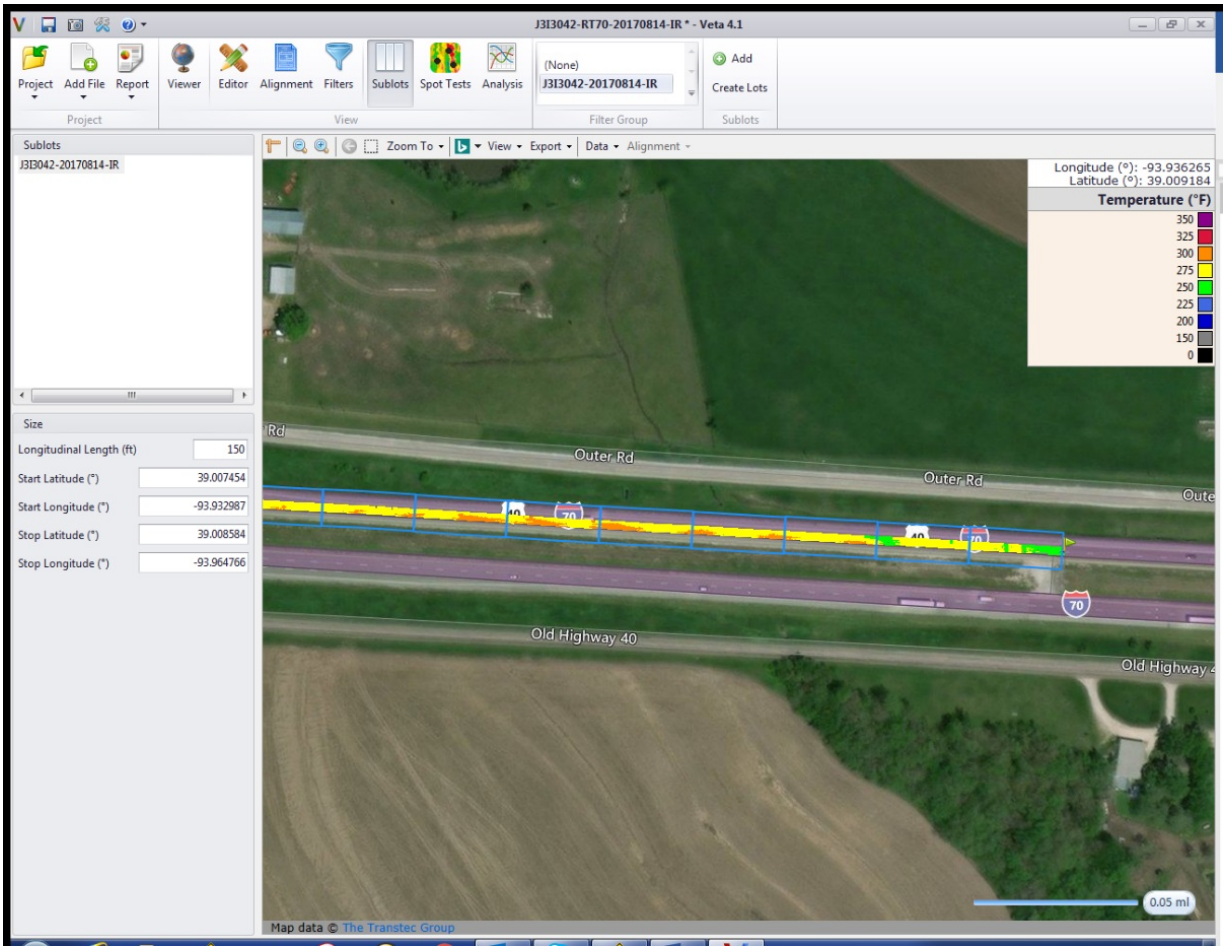


Figure 27: Example of a Veta Sublot screen (J3I3042, RT70).

Note the data gap at a bridge in the screenshot in Figure 28. 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 80oC, 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 28: 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 29.

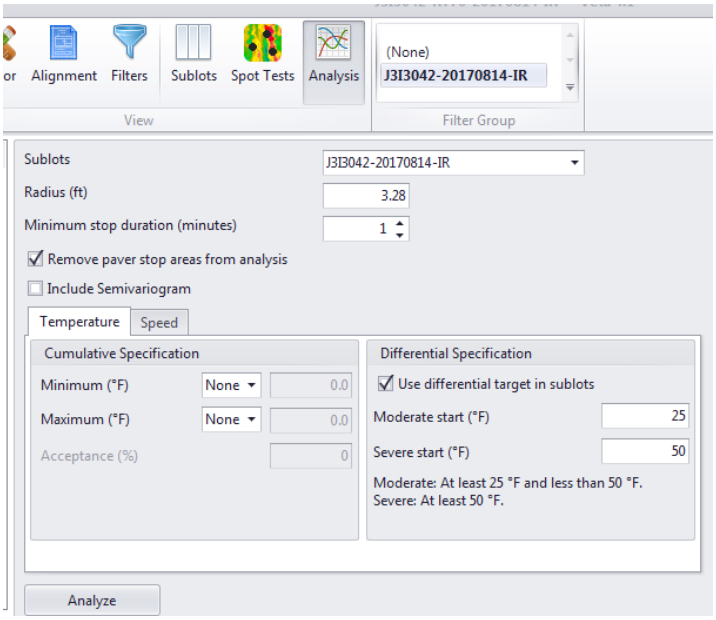


Figure 29: Example of a Veta Analysis setup for IR data analysis (J3I3042, RT70).

A typical Veta thermal profile, time diagram, and paver speed plot are shown in Figure 30. 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.

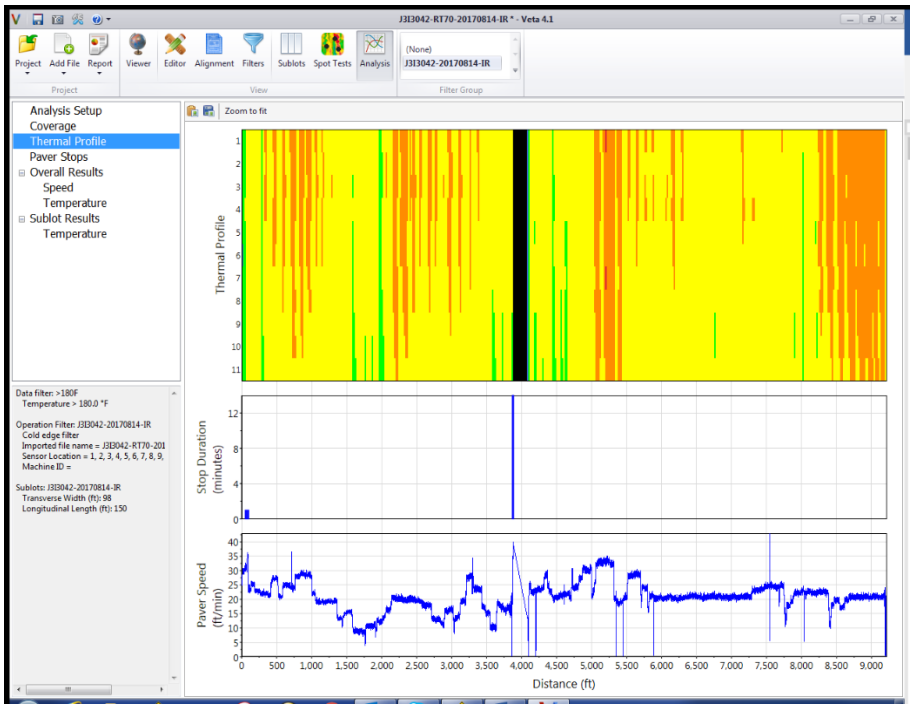


Figure 30: Example of a Veta IR data analysis results (J3I3042, RT70).

The Paver Stop map (Figure 31) plots a pink circle indicating paver stop locations, and text indicating stop duration in minutes.

Figure 31: Example of a Veta Paver Stop plot (J3I3042, RT70).

A sample Veta temperature differential report is shown in Figure 32. The reported length is 9,038 ft. (approximately 600 ft. different from the MOBA reported length).

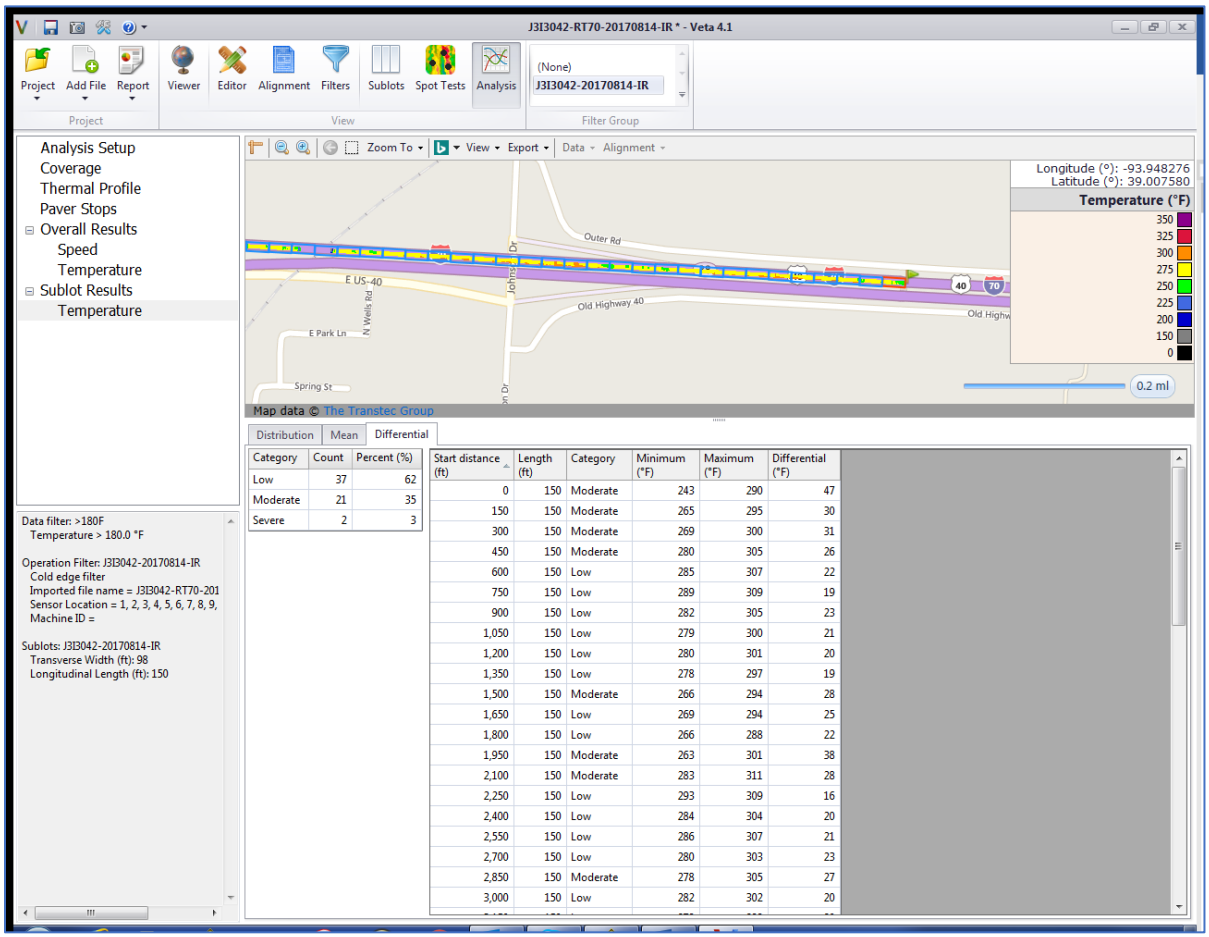


Figure 32: Example of a Veta IR Temperature Differential report (J3I3042, RT70).

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 9.

Table 9. MoDOT IC Coverage Classification.

Classification	% Coverage
Passing	>90
Moderate	70 < < 90
Deficient	< 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 33). 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.

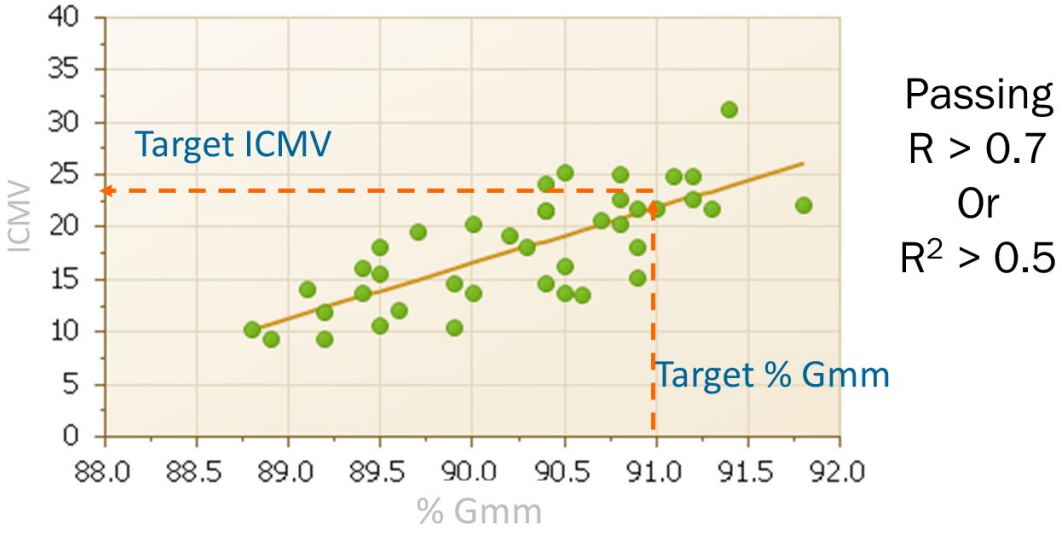
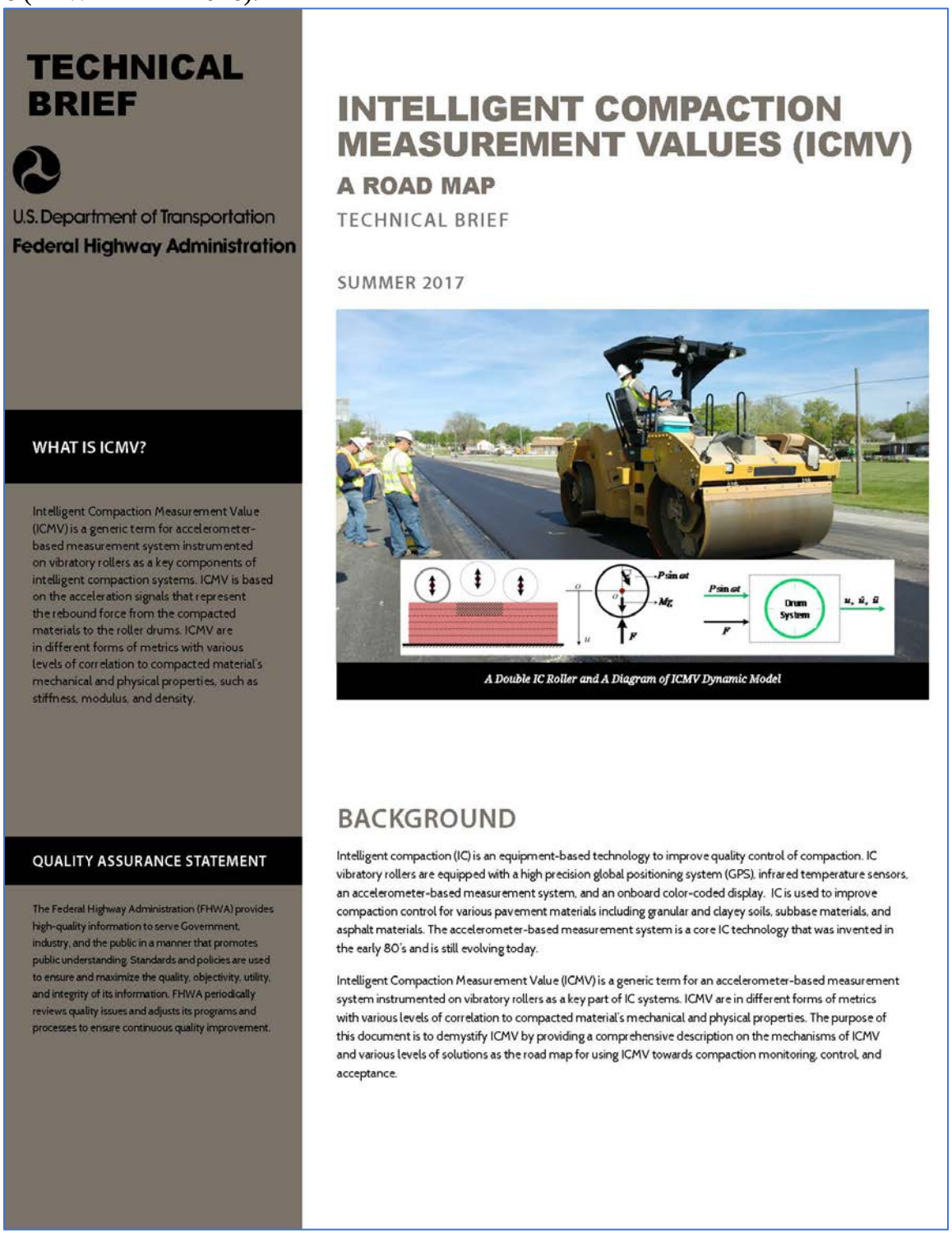


Figure 33: Target ICMV determined by Correlation between ICMV and Acceptance Spot Tests from Trial Section Data.

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 34: FWHA 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 35).

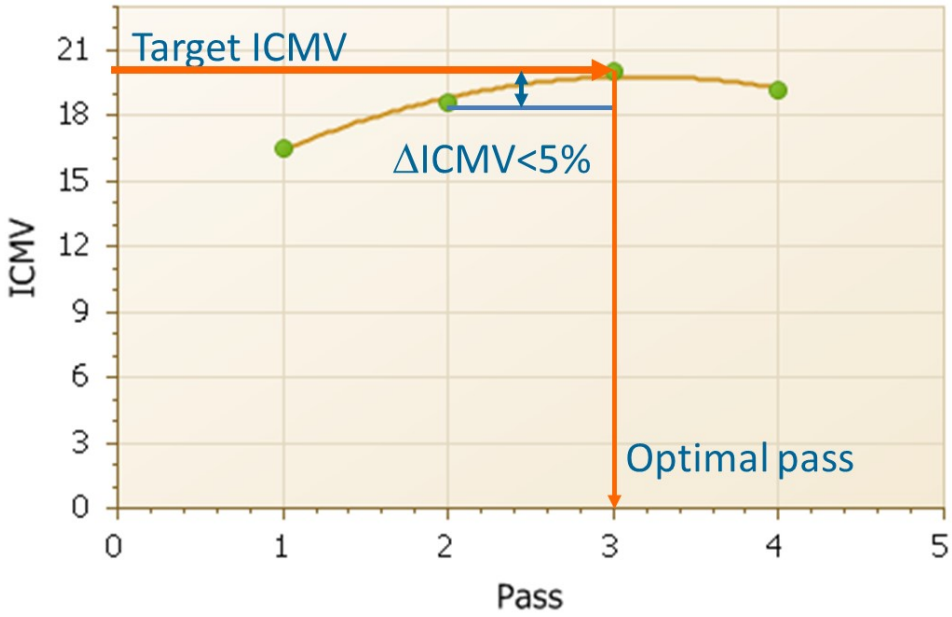


Figure 35: Target ICMV determined by an ICMV Compaction Curve when Acceptance Spot Tests from Trial Section Data are Not Available.

The target ICMV coverage was based on MoDOT IC specification, as shown in Table 10.

Table 10. MoDOT Target ICMV Coverage Classification.

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

Mat Temperature

Based on MoDOT Specification Section 403.15 (Figure 36), 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.

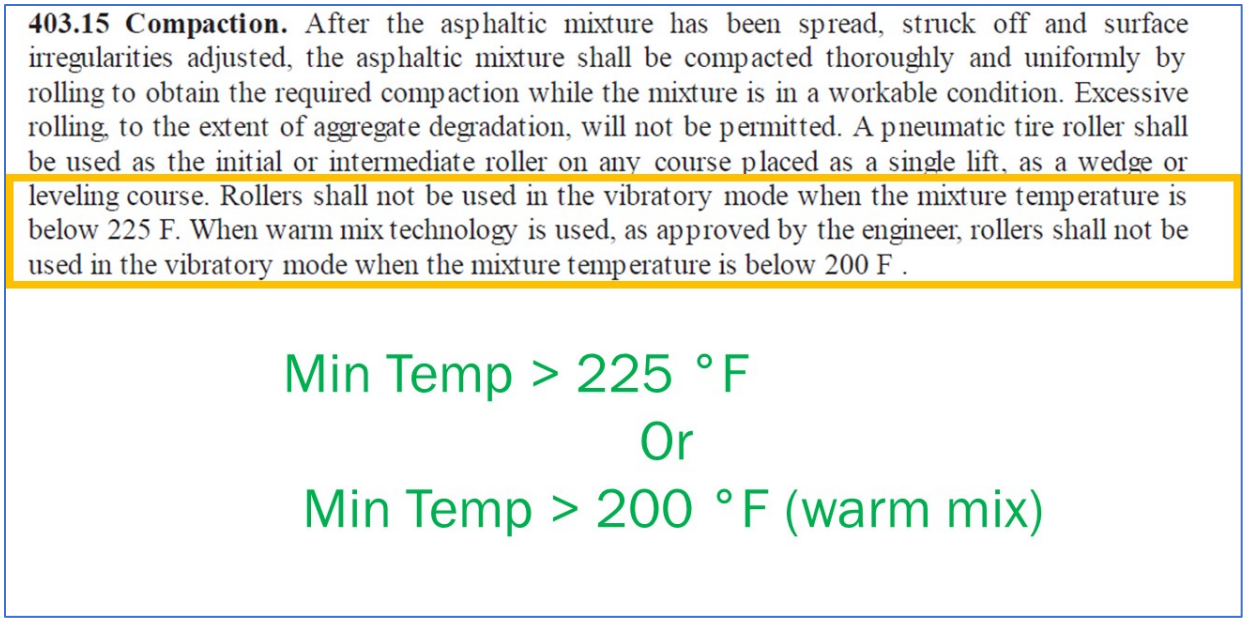


Figure 36: MODOT Requirement for Mat Temperatures during vibratory compaction.

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 37). While as demonstrated in Figure 37, 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.

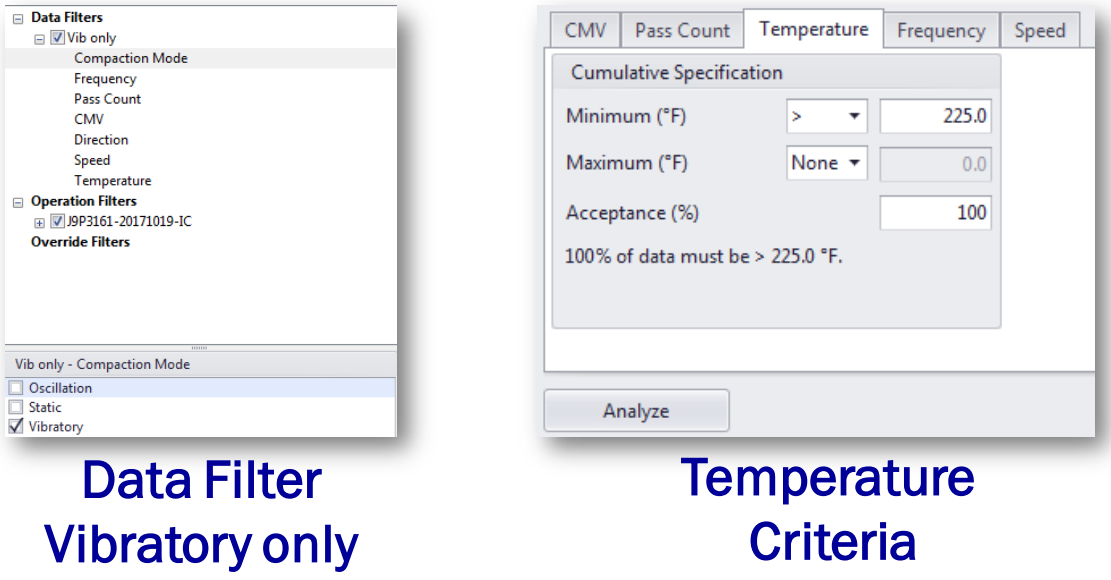


Figure 37: Veta Data Filter and Analysis Setup for MODOT Requirement for Mat Temperatures during vibratory compaction.

Analysis Example

An example of a complete IC analysis is presented below for 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 38).
- 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 39. 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 38: Trial Section Tests on 4/24/2017 (J1P3005 RT 24).

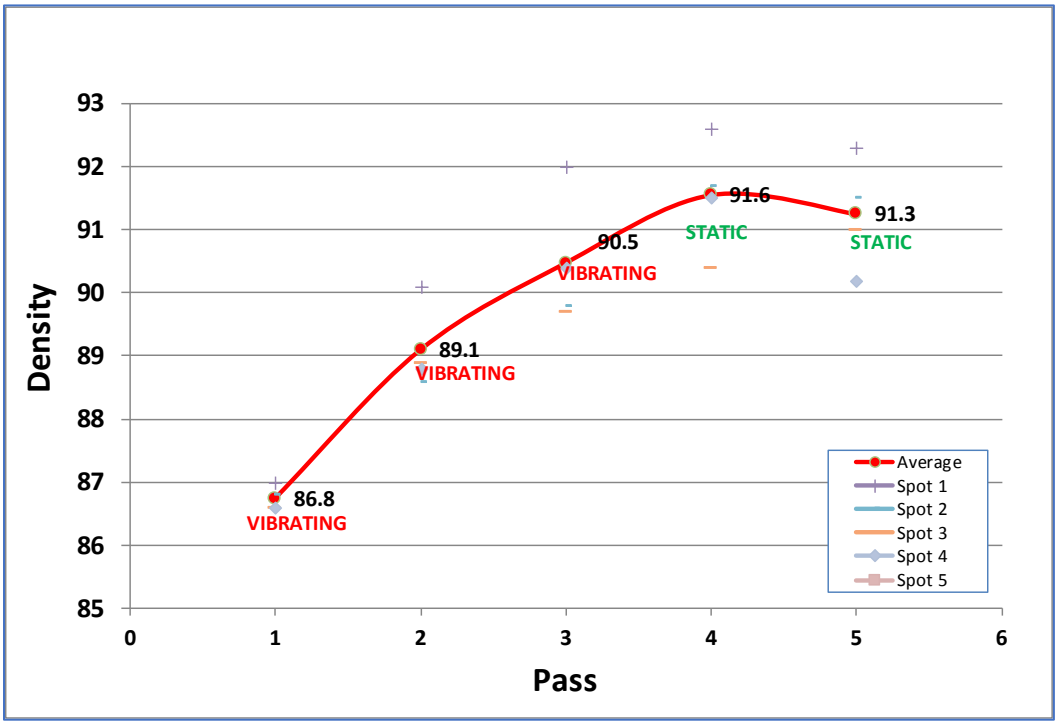


Figure 39: Compaction Curve from the Trial Section on 4/24/2017 (J1P3005 RT 24).

The VisionLink IC data file was imported to Veta for analysis. Figure 40 shows the pass count map.

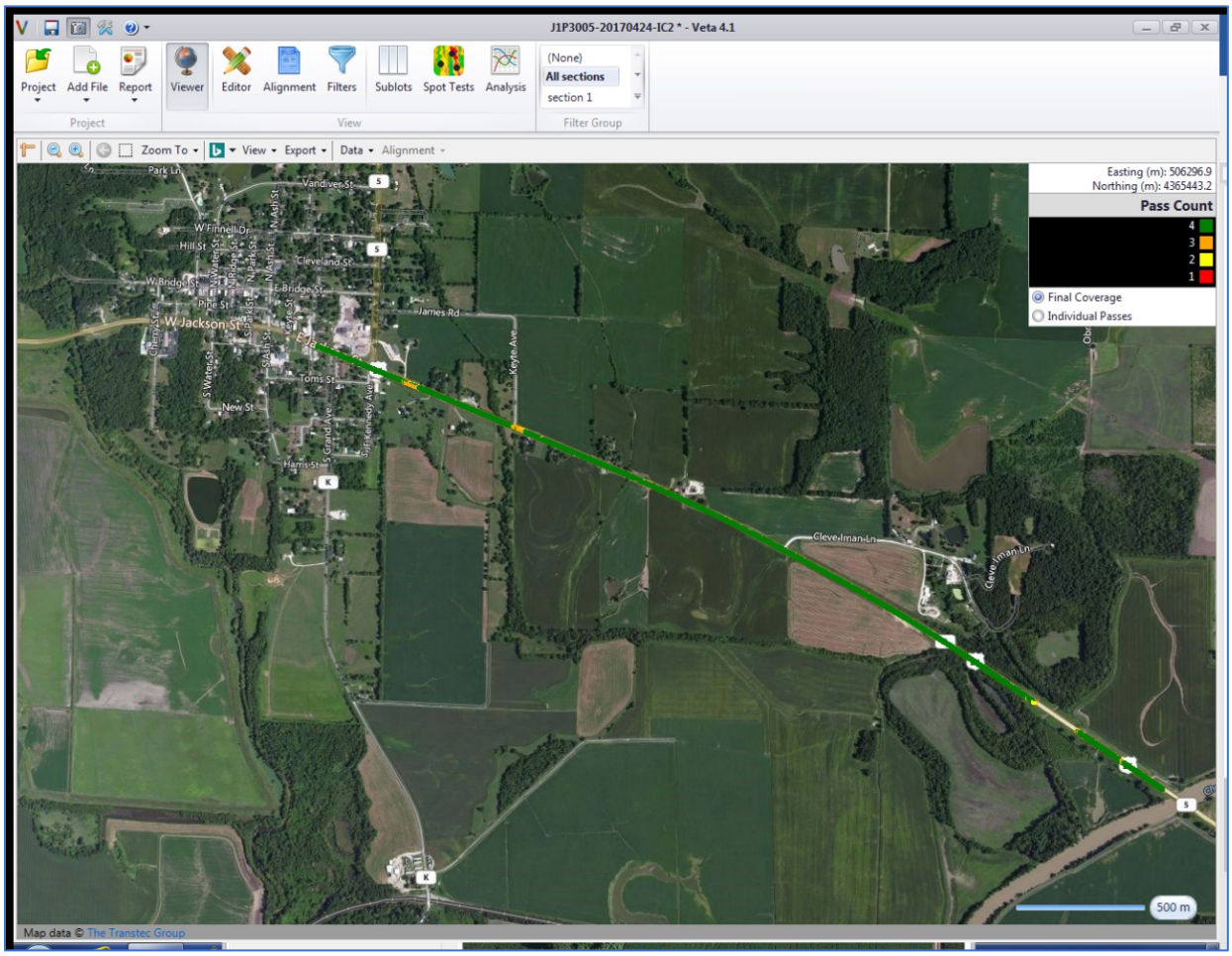


Figure 40: An Example Veta Analysis Screen showing Pass Count map (J1P3005 RT 24).

Two filter groups were created, or Section 1 and Section 2 (Figure 41). A third filter group was created by combining both sections.

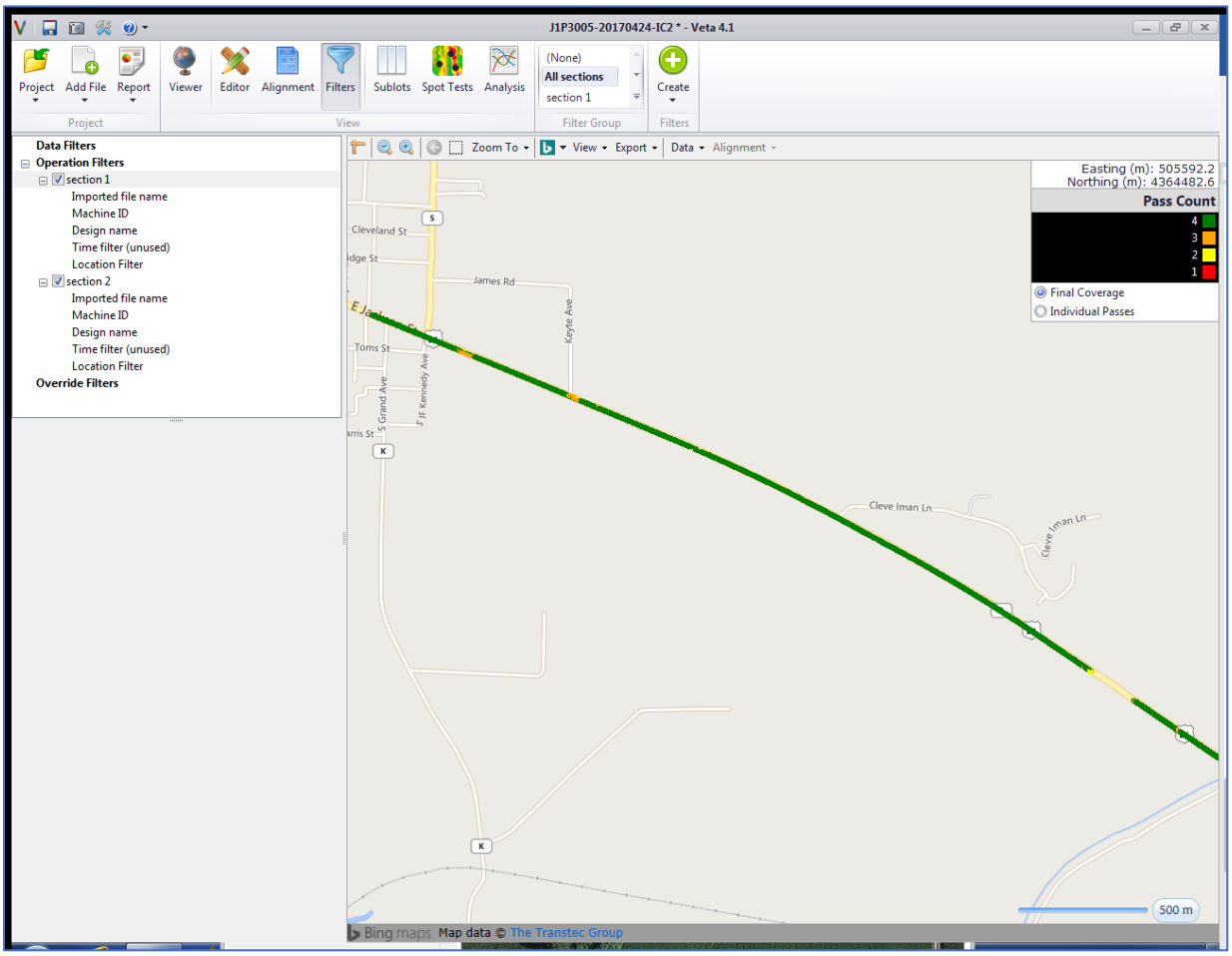


Figure 41: An Example Veta Analysis Screen showing Filter Groups (J1P3005 RT 24).

Spot test data of core density were imported to Veta's Spot Test Screen (Figure 42). The four core density tests correspond to the second set of four test locations within the trial section.

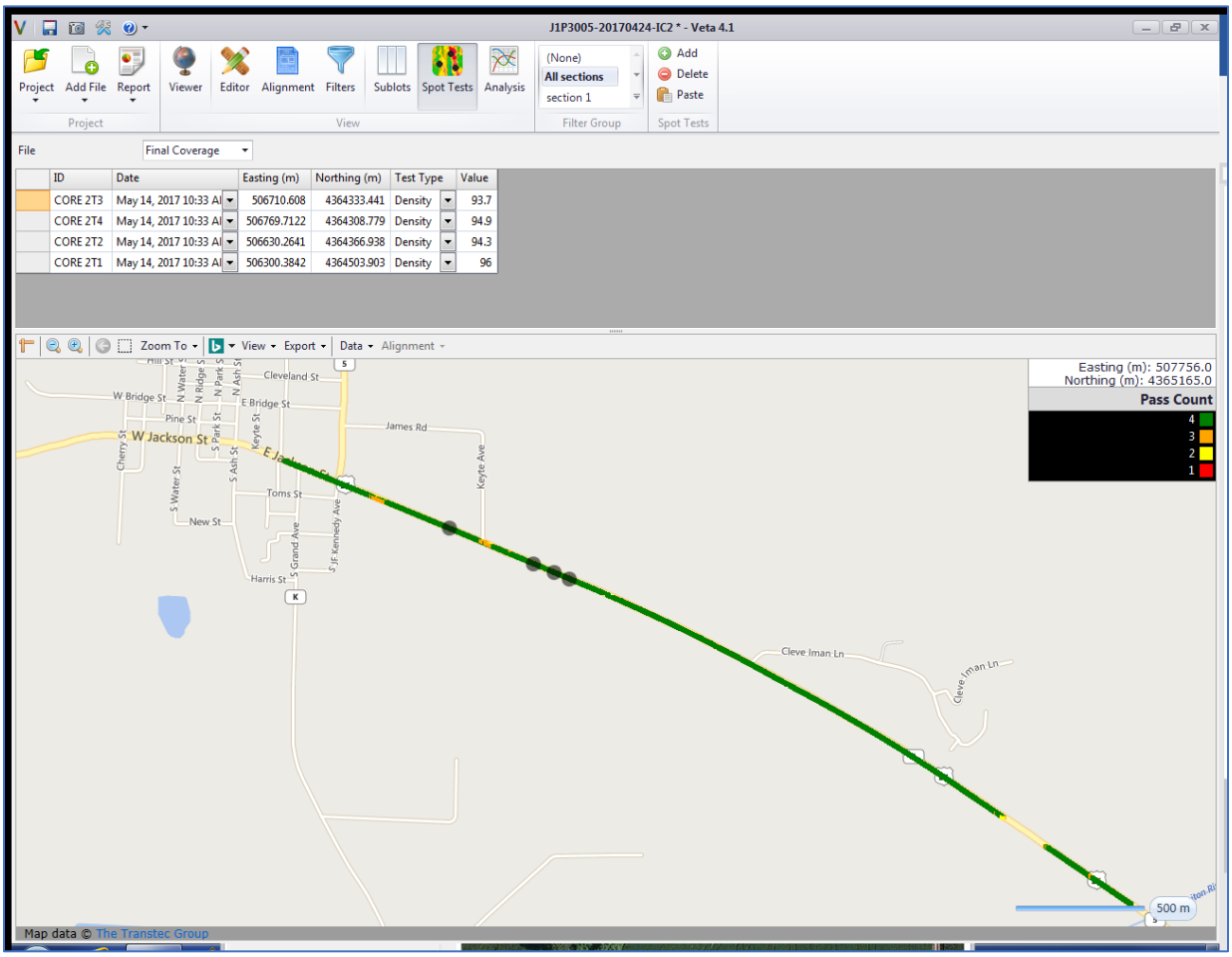


Figure 42: An Example Veta Analysis Screen showing spot tests (J1P3005 RT 24).

The first round of the IC analysis is used to inspect the correlation analysis between CMV and core density (Figure 43). 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.

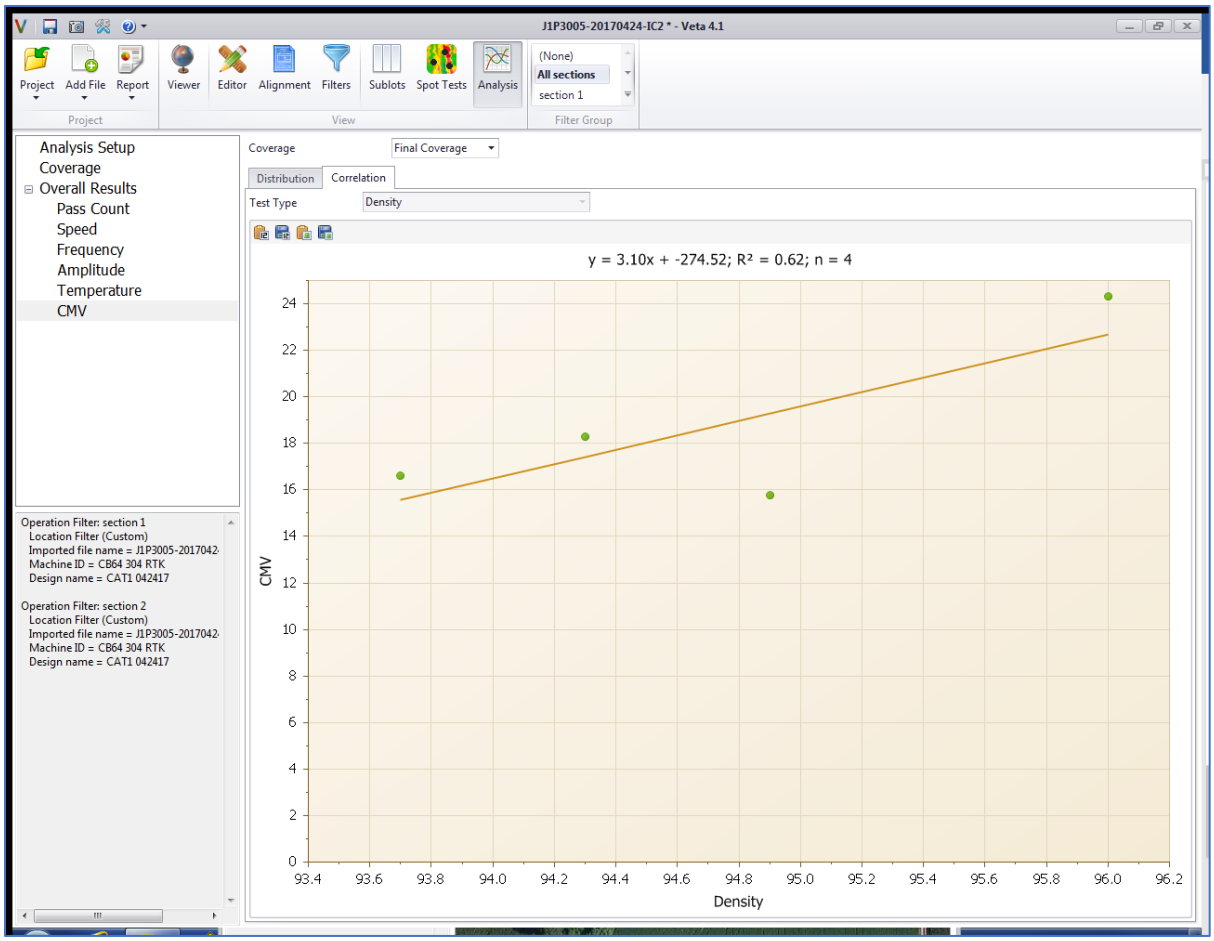


Figure 43: An Example Veta Analysis Screen showing correlation tests between ICMV and spot tests (J1P3005 RT 24).

The roller coverage for the target passes (four) is 95% (Figure 44), which passes the 90% requirement criteria. The ICMV coverage for the target ICMV is 92% (Figure 45), which passes the 70% criteria (i.e., not flagged).

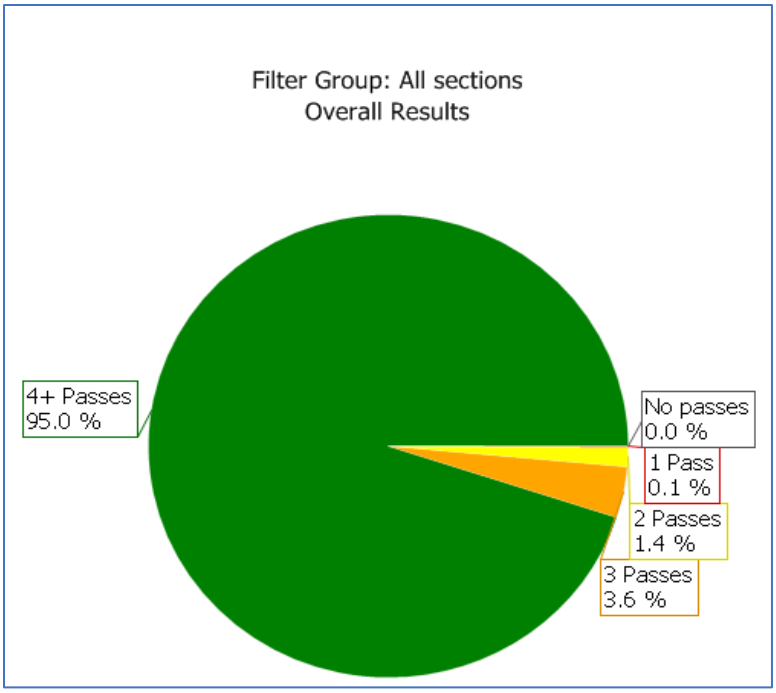


Figure 44: An Example Veta Analysis Screen showing the Roller Coverage report (J1P3005 RT 24).

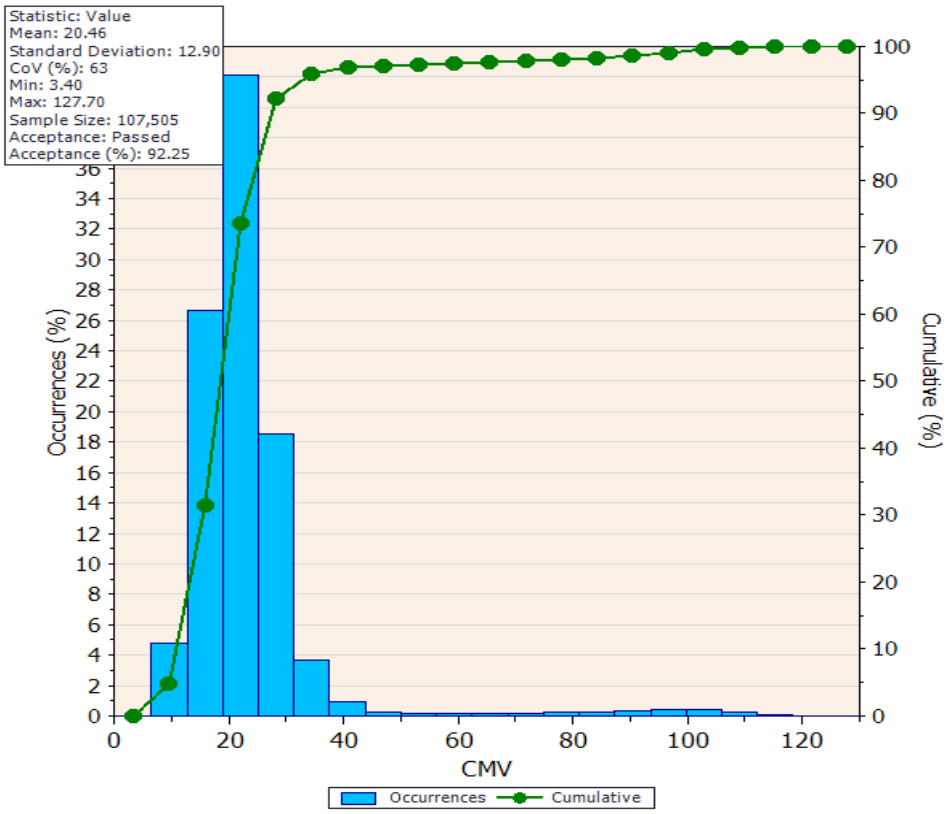


Figure 45: An Example Veta Analysis Screen showing the ICMV Coverage report (J1P3005 RT 24).

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 46), which fails the criteria of 100% (based on the MoDOT specification requirements).

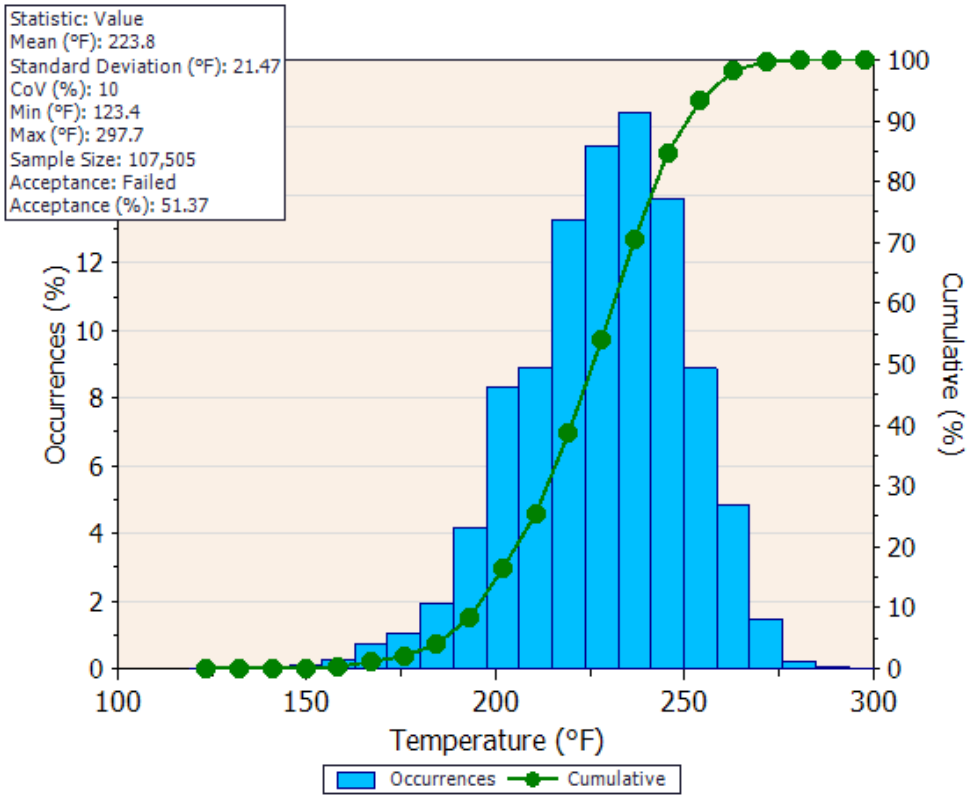
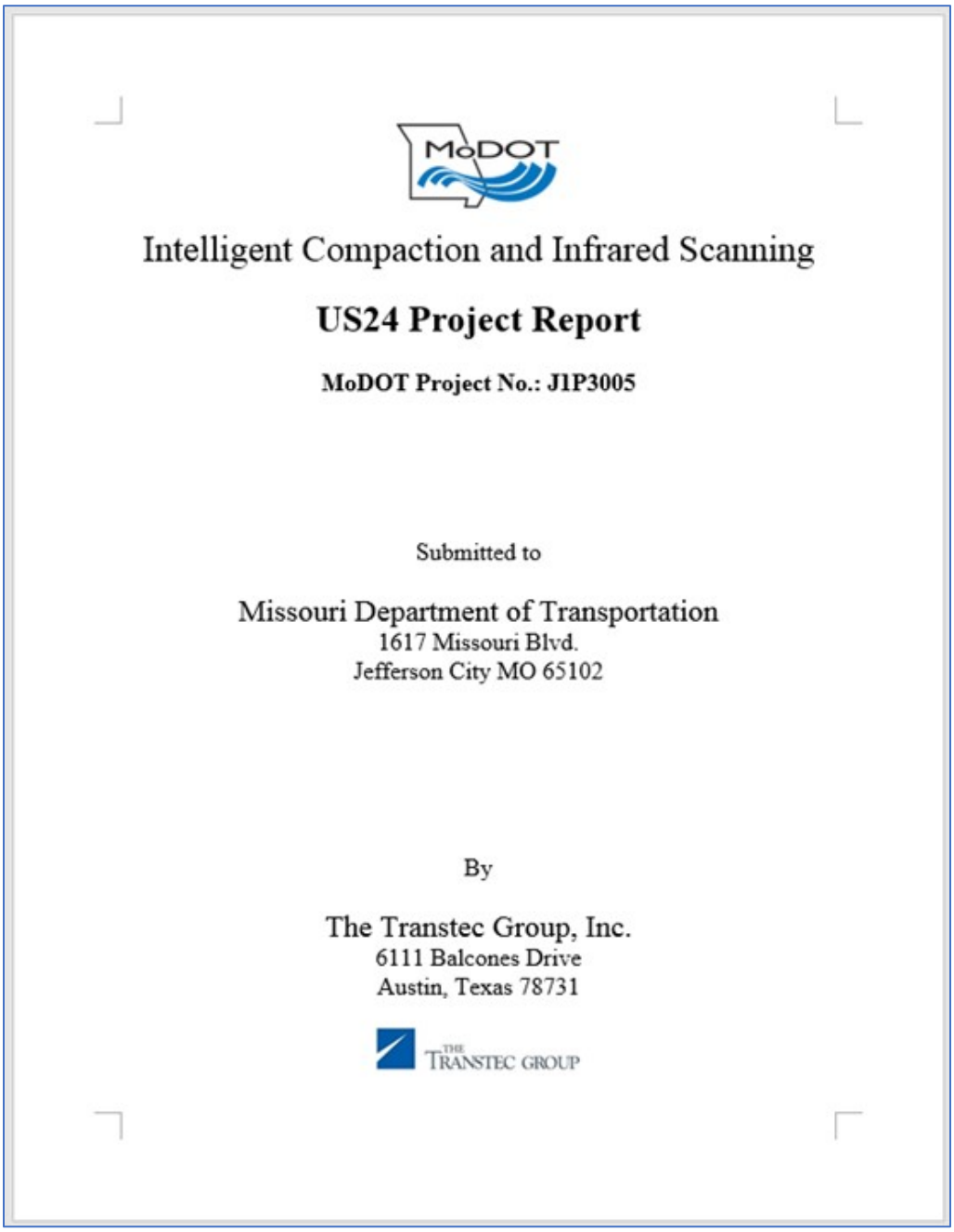


Figure 46: An Example Veta Analysis Screen showing the Mat Temperature report (J1P3005 RT 24).

Summary of Results

An individual report was produced for each field project (Figure 47). The trial section compaction curve, summary of MOBA/Veta temperature segregation reports, and summary of IC roller coverage reports are presented for each project, below.



Intelligent Compaction and Infrared Scanning

US24 Project Report

MoDOT Project No.: J1P3005

Submitted to

Missouri Department of Transportation
1617 Missouri Blvd.
Jefferson City MO 65102

By

The Transtec Group, Inc.
6111 Balcones Drive
Austin, Texas 78731

THE TRANSTEC GROUP

Figure 47: An Example MoDOT IC-IR Project Report.

Project No. 1 - J5P3117, RT 52

Trial Section (5/9/2017)

Optimum Rolling Pattern: The compaction curve is shown in Figure 48. The rolling pattern established was a total of eight vibratory passes with the two double drum rollers. The rollers were set to operate at high frequency and low amplitude.

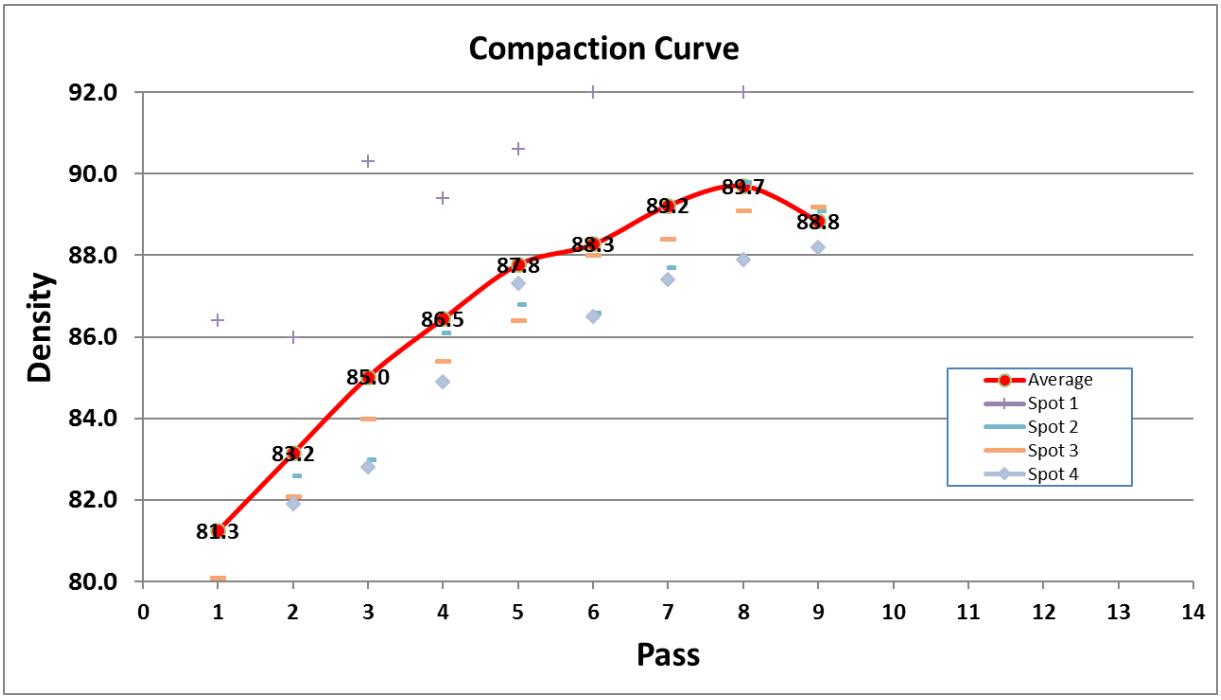


Figure 48 Compaction Curve from the Trial Section on 5/9/2017 (Project No. 1 - J5P3117, RT 52).

Trial Section (5/12/2017)
Optimum Rolling Pattern: The compaction curve is shown in Figure 49. The rolling pattern established was four vibratory passes at high frequency and high amplitude with the breakdown IC rollers, followed by four static passes by the intermediate double drum roller, and four passes by the pneumatic roller.

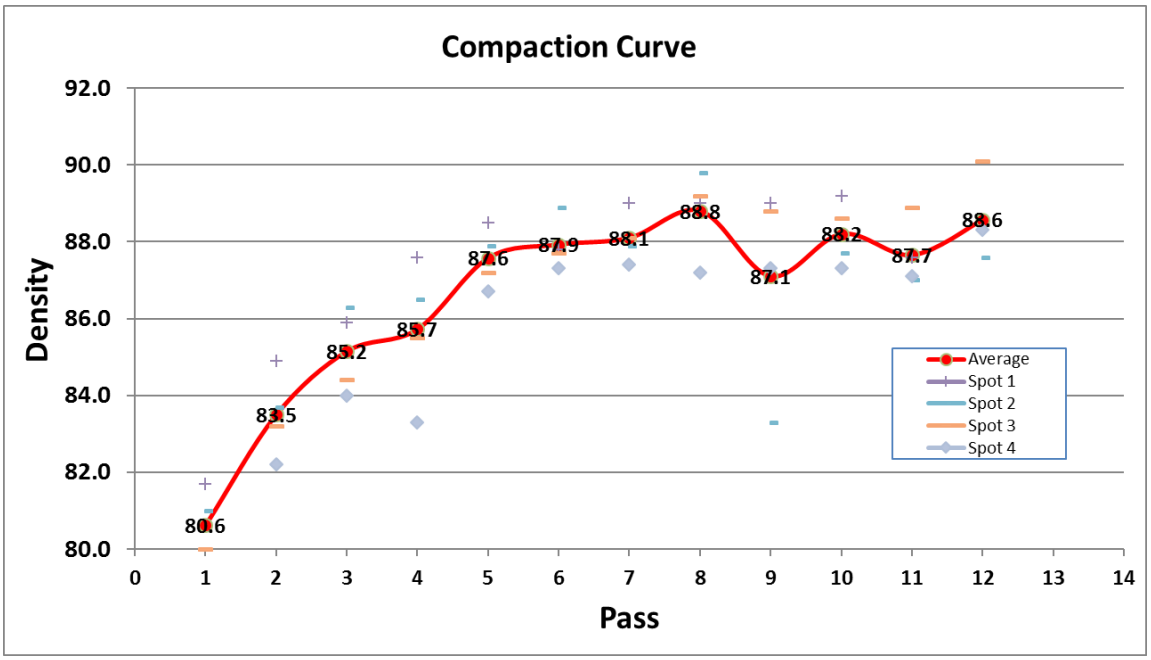


Figure 49 Compaction Curve from the Trial Section on 5/12/2017 (Project No. 1 - J5P3117, RT 52).

A summary of IR results is shown in Table 11, Figure 50, and Figure 51. Most of the temperature segregation was in the "no segregation" and "moderate segregation" categories.

Table 11: Summary of IR Results (Project No. 1 - J5P3117, RT 52)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	5/9/2017	33	*48*	33	*48*	3	*4*	33	*53*	27	*44*	2	*3*
2	5/10/2017	22	*61*	14	*39*	0	*0*	23	*62*	14	*38*	0	*0*
3	5/12/2017	38	*63*	22	*37*	0	*0*	44	*71*	18	*29*	0	*0*
4	5/13/2017	33	*46*	38	*54*	0	*0*	41	*56*	32	*44*	0	*0*
5	5/15/2017	65	*73*	24	*27*	0	*0*	78	*85*	14	*15*	0	*0*
6	5/16/2017	21	*27*	56	*73*	0	*0*	39	*49*	40	*51*	0	*0*
7	5/18/2017	46	*61*	29	*38*	1	*1*	47	*60*	31	*39*	1	*1*
8	6/5/2017	58	*75*	19	*25*	0	*0*	62	*78*	18	*22*	0	*0*
9	6/6/2017	37	*61*	24	*39*	0	*0*	46	*73*	17	*27*	0	*0*
10	6/7/2017	48	*57*	36	*42*	1	*1*	58	*67*	29	*33*	0	*0*
11	6/26/2017	12	*38*	17	*59*	1	*3*	13	*44*	16	*53*	1	*3*
12	6/27/2017	67	*62*	37	*80*	5	*5*	5	*38*	7	*54*	1	*8*
13	6/28/2017	67	*62*	37	*35*	3	*3*	72	*73*	25	*26*	1	*1*
14	6/29/2017	30	*65*	16	*35*	0	*0*	32	*67*	16	*33*	0	*0*
15	7/6/2017	59	*79*	15	*20*	1	*1*	63	*81*	15	*19*	0	*0*
16	7/10/2017	59	*79*	13	*18*	2	*3*	66	*86*	8	*11*	2	*3*
17	7/11/2017	62	*73*	15	*18*	8	*9*	68	*77*	14	*16*	6	*7*
18	7/12/2017	22	*92*	2	*8*	0	*0*	23	*96*	1	*4*	0	*0*
19	7/13/2017	32	*75*	10	*23*	1	*2*	38	*86*	6	*14*	0	*0*
Notes:	*. Veta results are for information only.												

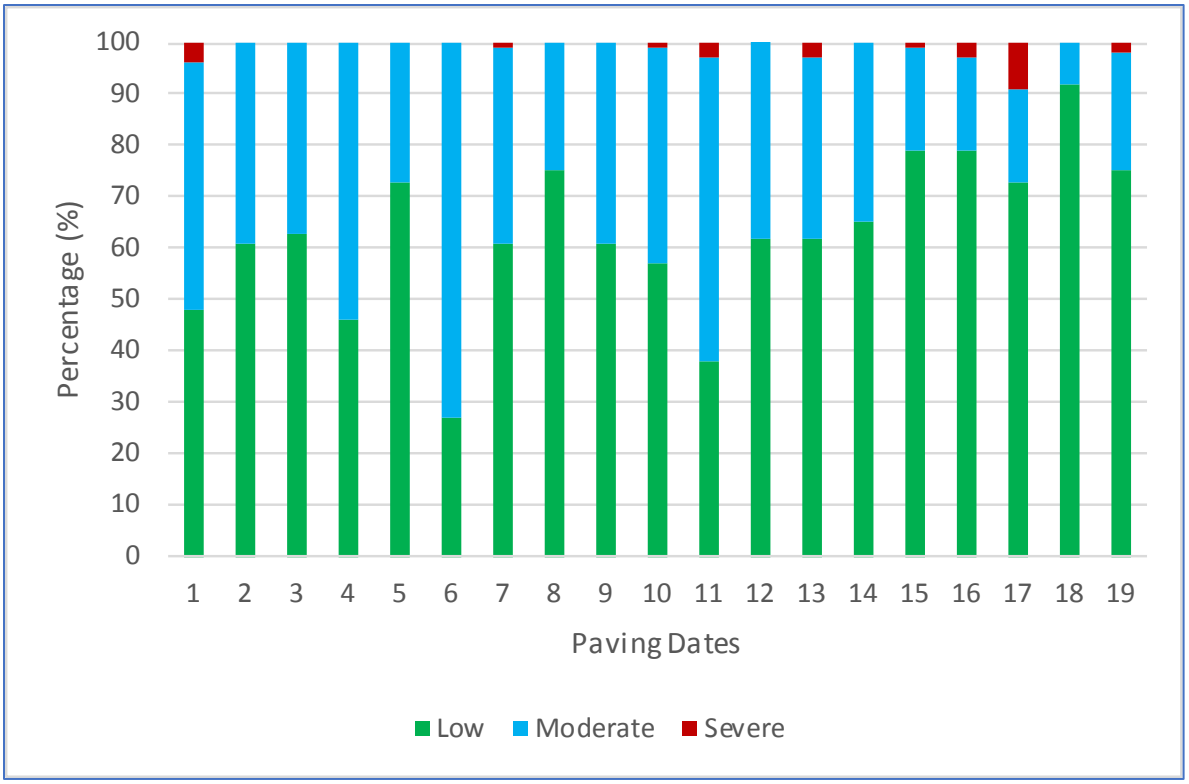


Figure 50: Summary of MOBA PPM Temperature Segregation Report (Project No. 1 - J5P3117, RT 52).

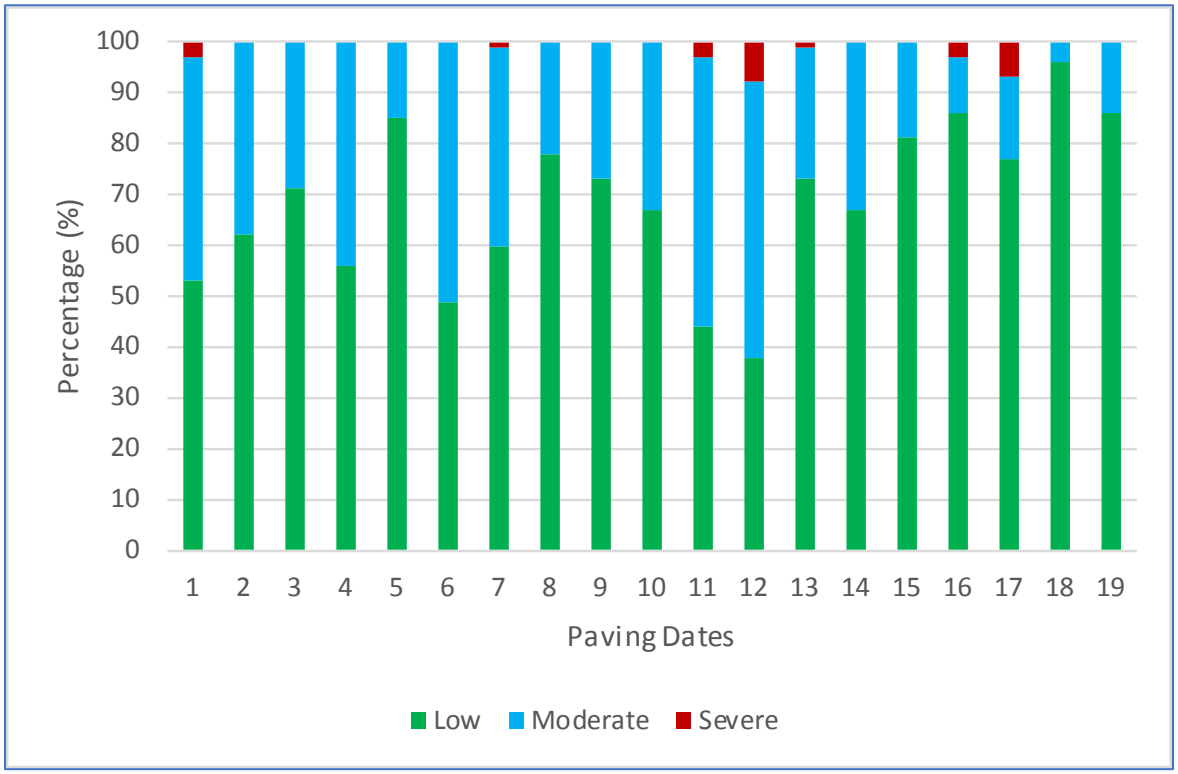


Figure 51: Summary of Veta Temperature Segregation Report (Project No. 1 - J5P3117, RT 52).

Note that the roller coverage reports are missing for Days 8, 11, and 15 due to malfunctioning of the IC system. The roller coverage results were mixed without apparent trends of improvement.

Table 12: Summary of IC Results (Project No. 1 - J5P3117, RT 52)

Day	*Date*	*Roller Coverage*		*ICMV*
		% Coverage	*Classification*	*(Target: min. 70%)*
1	5/9/2017	83.16	Moderate	*
2	5/10/2017	73.33	Moderate	*
3	5/12/2017	84.69	Moderate	*
4	5/13/2017	84.16	Moderate	*
5	5/15/2017	92.15	Passing	*
6	5/16/2017	77.8	Moderate	*
7	5/18/2017	87.51	Moderate	*
8	6/5/2017	_	_	_
9	6/6/2017	82.18	Moderate	*
10	6/7/2017	88.78	Moderate	*
11	6/26/2017	_	_	_
12	6/27/2017	81.36	Moderate	Roller 2 & 3 Only
13	6/28/2017	76.56	Moderate	Roller 2 & 3 Only
14	6/29/2017	81.47	Moderate	*
15	7/6/2017	_	_	_
16	7/10/2017	82.43	Moderate	Roller 2 & 3 Only
17	7/11/2017	87.85	Moderate	*
18	7/12/2017	86.73	Moderate	*
19	7/13/2017	87.18	Moderate	*
				Total

Notes:

* Not analyzed since no target ICMV was determined from trial sections.

Again, the roller coverage reports are missing for Days 8, 11, and 15 due to malfunctioning of the IC system. The roller coverage results were mixed without apparent trends of improvement.

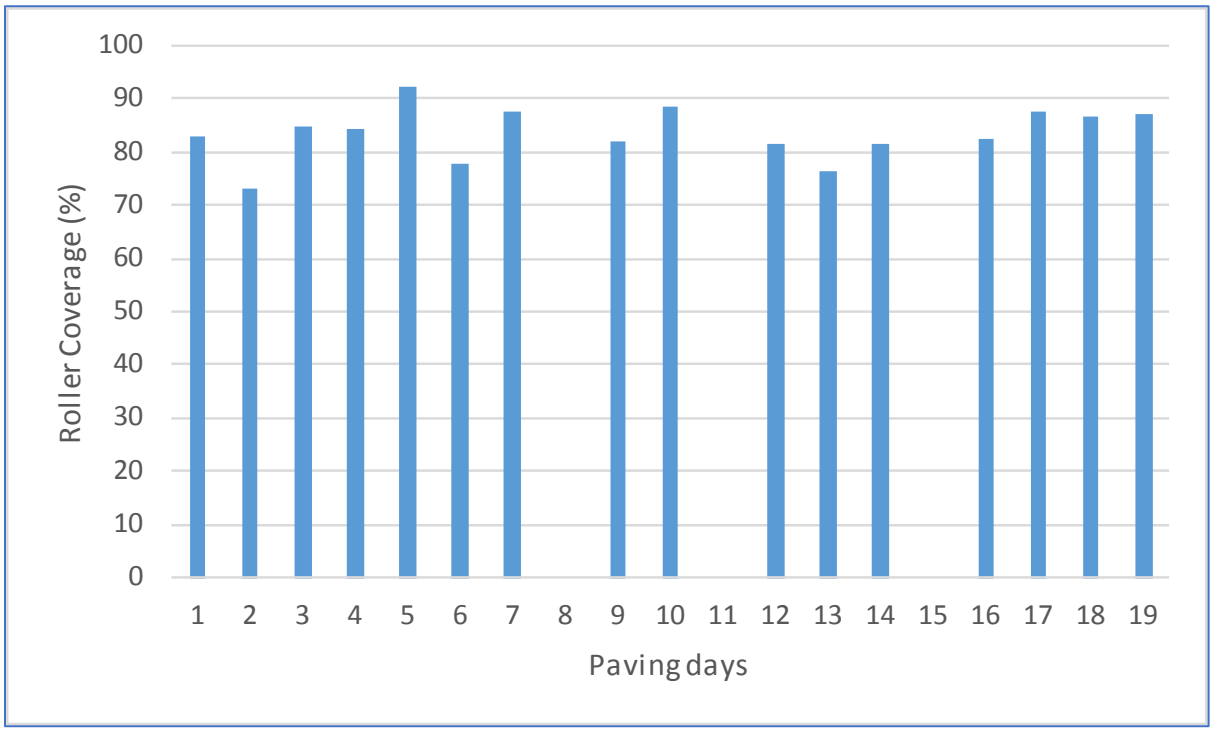


Figure 52: Summary of Roller Coverage Report (Project No. 1 - J5P3117, RT 52).

Project No. 2 - J4I3111, RT 29

Trial section tests were conducted on 8/25/2017 and 8/26/2017 for the SP190B and SP095B mixtures, respectively.

Trial Section – 8/25/2017 (SP190B)

Optimum Rolling Pattern: The compaction curve is shown in Figure 53. The rolling pattern established was seven vibratory passes for the breakdown IC rollers (echelon). From observations from the data, the rollers were set to operate at low frequency and low amplitude.

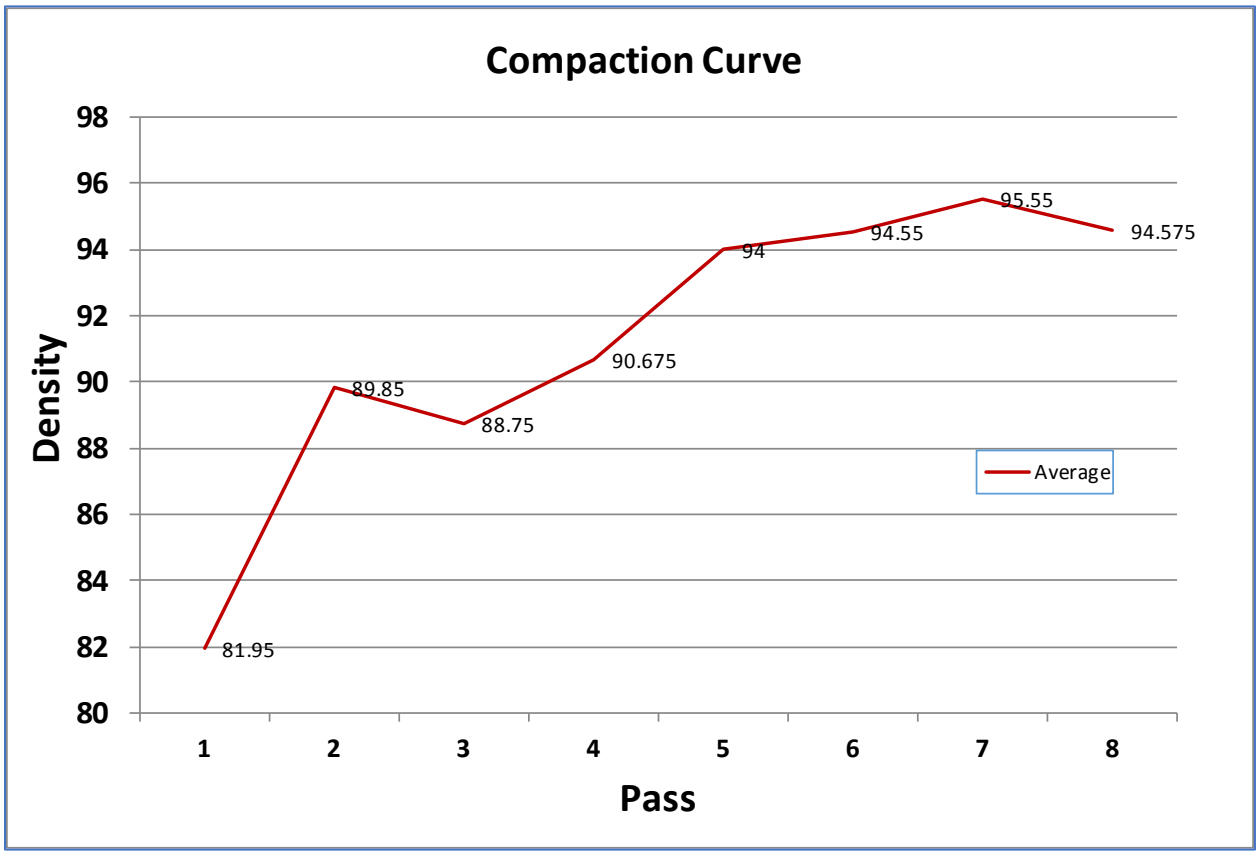


Figure 53 Compaction Curve SP190B from the Trial Section on 8/25/2017 (Project No. 2 - J4I3111, RT 29).

Trial Section – 8/26/2017 (SP095B)
Optimum Rolling Pattern: The compaction curve is shown in Figure 54. The rolling pattern established was five vibratory passes for the breakdown IC rollers. From observations from the data, the rollers were set to operate at low frequency and low amplitude.

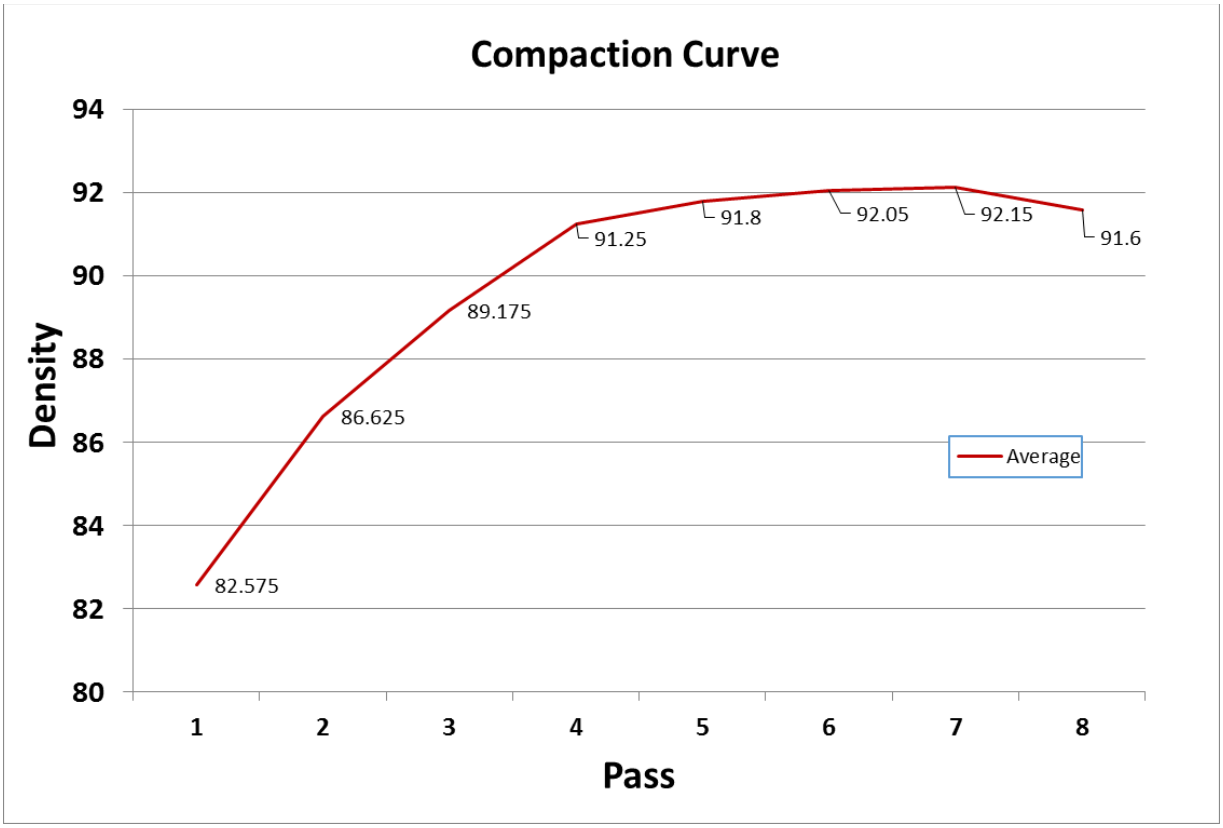


Figure 54 Compaction Curve SP095B from the Trial Section on8/26/2017 (Project No. 2 - J4I3111, RT 29).

A summary of IR results is shown in Table 13, Figure 55, and Figure 56. There was moderate temperature segregation with limited severe segregation. Note that MOBA PPM results are not available for Days 6 and 10 due to missing raw data, and Veta IR results were not available for Day 10 due to missing raw data. Note that Day 12 results from MOBA PPM and Veta are significantly different.

Table 13: Summary of IR Results (Project No. 2 - J4I3111, RT 29)

#	Dir/Lane/Lift	Date	MOBA PPM						Veta*					
			Low		Moderate		Severe		Low		Moderate		Severe	
			#	%	#	%	#	%	#	%	#	%	#	%
1	SB/2/Base	8/25/2017	14	*74*	4	*21*	1	*5*	9	*50*	8	*44*	1	*6*
2	SB/2/Surface	8/26/2017	9	*60*	5	*33*	1	*7*	5	*36*	8	*57*	1	*7*
3	SB/3/Base		37	*82*	6	*13*	2	*4*	28	*64*	13	*30*	3	*7*
4	SB/3/Surface	8/27/2017	41	*91*	3	*7*	1	*2*	25	*57*	16	*36*	3	*7*
5	NB/2/Base	9/9/2017	16	*67*	7	*29*	1	*4*	29	*63*	13	*28*	4	*9*
6	SB/1/Base		**						30	*65*	13	*28*	3	*7*
7	NB/1/Base	9/10/2017	17	*68*	5	*20*	3	*12*	22	*48*	19	*41*	5	*11*
8	NB/1/Surface		40	*83*	7	*15*	1	*2*	27	*59*	15	*33*	4	*9*
9	NB/2/Surface		21	*44*	20	*42*	7	*15*	10	*22*	30	*65*	6	*13*
10	SB/1/Surface		**											
11	NB/3/Base	9/15/2017	28	*97*	1	*3*	0	*0*	27	*87*	3	*10*	1	*3*
12	NB/3/Surface	9/16/2017	39	*85*	5	*11*	2	*4*	10	*22*	24	*52*	12	*26*
	Notes:	* Veta results are for information only. ** Data missing.												

Again, the MOBA PPM results are not available for Days 6 and 10 due to missing raw data, and Veta IR results were not available for Day 10 due to missing raw data.

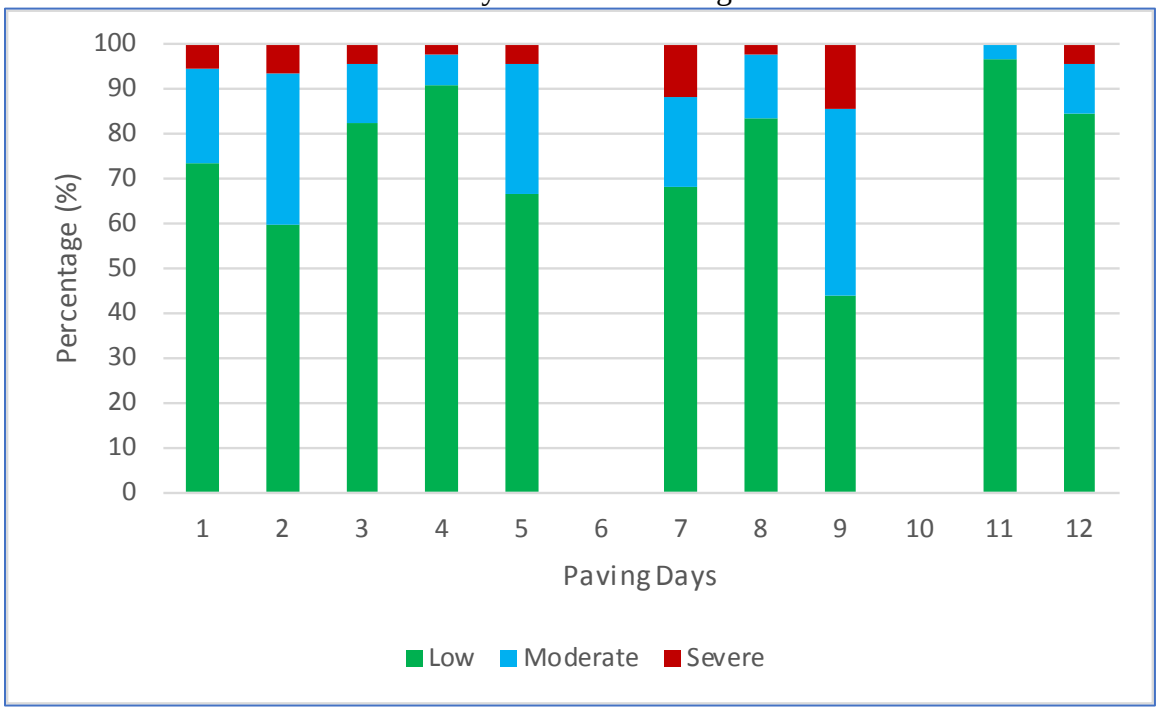


Figure 55: Summary of MOBA PPM Temperature Segregation Report (Project No. 2 - J4I3111, RT 29).

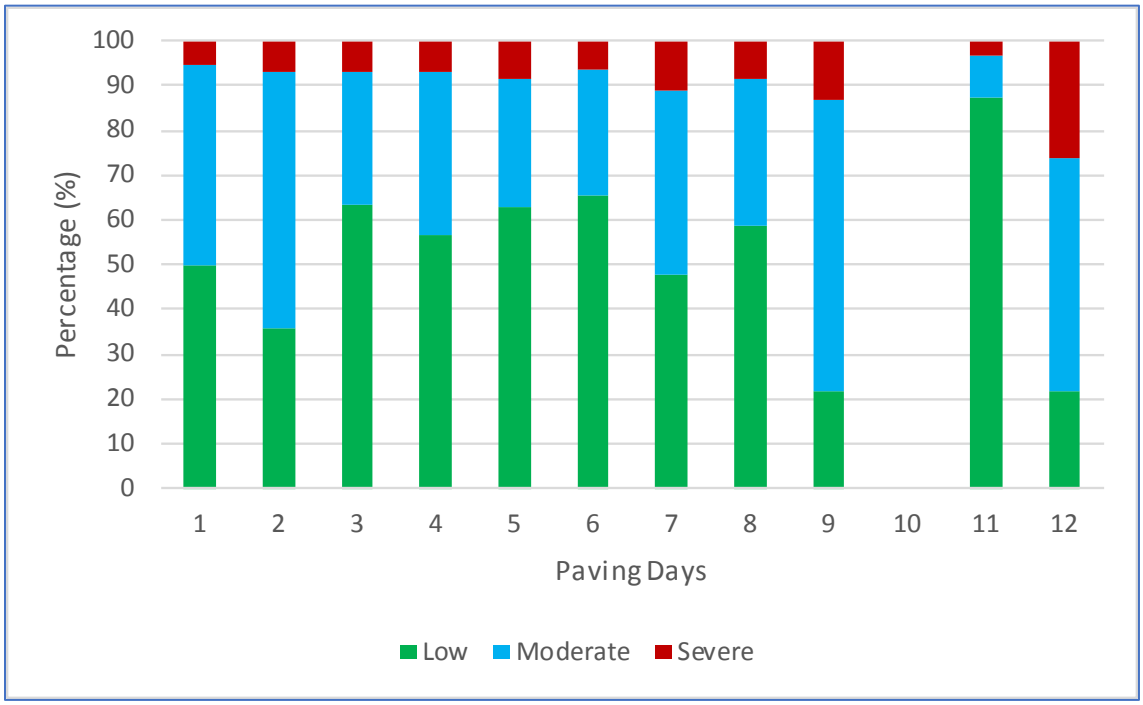


Figure 56: Summary of Veta Temperature Segregation Report (Project No. 2 - J4I3111, RT 29).

Table 14 and Figure 57 provide a summary of the roller coverage results. The roller coverage results were mixed without apparent trends of improvement.

Table 14: Summary of IC Results (Project No. 2 - J4I3111, RT 29)

No.	*Date*	*Dir/Lane/Lift*	*Target Passes*		*Target ICMV*		*Temperature for vibratory*	
			% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	8/25/2017	SB/2/Base	84	Moderate	2.2	Flagged	68	Failed
2	8/26/2017	SB/2/Surface	98	Passed	*	Flagged	6	Failed
3		SB/3/Base	79	Moderate	0.62	Flagged	90	Failed
4	8/27/2017	SB/3/Surface	96	Passed	*	Flagged	11	Failed
5	9/9/2017	NB/2/Base	91	Passed	0.31	Flagged	100	Passed
6		SB/1/Base	75	Moderate	0.24	Flagged	25	Failed
7	9/10/2017	NB/1/Base	63	Failed	0.14	Flagged	65	Failed
8		NB/1/Surface	67	Failed	*	Flagged	65	Failed
9		NB/2/Surface	95	Passed	*	Flagged	36	Failed
10		SB/1/Surface	91	Passed	*	Flagged	33	Failed
11	9/15/2017	NB/3/Base	96	Passed	0.68	Flagged	24	Failed
12	9/16/2017	NB/3/Surface	100	Passed	*	Flagged	33	Failed

Notes: Minimum temprarture for vibratory passes is 200F since Warm Mix Technology was used.

* Not calculated

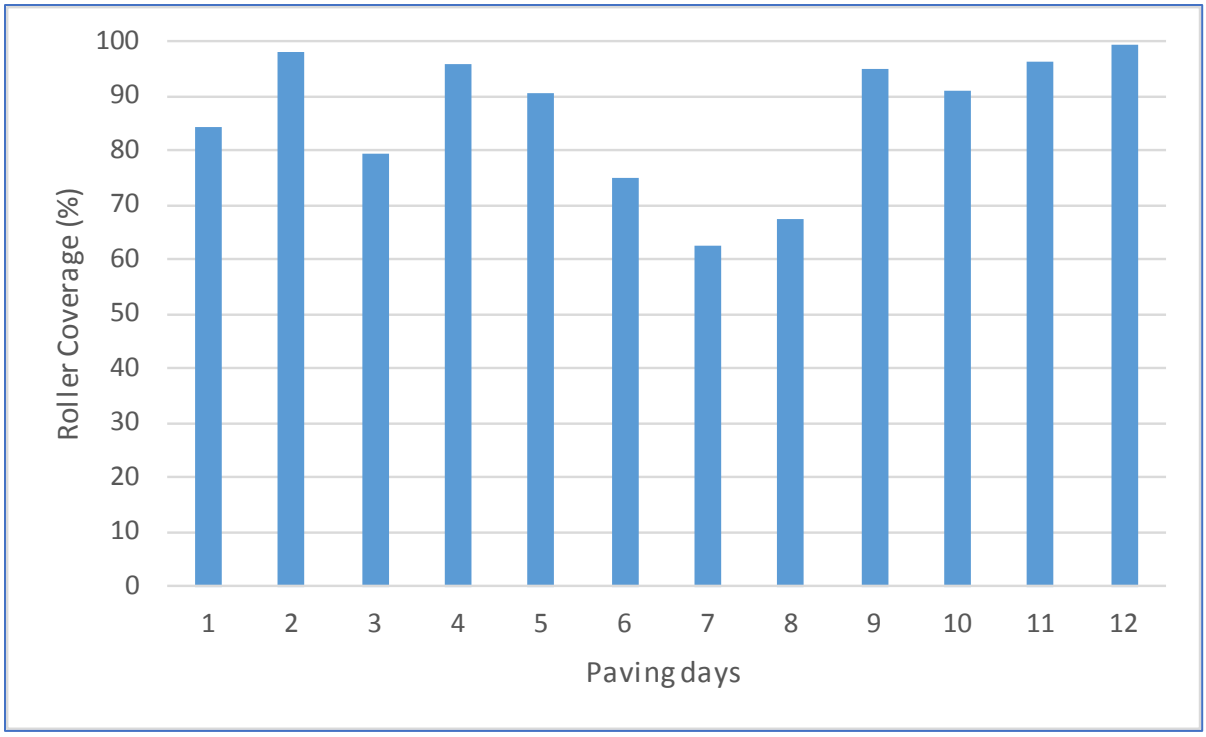


Figure 57: Summary of Roller Coverage Report (Project No. 2 - J4I3111, RT 29).

Project No. 3 - J3I3042, I-70

Trial Section (8/14/2017)
Optimum Rolling Pattern: The compaction curve is shown in Figure 59. The rolling pattern established was a total of seven vibratory passes with the breakdown IC rollers. The rollers were set to operate at high frequency and low amplitude.

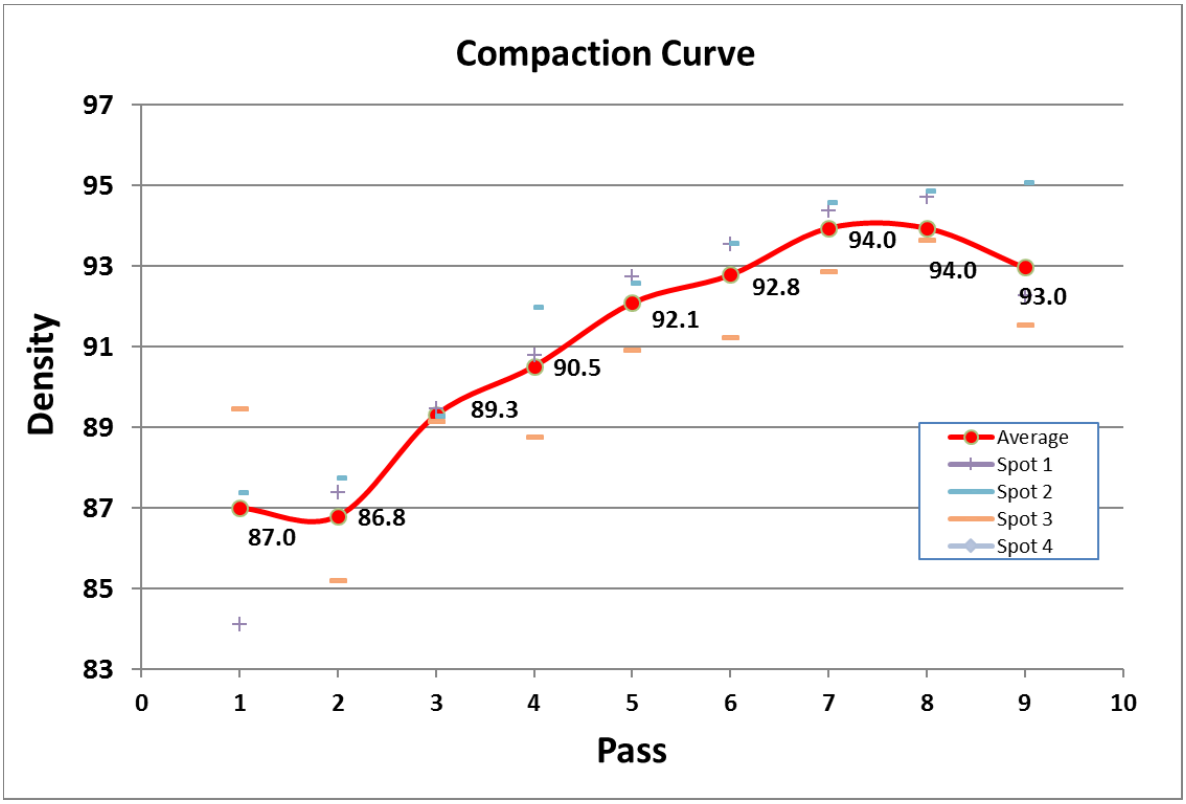


Figure 58: Density Compaction Curve from the Trial Section on 8/14/2017 (Project No. 3-J3I3042, I-70)

The Volvo ICMV-EDV were extracted from test locations of the trial section. The compaction curves from both the nuclear density gauge (NDG) and EDV are compared in the Figure 59.

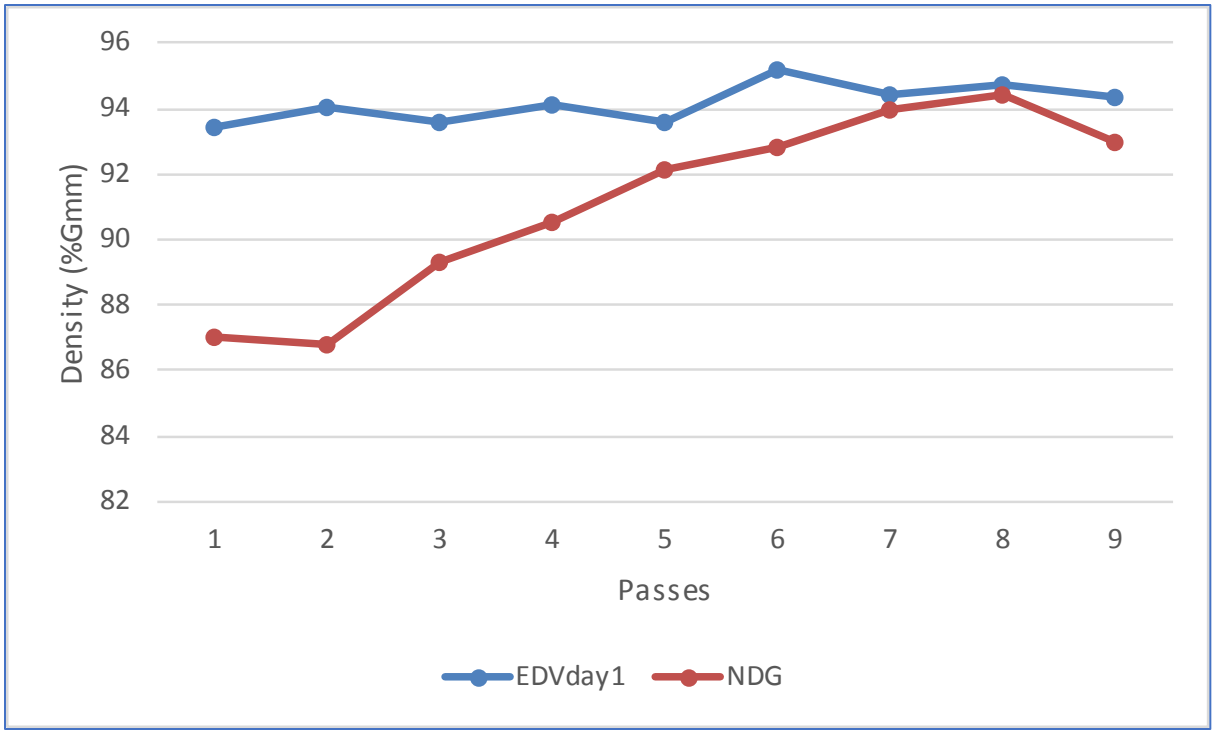


Figure 59: NDG Density and ICMV Compaction Curves from the Trial Section on 8/14/2017 (Project No. 3 - J3I3042, I-70)

A summary of IR results is shown in Table 15 and Table 16, and Figure 60 through Figure 63. There was no noticeable severe temperature segregation for most paving days, with the exception of Day 6, which showed severe temperature segregation. The lack of use of MTV may be one of factors causing the severe temperature segregation on Day 6.

The MOBA PPM report for Day 5 (8/23/2017), shown in Figure 60, includes an 10,000-ft. offset error in DMI. The reported length is only 3,088 ft., but the actual length is 13,215 ft. Therefore, the reported number of sublots are incorrect due to the incorrect DMI (see Table 16). Since Veta uses GPS as references, the Veta IR report, shown in Figure 61, is correct since it is not influenced by the incorrect DMI. The Veta reported length is 13,215 ft. The actual length was further verified by the IC data. Note that Day 5 results in Figure 62 are incorrect since the MOBA PPM used incorrect DMI references, while the Day 5 result in Figure 63 are correct since Veta uses GPS reference instead of DMI.

Table 15: Summary of IR Results (Project No. 3 - J3I3042, I-70)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	8/14/2017	37	*57*	25	*38*	3	*5*	37	*62*	21	*35*	2	*3*
2	8/15/2017	43	*70*	18	*30*	0	*0*	42	*70*	18	*30*	0	*0*
3	8/17/2017	42	*59*	28	*39*	1	*1*	44	*62*	27	*38*	0	*0*
4	8/18/2017	27	*56*	20	*42*	1	*2*	27	*59*	18	*39*	1	*2*
5	8/23/2017	2	*10*	17	*81*	2	*10*	55	*63*	31	*35*	2	*2*
6	8/24/2017	2	*8*	0	*0*	23	*92*	2	*8*	0	*0*	23	*92*
7	8/25/2017	26	*42*	34	*55*	2	*3*	27	*44*	33	*54*	1	*2*
8	8/28/2017	56	*58*	41	*42*	0	*0*	48	*49*	49	*51*	0	*0*
9	8/29/2017	43	*54*	36	*45*	1	*1*	39	*49*	40	*51*	0	*0*
10	8/30/2017	34	*52*	30	*46*	1	*2*	28	*43*	35	*54*	2	*3*
11	8/31/2017	34	*34*	60	*61*	5	*5*	30	*31*	61	*64*	5	*5*
12	9/5/2017	37	*47*	42	*53*	0	*0*	37	*47*	41	*53*	0	*0*
13	9/6/2017	46	*47*	51	*53*	0	*0*	45	*47*	51	*53*	0	*0*
14	9/7/2017	37	*45*	41	*50*	4	*5*	39	*48*	40	*49*	2	*2*
15	9/8/2017	51	*54*	42	*45*	1	*1*	53	*57*	39	*42*	1	*1*
16	9/11/2017	60	*61*	39	*39*	0	*0*	60	*61*	38	*39*	0	*0*
17	9/12/2017	43	*49*	42	*48*	2	*2*	40	*47*	45	*52*	1	*1*
18	9/13/2017	29	*56*	22	*42*	1	*2*	29	*55*	22	*42*	2	*4*
19	9/22/2017	10	*56*	7	*39*	1	*6*	8	*47*	9	*53*	0	*0*
Notes:	*. Veta results are for information only.												

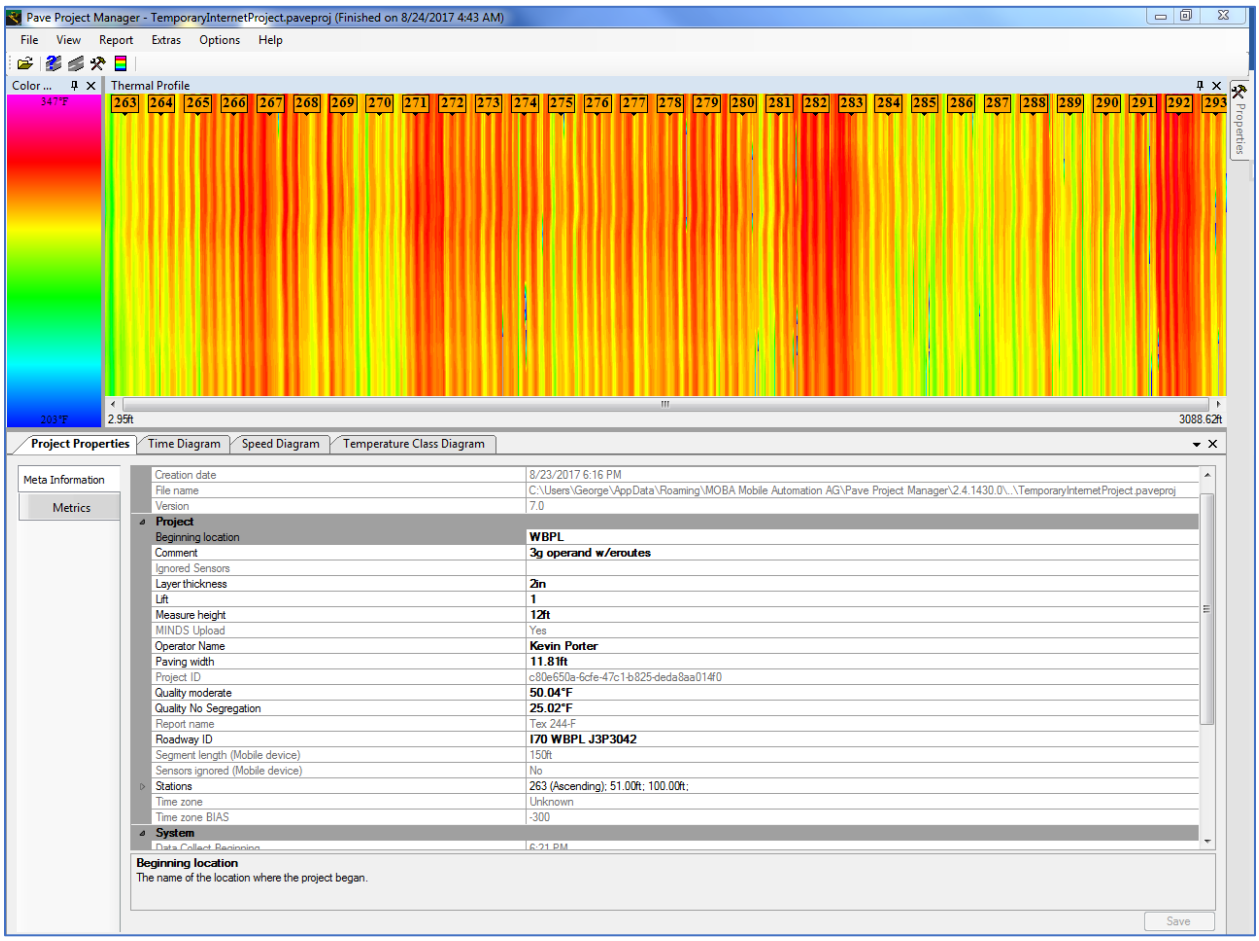


Figure 60: Incorrect distance reported by MOBA PPM for the data on 8/23/2017 (J3I3042, I-70).

Table 16: Incorrect number of sublots reported by MOBA PPM for the data on 8/23/2017 (Project No. 3 - J3I3042, I-70).

Thermal Profile Results Summary				
Number of Profiles	Moderate 25.0°F < differential <= 50.0°F		Severe differential > 50.0°F	
21	Number	Percent	Number	Percent
	17	81	2	10

Distribution | Mean | Differential

Category	Count	Percent (%)
Low	55	63
Moderate	31	35
Severe	2	2

Start distance (ft)	Length (ft)	Category	Minimum (°F)	Maximum (°F)	Differential (°F)
0	150	Moderate	255	294	39
150	150	Low	276	299	22
300	150	Low	282	299	17
450	150	Low	281	305	24
600	150	Low	281	305	24
750	150	Low	283	306	24
900	150	Low	282	307	25
1,050	150	Moderate	278	310	32
1,200	150	Low	293	312	19
1,350	150	Low	291	312	21
1,500	150	Moderate	293	320	27
1,650	150	Low	298	316	18
1,800	150	Low	300	321	21
1,950	150	Moderate	289	318	29
2,100	150	Low	294	317	23
2,250	150	Low	284	303	19
2,400	150	Low	287	309	21
2,550	150	Moderate	288	320	32
2,700	150	Low	292	310	18
2,850	150	Moderate	275	303	27
3,000	150	Moderate	270	301	31

Figure 61: Correct IR Segregation Reported by Veta for the data on 8/23/2017 (Project No. 3 - J3I3042, I-70).

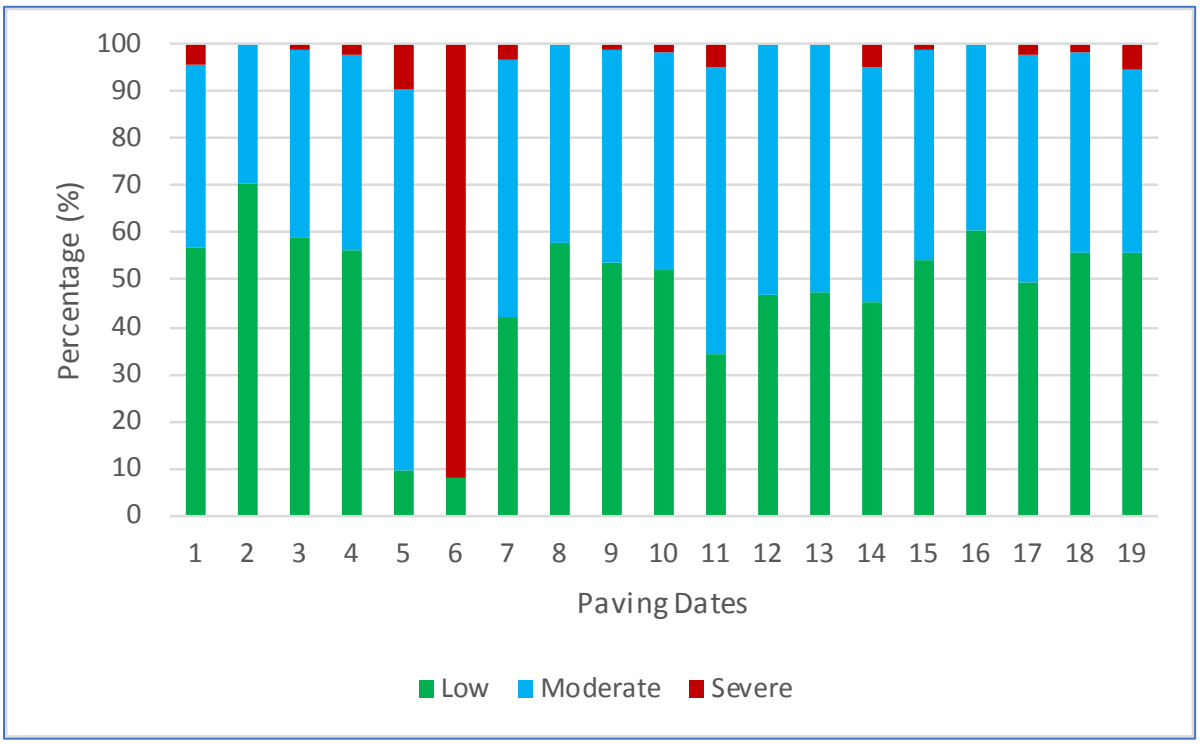


Figure 62: Summary of MOBA PPM Temperature Segregation Report (Project No. 3 - J3I3042, I-70).

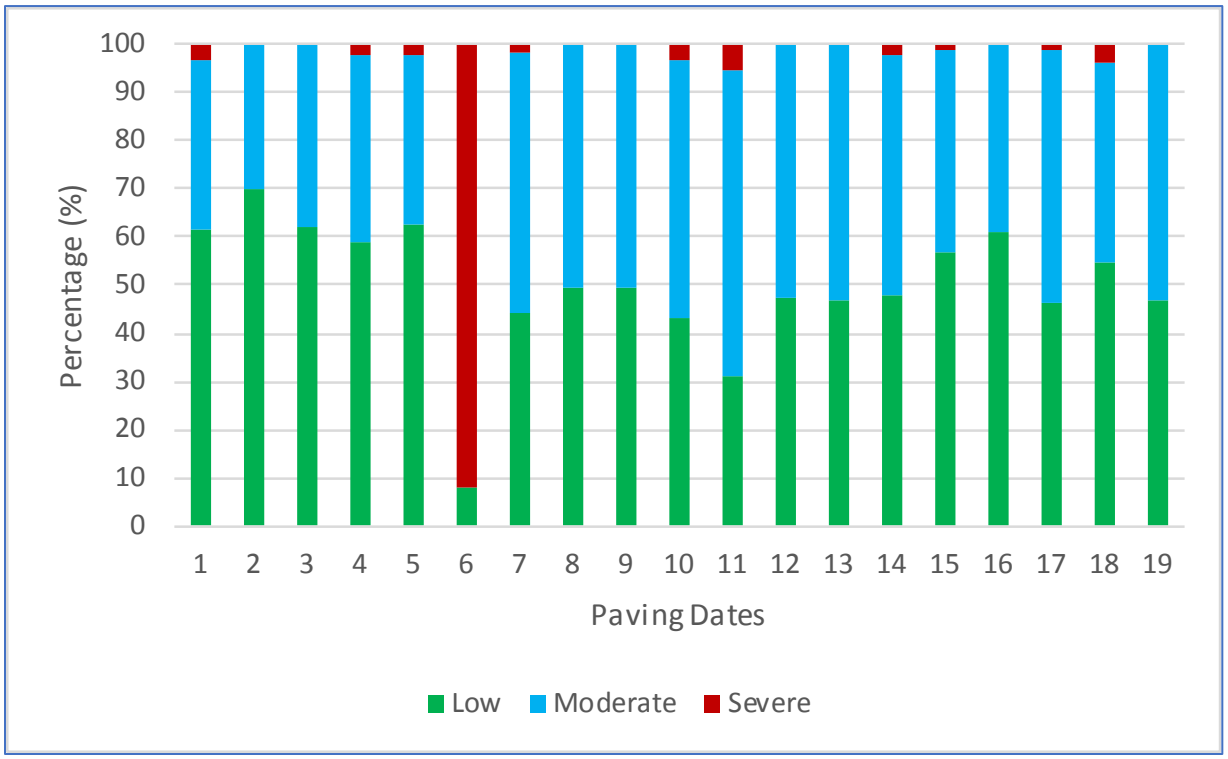


Figure 63: Summary of Veta Temperature Segregation Report (Project No. 3 - J3I3042, I-70).

Table 17 and Figure 64 provide a summary of the roller coverage results. The roller coverage results were mixed but the trend indicated slight improvements as the project progressed. The IC data on 8/23/2017 (Day 5) included an incorrect boundary file provided by the contractor (see the tangled lines of boundary in Figure 65). Therefore, no roller coverage analysis could be performed for this date.

Table 17: Summary of IC Results (Project No. 3 - J3I3042, I-70)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverag	Classification
1	8/14/2017	74	Moderate	88	Not Flagged	0.9	Failed
2	8/15/2017	76	Moderate	NA	NA	4.0	Failed
3	8/17/2017	80	Moderate	NA	NA	1.0	Failed
4	8/18/2017	82	Moderate	NA	NA	3.0	Failed
5	8/23/2017		Failed	NA	NA		Failed
6	8/24/2017	82	Moderate	NA	NA	4.0	Failed
7	8/25/2017	79	Moderate	NA	NA	1.4	Failed
8	8/28/2017	77	Moderate	NA	NA	3.0	Failed
9	8/29/2017	79	Moderate	NA	NA	3.0	Failed
10	8/30/2017	78	Moderate	NA	NA	3.9	Failed
11	8/31/2017	89	Moderate	NA	NA	0.5	Failed
12	9/5/2017	94	Passed	NA	NA	0.0	Failed
13	9/6/2017	90	Passed	NA	NA	0.1	Failed
14	9/7/2017	91	Passed	NA	NA	0.5	Failed
15	9/8/2017	91	Passed	NA	NA	0.1	Failed
16	9/11/2017	97	Passed	NA	NA	0.1	Failed
17	9/12/2017	97	Passed	NA	NA	0.9	Failed
18	9/13/2017	96	Passed	NA	NA	0.3	Failed
19	9/22/2017	80	Moderate	NA	NA	5.4	Failed

Notes: Target passes coverage for breakdown only.
8/23/2017 analysis is skipped due to an incorrect boundary file.

The IC data on 8/23/2017 (Day 5) included an incorrect boundary file provided by the contractor. Therefore, no roller coverage analysis could be performed for this date.

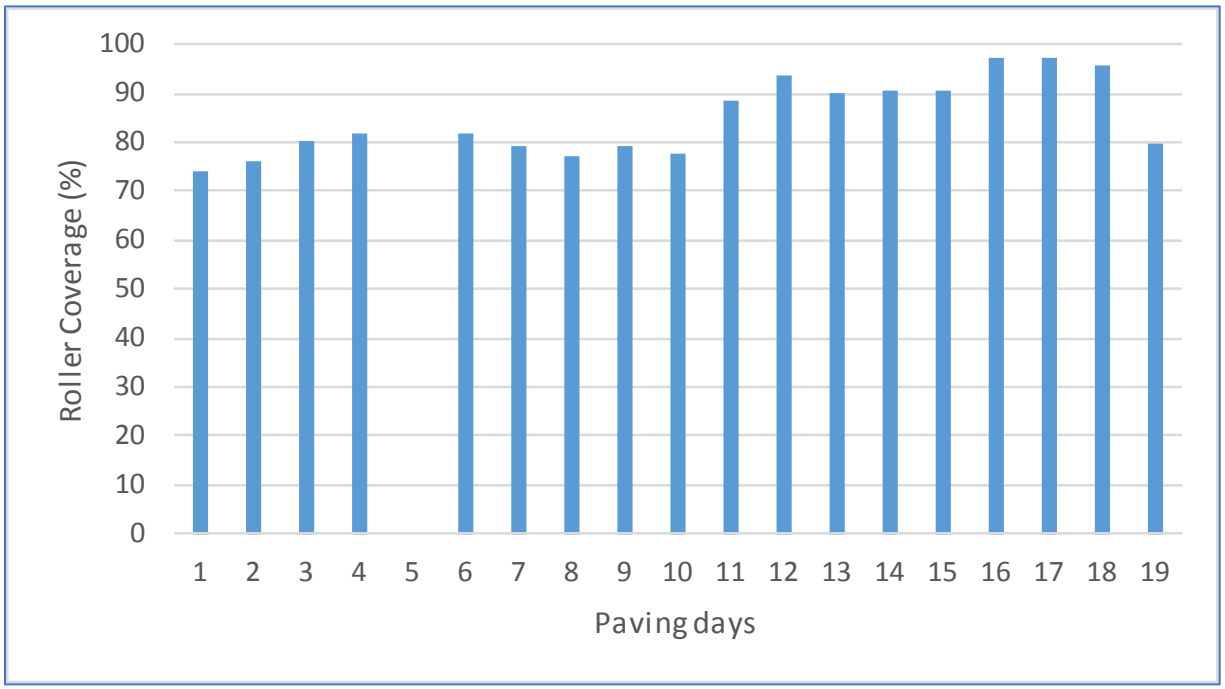


Figure 64: Summary of Roller Coverage Report. (Project No. 3 - J3I3042, I-70)

Figure 65: Incorrect Boundary File for 8/23/2017 (Project No. 3 - J3I3042, I-70).

Project No. 4 - JP3099, RT 36

Trial Section (5/8/2017)
Optimum Rolling Pattern: No compaction curve is provided, but the rolling pattern for the breakdown IC roller was three vibratory passes followed by another three vibratory passes for the intermediate roller. The rollers were set to operate at high frequency and low amplitude. The compaction curve data was not provided by the contractor.

A summary of IR results is shown in Table 18, Figure 66, and Figure 67. The temperature segregation was mostly in "No Segregation" and "Moderate Segregation" categories with very limited severe temperature segregation.

Table 18: Summary of IR Results (Project No. 4 - JP3099, RT 36)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	5/8/2017	43	*53*	37	*46*	1	*1*	48	*59*	30	*37*	4	*5*
2	5/9/2017	57	*75*	18	*24*	1	*1*	58	*75*	18	*23*	1	*1*
3	5/10/2017	42	*76*	16	*24*	0	*0*	50	*72*	18	*26*	1	*1*
4	5/11/2017	19	*70*	7	*26*	1	*4*	20	*77*	4	*15*	2	*8*
5	5/15/2017	94	*94*	6	*6*	0	*0*	93	*92*	8	*8*	0	*0*
6	5/16/2017	70	*79*	19	*21*	0	*0*	67	*74*	24	*26*	0	*0*
7	5/17/2017	58	*87*	9	*13*	0	*0*	56	*82*	12	*18*	0	*0*
Notes:	*. Veta results are for information only.												

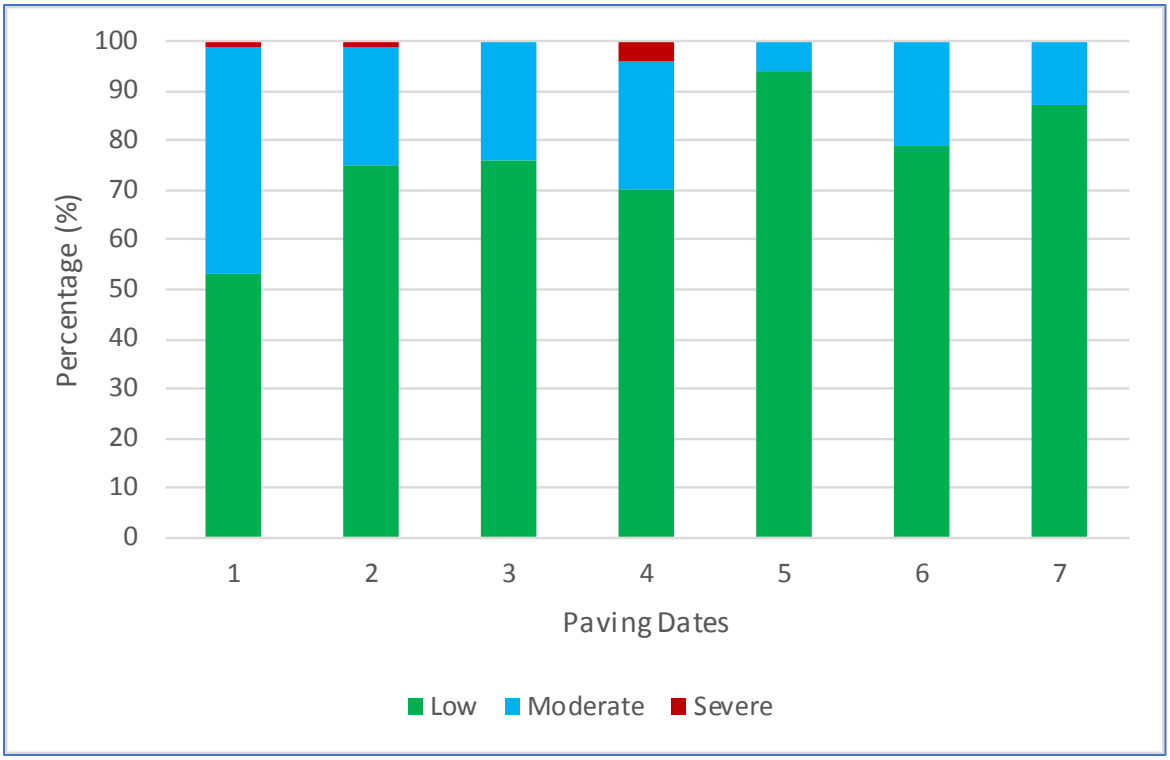


Figure 66: Summary of MOBA PPM Temperature Segregation Report (Project No. 4 - JP3099, RT 36).

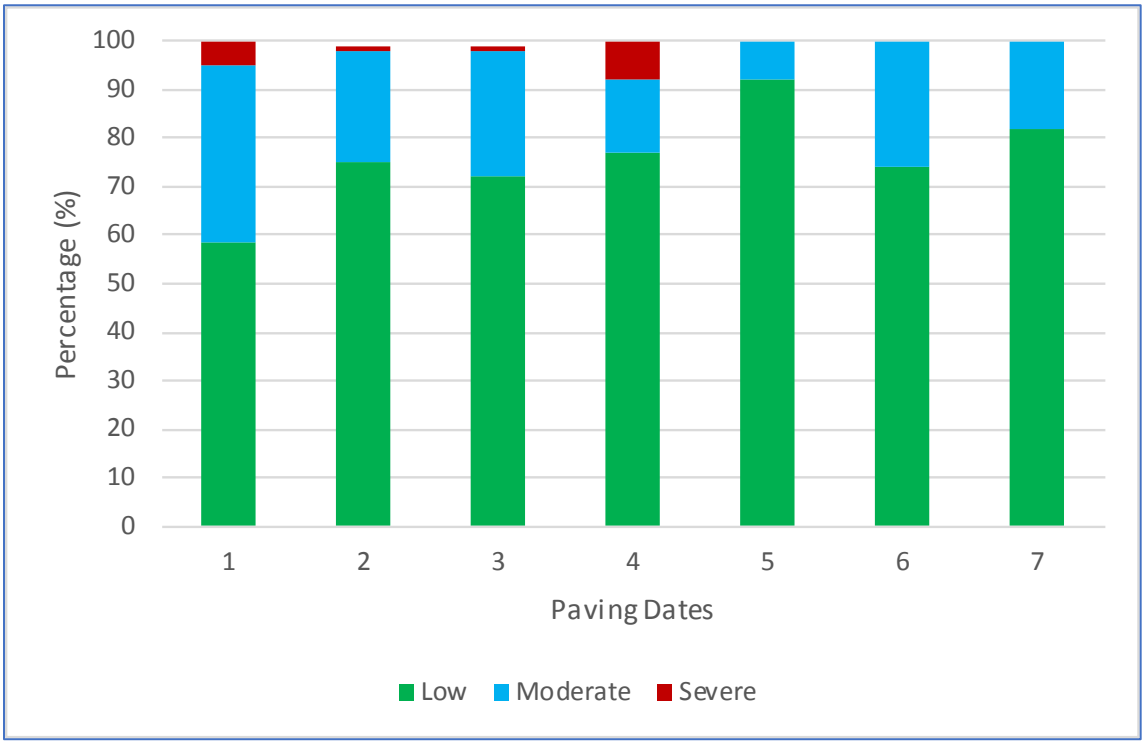


Figure 67: Summary of Veta Temperature Segregation Report (Project No. 4 - JP3099, RT 36).

Table 19 and Figure 68 provide a summary of the IC results. The roller coverage results were mixed but the trend indicated improvements as the project progressed.

Table 19: Summary of IC Results (Project No. 4 - JP3099, RT 36)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibrotory*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	5/8/2017	50	Failed	NA	NA	17	Failed
2	5/9/2017	80	Moderate	NA	NA	35	Failed
3	5/10/2017	98	Passed	NA	NA	3	Failed
4	5/11/2017	98	Passed	NA	NA	9	Failed
5	5/15/2017	99	Passed	NA	NA	11	Failed
6	5/16/2017	84	Moderate	NA	NA	5	Failed
7	5/17/2017	99	Passed	NA	NA	8	Failed

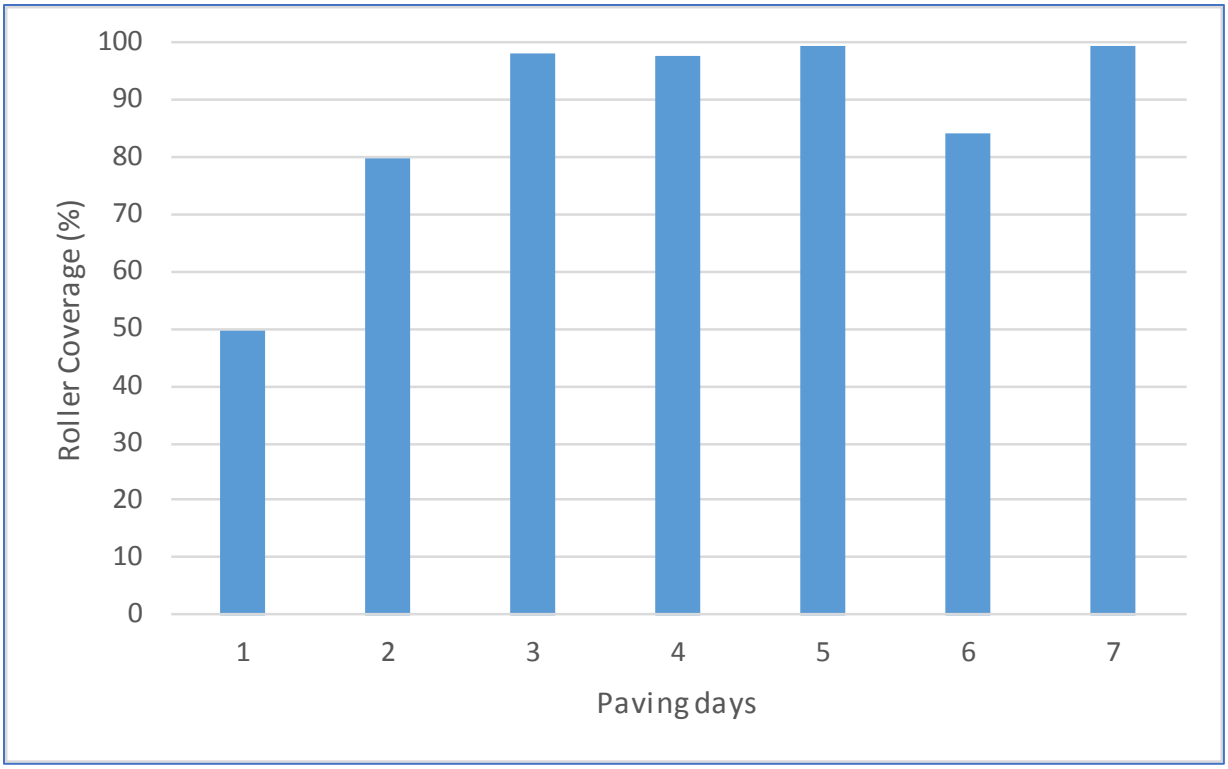


Figure 68: Summary of Roller Coverage Report (Project No. 4 - JP3099, RT 36).

Project No. 5 - J2P3100, RT 36

Trial Section (5/25/2017)
Optimum Rolling Pattern: No compaction curve is provided. The rolling pattern for the breakdown IC roller is three vibratory passes followed by another three vibratory passes for the intermediate roller. The rollers were set to operate at high frequency and low amplitude.

A summary of IR results is shown in Table 20, Figure 69, and Figure 70. The temperature segregation was mostly in "No Segregation" and "Moderate Segregation" categories with very limited severe temperature segregation.

Table 20: Summary of IR Results (Project No. 5 - J2P3100, RT 36)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	5/25/2017	83	*86*	10	*10*	4	*4*	79	*80*	15	*15*	5	*5*
2	5/30/2017	47	*82*	7	*12*	3	*5*	48	*83*	5	*9*	5	*9*
3	5/31/2017	60	*91*	6	*9*	0	*0*	60	*90*	7	*10*	0	*0*
4	6/1/2017	27	*84*	5	*16*	0	*0*	26	*81*	6	*19*	0	*0*
5	6/5/2017	60	*79*	13	*17*	3	*4*	62	*82*	12	*16*	2	*3*
6	6/6/2017	49	*75*	16	*25*	0	*0*	56	*85*	10	*15*	0	*0*
7	6/12/2017	76	*75*	25	*25*	0	*0*	74	*72*	28	*27*	1	*1*
8	6/13/2017	25	*74*	9	*26*	0	*0*	27	*79*	7	*21*	0	*0*
9	6/16/2017	85	*89*	10	*10*	1	*1*	85	*89*	10	*11*	0	*0*
10	6/19/2017	40	*89*	5	*11*	0	*0*	40	*89*	5	*11*	0	*0*
11	6/20/2017	40	*80*	9	*18*	1	*2*	40	*78*	9	*18*	2	*4*
12	6/21/2017	23	*82*	4	*4*	1	*4*	21	*75*	6	*21*	1	*4*
Notes:	*. Veta results are for information only.												

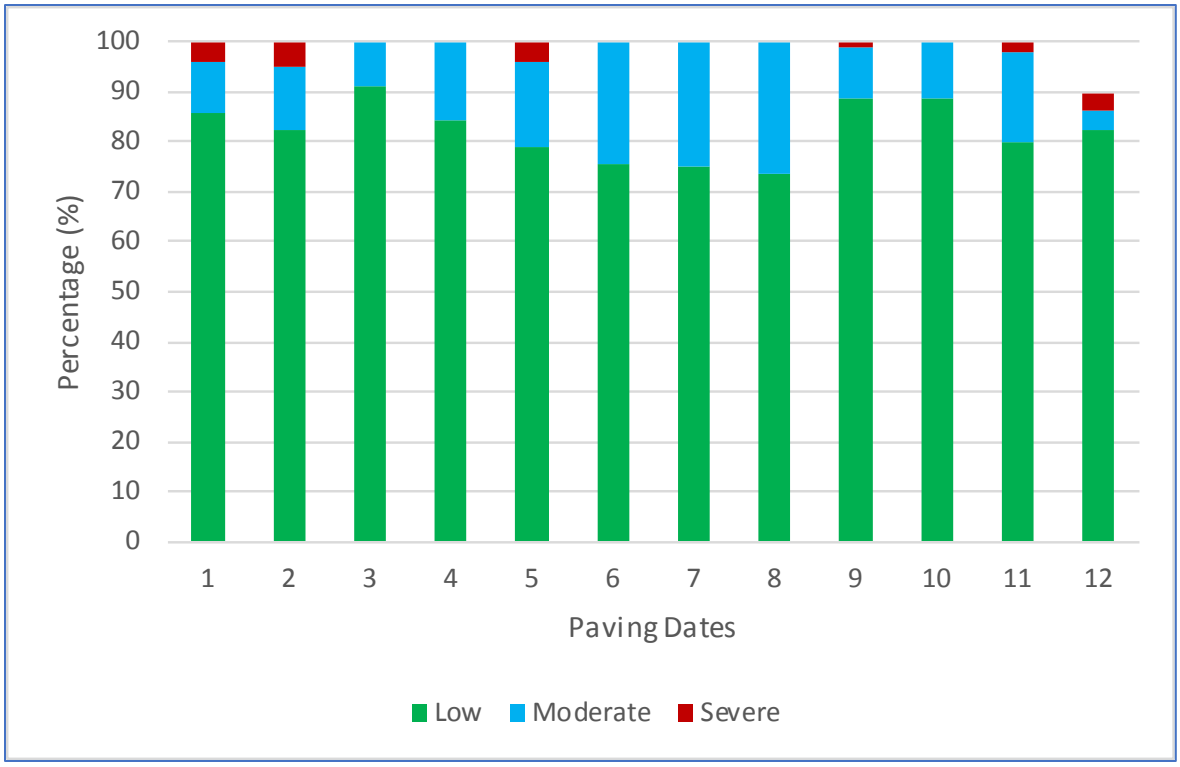


Figure 69: Summary of MOBA PPM Temperature Segregation Report (Project No. 5 - J2P3100, RT 36).

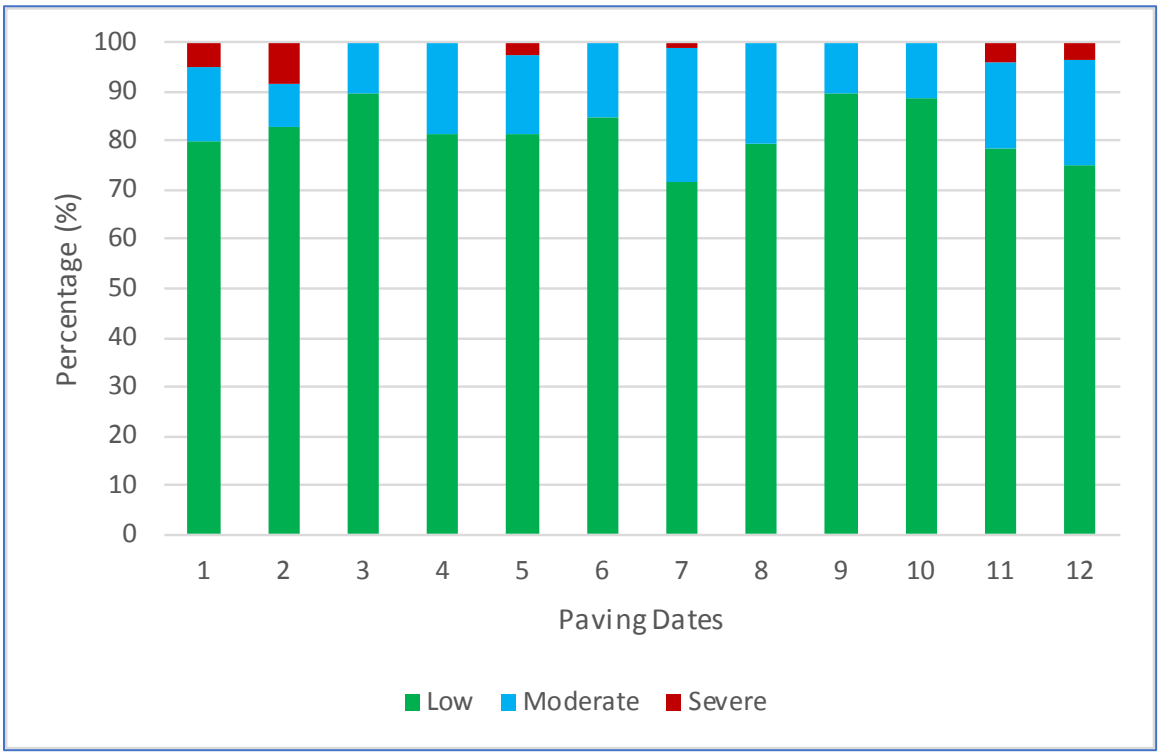


Figure 70: Summary of Veta Temperature Segregation Report (Project No. 5 - J2P3100, RT 36).

Table 21 and Figure 71 provide a summary of the IC results. The roller coverage results were mixed without apparent trends for improvements.

Table 21: Summary of IC Results (Project No. 5 - J2P3100, RT 36)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverag	Classification
1	5/25/2017	66	Failed	NA	NA	29	Failed
2	5/30/2017	98	Passed	NA	NA	50	Failed
3	5/31/2017	91	Passed	NA	NA	29	Failed
4	6/1/2017	63	Failed	NA	NA	17	Failed
5	6/5/2017	78	Moderate	NA	NA	10	Failed
6	6/6/2017	89	Moderate	NA	NA	38	Failed
7	6/12/2017	79	Moderate	NA	NA	27	Failed
8	6/13/2017	96	Passed	NA	NA	26	Failed
9	6/16/2017	94	Passed	NA	NA	29	Failed
10	6/19/2017	46	Failed	NA	NA	14	Failed
11	6/20/2017	89	Moderate	NA	NA	18	Failed
12	6/21/2017	90	Passed	NA	NA	5	Failed

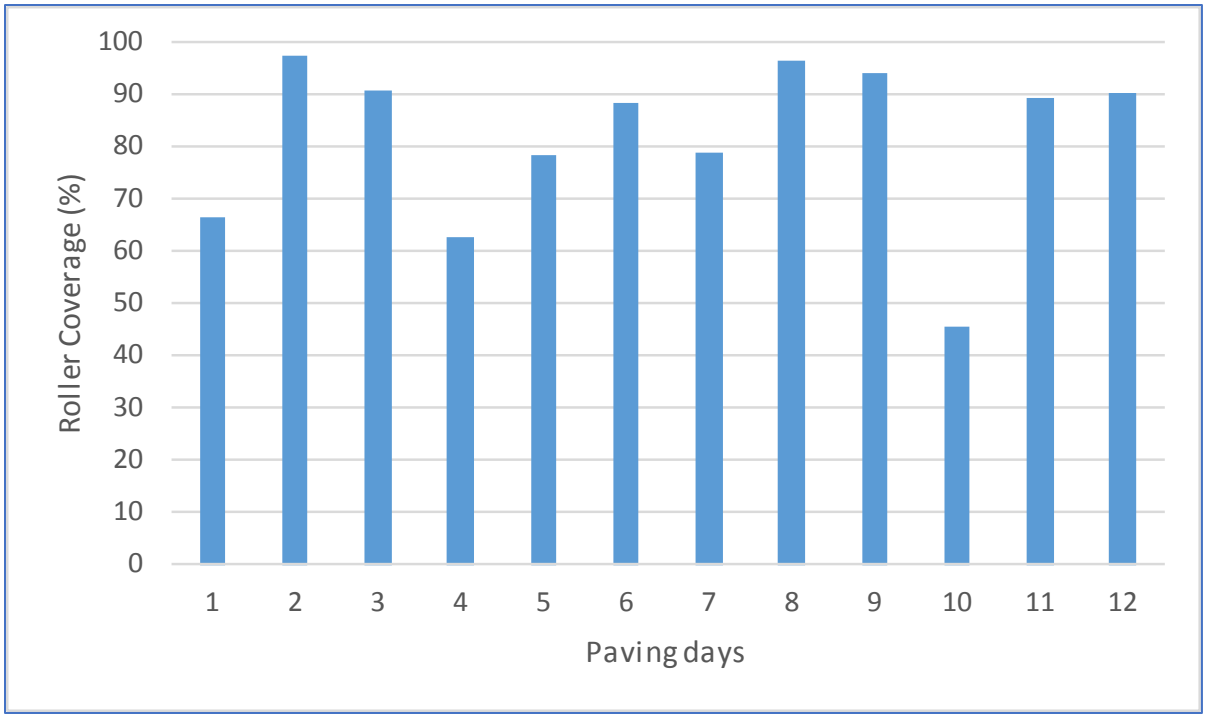


Figure 71: Summary of Roller Coverage Report (Project No. 5 - J2P3100, RT 36).

Project No. 6 - J2P3051, RT 24

Trial Section (10/21/2016)
Optimum Rolling Pattern: The optimum number of passes, six, was established based on the compaction curve in Figure 72.

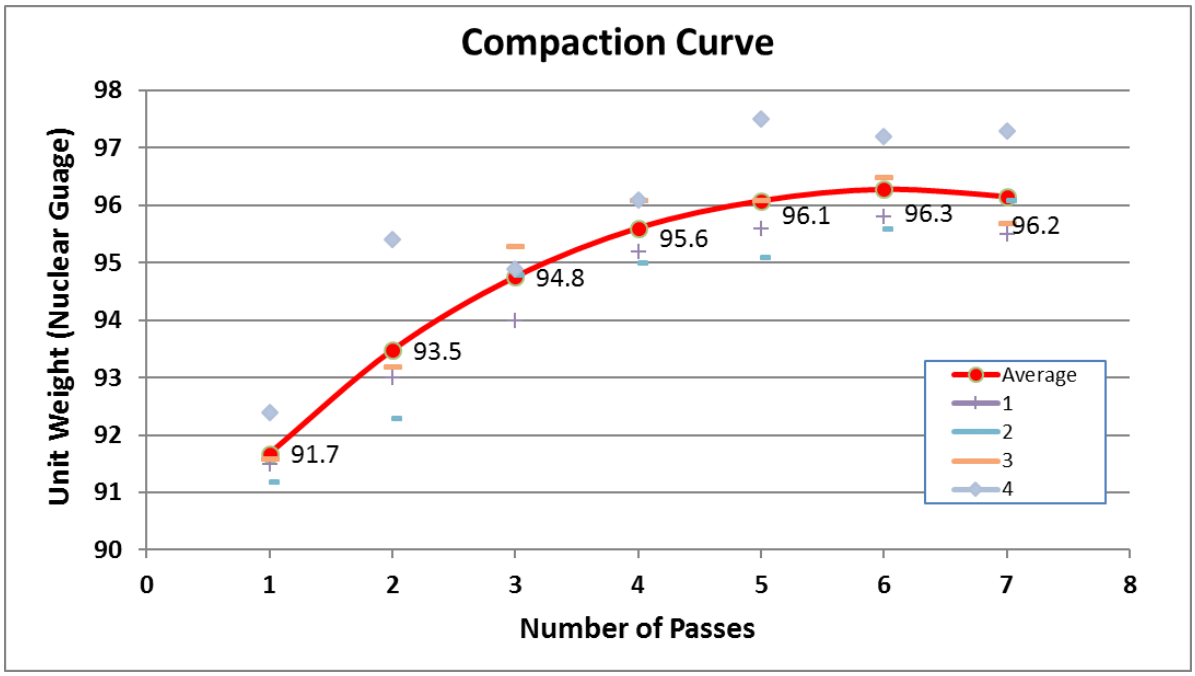


Figure 72: Compaction Curve from the Trial Section on 10/21/2016 (Project No. 6 - J2P3051, RT 24).

Trial Section (10/27/2016)
Optimum Rolling Pattern: The optimum number of passes, three (vibratory, static, vibratory), was established based on the compaction curve in Figure 73. However, there were no vibrating rolling passes used in the actual production passes.

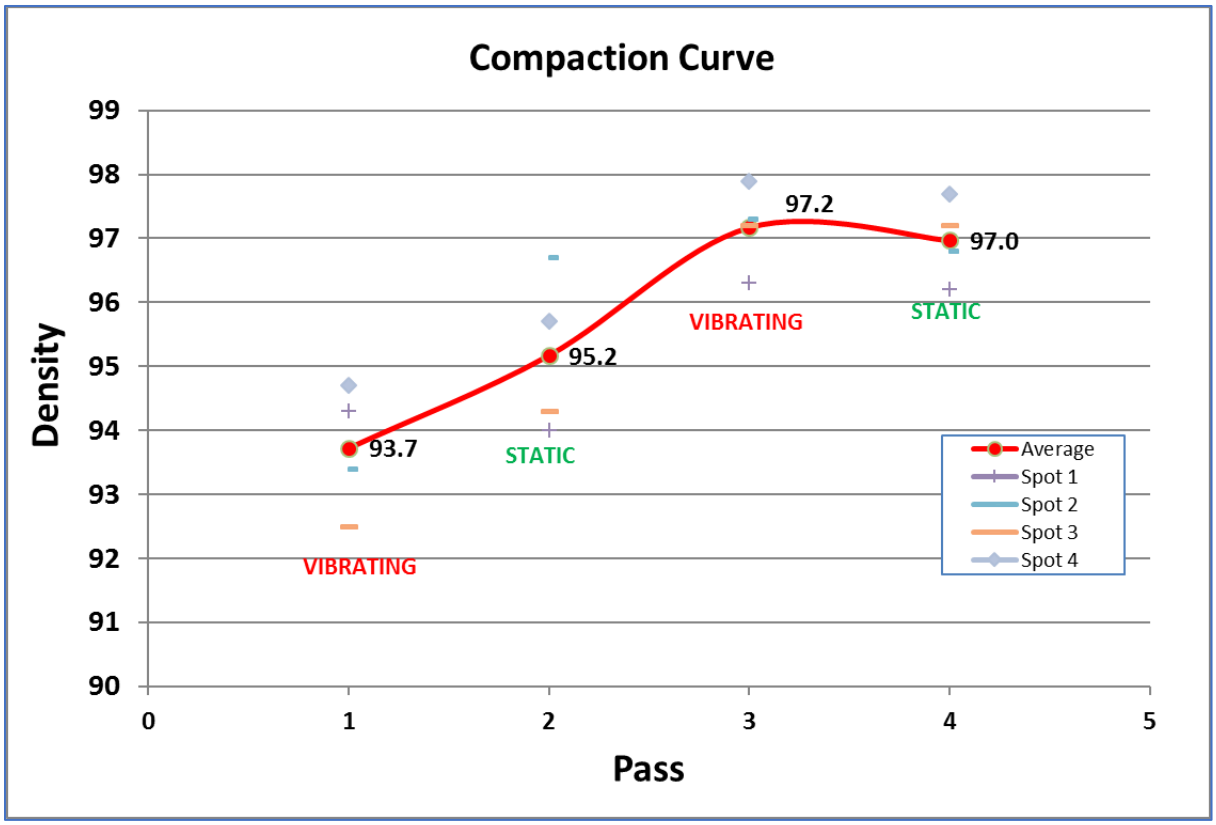


Figure 73: Compaction Curve from the Trial Section on 10/27/2016 (Project No. 6 - J2P3051, RT 24).

A summary of IR results is shown in Table 22, Figure 74, and Figure 75. There was significant severe temperature segregation for most of the paving days. The MOBA IR data for 10/22, 10/27, 10/28 roll-over, and its reports cannot be separated for daily reports. Veta filters and separates each day's data from the MOBA IR data based on time stamps.

Table 22: Summary of IR Results (Project No. 6 - J2P3051, RT 24)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	10/21/2016	1	2	14	*33*	28	*65*	*0*	*0*	11	*26*	31	*74*
2	10/22/2016	0	0	120	*66*	63	*34*	*1*	*2*	41	*73*	14	*25*
3	10/27/2016	0	0	120	*66*	63	*34*	*3*	*20*	11	*73*	1	*7*
4	10/28/2016	0	0	120	*66*	63	*34*	*2*	*3*	53	*80*	11	*17*
5	10/31/2016	3	4	66	*89*	5	*7*	*3*	*3*	79	*91*	5	*6*
6	11/1/2016	2	2	60	*85*	9	*13*	*0*	*0*	46	*67*	23	*33*
7	11/2/2016	1	1	58	*88*	7	*11*	*0*	*0*	44	*69*	20	*31*
8	11/3/2016	1	5	11	*55*	8	*40*	*0*	*0*	13	*68*	6	*32*

Notes:

* Veta report is for information only

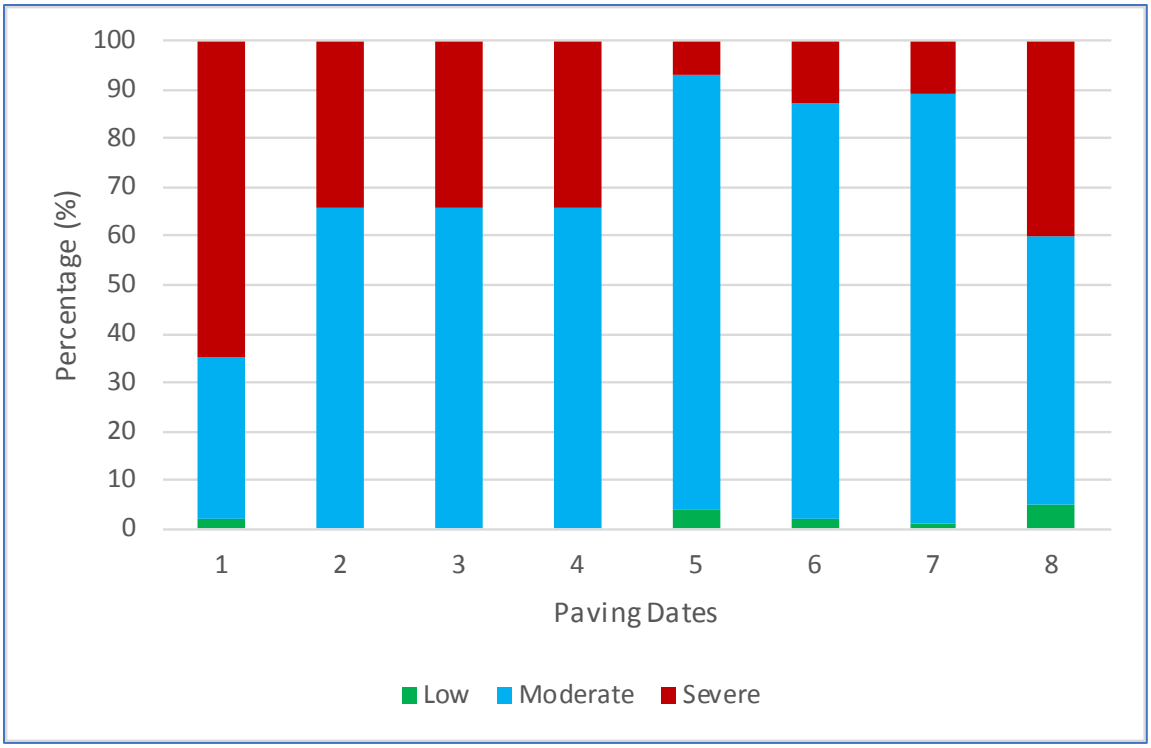


Figure 74: Summary of MOBA PPM Temperature Segregation Report (Project No. 6 - J2P3051, RT 24).

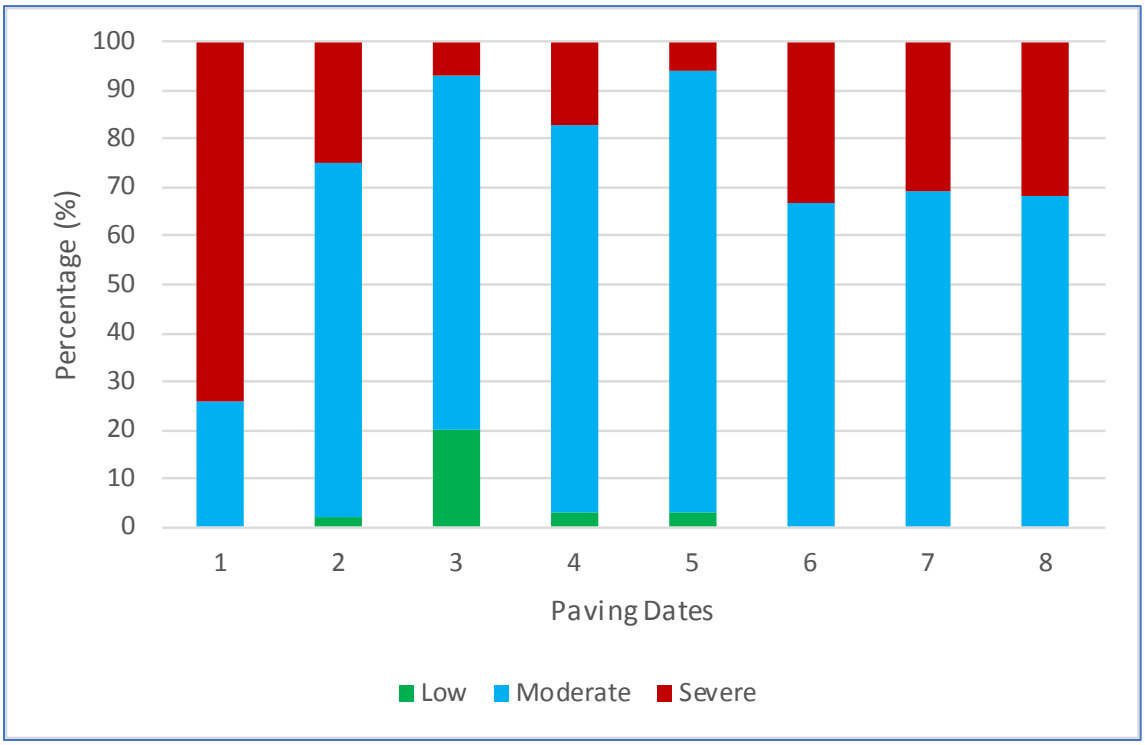


Figure 75: Summary of Veta Temperature Segregation Report (Project No. 6 - J2P3051, RT 24).

Table 23 and Figure 76 provide a summary of the roller coverage results. Most of the roller coverage are in the deficient category, and unexpectedly, the roller coverage was trending lower as the project progressed.

Table 23: Summary of IC Results (Project No. 6 - J2P3051, RT 24)

Day	*Date*	*Roller Coverage* *% Coverage*	*Classification*	*ICMV* *(Target: min. 70%)*	*Temperature* *(vibratory passes <225 ° F)*
1	10/21/2016	70.9	Moderate	*	NA
2	10/22/2016	63.7	Deficient	*	NA
3	10/27/2016	64.5	Deficient	*	NA
4	10/28/2016	43.9	Deficient	*	NA
5	10/31/2016	51.7	Deficient	*	NA
6	11/1/2016	52.3	Deficient	*	NA
7	11/2/2016	58.9	Deficient	*	NA
8	11/3/2016	37.1	Deficient	*	NA

Notes:

* Not analyzed since no target ICMV was determined from trial sections.

NA - Not applicable, compaction performed in static mode only

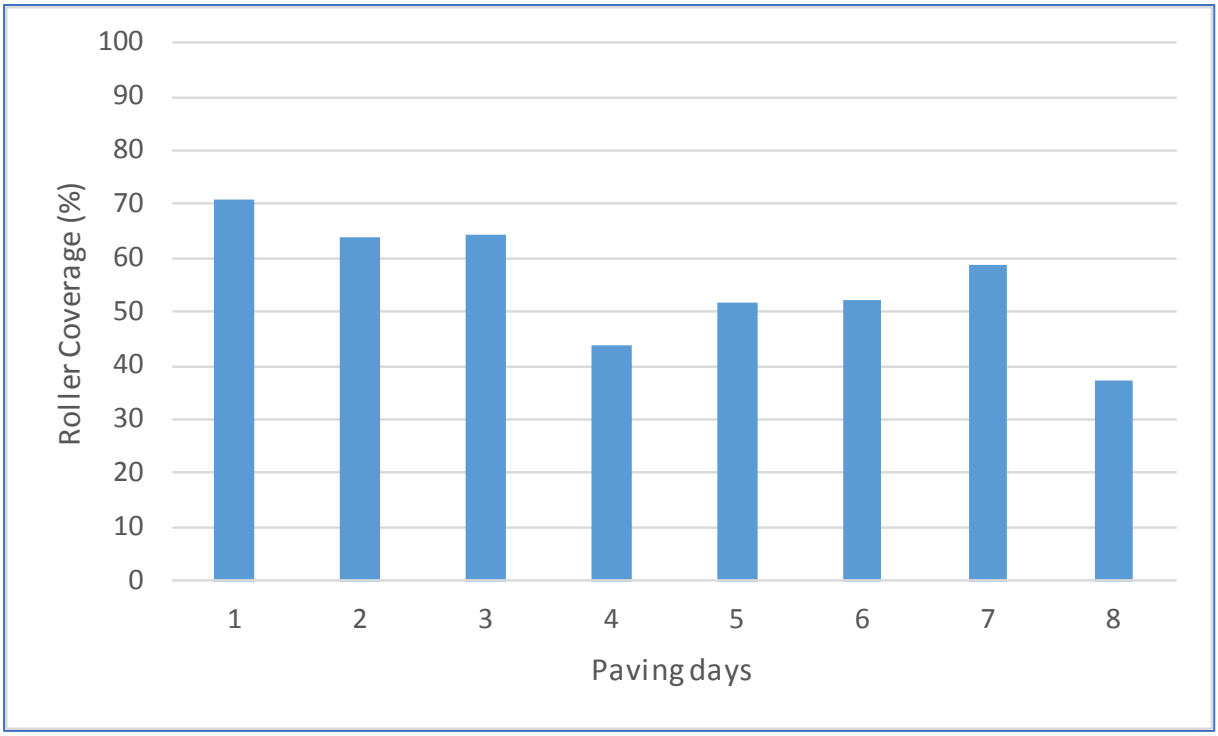


Figure 76: Summary of Roller Coverage Reports (Project No. 6 - J2P3051, RT 24).

Project No. 7 - J1P3005, RT 24

Trial Section (4/24/2017)
Optimum Rolling Pattern: The compaction curve is shown in Figure 77. The rolling pattern for the breakdown IC roller was four passes, with three vibratory passes and one static pass. The roller was set to operate at high frequency and low amplitude.

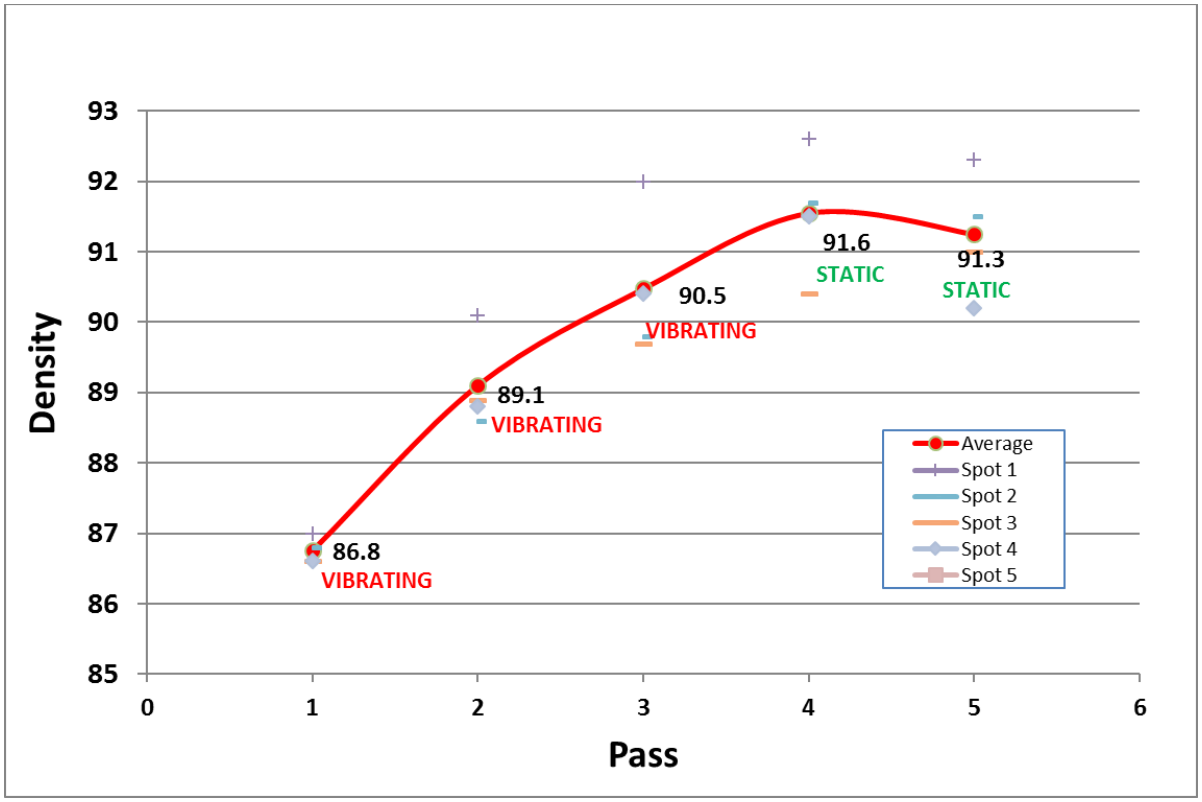


Figure 77: Compaction Curve– Trial Section (4/24/2017) (Project No. 7 - J1P3005, RT 24)

A summary of IR results is shown in Table 24, Figure 78, and Figure 79. An MTV was used only on Day 2 (4/25/2017). The summary temperature segregation reports in Figure 78 and Figure 79 show that the use of MTV on Day 2 reduced severe temperature segregation significantly compared with other paving days without the use of MTV.

Table 24: Summary of IR Results (Project No. 7 - J1P3005, RT 24)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	4/24/2017	0	*0*	3	*3*	87	*97*	0	*0*	1	*1*	77	*99*
2	4/25/2017	17	*15*	87	*80*	5	*5*	16	*20*	61	*76*	3	*4*
3	5/2/2017	0	*0*	26	*23*	85	*77*	0	*0*	18	*18*	82	*82*
4	5/5/2017	0	*0*	16	*15*	92	*85*	0	*0*	19	*20*	78	*80*
5	5/6/2017	0	*0*	29	*25*	86	*75*	0	*0*	25	*24*	78	*76*
6	5/8/2017	0	*0*	34	*31*	77	*69*	0	*0*	25	*25*	74	*75*
7	5/9/2017	0	*0*	77	*59*	53	*41*	0	*0*	70	*60*	47	*40*
8	5/15/2017	0	*0*	62	*54*	52	*46*	0	*0*	56	*55*	45	*45*
9	5/16/2017	0	*0*	23	*64*	13	*36*	0	*0*	39	*47*	44	*53*
10	5/17/2017	0	*0*	31	*61*	20	*39*	0	*0*	26	*57*	20	*43*
Notes:	*. Veta results are for information only.												

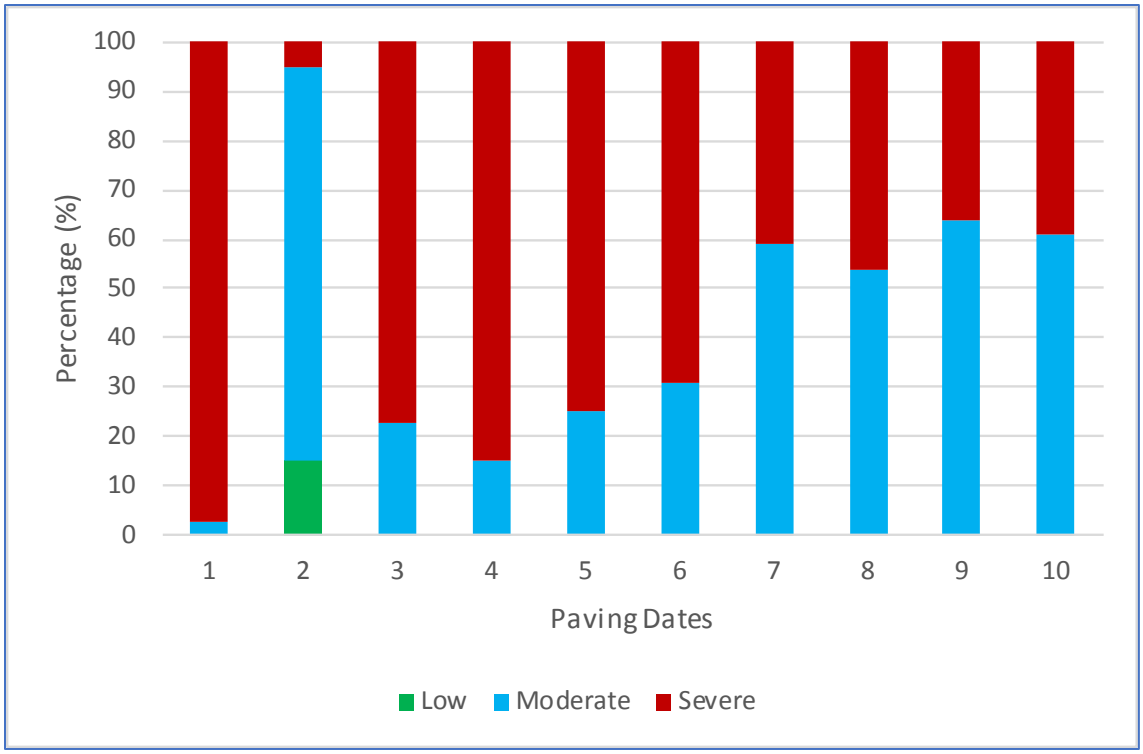


Figure 78: Summary of MOBA PPM Temperature Segregation Report (Project No. 7 - J1P3005, RT 24).

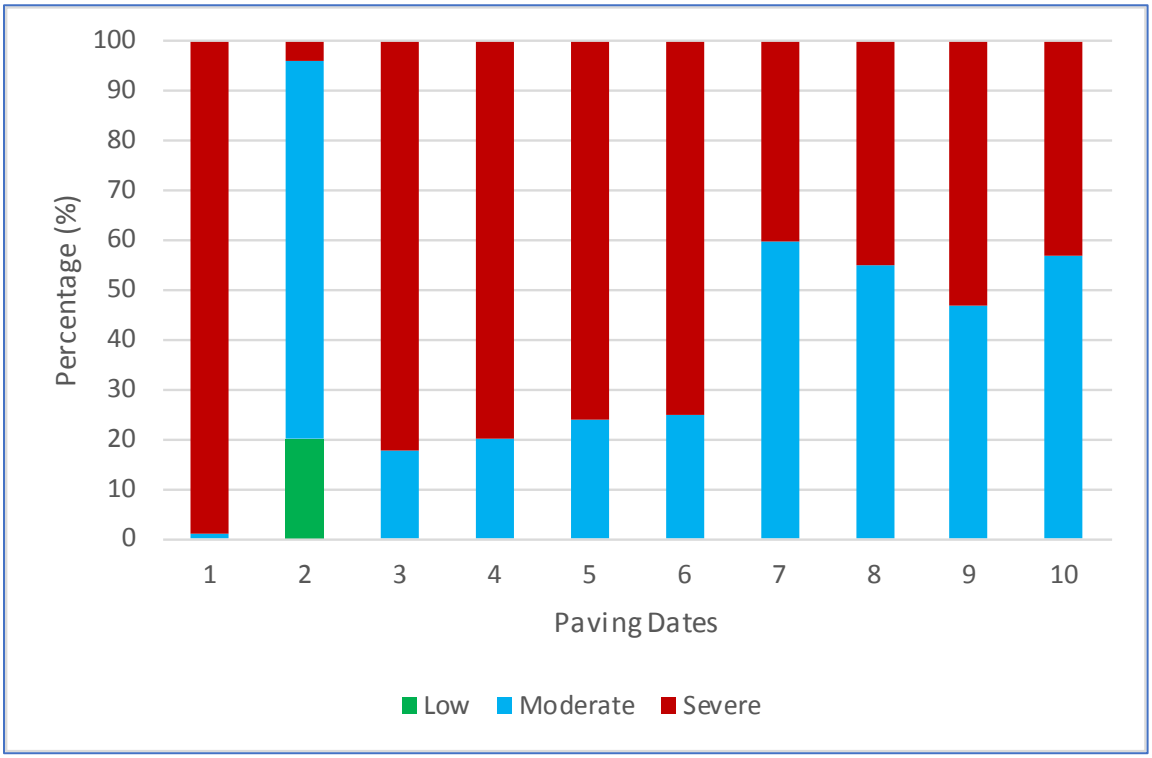


Figure 79: Summary of Veta Temperature Segregation Report (Project No. 7 - J1P3005, RT 24).

Table 25 and Figure 80 provide a summary of the IC results. Note that there were missing IC data for Day 10 (5/17/2017) due to malfunctioning of IC system. The roller coverages were excellent except for Day 10.

Table 25: Summary of IC Results (Project No. 7 - J1P3005, RT 24)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	4/24/2017	95.5	Passed	92.25	Pass	51.37	Failed
2	4/25/2017	97.7	Passed	91.45	Pass	47.55	Failed
3	5/2/2017	99.6	Passed	NA	NA	57.32	Failed
4	5/5/2017	99.6	Passed	NA	NA	58.68	Failed
5	5/6/2017	99.3	Passed	NA	NA	68.86	Failed
6	5/8/2017	98.5	Passed	NA	NA	67.71	Failed
7	5/9/2017	95.4	Passed	NA	NA	52.86	Failed
8	5/15/2017	94.3	Passed	NA	NA	54.67	Failed
9	5/16/2017	95.5	Passed	NA	NA	0	NA
10	5/17/2017	22	Failed	NA	NA	0	NA
Notes: Minimum temperature for the vibratory pass is 225F Static only for 5/16-17 5/17 IC data has missed 4,340 ft							

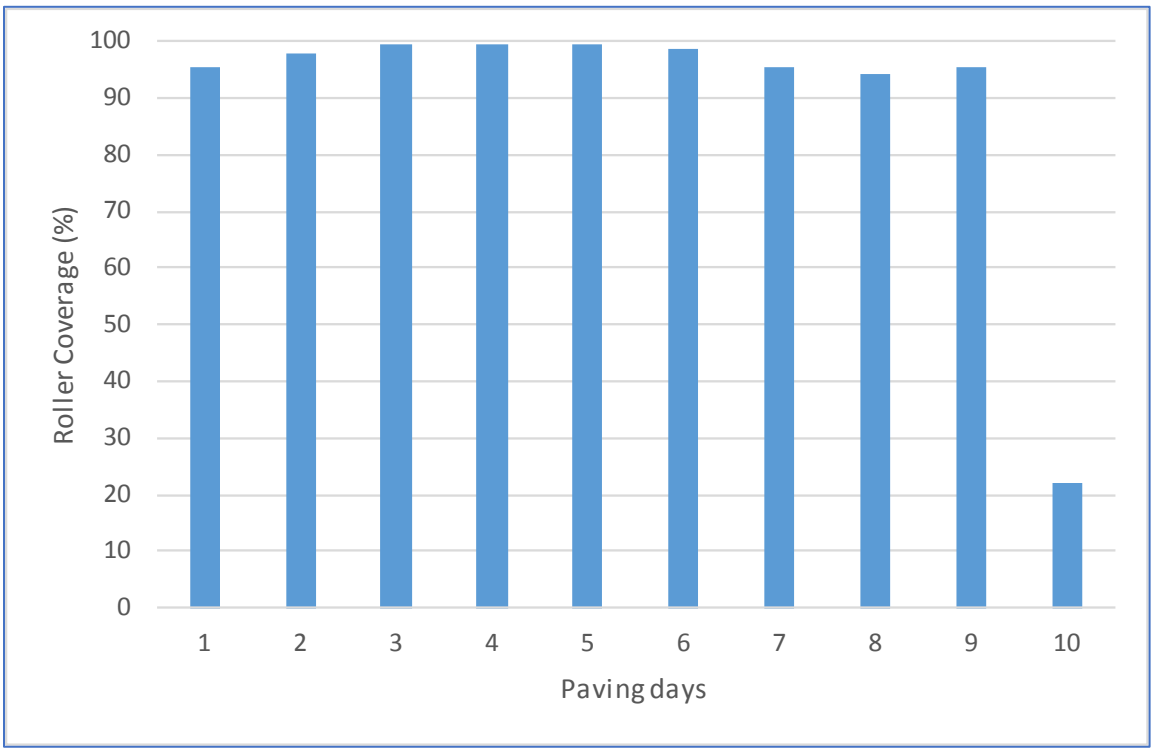


Figure 80: Summary of Roller Coverage Report (Project No. 7 - J1P3005, RT 24).

Project No. 8 - J9P3161, RT 17

Trial Section (9/28/2017)

Optimum Rolling Pattern: The compaction curve was plotted based on the trial section data, as shown in Figure 81. It was determined by the RE and the contractor that the rolling pattern for the breakdown IC roller is three vibratory passes followed by a finishing roller.

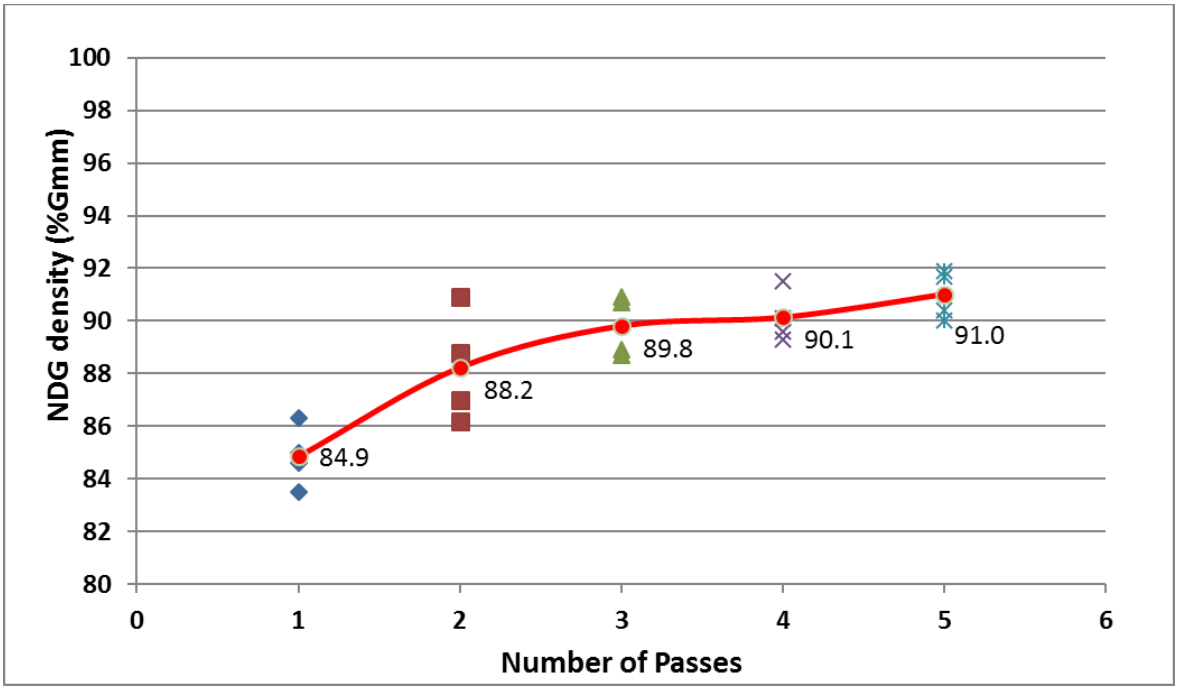


Figure 81: Compaction Curve from the Trial Section on 9/28/2017 (Project No. 8 - J9P3161, RT 17).

Trial Section (10/2/2017)
Optimum Rolling Pattern: The compaction curve was plotted based on the trial section data, as shown in Figure 82. It was determined by the RE and the contractor that the rolling pattern for the breakdown IC roller is three passes (one vibratory pass and two static passes) followed by a finishing roller. Since only one vibratory pass was used, the ICMV (CMV in this case) was not analyzed.

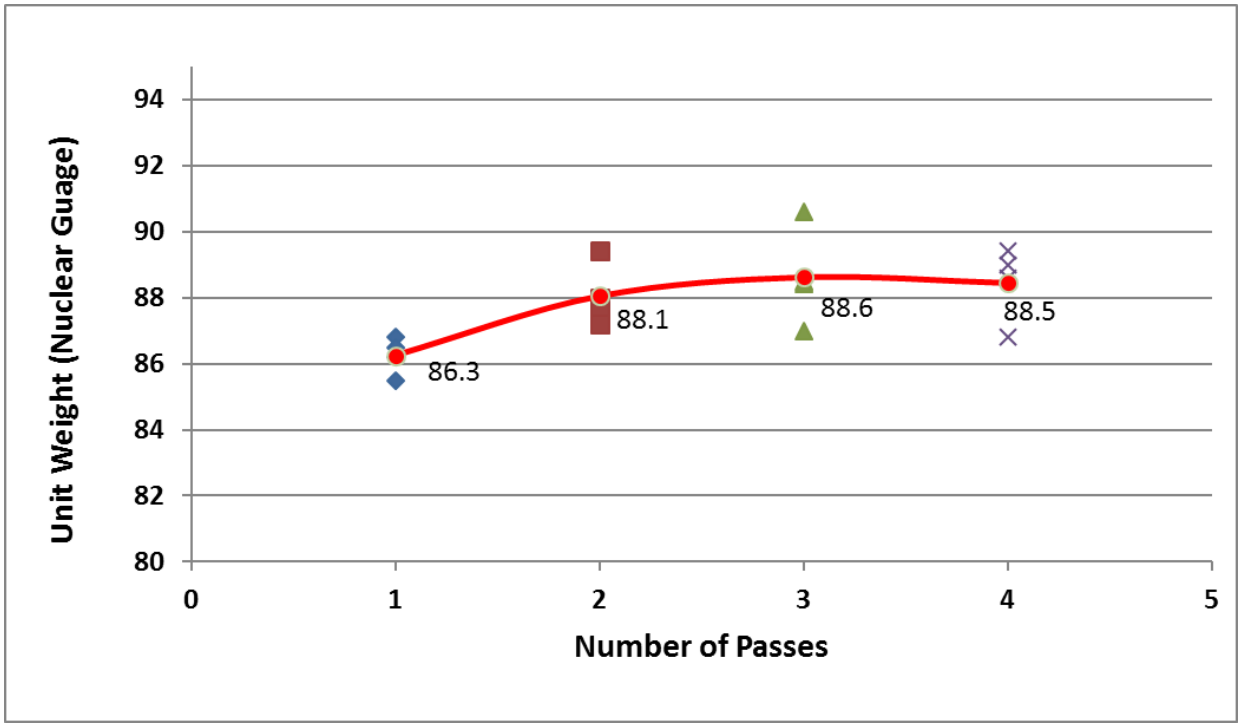


Figure 82: Compaction Curve from the Trial Section (2017-10-2) (Project No. 8 - J9P3161, RT 17)

A summary of IR results is shown in Table 11, Table 26, Figure 83, and Figure 84. The temperature segregation was mostly in “No Segregation” and “Moderate Segregation” categories with very limited severe temperature segregation, likely due to the use of an MTV.

Table 26: Summary of IR Results (Project No. 8 - J9P3161, RT 17)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	9/28/2017	20	*15*	98	*75*	12	*9*	16	*12*	100	*75*	17	*13*
2	9/29/2017	37	*20*	128	*68*	22	*12*	14	*8*	139	*79*	22	*13*
3	9/30/2017	14	*12*	85	*75*	14	*12*	12	*11*	86	*77*	14	*13*
4	10/2/2017	8	*16*	36	*73*	5	*10*	11	*23*	34	*71*	3	*6*
5	10/12/2017	33	*21*	117	*76*	4	*3*	35	*23*	112	*73*	6	*4*
6	10/13/2017	48	*27*	127	*71*	5	*3*	52	*29*	120	*67*	6	*3*
7	10/14/2017	32	*23*	100	*72*	6	*4*	39	*28*	95	*69*	3	*2*
8	10/16/2017	42	*41*	60	*58*	1	*1*	56	*55*	46	*45*	0	*0*
9	10/17/2017	43	*29*	101	*68*	4	*3*	44	*30*	98	*67*	5	*3*
10	10/18/2017	78	*51*	70	*46*	5	*3*	85	*56*	60	*40*	6	*4*
11	10/19/2017	70	*65*	32	*30*	6	*6*	71	*67*	30	*28*	5	*5*
Notes:	*. Veta results are for information only. 9/28 Section 1 IR data include incorrect DMI, length, nuumber of sublots. 10/16 Section 1 data is calibration. Section 2 and 3 are disjointed due to a loss data caused by blown fuse.												

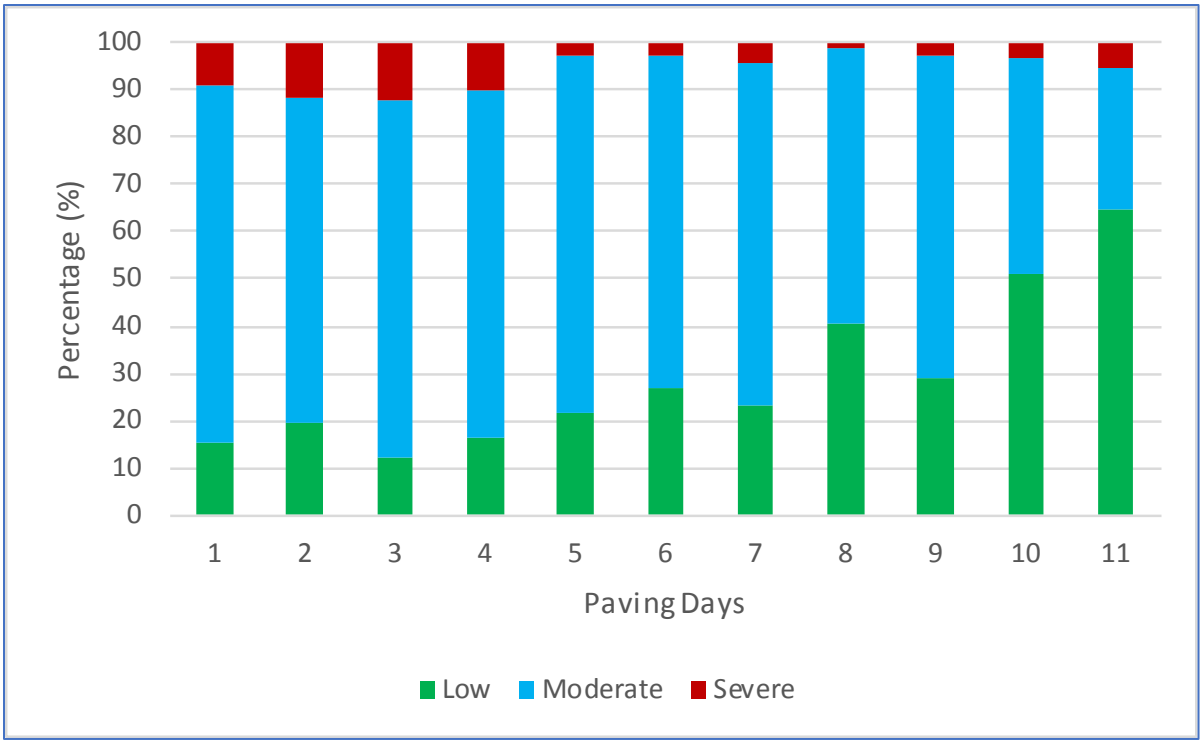


Figure 83: Summary of MOBA PPM Temperature Segregation Report (Project No. 8 - J9P3161, RT 17).

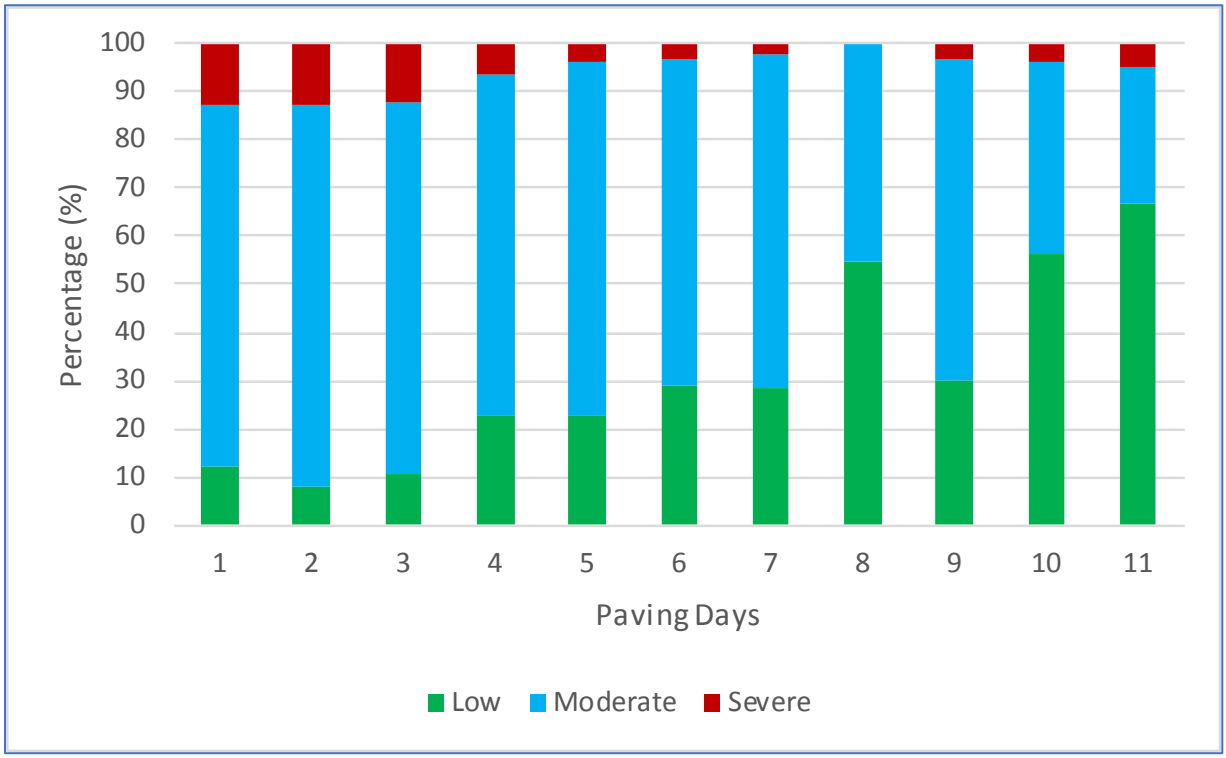


Figure 84: Summary of Veta Temperature Segregation Report (Project No. 8 - J9P3161, RT 17).

Table 27 and Figure 85 provide a summary of the roller coverage results. The roller coverage results were excellent throughout all paving days.

Table 27: Summary of IC Results (Project No. 8 - J9P3161, RT 17).

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverag	Classification
1	9/28/2017	90	Moderate	NA	NA	2.5	Failed
2	9/29/2017	94	Passed	NA	NA	1.8	Failed
3	9/30/2017	99	Passed	NA	NA	10.5	Failed
4	10/2/2017	97	Passed	NA	NA	25.0	Failed
5	10/12/2017	97	Passed	NA	NA	35.0	Failed
6	10/13/2017	92	Passed	NA	NA	37.8	Failed
7	10/14/2017	96	Passed	NA	NA	25.8	Failed
8	10/16/2017	92	Passed	NA	NA	35.1	Failed
9	10/17/2017	96	Passed	NA	NA	21.5	Failed
10	10/18/2017	99	Passed	NA	NA	22.0	Failed
11	10/19/2017	97	Passed	NA	NA	16.9	Failed

Notes: Target passes coverage for breakdown only.
Rolling pattern changed on 10/2

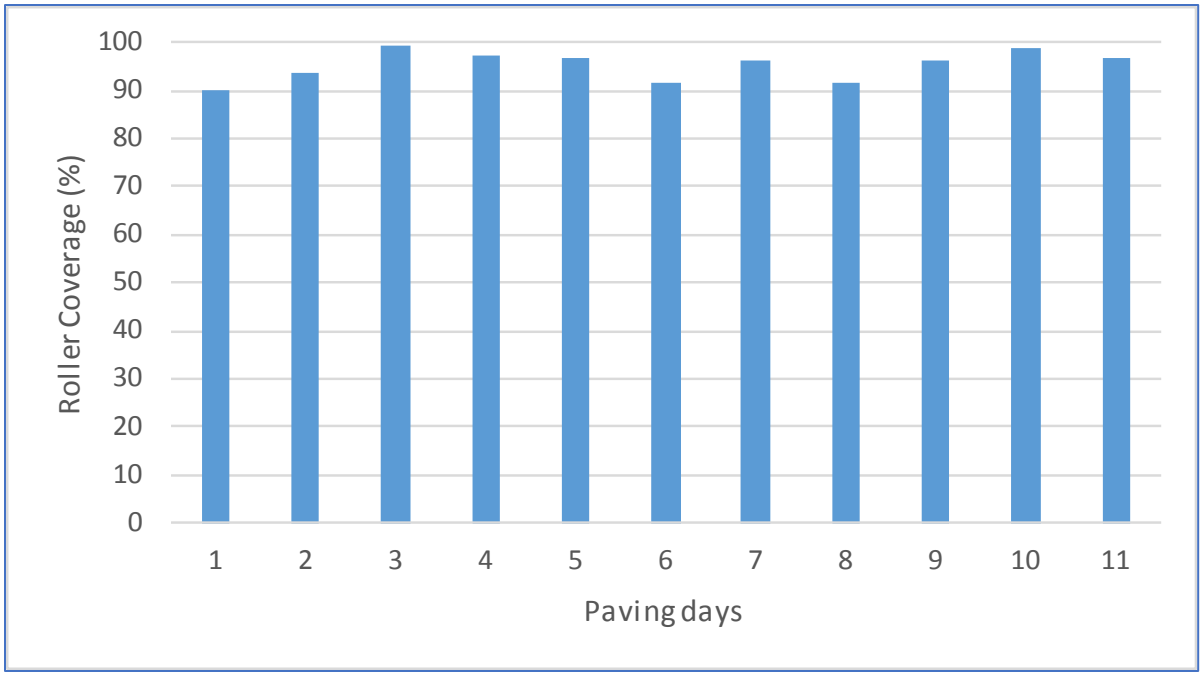


Figure 85: Summary of Roller Coverage Report (Project No. 8 - J9P3161, RT 17).

Project No. 9 - J6S3123, RT 61

Trial Section (5/31/2017)
Optimum Rolling Pattern: The compaction curve is shown in Figure 86. The rolling pattern established was three vibratory passes for the breakdown IC rollers and two vibratory passes for the intermediate roller. The rollers were set to operate at high frequency and low amplitude.

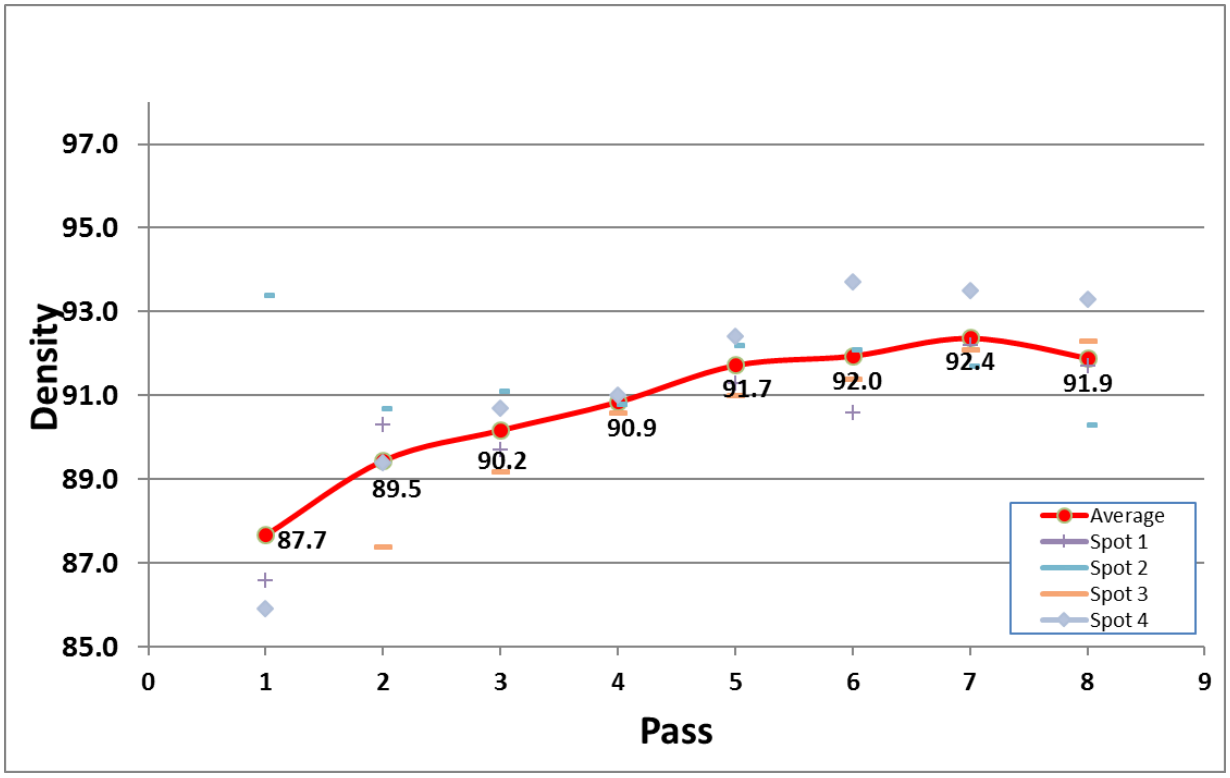


Figure 86 Compaction Curve– Trial Section (5/31/2017) (Project No. 9 - J6S3123, RT 61)

A summary of IR results is shown in Table 28, Figure 87 and Figure 88. The temperature segregation was mostly in "No Segregation" and "Moderate Segregation" categories with a limited amount of severe temperature segregation.

Table 28: Summary of IR Results (Project No. 9 - J6S3123, RT 61)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	5/31/2017	6	*40*	6	*40*	3	*20*	3	*20*	8	*53*	4	*27*
2	6/1/2017	68	*61*	24	*22*	19	*17*	68	*62*	32	*29*	9	*8*
3	6/2/2017	131	*89*	12	*8*	4	*3*	132	*91*	12	*8*	1	*1*
4	6/3/2017	94	*86*	13	*12*	2	*2*	96	*88*	11	*10*	2	*2*
5	6/5/2017	53	*64*	16	*19*	14	*17*	53	*67*	17	*22*	9	*11*
6	6/6/2017	55	*57*	31	*32*	11	*11*	63	*61*	30	*29*	11	*11*
7	6/7/2017	65	*54*	41	*34*	14	*12*	79	*68*	27	*23*	10	*9*
8	6/8/2017	38	*61*	16	*26*	8	*13*	39	*61*	17	*27*	8	*13*
9	6/9/2017	68	*58*	32	*27*	17	*15*	62	*54*	37	*32*	16	*14*
Notes:	*. Veta results are for information only.												

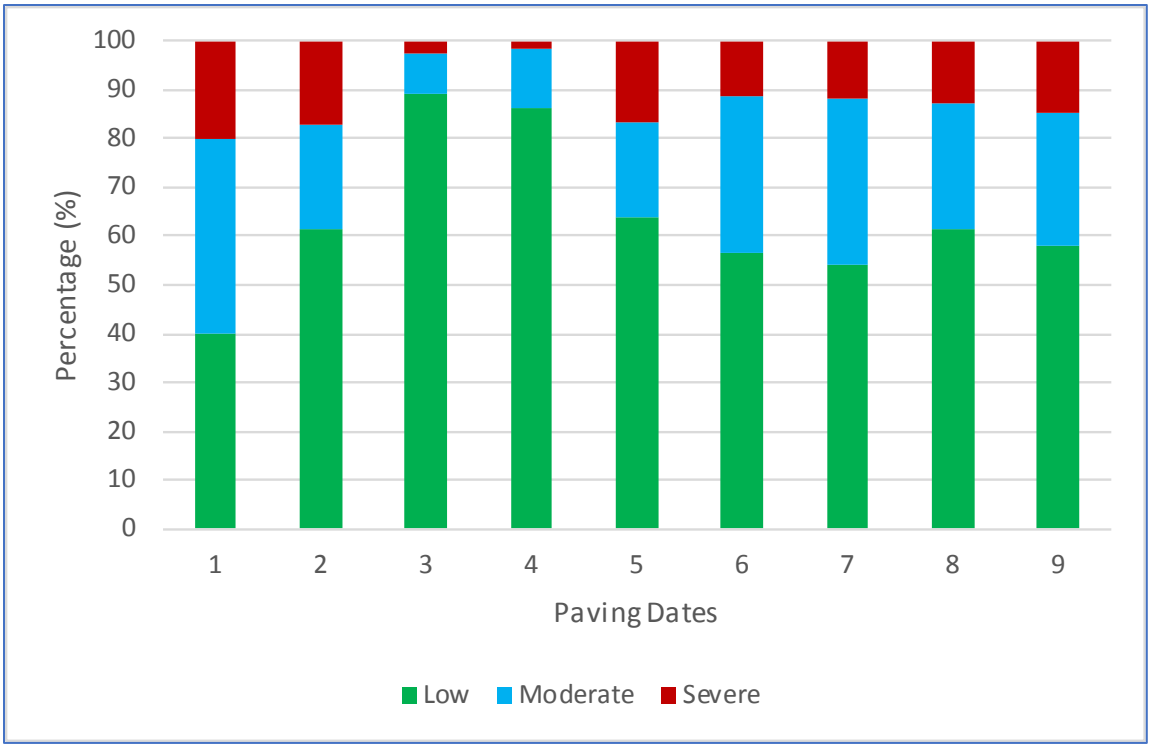


Figure 87: Summary of MOBA PPM Temperature Segregation Report (Project No. 9 - J6S3123, RT 61).

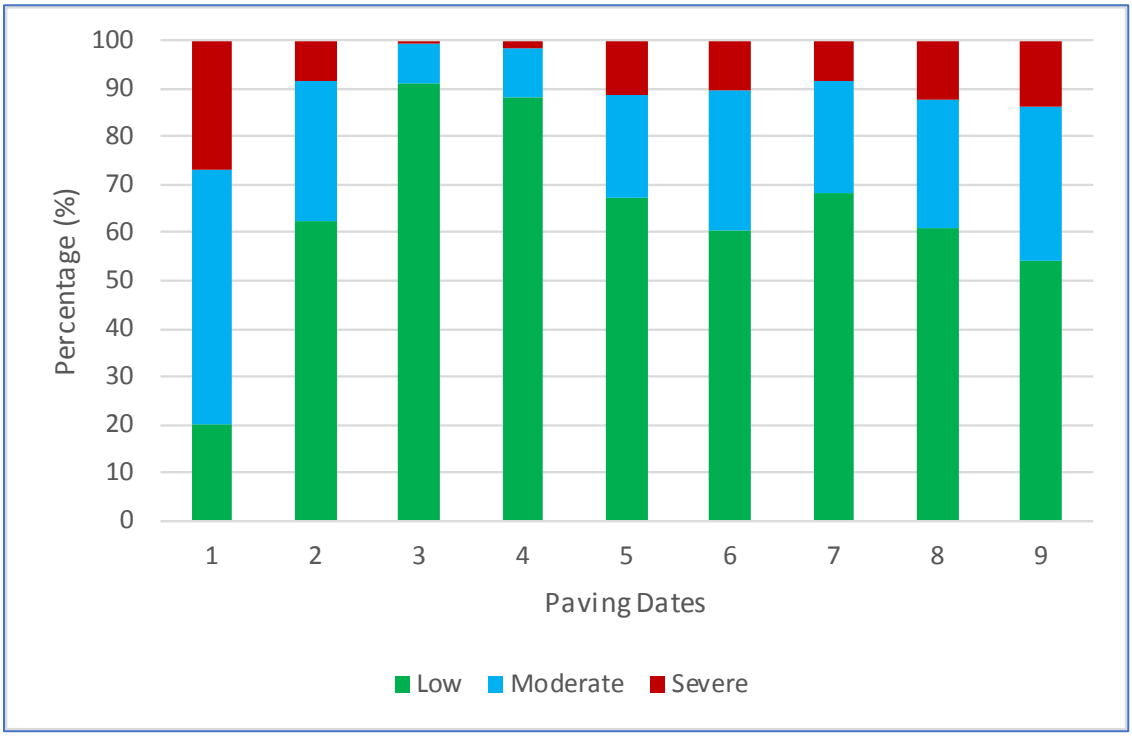


Figure 88: Summary of Veta Temperature Segregation Report (Project No. 9 - J6S3123, RT 61).

Table 29 and Figure 89 provide a summary of the IC results. The roller coverages were poor without trends of improvement.

Table 29: Summary of IC Results (Project No. 9 - J6S3123, RT 61)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	5/31/2017	59	Failed	30.92	Flagged	2	Failed
2	6/1/2017	20	Failed	19.27	Flagged	10	Failed
3	6/2/2017	71	Moderate	5.85	Flagged	26	Failed
4	6/3/2017	64	Failed	5.81	Flagged	33	Failed
5	6/5/2017	53	Failed	12.19	Flagged	24	Failed
6	6/6/2017	47	Failed	11.4	Flagged	26	Failed
7	6/7/2017	23	Failed	0.68	Flagged	43	Failed
8	6/8/2017	48	Failed	11.26	Flagged	34	Failed
9	6/9/2017	43	Failed	17.34	Flagged	39	Failed

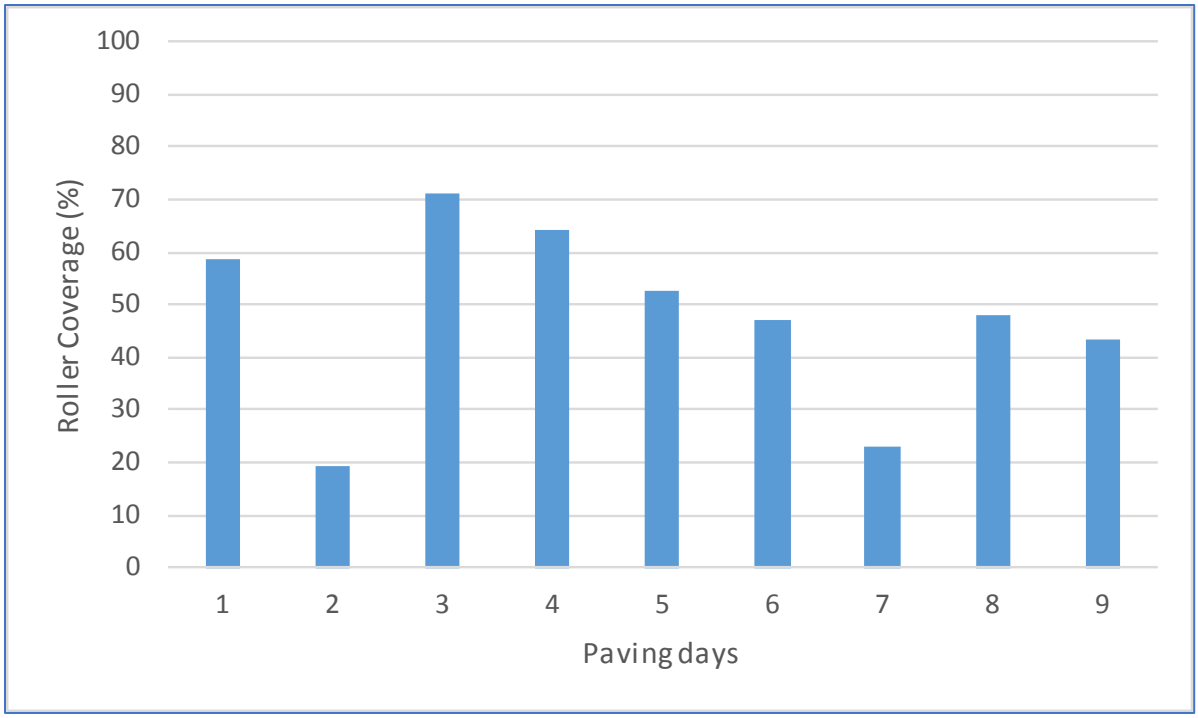


Figure 89: Summary of Roller Coverage Report (Project No. 9 - J6S3123, RT 61).

Project No. 10 - J7I3072, RT 49

Trial Section (6/12/2017)
Optimum Rolling Pattern: The compaction curve is shown in Figure 86. The rolling pattern established was two vibratory passes for the breakdown IC rollers, two static passes by the pneumatic roller, and one vibratory and one static pass for the second intermediate roller. The rollers were set to operate at high frequency and low amplitude.

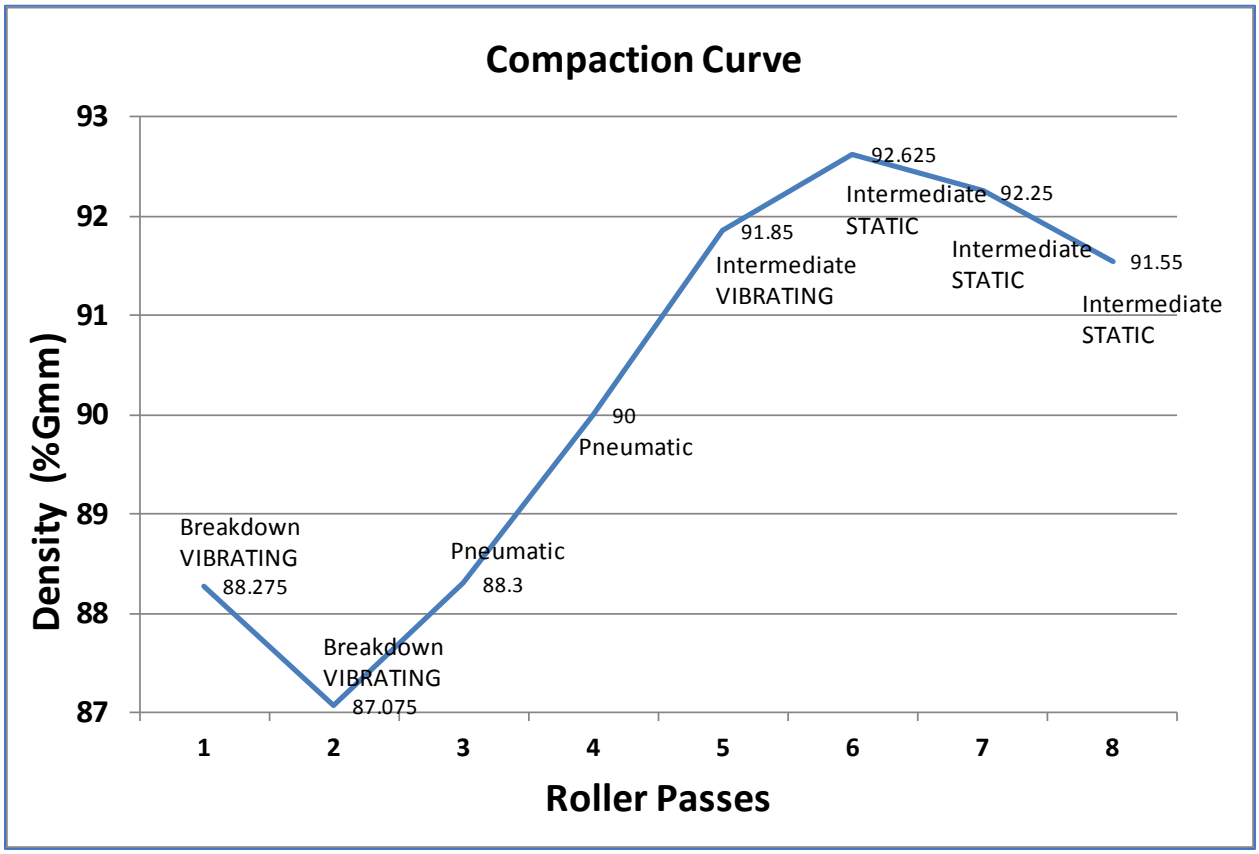


Figure 90 Compaction Curve– Trial Section (6/12/2017) (Project No. 10 - J7I3072, RT 49)

A summary of IR results is shown in Table 30, Figure 91, and Figure 92. The temperature segregation was mostly in "No Segregation" and "Moderate Segregation" categories but the Day 8 data indicated severe temperature segregation.

Table 30: Summary of IR Results (Project No. 10 - J7I3072, RT 49)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	6/5/2017	3	*23*	10	*77*	0	*0*	5	*42*	7	*58*	0	*0*
2	6/16/2017	1	*17*	5	*83*	0	*0*	1	*8*	11	*92*	0	*0*
3	6/19/2017	26	*44*	28	*47*	5	*8*	30	*52*	26	*45*	2	*3*
4	6/20/2017	51	*50*	51	*50*	1	*1*	57	*55*	44	*42*	3	*3*
5	6/21/2017	15	*19*	54	*68*	10	*13*	36	*46*	40	*51*	3	*4*
6	6/22/2017	52	*54*	41	*42*	4	*4*	54	*56*	37	*39*	5	*5*
7	6/23/2017	19	*43*	19	*43*	6	*14*	20	*47*	18	*42*	5	*12*
8	6/24/2017	15	*18*	34	*41*	33	*40*	20	*24*	34	*41*	28	*34*
9	6/26/2017	64	*57*	47	*42*	2	*2*	62	*55*	42	*38*	8	*7*
10	6/27/2017	10	*37*	15	*56*	2	*7*	12	*46*	13	*50*	1	*4*
11	6/28/2017	44	*43*	57	*56*	1	*1*	50	*49*	50	*49*	2	*2*
12	6/29/2017	58	*49*	57	*48*	3	*3*	67	*57*	50	*42*	1	*1*
13	7/6/2017	39	*57*	28	*41*	1	*1*	48	*69*	20	*29*	2	*3*
Notes:	*. Veta results are for information only.												

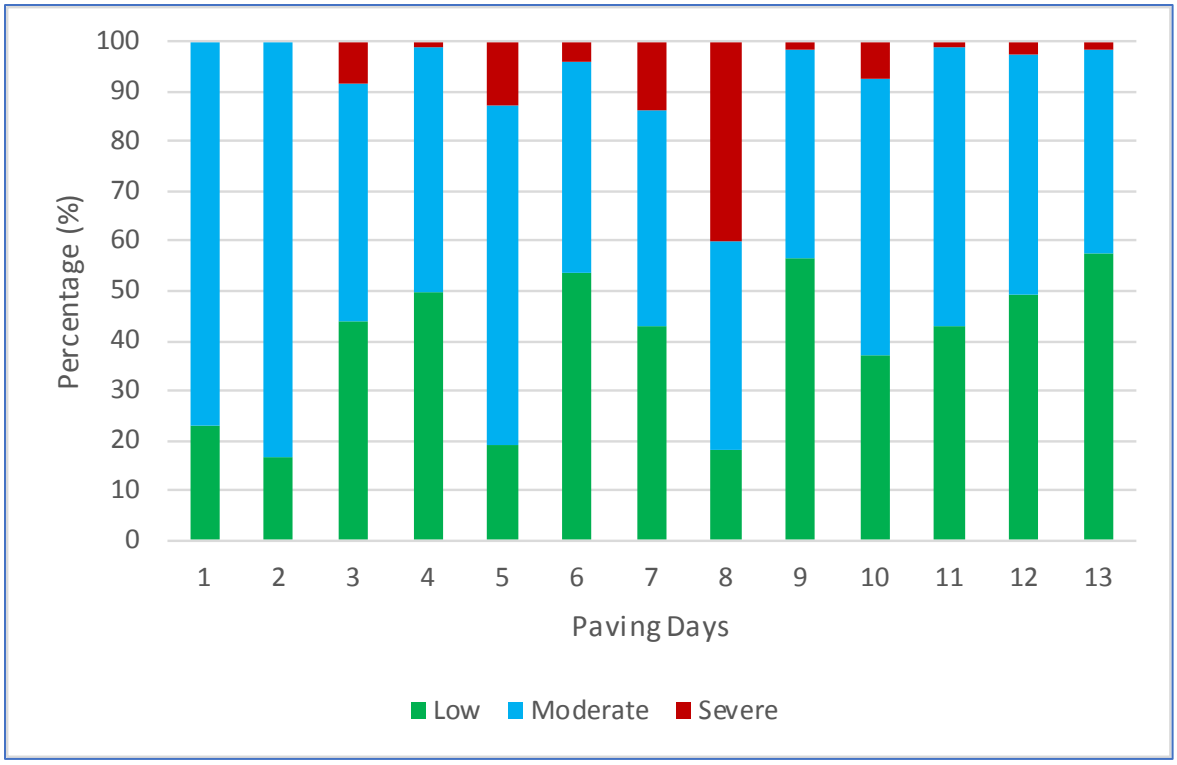


Figure 91: Summary of MOBA PPM Temperature Segregation Report (Project No. 10 - J7I3072, RT 49).

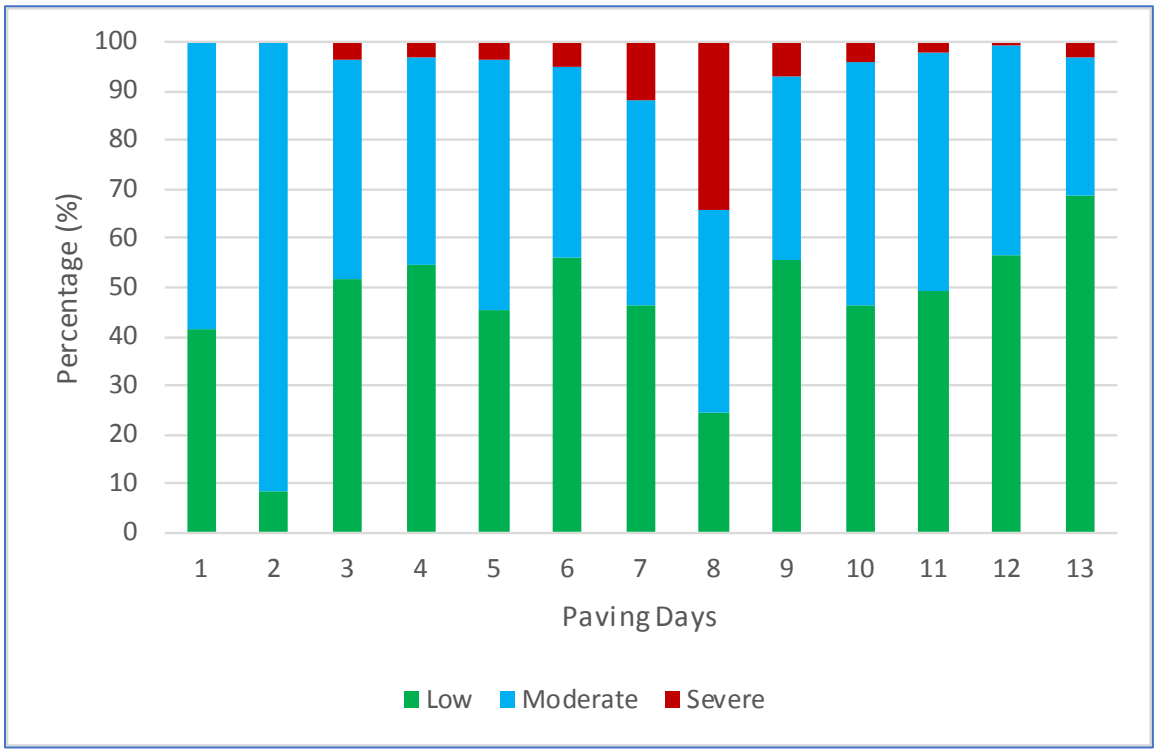


Figure 92: Summary of Veta Temperature Segregation Report (Project No. 10 - J7I3072, RT 49).

Table 31 and Figure 93 provide a summary of the roller coverage results. The roller coverage was excellent after improving from Day 1.

Table 31: Summary of IC Results (Project No. 10 - J7I3072, RT 49)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	6/5/2017	77	Moderate	*	NA	0	Failed
2	6/16/2017	100	Passed	*	NA	1	Failed
3	6/19/2017	98	Passed	*	NA	2	Failed
4	6/20/2017	89	Moderate	*	NA	7	Failed
5	6/21/2017	99	Passed	*	NA	3	Failed
6	6/22/2017	98	Passed	*	NA	5	Failed
7	6/23/2017	97	Passed	*	NA	3	Failed
8	6/24/2017	97	Passed	*	NA	6	Failed
9	6/26/2017	95	Passed	*	NA	1	Failed
10	6/27/2017	98	Passed	*	NA	0	Failed
11	6/28/2017	97	Passed	*	NA	1	Failed
12	6/29/2017	99	Passed	*	NA	0	Failed
13	7/6/2017	97	Passed	*	NA	16	Failed

Notes:

* Data not available

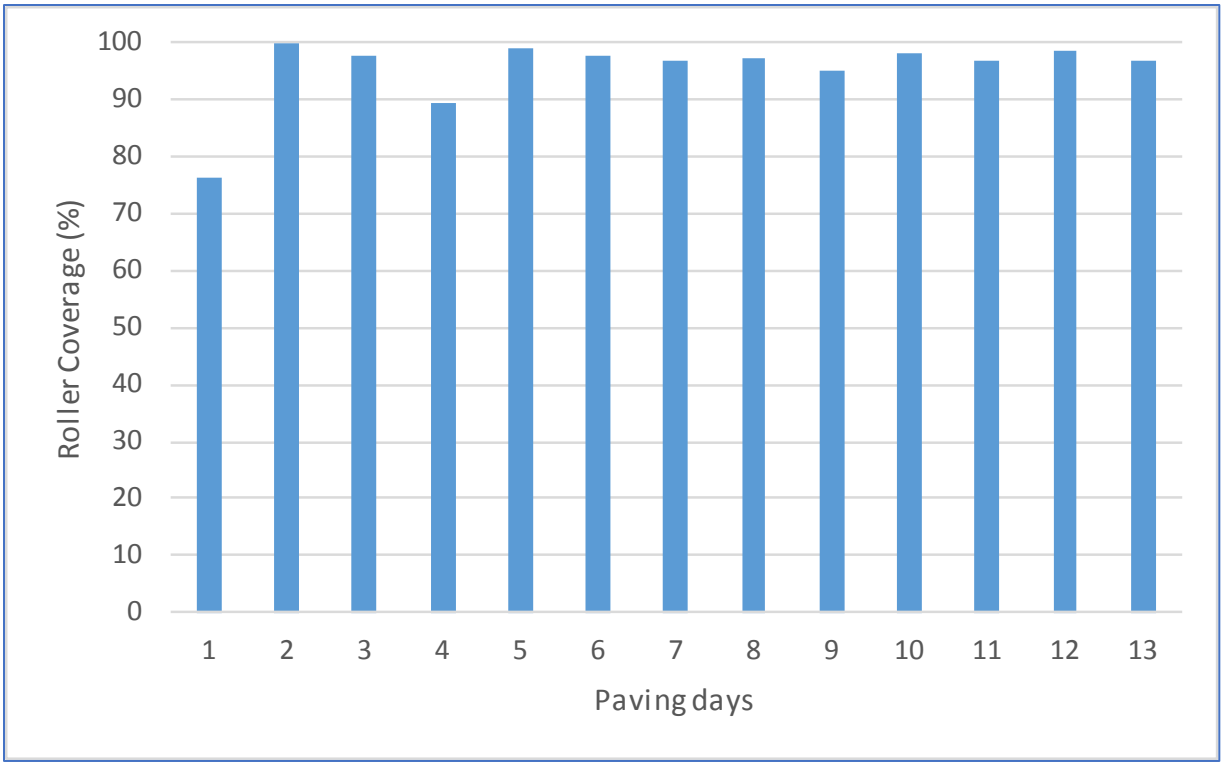


Figure 93: Summary of Roller Coverage Report (Project No. 10 - J7I3072, RT 49).

Project No. 11 - J1S3028, RT 69

Trial Section-1 (6/30/2017)
Optimum Rolling Pattern: The compaction curve is shown in Figure 94. The rolling pattern established was for the breakdown (CAT CB66B) IC roller to have one vibratory pass, one static pass, and one more vibratory pass. The roller was set to operate at high frequency and low amplitude.

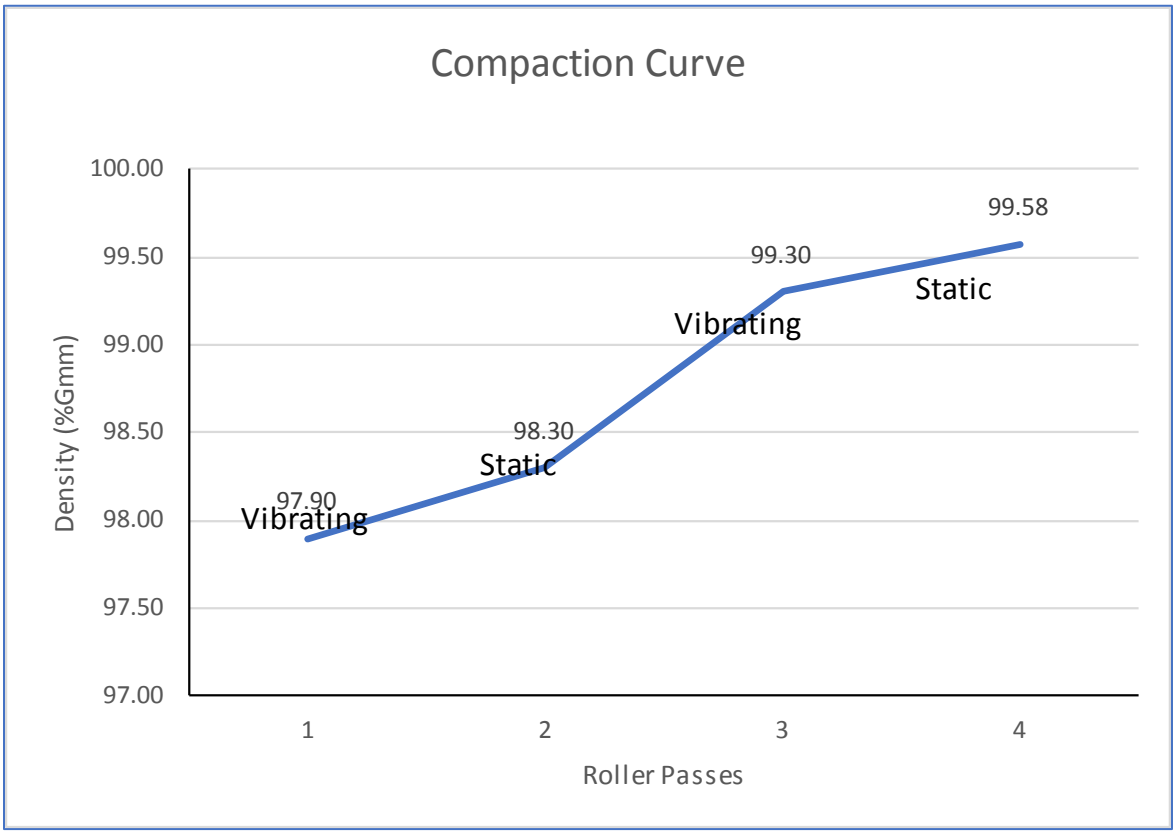


Figure 94 Compaction Curve from the Trial Section-1 on 6/30/2017 (Project No. 11 - J1S3028, RT 69).

Trial Section-2 (6/30/2017)
Optimum Rolling Pattern: The compaction curve is shown in Figure 95. The rolling pattern established was for the breakdown (CAT CB66B) IC roller to have one vibratory pass, and two static passes. The roller was set to operate at high frequency and low amplitude.

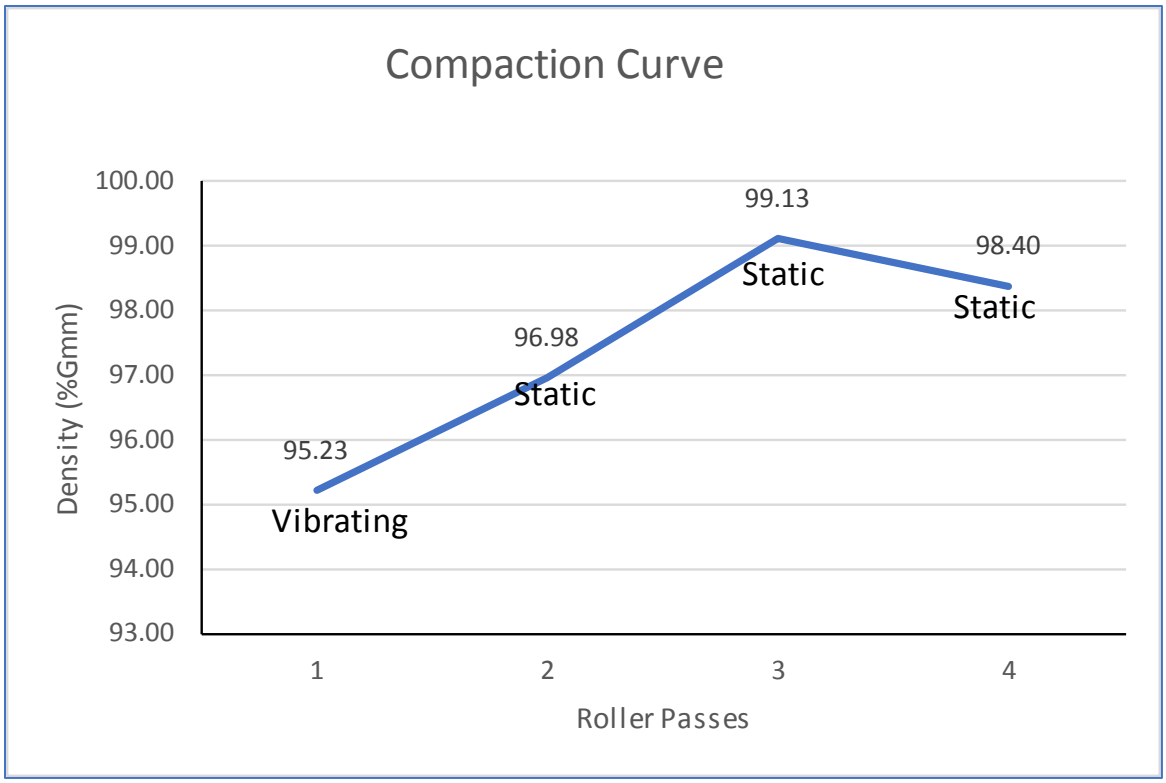


Figure 95 Compaction Curve from the Trial Section-2 on 6/30/2017 (Project No. 11 - J1S3028, RT 69).

Trial Section (7/6/2017)
Optimum Rolling Pattern: The compaction curve is shown in Figure 96. The rolling pattern established was for the breakdown (Hamm HD+140i) IC roller to have one vibratory pass, and two static passes. The roller was set to operate at high frequency and low amplitude.

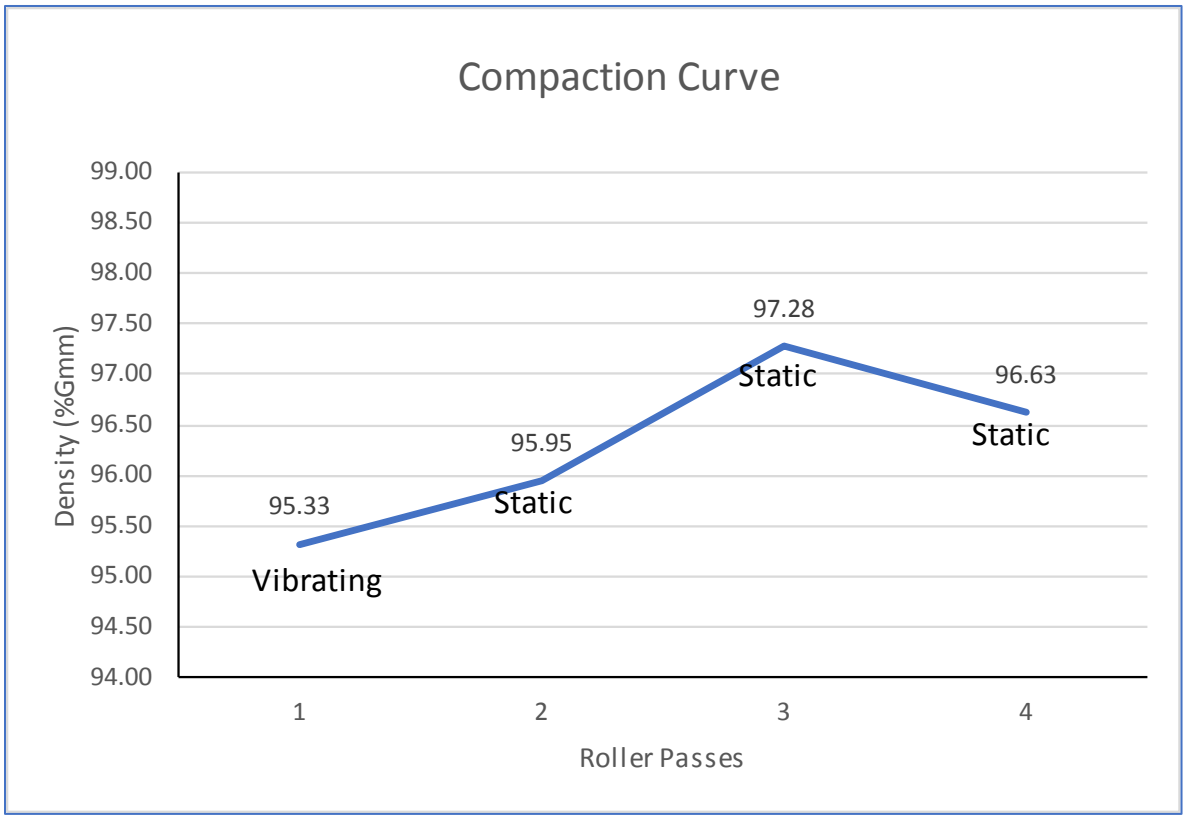


Figure 96. Compaction Curve from the Trial Section on 7/6/2017 (Project No. 11 - J1S3028, RT 69).

A summary of IR results is shown in Table 32, Figure 97, and Figure 98. The temperature segregation is generally in the "No segregation" and "Moderate Segregation" categories with limited severe temperature segregation.

Table 32: Summary of IR Results (Project No. 11 - J1S3028, RT 69)

Day	*Date*	*MOBA PPM*						*Veta**					
		Low		*Moderate*		*Severe*		*Low*		*Moderate*		*Severe*	
		#	*%*	*#*	*%*	*#*	*%*	*#*	*%*	*#*	*%*	*#*	*%*
1	6/30/2017	8	*36*	13	*59*	1	*5*	26	*46*	27	*48*	3	*5*
2	7/1/2017	47	*52*	38	*42*	5	*6*	45	*51*	33	*37*	11	*12*
3	7/5/2017	74	*65*	34	*30*	6	*5*	67	*61*	40	*36*	3	*3*
4	7/6/2017	72	*58*	42	*34*	10	*8*	71	*65*	35	*32*	4	*4*
5	7/7/2017	56	*64*	24	*27*	8	*9*	54	*62*	22	*25*	11	*13*
Notes:	*Veta results are for information only.												

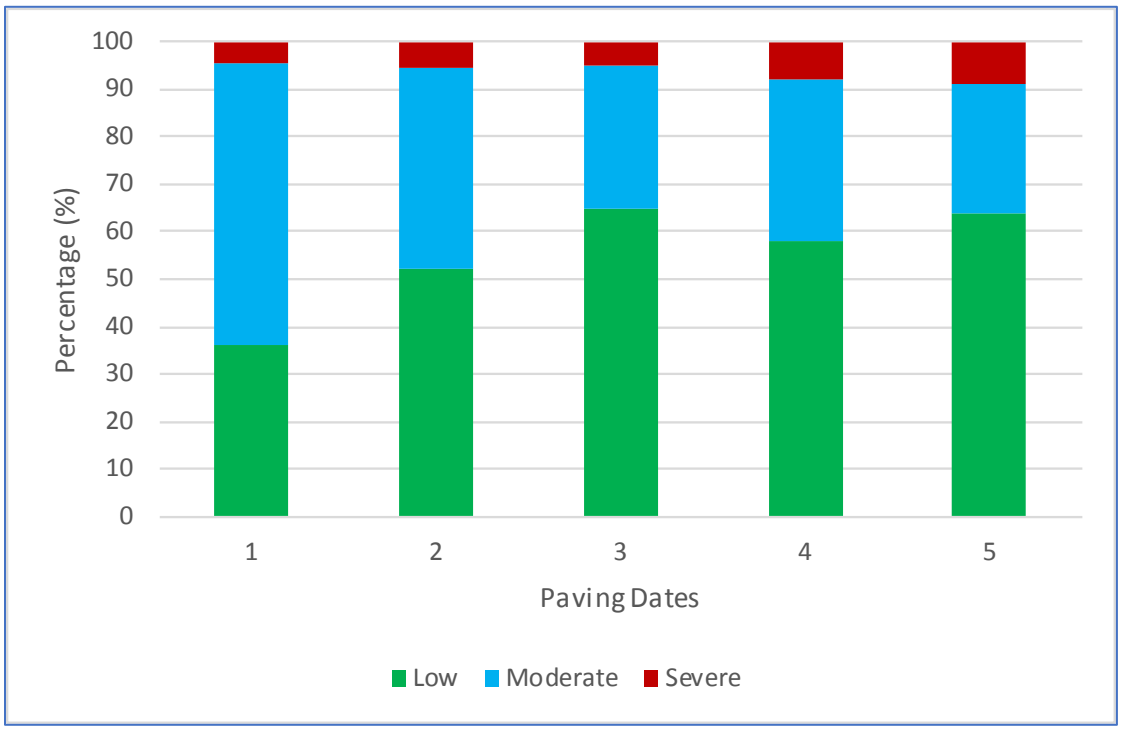


Figure 97: Summary of MOBA PPM Temperature Segregation Report (Project No. 11 - J1S3028, RT 69).

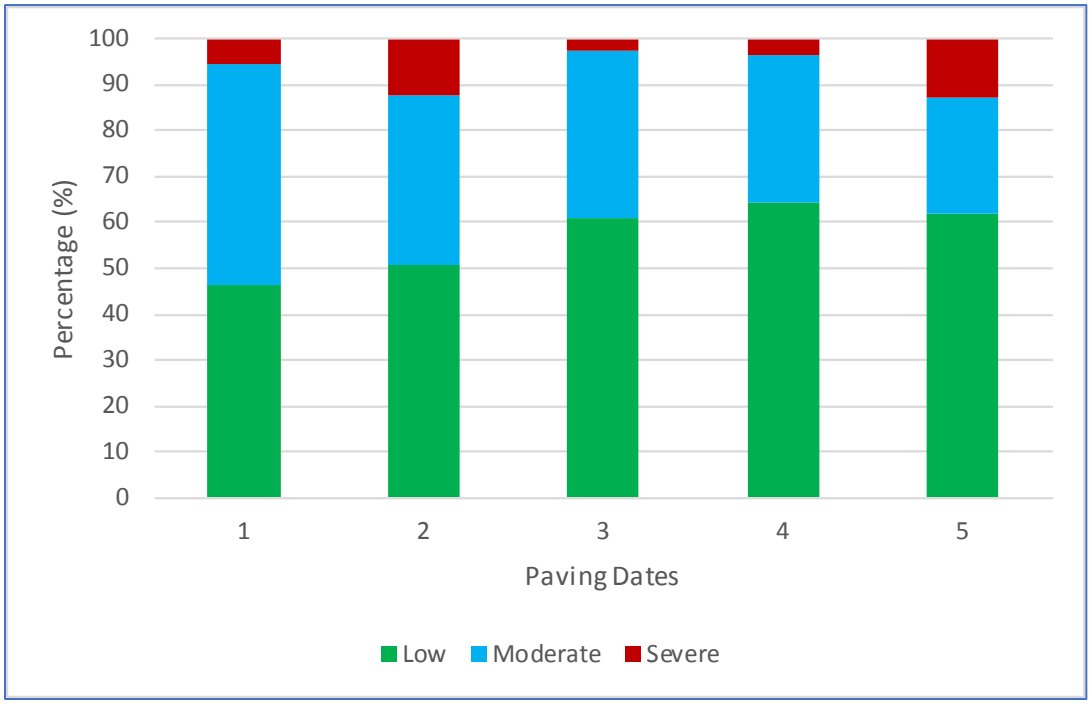


Figure 98: Summary of Veta Temperature Segregation Report (Project No. 11 - J1S3028, RT 69).

Table 33 and Figure 99 provide a summary of the roller coverage results. The roller coverages were excellent but fell on the last two days.

Table 33: Summary of IC Results (Project No. 11 - J1S3028, RT 69)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	6/30/2017	98	Passed	*	NA	*	Failed
2	7/1/2017	99	Passed	*	NA	*	Failed
3	7/5/2017	99	Passed	*	NA	*	Failed
4	7/6/2017	60	Failed	*	NA	34	Failed
5	7/7/2017	61	Failed	*	NA	34	Failed

Notes: * Insufficient data.

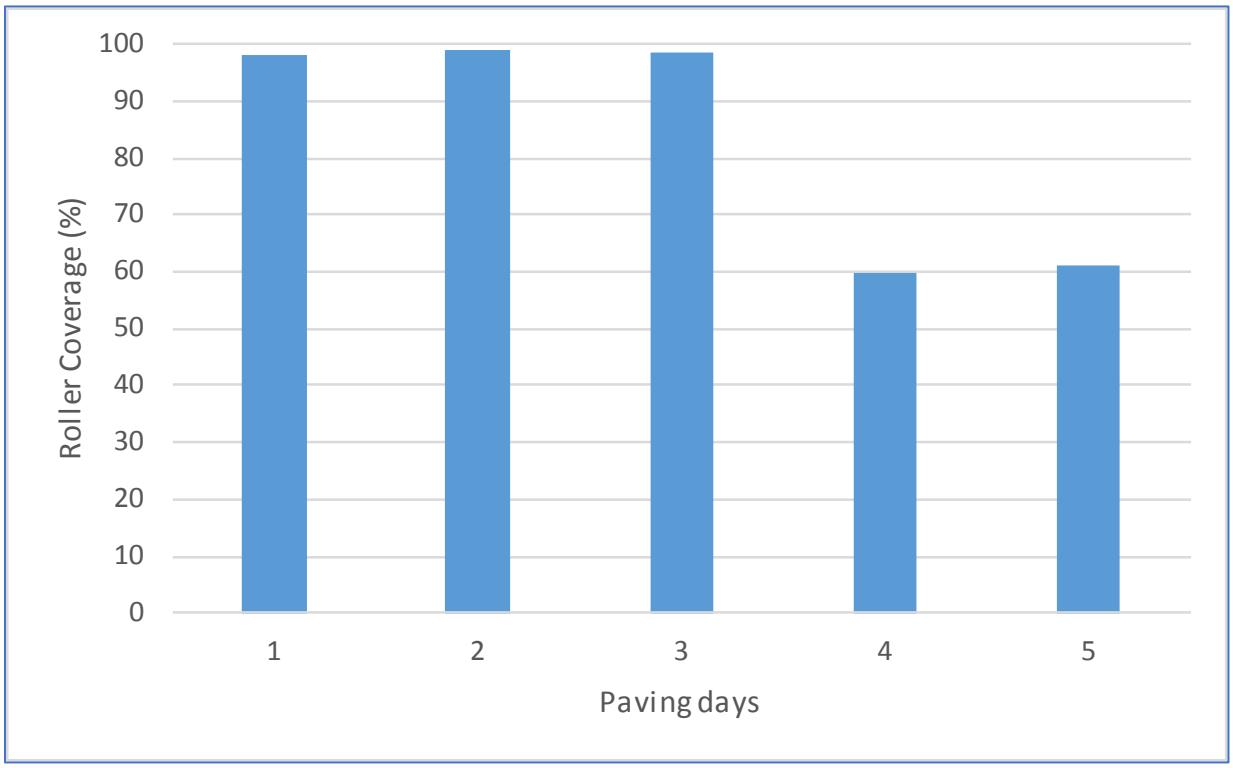


Figure 99: Summary of Roller Coverage Report (J1S3028, RT69).

Project No. 12 - J5P3170, RT 5

Trial Section (9/8/2017)
Optimum Rolling Pattern: The compaction curve is shown in Figure 100. However, the final rolling pattern for the breakdown IC rollers were determined to be six static passes for the breakdown rollers in echelon.

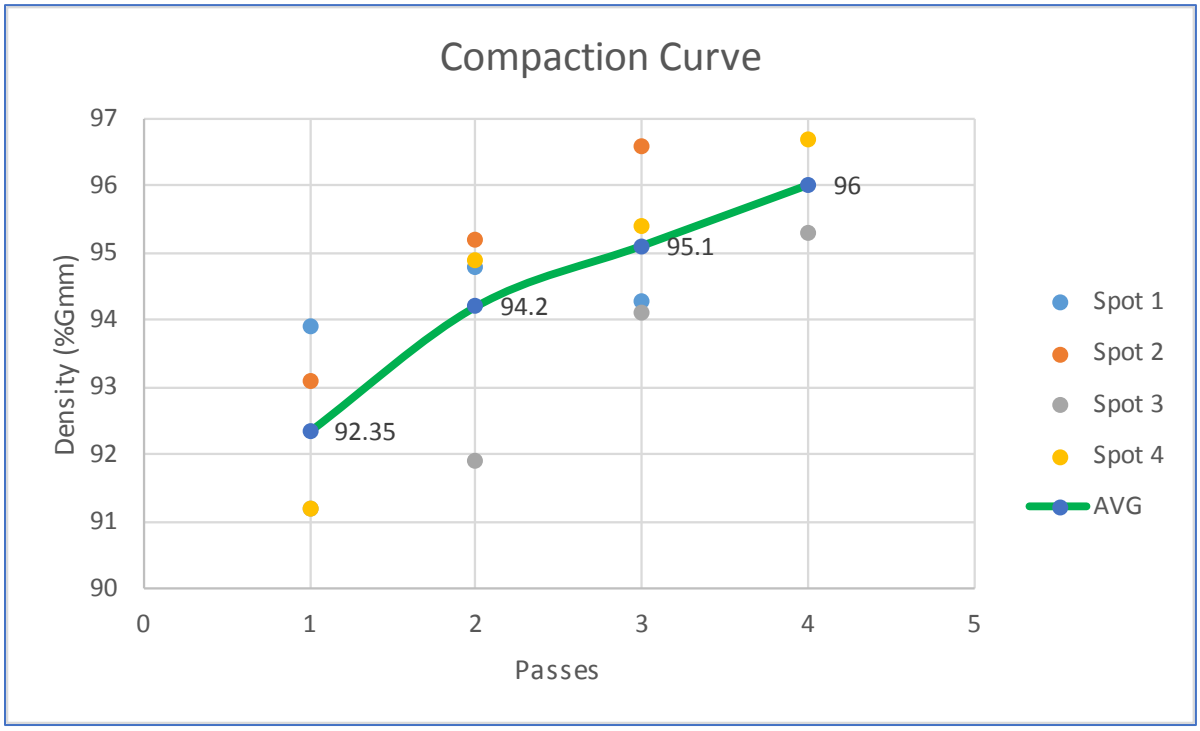


Figure 100: Density Compaction Curve from the Trial Section on 9/8/2017 (Project No. 12 - J5P3170, RT 5).

A summary of IR results is shown in Table 34, Figure 101, and Figure 102. There was severe temperature segregation throughout all paving days.

Table 34: Summary of IR Results (Project No. 12 - J5P3170, RT 5)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	9/8/2017	0	*0*	13	*14*	81	*86*	0	*0*	11	*12*	81	*88*
2	9/9/2017	3	*3*	17	*18*	74	*79*	2	*2*	19	*20*	72	*77*
3	9/11/2017	0	*0*	37	*21*	137	*79*	4	*2*	34	*21*	126	*77*
4	9/12/2017	1	*1*	27	*17*	127	*82*	1	*1*	29	*19*	123	*80*
5	9/13/2017	1	*1*	41	*26*	116	*73*	4	*2*	48	*30*	110	*68*
6	9/14/2017	0	*0*	54	*31*	121	*69*	6	*3*	52	*30*	118	*67*
7	9/15/2017	0	*0*	53	*40*	80	*60*	6	*4*	68	*46*	75	*50*
8	9/16/2017	0	*0*	48	*35*	88	*65*	1	*1*	58	*39*	91	*61*
9	9/18/2017	0	*0*	24	*32*	52	*68*	3	*4*	28	*35*	49	*61*
10 (NB)	9/19/2017	0	*0*	4	*14*	24	*86*	0	*0*	3	*11*	25	*89*
10 (SB)	9/19/2017	4	*4*	30	*26*	80	*70*	4	*3*	39	*34*	73	*63*
	Totals	9		348		980		31		389		943	
Notes:	*. Veta results are for information only.												

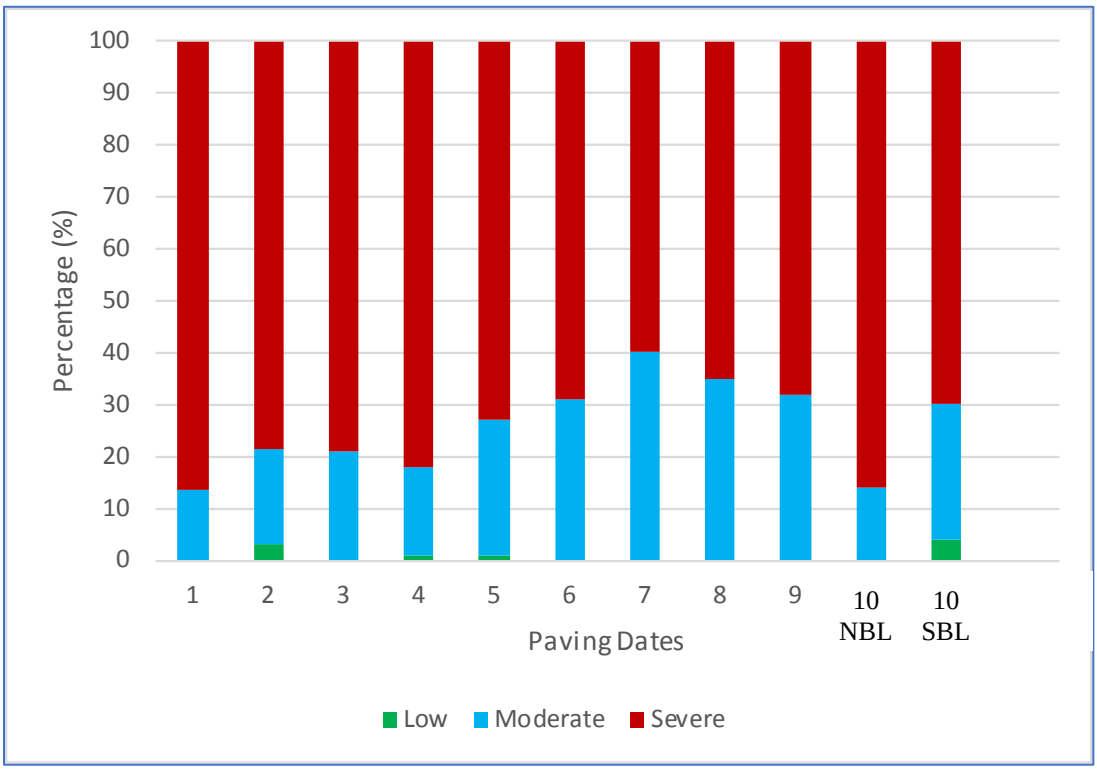


Figure 101: Summary of MOBA PPM Temperature Segregation Report (Project No. 12 - J5P3170, RT 5).

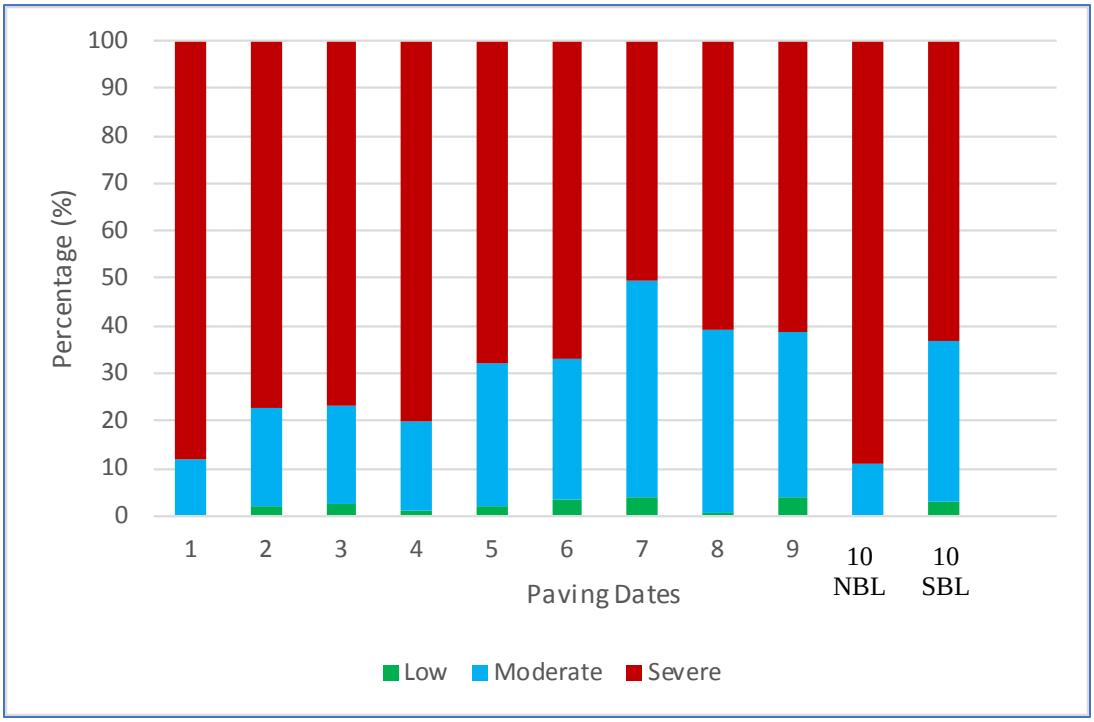


Figure 102: Summary of Veta Temperature Segregation Report (Project No. 12 - J5P3170, RT 5).

Table 35 and Figure 103 provide a summary of the roller coverage results. The roller coverage results were mostly moderate with no apparent trends.

Table 35: Summary of IC Results (Project No. 12 - J5P3170, RT 5).

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	9/8/2017	86.5	Moderate	NA	NA	NA	NA
2	9/9/2017	94.5	Passed	NA	NA	NA	NA
3	9/11/2017	85.81	Moderate	NA	NA	NA	NA
4	9/12/2017	86.55	Moderate	NA	NA	NA	NA
5	9/13/2017	85.81	Moderate	NA	NA	NA	NA
6	9/14/2017	85.92	Moderate	NA	NA	NA	NA
7	9/15/2017	74.81	Moderate	NA	NA	NA	NA
8	9/16/2017	86.39	Moderate	NA	NA	NA	NA
9	9/18/2017	86.06	Moderate	NA	NA	NA	NA
10	9/19/2017 (NBL)	97.41	Passed	NA	NA	NA	NA
10	9/19/2017 (SBL)	86.76	Moderate	NA	NA	NA	NA
Notes:	Target passes coverage for breakdown only. Due to use of only static passes, no target ICMV coverage nor temperature for vibratory passes are analyzed.						

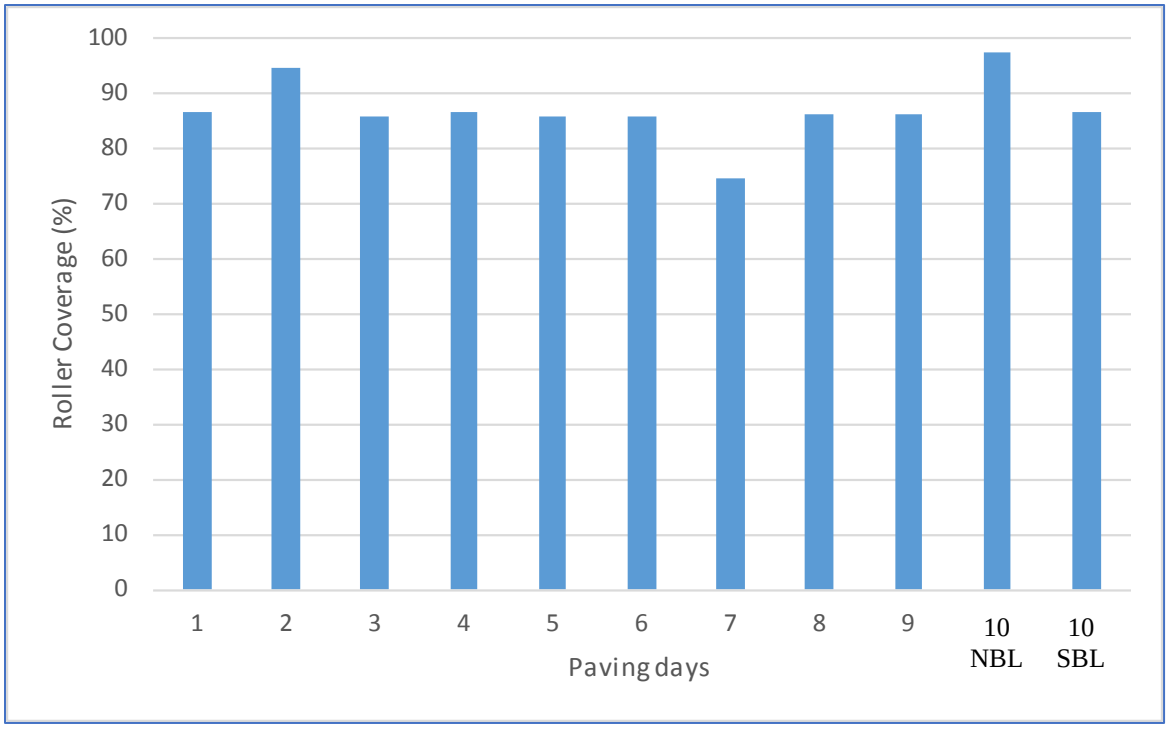


Figure 103: Summary of Roller Coverage Report (Project No. 12 - J5P3170, RT 5).

Project No. 13 - J9P3296, RT 17

Trial Section (7/5/2017)
Optimum Rolling Pattern: The compaction curve is shown in Figure 104. Even though the compaction curve was established, the aggregates in the core appeared to be crushed (Figure 105), likely due to over compaction. Therefore, it was determined by the RE and the contractor that the rolling pattern for the breakdown IC roller is three static passes followed by a finishing roller. Since no vibratory passes were used, the ICMV (EDV in this case) is not collected nor analyzed.

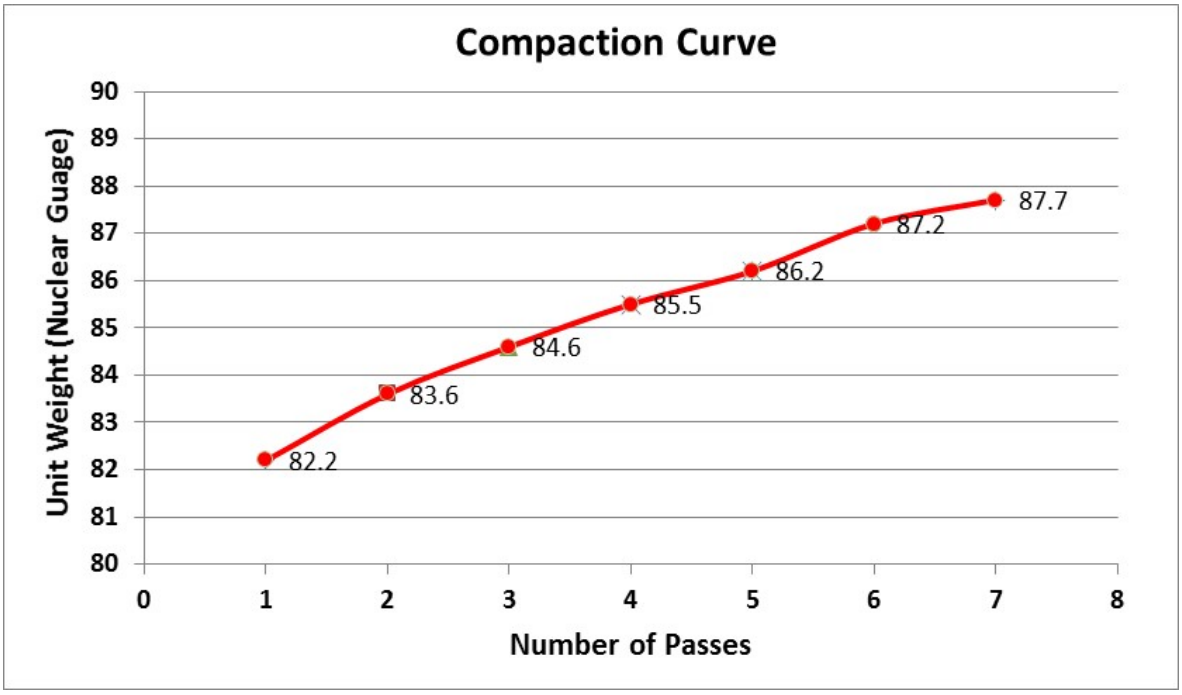


Figure 104: Compaction Curve from the Trial Section on 5/7/2017 (Project No. 13 - J9P3296, RT 17).

Even though the compaction curve was established, the aggregates in the core appeared to be crushed (Figure 105), likely due to over compaction.

Figure 105: Core Sample from the Trial Section on 5/7/2017 (Project No. 13 - J9P3296, RT 17).

A summary of IR results is shown in Table 36, Figure 106, and Figure 107. Note that due to paving close to structures at nighttime, the contractor elected not to use IR for 7/21/2017, and therefore there are no IR data for that date. Overall, there was severe temperature segregation throughout all paving days.

Table 36: Summary of IR Results (Project No. 13 - J9P3296, RT 17)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	7/5/2017	0	0	1	14	6	86	0	0	0	0	7	100
2	7/7/2017	0	0	10	17	50	83	4	4	20	21	71	75
3	7/8/2017	0	0	15	19	62	81	1	1	39	30	91	69
4	7/10/2017	2	2	39	31	85	67	3	3	32	28	81	70
5	7/11/2017	0	0	14	14	86	86	10	6	48	27	119	67
6	7/12/2017	14	9	44	28	99	63	22	14	37	24	95	62
7	7/17/2017	0	0	11	17	54	83	20	14	50	34	76	52
8	7/21/2017	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	7/26/2017	16	10	38	24	105	66	11	7	48	30	103	64
10	7/31/2017	12	7	53	30	113	63	13	7	52	29	116	64
11	8/1/2017	14	9	61	39	81	52	16	10	66	41	78	49
12	8/4/2017	6	4	60	37	98	60	8	5	57	38	87	57
13	8/7/2017	9	5	82	45	92	50	8	5	67	42	83	53
14	8/8/2017	4	2	87	49	87	49	8	5	68	45	76	50
15	8/12/2017	36	20	95	54	46	26	39	20	103	52	58	29
16	8/18/2017	26	16	100	60	41	25	28	16	94	55	48	28

Notes: *. Veta results are for information only.
The IR data for 7/21 were not collected since the contractor elected not to use it close to structures at night time.

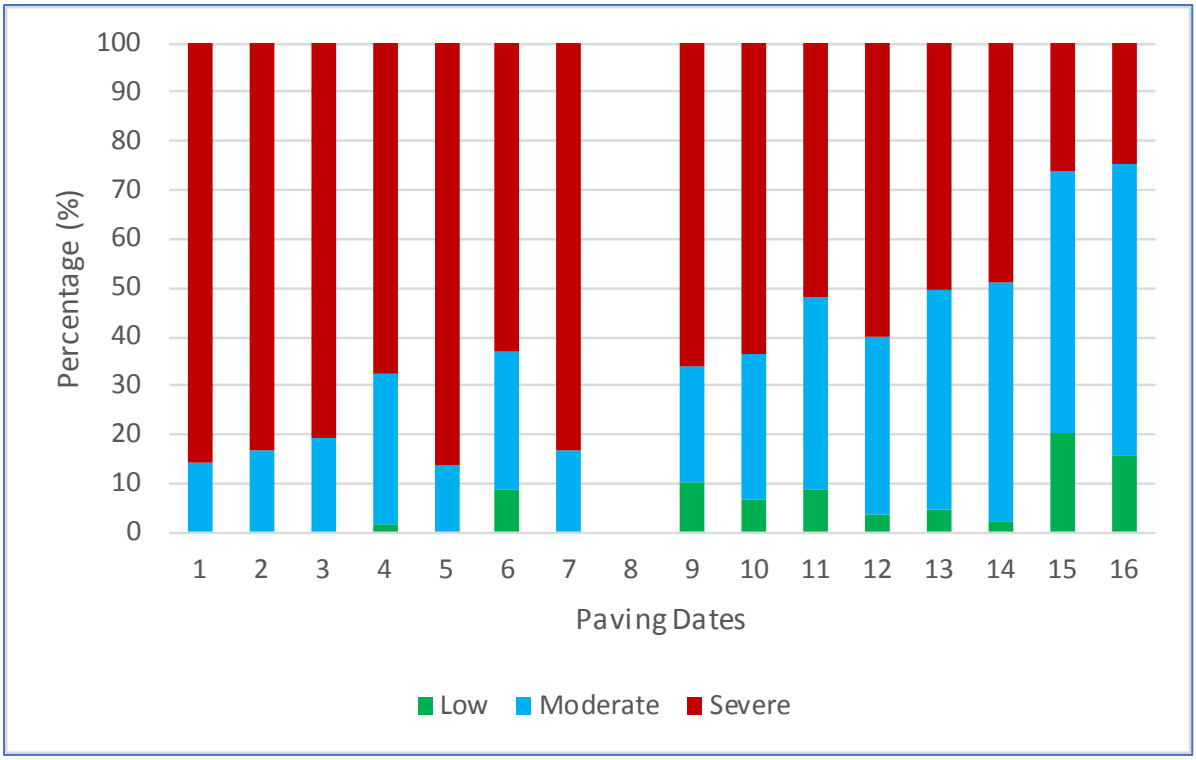


Figure 106: Summary of MOBA PPM Temperature Segregation Report (Project No. 13 - J9P3296, RT 17).

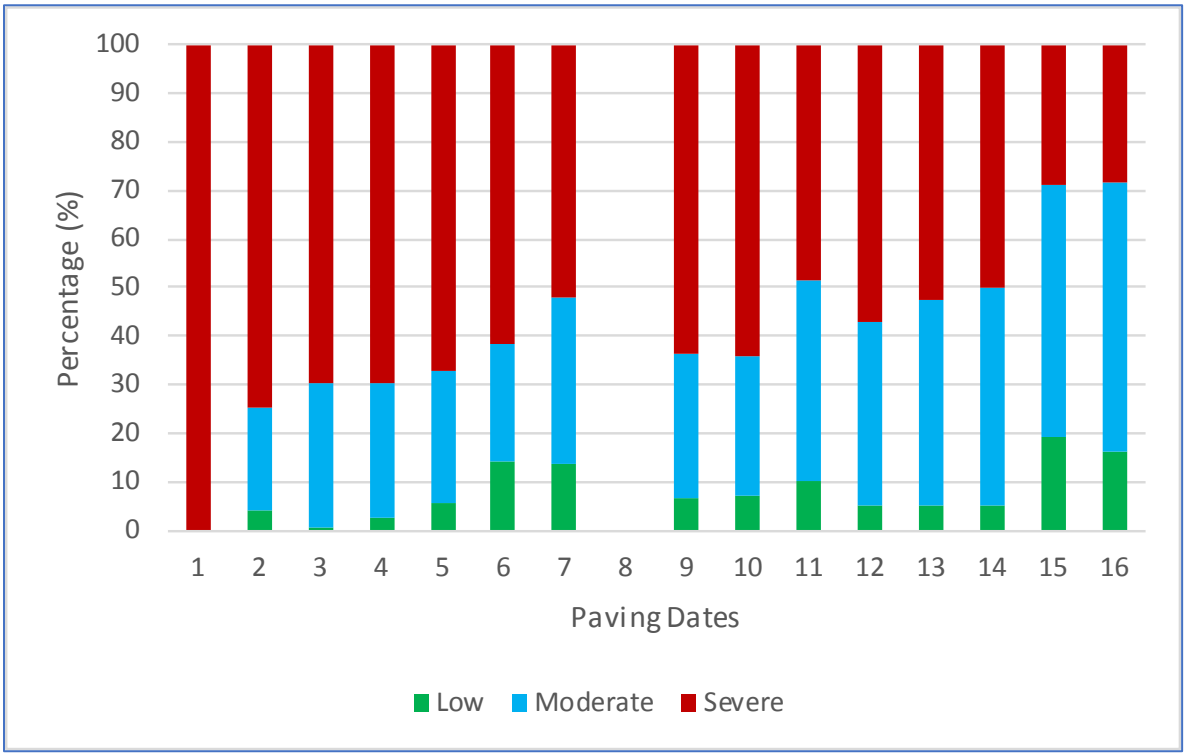


Figure 107: Summary of Veta Temperature Segregation Report (Project No. 13 - J9P3296, RT 17).

Table 37 and Figure 108 provide a summary of the roller coverage results. The roller coverage results were excellent after improving from Day 1.

Table 37: Summary of IC Results (Project No. 13 - J9P3296, RT 17)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	7/5/2017	65.8	Failed	NA	NA	NA	NA
2	7/7/2017	99.1	Passed	NA	NA	NA	NA
3	7/8/2017	99.6	Passed	NA	NA	NA	NA
4	7/10/2017	98.5	Passed	NA	NA	NA	NA
5	7/11/2017	98.7	Passed	NA	NA	NA	NA
6	7/12/2017	98.9	Passed	NA	NA	NA	NA
7	7/17/2017	98.9	Passed	NA	NA	NA	NA
8	7/21/2017	97.3	Passed	NA	NA	NA	NA
9	7/26/2017	98.1	Passed	NA	NA	NA	NA
10	7/31/2017	98.2	Passed	NA	NA	NA	NA
11	8/1/2017	97.3	Passed	NA	NA	NA	NA
12	8/2/2017	98.7	Passed	NA	NA	NA	NA
13	8/7/2017	99	Passed	NA	NA	NA	NA
14	8/8/2017	99.2	Passed	NA	NA	NA	NA
15	8/12/2017	98.8	Passed	NA	NA	NA	NA
16	8/18/2017	99.4	Passed	NA	NA	NA	NA

Notes:

The paving on 7/5 is short with only 1000 ft.
No sufficient vibratory passes were used.
Target ICMV and temperarture requirements were not analyzed.

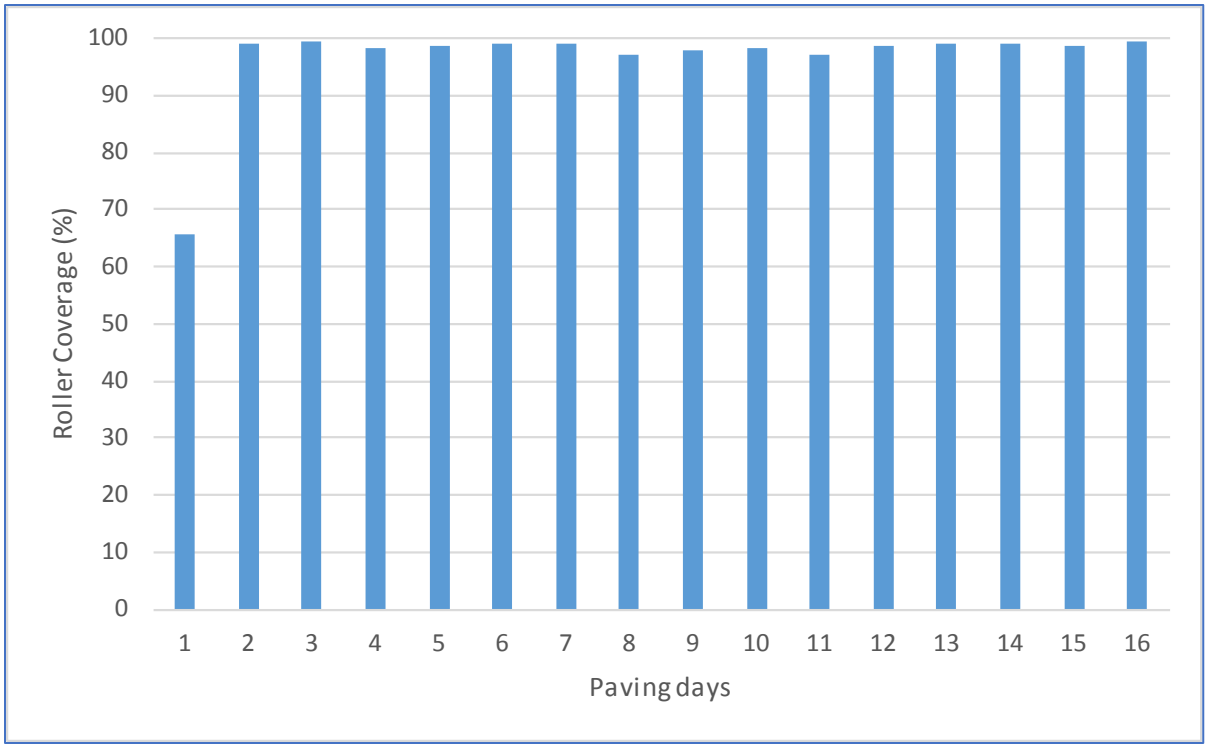


Figure 108: Summary of Roller Coverage Report (Project No. 13 - J9P3296, RT 17).

Comparison of IC-IR 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 109 shows a comparison of overall average temperature segregation by project.

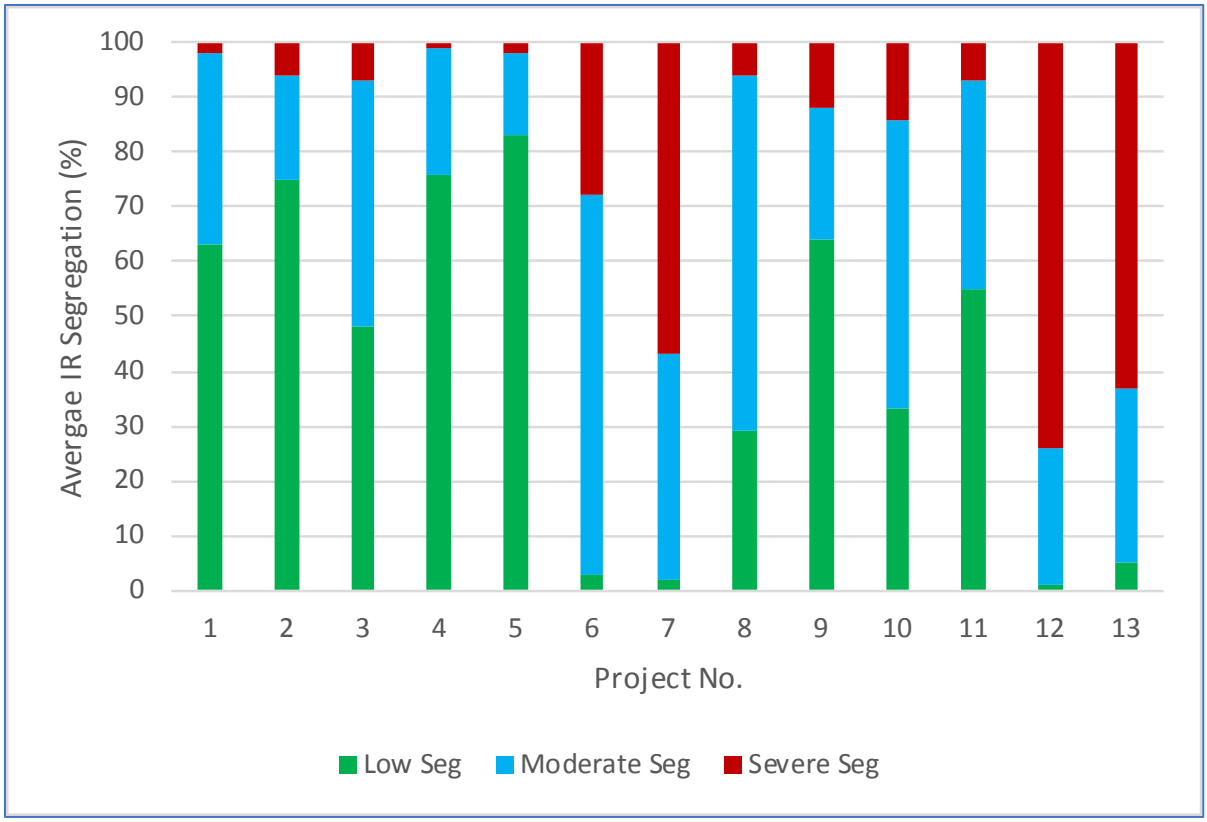


Figure 109: Comparison of IR Segregation for all projects.

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 110 shows a comparison of overall temperature segregation by contractor.

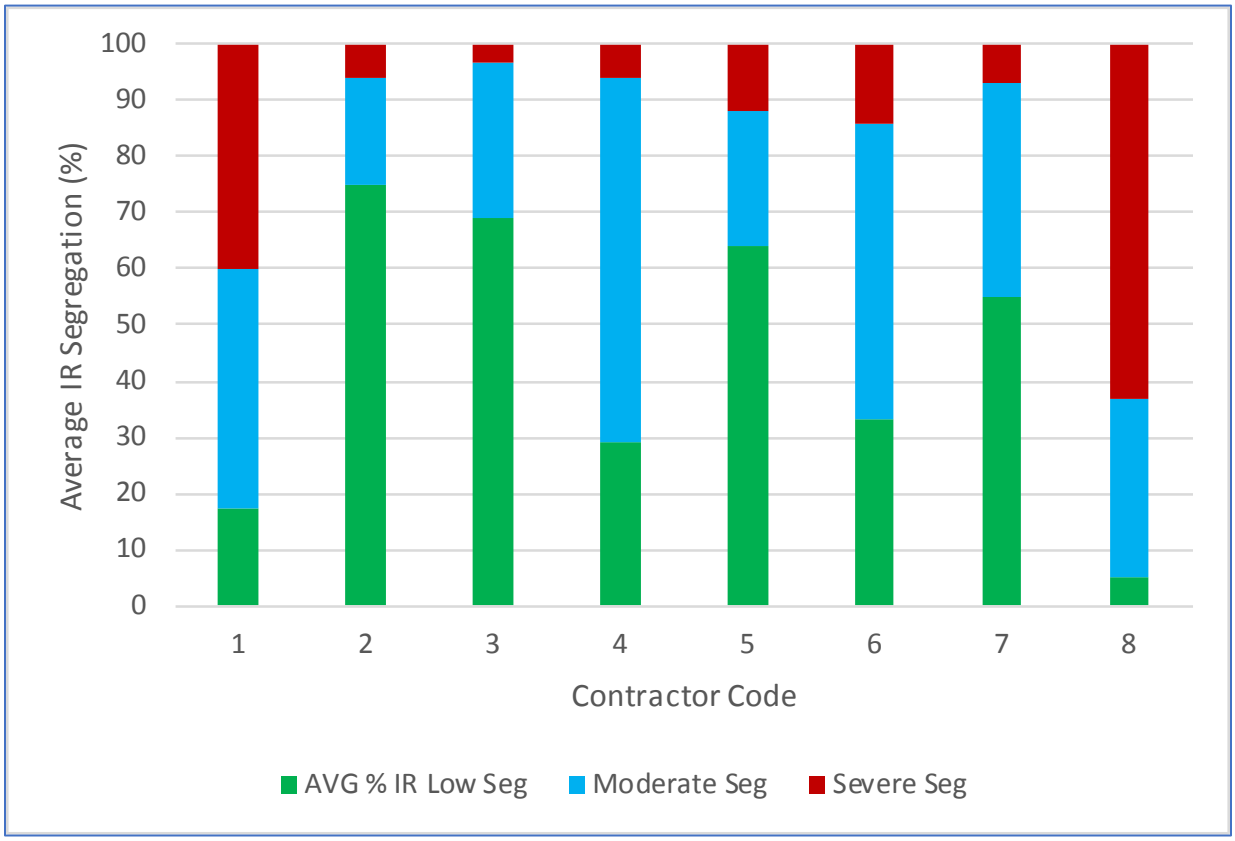


Figure 110: Comparison of IR Segregation for projects by coded contractors.

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 111 provides an overall summary of IC coverage for all projects.

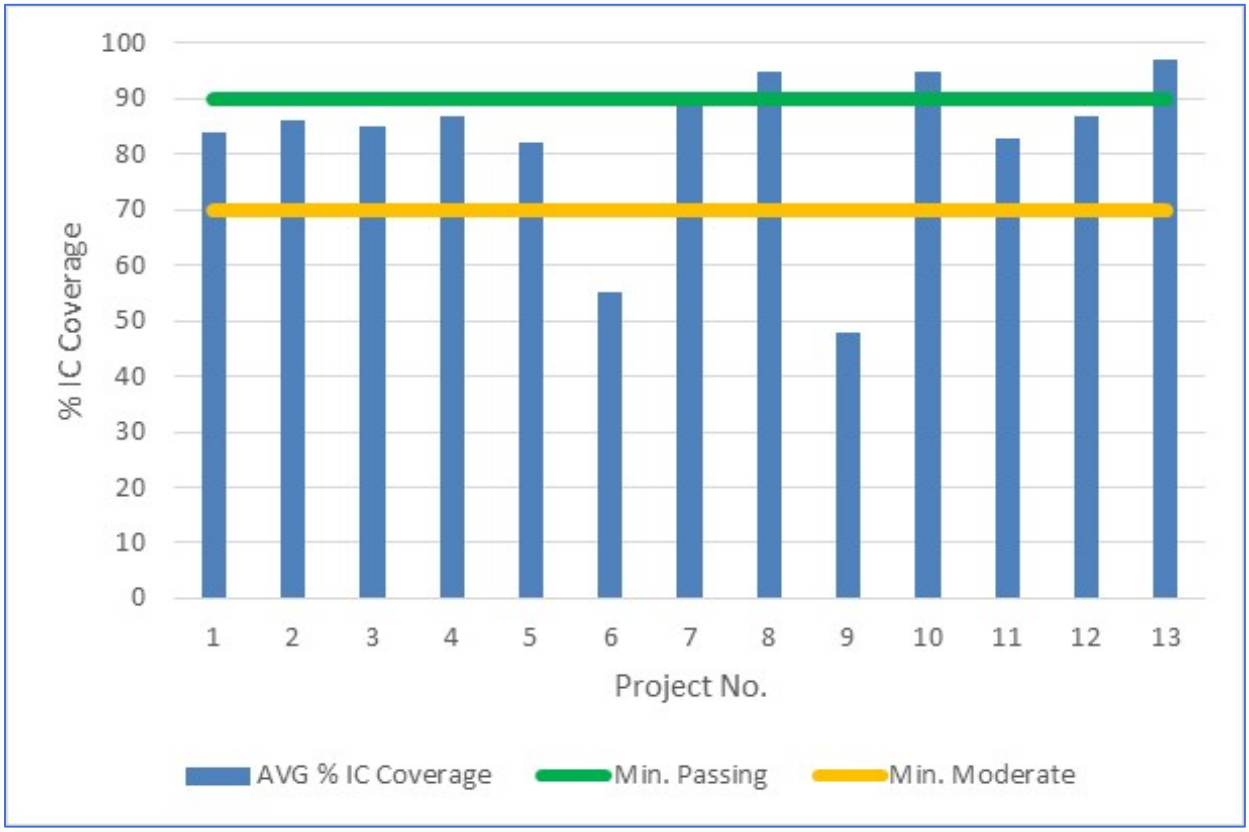


Figure 111: Comparison of IC Coverage for all projects.

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).

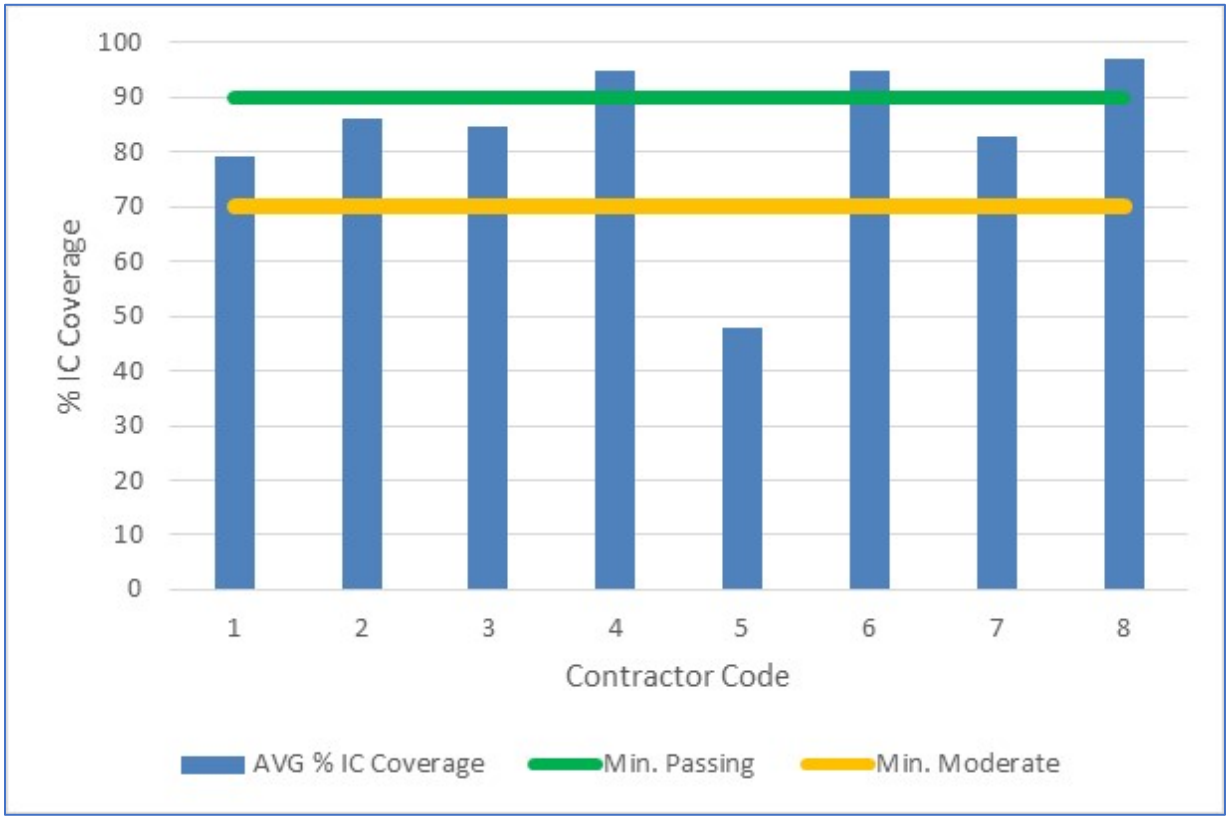


Figure 112: Comparison of IC Coverage for projects by coded contractors.

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 incorrect 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 38 Summarizes the IC-IR Data Completion for the 13 field projects.

Table 38. 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
13	J9P3296	SE	Texas	17	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 39 Summarizes the completion of IC-IR check lists and forms for the 13 field projects.

Table 39. 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

IC-IR Specification Reviews

The marked-up versions of MoDOT IC and IR specifications were submitted to MoDOT. The following are the highlights of recommended modifications and comments.

IR Specification

Equipment Requirements

- The current equipment and software requirement is vendor-specific.
- It is recommended to make it generic to allow various thermal profile technologies: infrared thermal scanners and thermal cameras.

Training Requirements

- The current 2-4 hours training is adequate for so-called just-in-time training.
- The requirement for trained personnel being onsite is adequate.

Data and Analysis Requirements

- The current requirement for data and analysis software is vendor-specific.
- It is recommended to make the data requirements generic to allow multiple vendors available.
- It is recommended to make the data analysis requirements to use the standard software, Veta, to resolve several issues: not tied to a specific vendor, avoiding pit falls of uncalibrated DMIs, avoid data management (e.g., data overwrite/missing due to data date stamp errors) and analysis (e.g., incorrect sublots) errors from vendors' software, taking advantage of the thermal cold edge and streak filters in Veta, etc.

Acceptance Requirements

- The current requirement for temperature segregation is consistent with AASHTO PP80-17.
- The AASHTO PP80-17 temperature segregation may not differentiate between moderate and severe temperature segregation.
- It is recommended to consider the Thermal Segregation Index developed by MnDOT in the future.
- It is recommended to consider increasing the unit cost for incentive and disincentive pay adjustment to motivate full utilization of the IR technologies.

IC Specification

Equipment Requirements

- The current IC equipment and software requirement is adequate.
- The current GPS equipment requirement is adequate.
- The IC quality control plan is adequate. It is recommended that plan be submitted to the RE for approval.

Training Requirements

- The current IC training requirement and certification is adequate and consistent with AASHTO PP81-17.
- It is recommended to elaborate the certification requirements: who administers such certification and the frequency per year.

Field Operation Requirements

- The trial section requirements is adequate to allow flexibility.
- The GPS boundary data measurement requirements are adequate.
- It is recommended to include a step-by-step procedure to define "target ICMV" more clearly. For example, conduct nuclear density gauge measurements along with GPS measurements in the trial section. Then, perform correlation analysis between nuclear density gauge measurements and ICMV. If the R^2 of the linear regression is greater than 0.5, the target ICMV can be determined based on the correlation equation and the required passing value of density.

Data and Analysis Requirements

- Regarding IC data, it is recommended to rename "formatted raw data" to "raw data". Due to the requirement of using Veta project file, all IC data will have to compatible with Veta anyway.
- It is recommended to define report elements that consist of: paving record forms (including GPS verification records, target rolling patterns, roller settings, paving start/end mile posts, quantity of asphalt), trial section data (if any), raw IC data, GPS boundary data, GPS core location data and core density data (if any), and Veta project file.

Acceptance Requirements

- The segment classification is adequate to consider data loss. However, it is recommended to include an exception for inadequate GPS coverage, which needs to be addressed during project selection.
- The minimum temperature requirements for vibratory passes should be re-examined since all 2017 projects have failed to meet this requirement.
- It is recommended to consider the Caltrans IC temperature requirement that accounts for IR temperature measurement variability on wet/dry asphalt surfaces (e.g., 20F deduction from the temperature requirements) and instructions for handling non-compliance.

- It is recommended to increase the unit cost for the incentive and disincentive.

Conclusions and Recommendations

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 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 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 a 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.