MoDOT Publication No. TBA

MoDOT Projects No. TR201902

Consultant Support for IC-PMTPS Projects

2018 Final Report

Submitted to

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

December 2018

By

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

1. Report No. TBA	2. Government Accession No.	3 Recipient Catalog No.	
4. Title and Subtitle Consultant Support for IC-PMTPS Projects 2018 Final Report		5. Report Date December 2018 6. Performing Organization Code	
7. Author(s) George Chang, Kiran Mohanraj, and David Merritt (Transtec Group) Victor (Lee) Gallivan (Gallivan Consulting, Inc.)		8. Performing Organization Report No.	
9. Performing Organization Name and Address The Transtec Group, Inc. 6111 Balcones Drive Austin TX 78731		10. Work Unit No. (TRAIS) 11. Contract or Grant No. MoDOT project #TR201902	
12. Sponsoring Agency Name and Address Missouri Department of Transportation (SPR) 1617 Missouri Blvd, PO Box 270 Jefferson City, MO 65102-0270		13. Type of Report and Period Covered 2018 Final report 14. Sponsoring Agency Code	
15. Supplementary Notes Contracting Officer's Representative: Bill Stone Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. MoDOT research reports are available in the Innovation Library at http://www.modot.org/services/or/byDate.htm.			
16. Abstract Due to the success of the MoDOT 2017 Intelligent Compaction (IC) and Infrared Scanning (IR) projects that demonstrate the QC improvements on 13 field projects, MoDOT has established a plan that includes further IC and Paver-mounted Thermal Profile Systems (PMTPS) projects in 2018-2019 and full implementation in 2021. To ensure the continuous success of the MoDOT IC-PMTPS projects in 2018 and beyond, MoDOT has procured Consulting Support for the selected IC-PMTPS projects in 2018-2019 (i.e., Phase II). This document details the results from the 2018 IC-PMTPS Projects and recommendations for the 2019 projects.			
17. Key words Compaction; Infrared analysis; Paving. Intelligent compaction, thermal profiles, roller, paver, asphalt, overlay, quality control.		18. Distribution Statement No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified.	20. Security Classif. (of this page) Unclassified.	21. No. of Pages 144	22. Price

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)

Table of Contents

LIST OF FIGURES

LIST OF TABLES

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

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

Chapter 1 - Introduction

Project Scope

Due to the success of the MoDOT 2017 Intelligent Compaction (IC) and Infrared Scanning (IR) projects that demonstrate the QC improvements on 13 field projects, MoDOT has established a plan that includes further IC and Paver-mounted Thermal Profile Systems (PMTPS) projects in 2018-2019 and full implementation in 2021. To ensure the continuous success of the MoDOT IC-PMTPS projects in 2018 and beyond, MoDOT has procured Consulting Support for the selected IC-PMTPS projects in 2018-2019 (i.e., Phase II).

The following details the Work Plan and Project Team for the Consulting Support for 2018-2019 IC-PMTPS Projects.

This report provides a summary results of the 2018 IC-PMTPS projects and recommendations for the upcoming 2019 IC-PMTPS projects.

Structure of this Report

This report includes the following chapters:

1. Introduction (this Chapter)
2. Work Plan and Activities
3. Pilot Innovation Technologies
4. Field Project Data Analysis and Results
5. Conclusions and Recommendations

Chapter 2 – Work Plan and Activities

The work plan for this project includes four (4) main tasks to be performed from July 1st, 2018 to December 31, 2019, for 18 months (NB: Project end date on January 31, 2020).

- Task 1 – Kick Off Meeting
- Task 2 – IC-PMTPS Training Courses
- Task 3 – IC-PMTPS Project Supports
- Task 4 – Final Report
- Task 5 – IC-PMTPS Feedback Meetings

The summary of the timeline of the tasks is presented in the following table.

Table 1. Summary of the timeline of the tasks

	2018						2019											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Months from NTP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Task 1: Kick Off Meeting																		
Task 2: Training Courses																		
Task 3: IC-IR Project Support																		
Task 4: IC-IR Fial Report																		
Task 5: IC-IR Feedback Meetings						X												X
Quarterly Reports			X			X			X			X			X			X

Training, projects and schedule will be determined by MoDOT.

The followings are detailed descriptions and deliverables for each task.

Task 1 – Kick Off Meeting

The consultant project team (Consultant) shall conduct a kick-off meeting with MoDOT. The purpose is to review the Work Plan and determine any updates or modifications, if needed.

Deliverables:

- The Consultant shall deliver the meeting minutes and updated work plan within 2 weeks from Notice to Proceed (NTP).

The kick meeting was conducted on June 29, 2018. The project schedule and training workshop plan were reviewed. See the meeting minutes for details.

Task 2 – IC-PMTPS Training Courses

Task 2-1: Update IC-PMTPS Protocol and Training Materials

Under MoDOT's instructions, the Consultant shall update IC-PMTPS Protocol and training materials including but not limit to:

- The Quality assurance (QA) procedure for IR temperature sensor verification (was included in the current MoDOT PMTPS specification).
- Check list for IR field operation (same as in 2017)
- New features in Veta (including Quality Control (QC) Chart and alignment offset tool).

The IC-PMTPS workshop materials were updated based on the latest version of Veta 5.2.

Task 2-2: Conduct IC-PMTPS Training Workshops

Under MoDOT's instructions, the Consultant shall conduct one-day long lecturer-led IC-PMTPS training courses for key personnel involved with the selected IC-PMTPS projects. The key personnel include but not limit to: paving contractors' IC-PMTPS QC managers and technicians, MoDOT resident engineers (RE) and inspectors.
The IC-PMTPS training courses will be scheduled by MoDOT as close to the start of the paving for the selected IC-PMTPS projects. Depending on the training facilities, computers, and trainees' locations, the dates and locations will be designated by the MoDOT project manager to facilitate the delivery of the training courses.

Deliverables:

- The Consultant shall deliver the updated Protocol and related materials as well as IC-PMTPS training course materials within 2 months from NTP.
- The Consultant shall conduct one-day IC-PMTPS training courses for selected IC-PMTPS project personnel within 18 months from NTP.

One workshop was conducted on September 7, 2018 at the MoDOT Chillicothe office. The workshop participants include MoDOT staff and contractors from three different paving companies.

Task 3 – IC-PMTPS Project Supports

Under MoDOT's instructions, the Consultant shall provide technical support to the selected IC-PMTPS projects. The information about the candidate IC-PMTPS projects for the Project Support is under Project Description of Chapter 4.

The level of technical support for each selected IC-PMTPS project will be determined by MoDOT based on its specific needs with combination of the following elements:

1. Onsite Technical Support
2. Pilot Innovation Technologies
3. IC-PMTPS Data Management and Analysis
4. IC-PMTPS Reports

Task 3-1: Onsite Technical Support

Task 3-1 may be optional for a selected IC-PMTPS project. If elected by MoDOT, the Consultant shall provide onsite field supports for the selected project during the first week of its paving operation. The targeted projects are those whose contractor personnel and/or MoDOT RE/inspectors that have no prior field experiences with IC-PMTPS projects.
Each field support includes 2 to 3 days onsite support and 2 days of travels for the Consultant. The purpose of such onsite support is to ensure proper IC-PMTPS operations and data reviews for the first days of paving. In case of concurrent field projects, the Consultant shall provide separate personnel for each field site.

For each selected IC-PMTPS project for onsite technical support, the Consultant shall conduct a project briefing with MoDOT project manager/inspector and contractors right before the Day 1 paving operation. The project briefing shall cover the check list of MoDOT IC-PMTPS project management Protocol and address any IC-PMTPS equipment and data issues, if any. As needed, the Consultant shall conduct just-in-time training to contractor's and MoDOT personnel including IC-PMTPS system/operation and Veta analysis.

As of in 2018, the research team has provided onsite field technical support for the Project No. 2 (RT 139, Putnam), 6 (RT CC, Christian), and 8 (RT 160, Greene).

Task 3-2: Pilot Innovation Technologies

Task 3-2 may be optional for a selected project. If elected by MoDOT, MoDOT will select IC-PMTPS projects to pilot innovation technologies to advance future MoDOT IC-PMTPS specifications. The consideration will include the availability of innovative technologies and prototypes as well as their compatibility with Veta. See later sections for the instruction of those innovative technologies.

Once elected by MoDOT, the Consultant will then coordinate with innovation technologies' vendors and MoDOT staff to include the selected innovation technologies in the selected MoDOT projects. It is anticipated that the prototype those innovation technologies will be provided by vendors at no cost to MoDOT, while MoDOT provides only the cost for the Consultant's effort. For piloting purpose, the consideration may also include non-IC-PMTPS projects that exempt from MoDOT IC-PMTPS requirements. The pilot data and results will be for information only.

As affected by the weather delays and availability of the prototypes, the field demonstration of the above innovative technologies is postponed from 2018 to 2019.

Task 3-3: IC-PMTPS Data Management and Analysis

Task 3-3 shall be required for all selected IC-PMTPS projects. The Consultant shall provide technical support for IC-PMTPS data management to contractors including IC-PMTPS data file naming convention, data submission to MoDOT SharePoint, and, etc. The Consultant shall also conduct IC-PMTPS data analysis and assist contractors to conduct their own data analysis. The

data analysis will also include those IC-PMTPS projects that are conducted prior to the NTP of this Consulting Support contract (e.g., US 71).

The analysis will include data observations, statistics analysis and correlation analysis to identify any IC-PMTPS equipment and system issues and to evaluate the quality levels of contractors' field operations.

As of in 2018, the research team has conducted data QA for all nine (9) IC-PMTPS projects. See later sections for further details.

Task 3-4: IC-PMTPS Reports

Task 3-4 shall be required for all selected IC-PMTPS projects. The Consultant shall produce a concise report for each selected project. The report will also include the IC-PMTPS projects that are conducted prior to the NTP of this Consulting support contract (e.g., US 71).

The report shall stress on the benefits and lessons learn on IC-PMTPS technologies from each project. If innovation technologies included, the results will be reviewed to provide recommendation for enhancing future MoDOT IC-PMTPS specification.

Deliverables:

- The Consultant shall produce individual reports for the selected IC-PMTPS projects within 18 months from NTP.

As of in 2018, the research team has produced IC-PMTPS Data Reviews documents for all nine (9) IC-PMTPS projects which the results are summarized in the later sections

Task 4 – IC-PMTPS Final Report

The Consultant shall complete a final report for all selected IC-PMTPS projects. The format is similar to the MoDOT 2017 IC-PMTPS project report.

Task 4-1: The Part I of the final report will include theIC-PMTPS projects completed in 2018.

Task 4-2: The Part II of the final report will include the IC-PMTPS projects completed in 2019.

Deliverables:

- The Consultant shall deliver the Part I of the draft final report within 4.5 months from NTP.
- The Consultant shall deliver the Part I of the final report within 6 months from NTP.
- The Consultant shall deliver the Part II of the final report within 16.5 months from NTP.
- The Consultant shall deliver the Part II of the final report within 18 months from NTP.

Due to the last 2018 field projects ends in November 2018, the draft 2018 final report will be submitted by the end of 2018 and finalized in January 2019.

Task 5 – IC-PMTPS Feedback Meetings

The Consultant shall also conduct IC-PMTPS project feedback meetings with all personnel involved in the 2018 and 2019 MoDOT IC-PMTPS projects. The purpose is to present lessons-learn from the projects completed in the current construction season and to discuss items for improvement and issues to be resolved for the next construction season.
Deliverables:

- The Consultant shall conduct the first IC-PMTPS project feedback meeting designated by MoDOT within 6 months from NTP.
- The Consultant shall conduct the second IC-PMTPS project feedback meeting designated by MoDOT within 18 months from NTP.

Due to the availability of the research team members and holiday schedule, the 2018 IC-PMTPS Feedback meeting will be postponed to January or February 2019.

Project Team

The project team is led by Dr. George K. Chang of Transtec Group as the principal investigator (PI). Dr. Chang has been the leader for FHWA National Intelligent Compaction (IC) implementation team since 2007. Dr. Chang is also the leader for the Veta development team for the Transportation Pooled Fund Study "TPF-5(334) Enhancement to the Intelligent Construction Data Management System (Veta) and Implementation ".

Mr. Kiran Mohanraj of the Transtec Group will serve as a Pavement Engineer (PE). Mr. Mohanraj has been a trainer for FHWA IC workshops and provides IC-PMTPS support.

Mr. Victor (Lee) Gallivan of Gallivan Consulting will serve as Sub-contractor (SCNT). Mr. Gallivan was formerly the FHWA project manager for the Transportation Pooled Fund Study on Intelligent Compaction.

Chapter 3 – Pilot Innovative Technologies

The candidate innovation technologies include those described in this chapter,

Vogele RoadScan thermal imaging system

Veta team has implemented the import feature for Vogele RoadScan data in Veta 5.2. It allows high precision GPS. The prototype may be available in 2019. A brief description of this innovative technology is as follows.

High-precision infrared camera with 100% measurement coverage

The heart of the RoadScan system is an infrared camera which scans the asphalt pavement behind the screed over the entire area. What sets the system apart is its unrivalled measuring accuracy. The VÖGELE system captures grids of 25 x 25cm-sized tiles at a measuring width of 10m. Each of these tiles contains up to 16 single measuring points which are then used to calculate a mean value. That allows the system to capture the newly paved surface with no gaps, and so no theoretical or computed values need to be added. The measurable temperature range of RoadScan lies between 0°C and 250°C with a tolerance of only ±2°C.

The purpose of RoadScan's other components is to capture the base temperature before paving (pyrometer), record precise positional data (high-precision GPS receiver) and document the wind strength and direction, ambient temperature, air pressure and humidity (weather station available as an option).

Integration into ErgoPlus 3

Just as one would expect of VÖGELE equipment, the RoadScan system is intuitive to operate and can easily be activated from the paver operator’s ErgoPlus 3 console. The user views the temperatures currently being recorded on the colour display, and these are clearly visualised using thermal images and in real time. The paver operator can program the colour scale to allow any deviation from the required temperature of the freshly paved asphalt to be quickly identified. That makes VÖGELE RoadScan an effective instrument for ensuring high paving quality – without unduly increasing the paving team's work load.

Encrypted recording of measurement data

The measurement data obtained using RoadScan is also stored in the paver operator's ErgoPlus 3 console. After paving, this data can be read off via an external data storage device. At the same time, VÖGELE has taken effective measures to protect the data via a specially designed memory stick which communicates with a VÖGELE interface on the paver operator's ErgoPlus 3 console; this in turn transfers the data in encrypted form. The data is then analysed in the office using the RoadScan Analysis web application, which presents the data in different types of diagrams and in a map view.

Integration into WITOS Paving

VÖGELE RoadScan can also be integrated into WITOS Paving. This innovative IT-based tool for the process optimization of asphalt job sites helps companies to plan more transparently and respond flexibly to interruptions in ongoing operations, significantly increasing overall cost efficiency.

Figure 1. Vogele RoadScan thermal imaging system

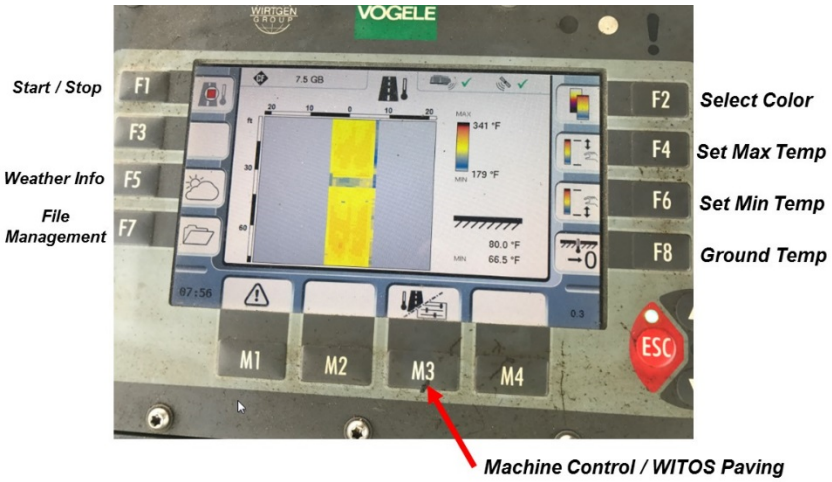


Figure 2. Vogele RoadScan thermal imaging system: Control Panel

Trimble/Caterpillar thermal imaging system

Prototypes may be available in August 2018. It uses AASHTO ICT standard format which is already implemented in Veta 5.2 beta. The prototype may be available in 2019. A brief description of this innovative technology is as follows.

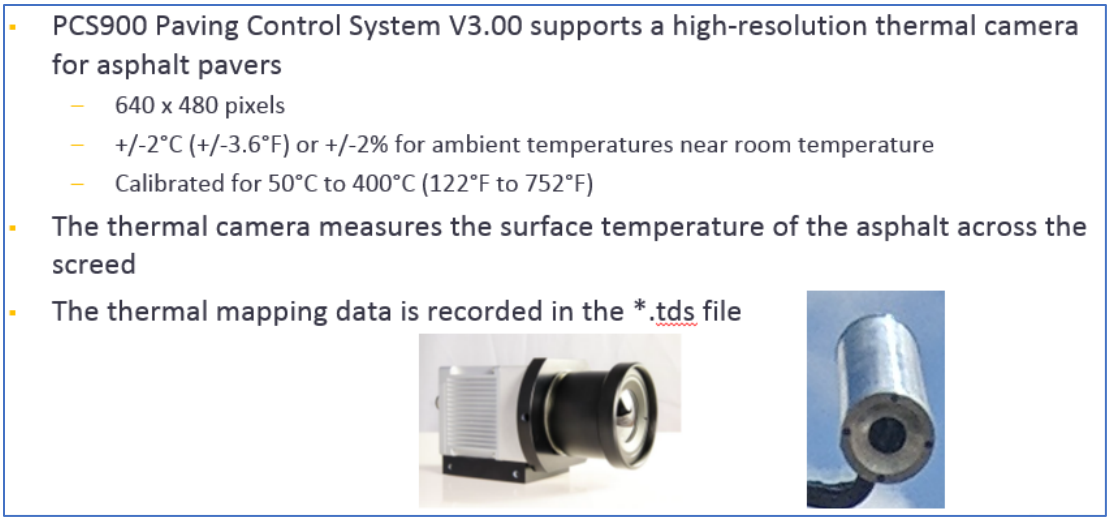


Figure 3. Trimble/Caterpillar thermal imaging system: Thermal Camera

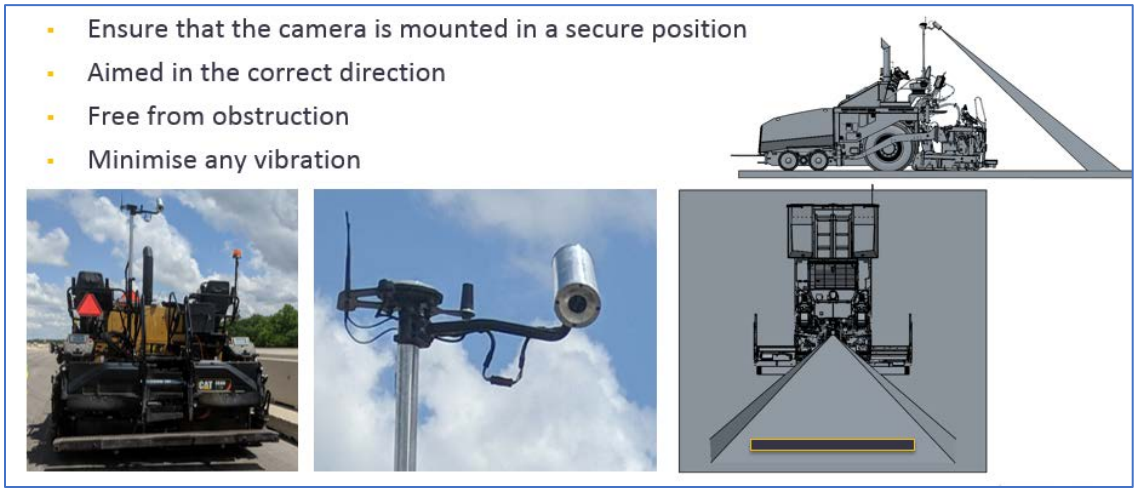


Figure 4. Trimble/Caterpillar thermal imaging system

Volvo PaveAssist thermal imaging system

The prototype may be available in 2019. A brief description of this innovative technology is as follows.

Deliver a high-quality mat surface that ensures high compact-ability and durability for the long road ahead. Thermal Profiling monitors the paved asphalt and detects temperature variations, helping you to ensure laid material is consistent throughout. By proactively evaluating the asphalt thermal quality, you can swiftly identify and correct process issues.

Figure 5. Volvo PaveAssist thermal imaging system

MOBA MCA (MOBA Compaction Assist) with Level 3-4 ICMV

MOBA MCA (MOBA Compaction Assist) with Level 3-4 ICMV (as advance IC system for improved ICMV measurements) The prototype may be available in 2019. A brief description of this innovative technology is as follows.

Figure 6. MOBA MCA (MOBA Compaction Assist)

Figure 7. MOBA MCA (MOBA Compaction Assist): Onboard Display

Caterpillar IC system with Level 3-4 ICMV

Caterpillar IC system with Level 3-4 ICMV (as advance IC system for improved ICMV measurements) The prototype may be available in 2019.

Caterpillar mount-on-paver GPS to generate paving boundary

Caterpillar mount-on-paver GPS to generate paving boundary. The research team has contacted Caterpillar's team regarding this technology.

LiDAR based scanning system to generate paving boundary

LiDAR based scanning system to generate paving boundary (e.g., TOPCON's SmoothRide system and Pavemetric's LCMS) TOPCON has made a presentation at MoDOT couple weeks ago and seems to have issues with IRI requirements.

GPS survey to obtain the centerline coordinates

GPS survey to obtain the centerline coordinates (Veta 5.1 would allow applying offsets from the centerline to create paving boundary) The 2018-2019 IC-PMTP project specifications require that latest versions of Veta.

Chapter 4 – Field Project Data Analysis and Results

Project Descriptions

The basic project information for the 2018 IC-PMTPS projects and the contractor codes are described as follows.

Table 2. 2018 IC-PMTPS Project Information.

2018 Proj No.	Job No.	District	County	Route	Contractor Code
1	4S3153	KC	Jackson	71	1
2	1L1800B	NW	Putnam	139	9
3	1I3169	NW	Harrison	35	7
4	9P3295	SE	Ozark	160	10
5	9P3187	SE	Cape Girardeau	61	3
6	8S3074	SW	Christian	CC	10
7	8S3075	SW	Christian	M	10
8	8P3051B	SW	Greene	160	10
9	J5S3207	CD	Callaway	54	1

Table 3. 2018 IC-PMTPS Contractor Code.

Contractors	Code
Capital	1
Ideker	2
Chester Bross	3
Herzog	7
Norris Asphalt	9
Leo Journagan	10

The schedule for the MoDOT IC-IR field projects is listed in Table 4.

Table 4. MoDOT IC-IR Project Schedule

No.	Job No.	District	County	Route	Start Date	End Date	Paving Days
1	4S3153	KC	Jackson	71	5/9/2018	5/17/2018	5
2	1L1800B	NW	Putnam	139	10/17/2018	11/6/2018	13
3	1I3169	NW	Harrison	35	10/11/2018	11/6/2018	13
4	9P3295	SE	Ozark	160	9/4/2018	9/19/2018	12
5	9P3187	SE	Cape Girardeau	61	9/19/2018	11/3/2018	26
6	8S3074	SW	Christian	CC	8/1/2018	8/7/2018	5
7	8S3075	SW	Christian	M	8/8/2018	8/9/2018	2
8	8P3051B	SW	Greene	160	7/26/2018	7/31/2018	3
9	J5S3207	CD	Callaway	54	10/22/2018	11/7/2018	6

The locations of the nine (9) IC-PMTPS projects in 2018 are illustrated in the following map.

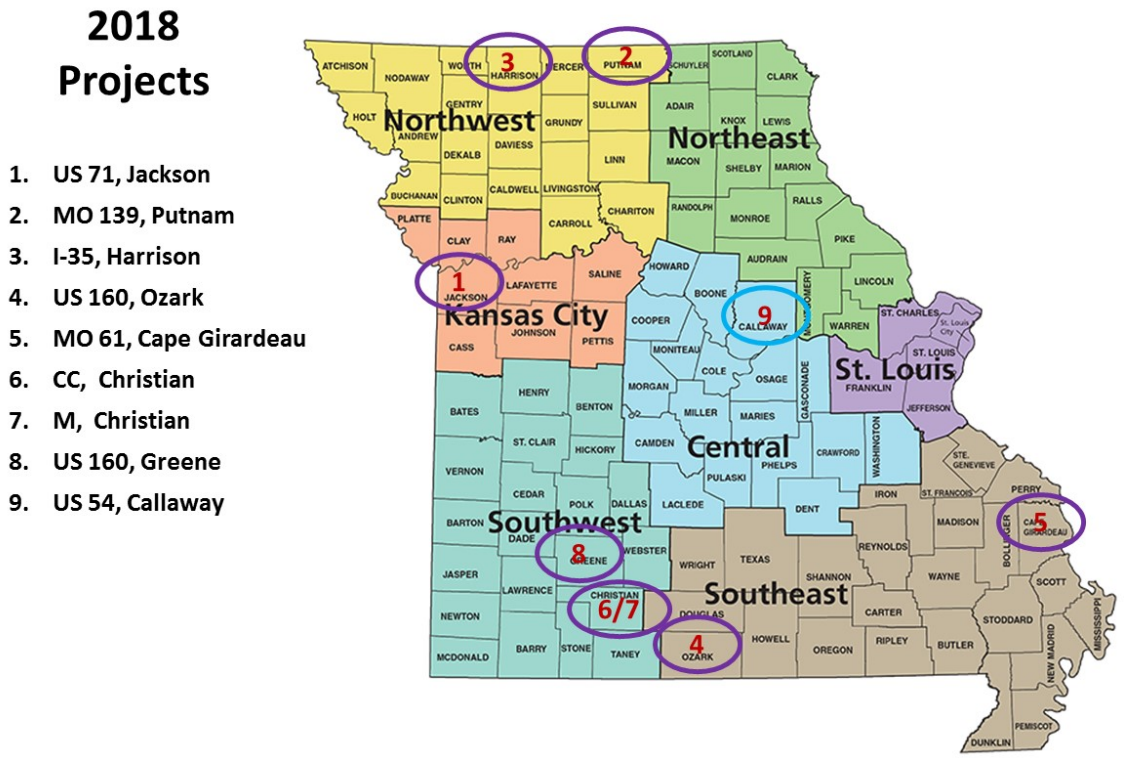


Figure 8. MoDOT 2018 IC-PMTPS Project Locations.

The IR and IC systems used for each of the MoDOT IC-IR field projects is listed in Table 5.

Table 5. MoDOT IC-IR Project Systems Used

No.	Job No.	District	County	Route	IR System	IC System
1	4S3153	KC	Jackson	71	MOBA-PAVEIR	Trimble
2	1L1800B	NW	Putnam	139	MOBA-PAVEIR	Caterpillar/ Trimble
3	1I3169	NW	Harrison	35	MOBA-PAVEIR	Trimble
4	9P3295	SE	Ozark	160	MOBA-PAVEIR	TOPCON
5	9P3187	SE	Cape Girardeau	61	MOBA-PAVEIR	Volvo
6	8S3074	SW	Christian	CC	MOBA-PAVEIR	TOPCON
7	8S3075	SW	Christian	M	MOBA-PAVEIR	TOPCON
8	8P3051B	SW	Greene	160	MOBA-PAVEIR	TOPCON
9	J5S3207	CD	Callaway	54	MOBA-PAVEIR	TOPCON

Data Analysis and Results

IR Data Analysis

Analysis Method

The IR data was analyzed using the MOBA PaveProj Program (PPM) reports as per the MoDOT IR specification. Veta (version 5.2) 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 9). 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 10). 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 11. The temperature segregation based on the above analysis method does not consider the effects of paver stops.

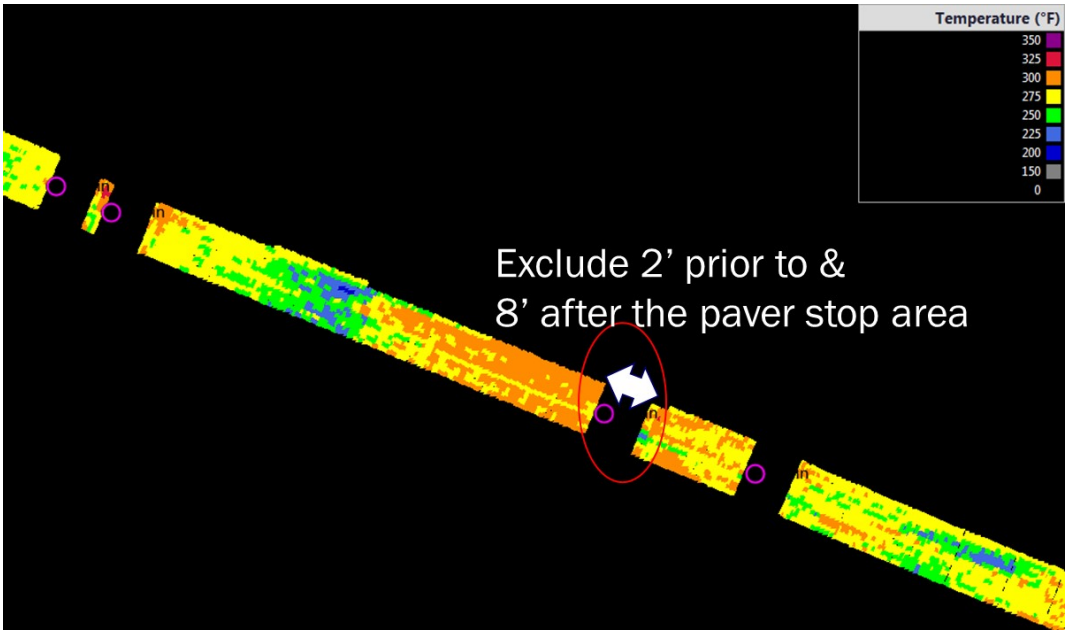


Figure 9: AASHTO PP80 IR Analysis Method: 10' exclusion around a paver stop location

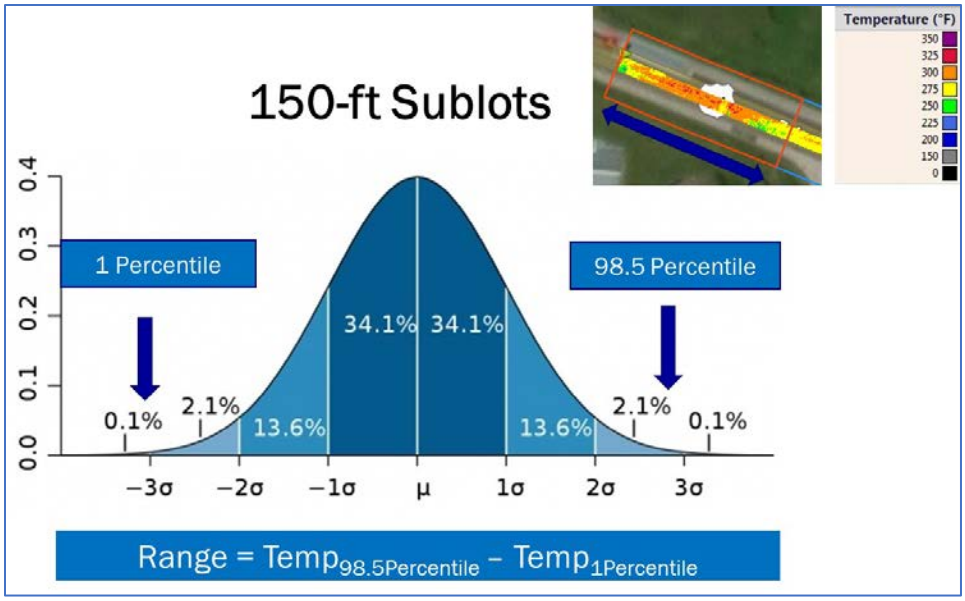


Figure 10: AASHTO PP80 IR Analysis Method: Computation of "Range" value

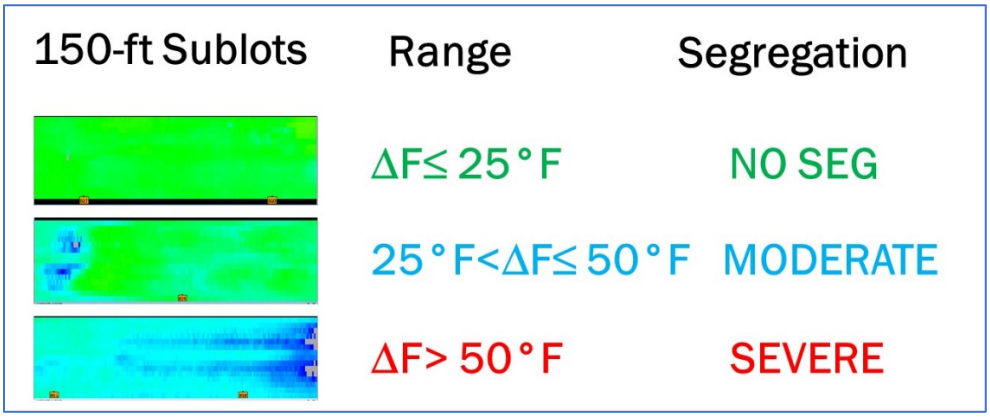


Figure 11: AASHTO PP80 IR Analysis Method: Segregation categories

Analysis Examples

An example of IR data analysis from the October 22, 2018 data from J5S3207 RT 54 is shown below. The MOBA PAVE-IR data were downloaded from the Cloud, and the corresponding MOBA PPM screenshot shown below.
The MOBA PAVE-IR data is imported to Veta 5.2 and save as J5S3207-20181022-IR.vetaproj. There are minor data points with invalid coordinates.

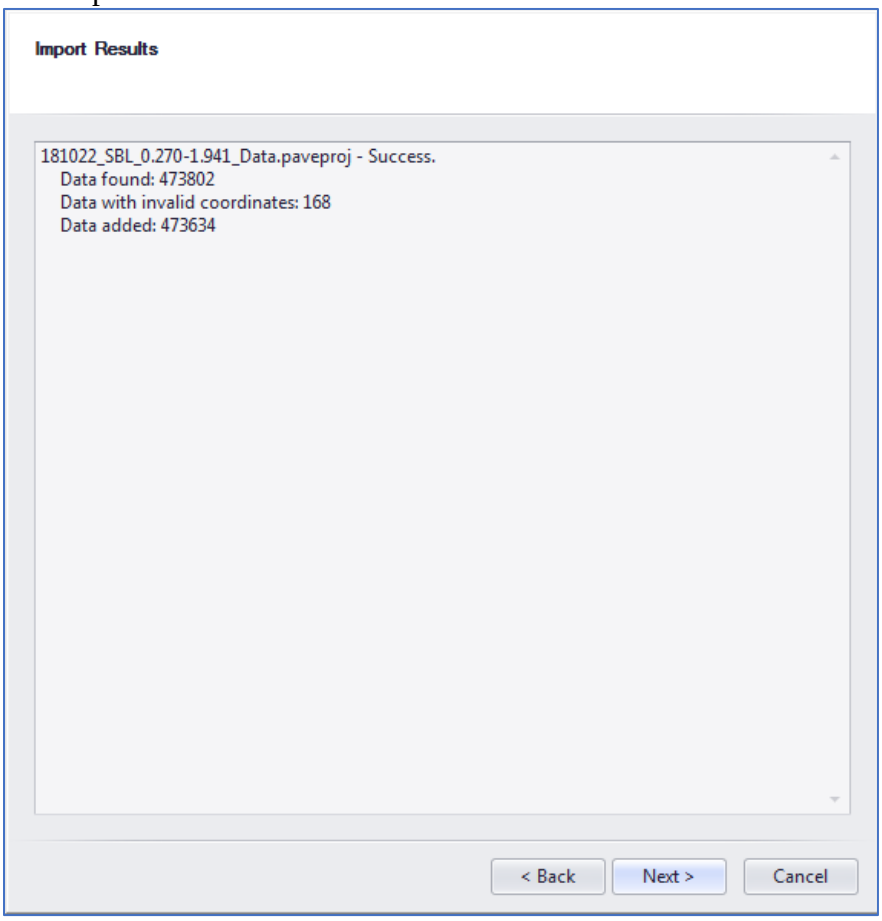


Figure 12: PMTP Data Import to Veta

The thermal profile data show cold edges.

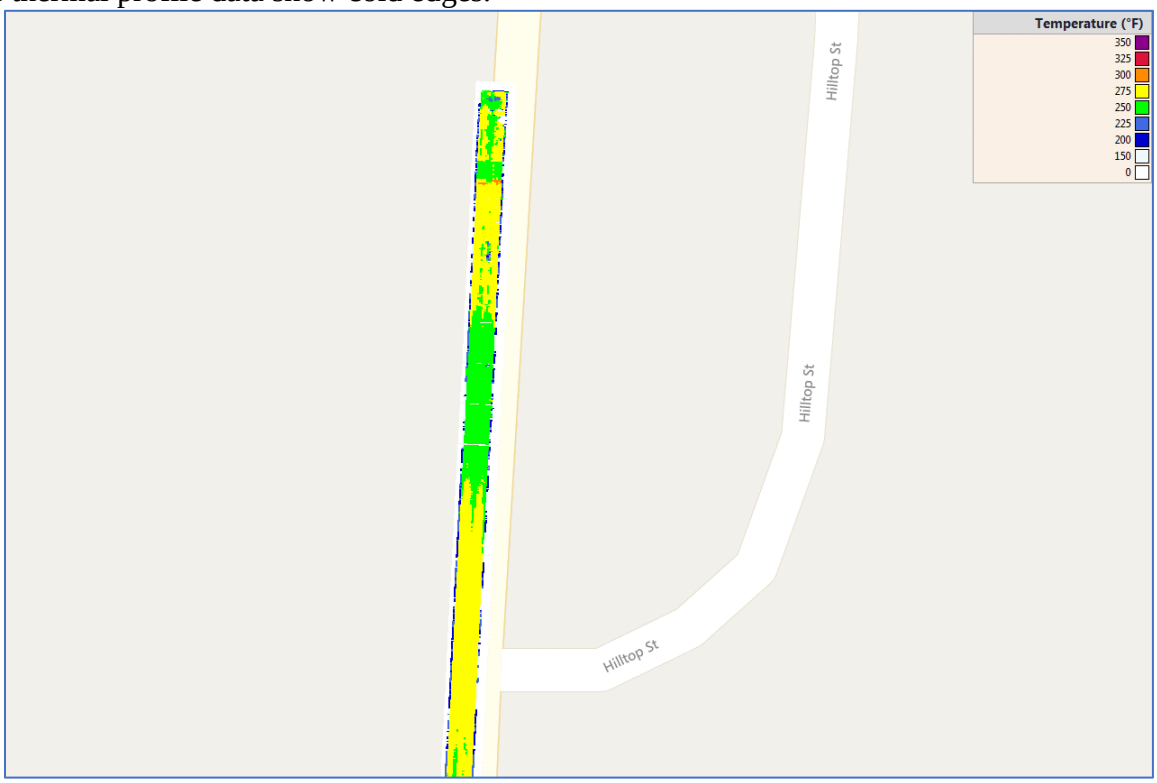


Figure 13: Veta View Screen for PMTP Data Analysis.

Setup a filter group, J5S3207-20181022-IR. Include a data filter to exclude temperature less than 180F. Include an Operation filter that exclude cold edges (and hot bracket).

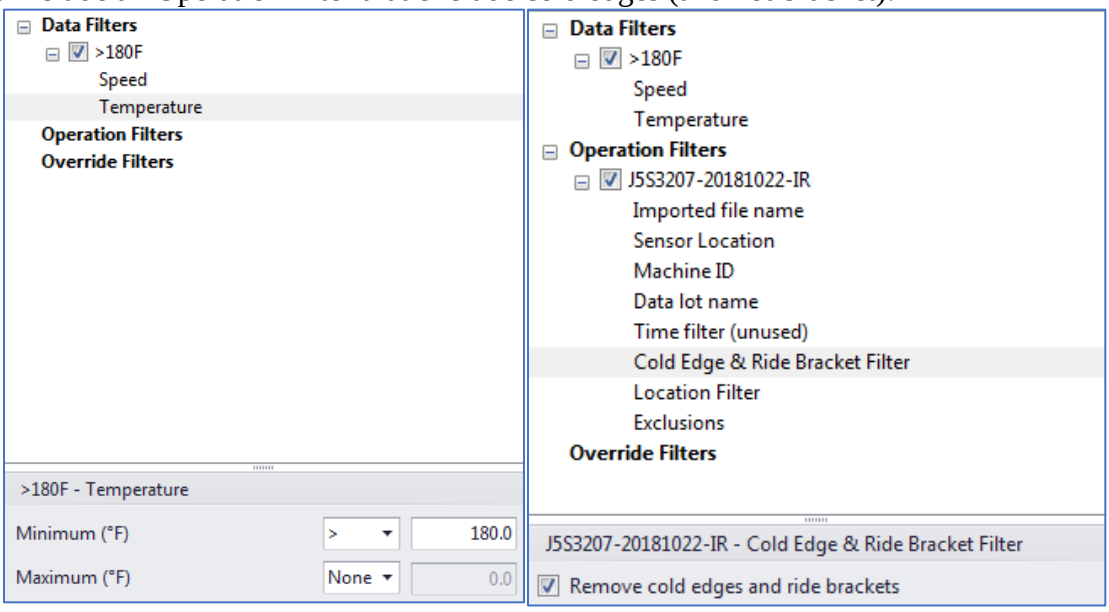


Figure 14: Veta Filter Group Screen of PMTP Data Analysis.

Apply the filter group and confirm the cold edges have been filtered out.

Figure 15: Veta Filter Group Screen of PMTP Data Analysis: after filtering.

Add 150-ft sublots.

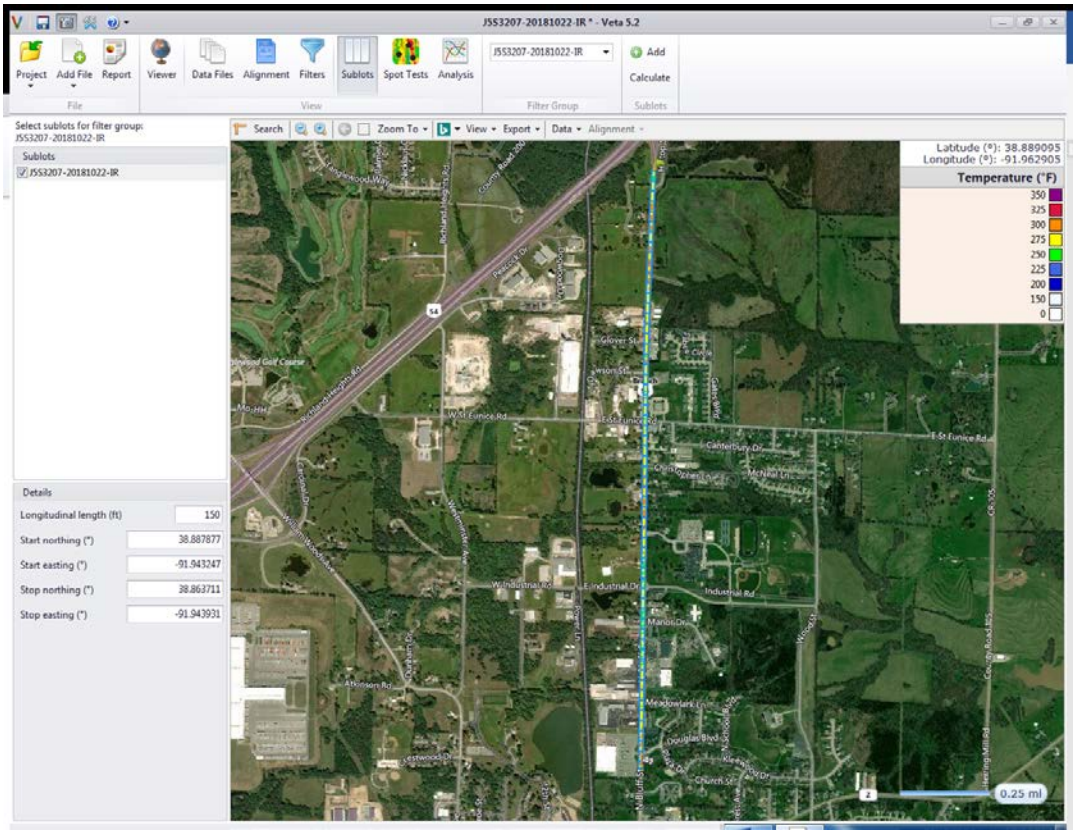


Figure 16: Veta Sublot Screen of PMTP Data Analysis.

Set up analysis:

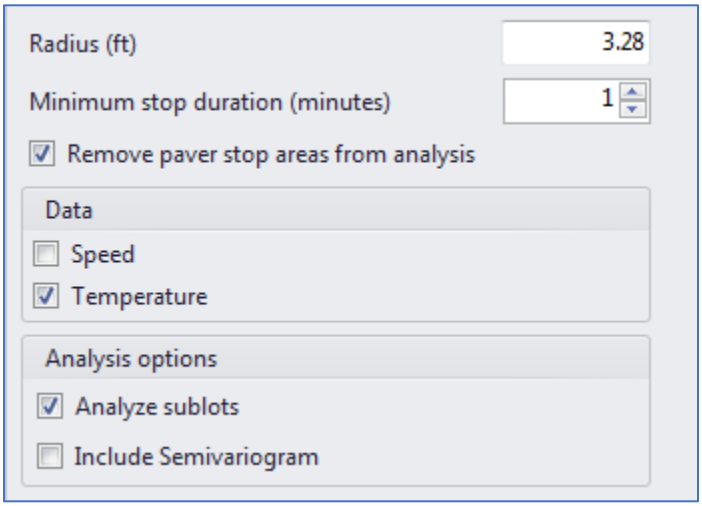


Figure 17: Veta Analysis Setup Screen of PMTP Data Analysis: Main Setup.

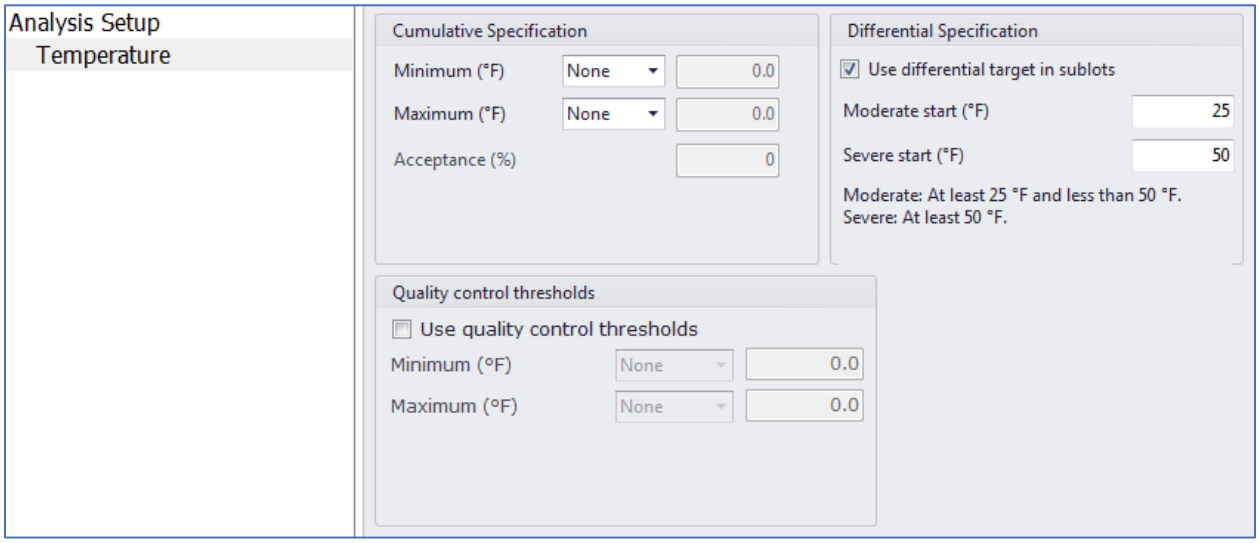


Figure 18: Veta Analysis Setup Screen of PMTP Data Analysis: Temperature Criteria

The coverage report shows a paving length as 8,828 ft.

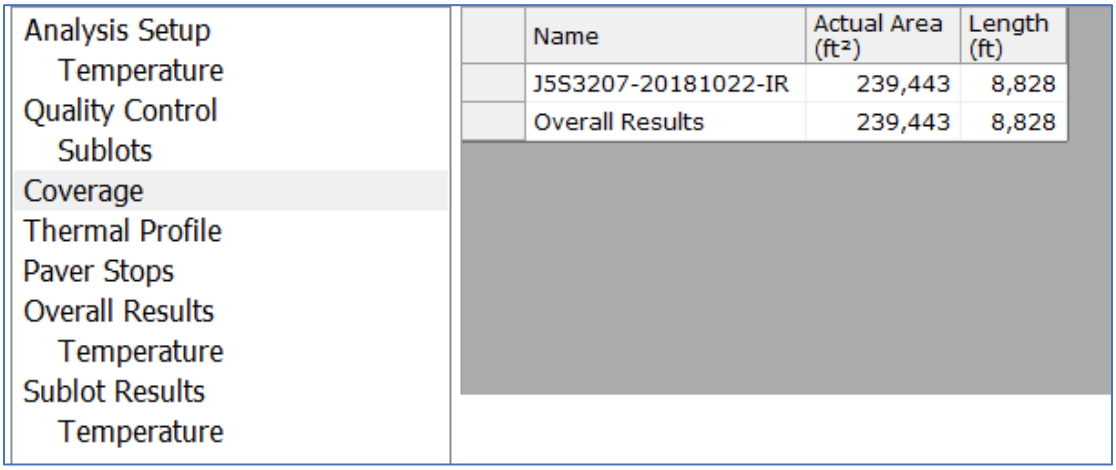


Figure 19: Veta Coverage Report Screen of PMTP Data Analysis.

The thermal profile, paver stops, and speed plots are as follows. Note that the thermal profile width changes at 5,550ft. It is recommended to verify with the contractor.

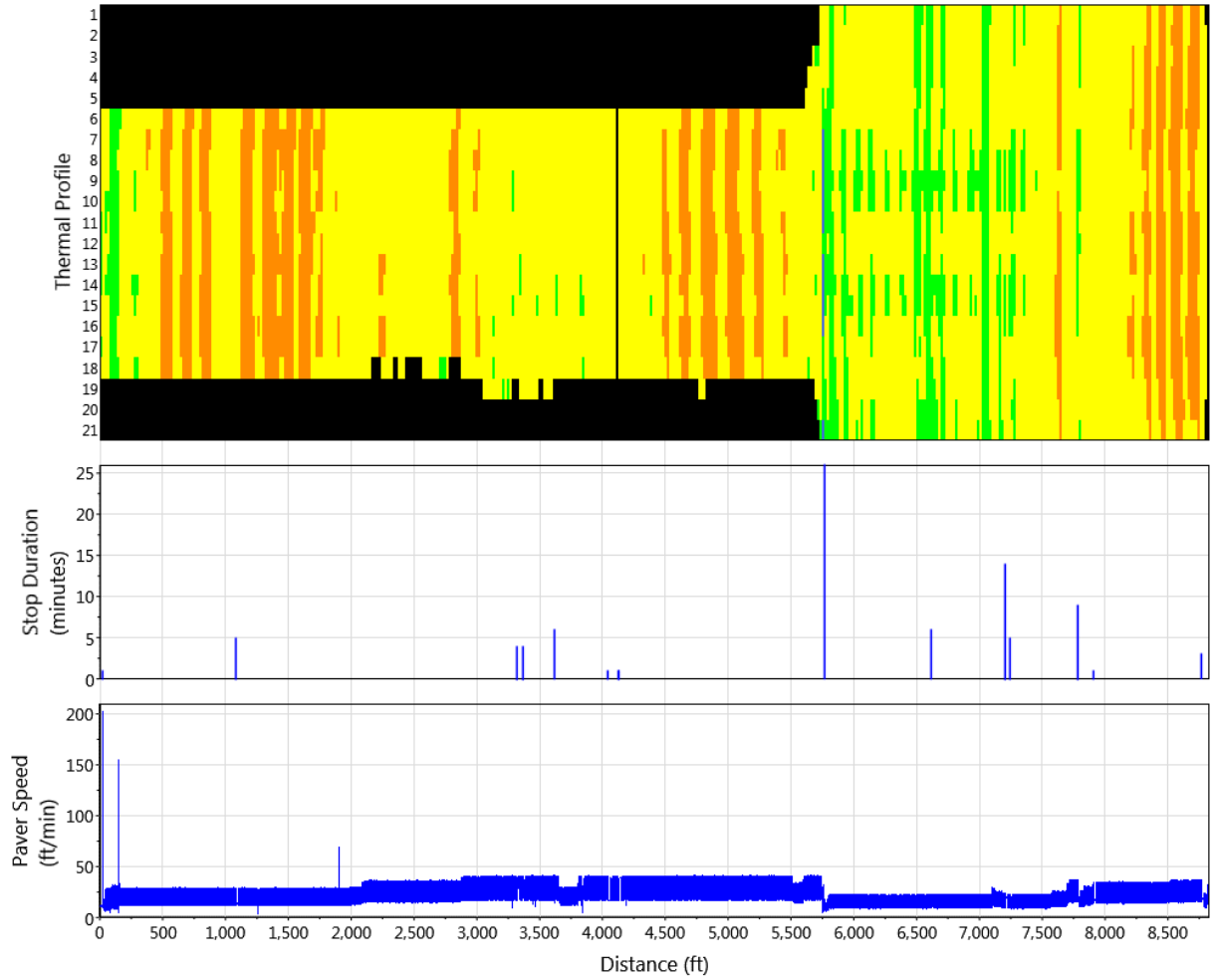


Figure 20: Veta Thermal Profile/Paver Stops/Paver Speed Screen of PMTP Data Analysis.

The paver stop maps:

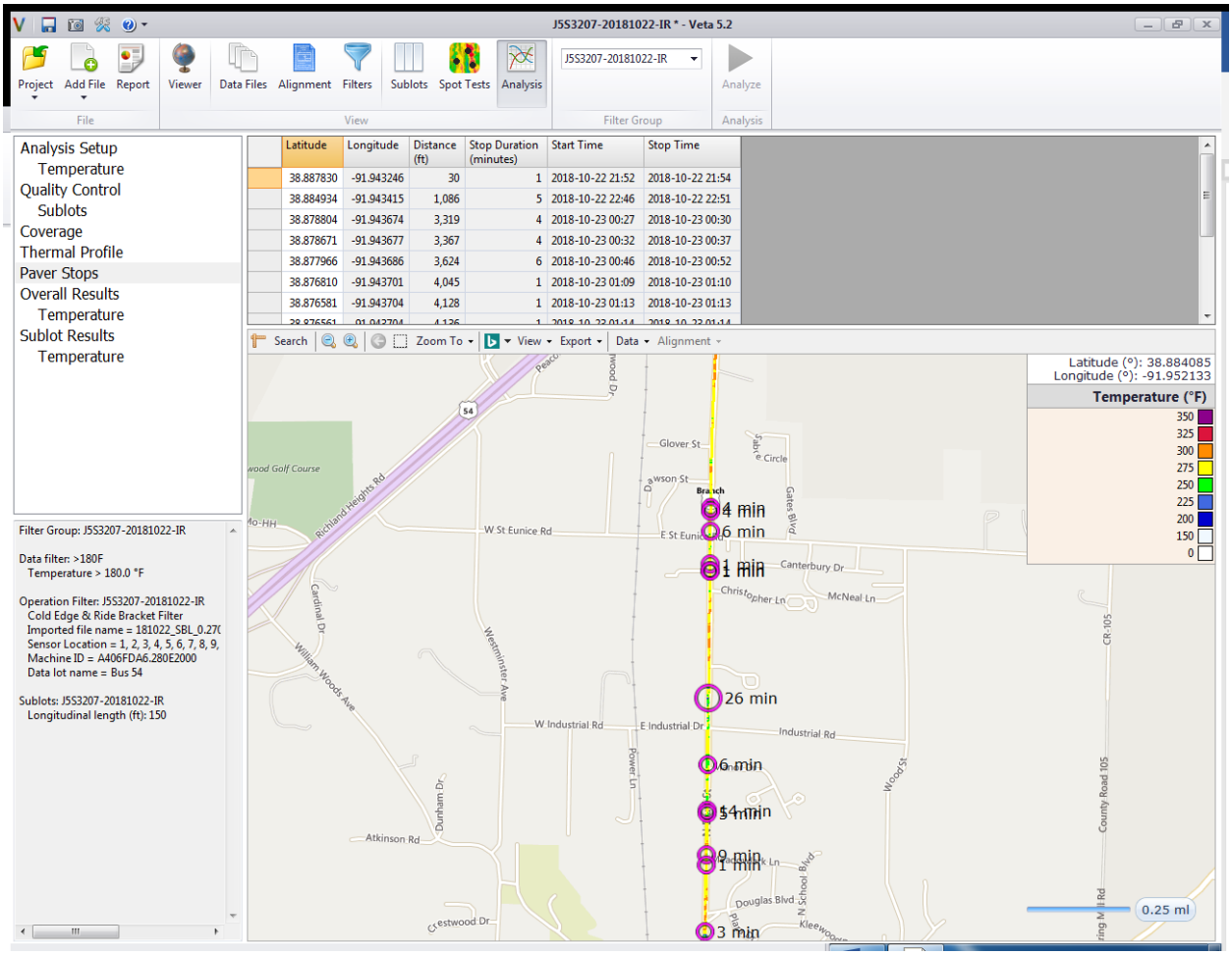


Figure 21: Veta Stop Map Screen of PMTP Data Analysis.

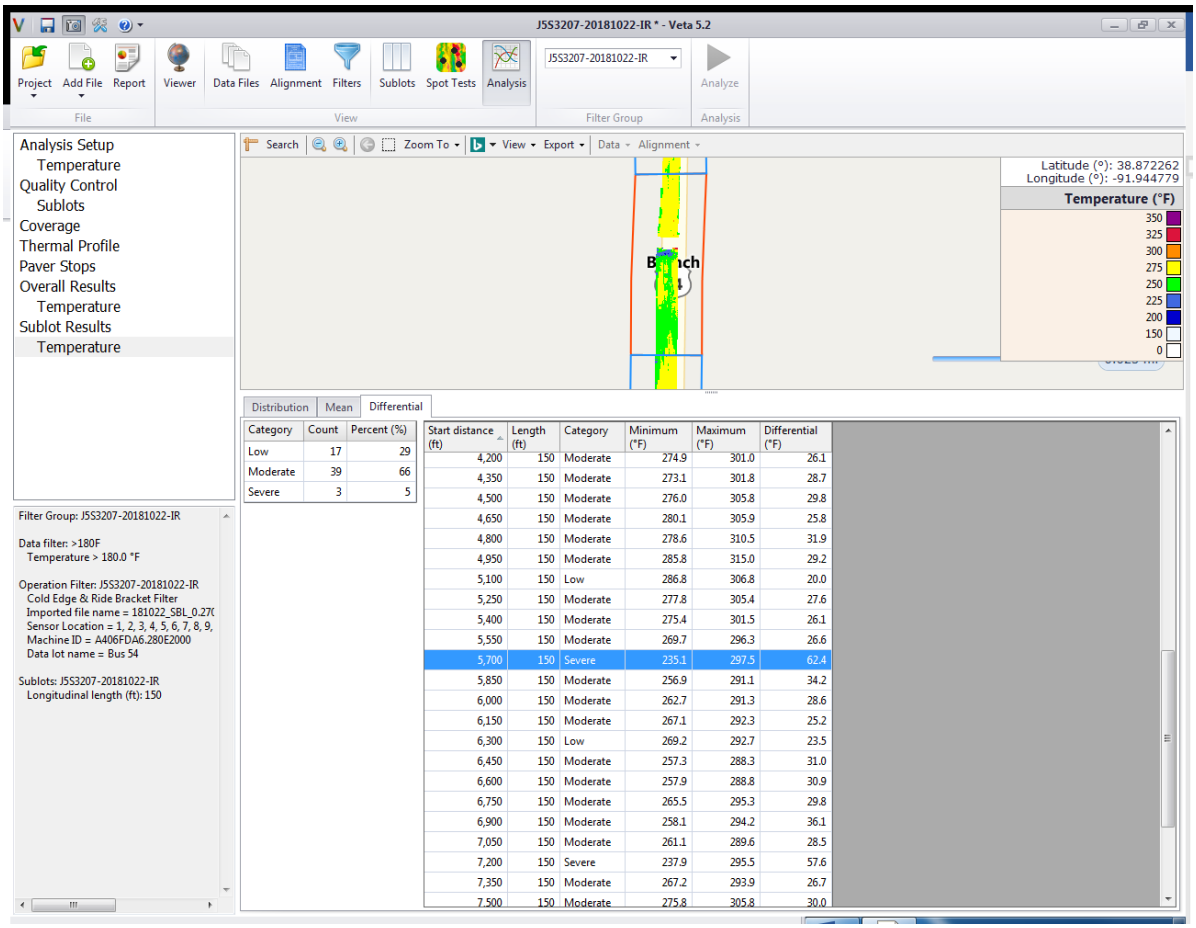
Temperature differential results are as follows:

Distribution | Mean | Differentia

Category	Count	Percent (%)
Low	17	29
Moderate	39	66
Severe	3	5

Figure 22: Veta Temperature Differential Report Screen of PMTP Data Analysis.

One example of the sublots with severe temperature segregation consists of a paver stop.



Category	Count	Percent (%)
Low	17	29
Moderate	39	66
Severe	3	5

Start distance (ft)	Length (ft)	Category	Minimum (°F)	Maximum (°F)	Differential (°F)
4,200	150	Moderate	274.9	301.0	26.1
4,350	150	Moderate	273.1	301.8	28.7
4,500	150	Moderate	276.0	305.8	29.8
4,650	150	Moderate	280.1	305.9	25.8
4,800	150	Moderate	278.6	310.5	31.9
4,950	150	Moderate	285.8	315.0	29.2
5,100	150	Low	286.8	306.8	20.0
5,250	150	Moderate	277.8	305.4	27.6
5,400	150	Moderate	275.4	301.5	26.1
5,550	150	Moderate	269.7	296.3	26.6
5,700	150	Severe	235.1	297.5	62.4
5,850	150	Moderate	256.9	291.1	34.2
6,000	150	Moderate	262.7	291.3	28.6
6,150	150	Moderate	267.1	292.3	25.2
6,300	150	Low	269.2	292.7	23.5
6,450	150	Moderate	257.3	288.3	31.0
6,600	150	Moderate	257.9	288.8	30.9
6,750	150	Moderate	265.5	295.3	29.8
6,900	150	Moderate	258.1	294.2	36.1
7,050	150	Moderate	261.1	289.6	28.5
7,200	150	Severe	237.9	295.5	57.6
7,350	150	Moderate	267.2	293.9	26.7
7,500	150	Moderate	275.8	305.8	30.0

Figure 23: Veta Temperature Differential Report Screen of PMTP Data Analysis: Detailed Sublot Analysis.

IC Data Analysis

Analysis Methods

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 6.

Table 6. MoDOT IC Coverage Classification.

Classification	% Coverage
Passing	>90
Moderate	70 < < 90
Deficient	< 70

The target ICMV can be determined based on the correlation between the ICMV data and acceptance spot tests from the trial section (Figure 24). 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.

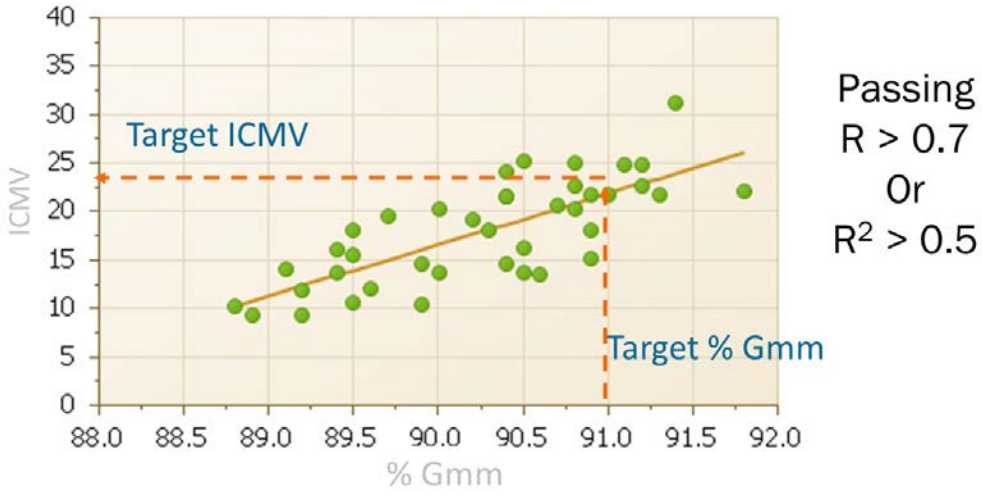


Figure 24: Target ICMV determined by Correlation between ICMV and Acceptance Spot Tests from Trial Section Data.

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).

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 25).

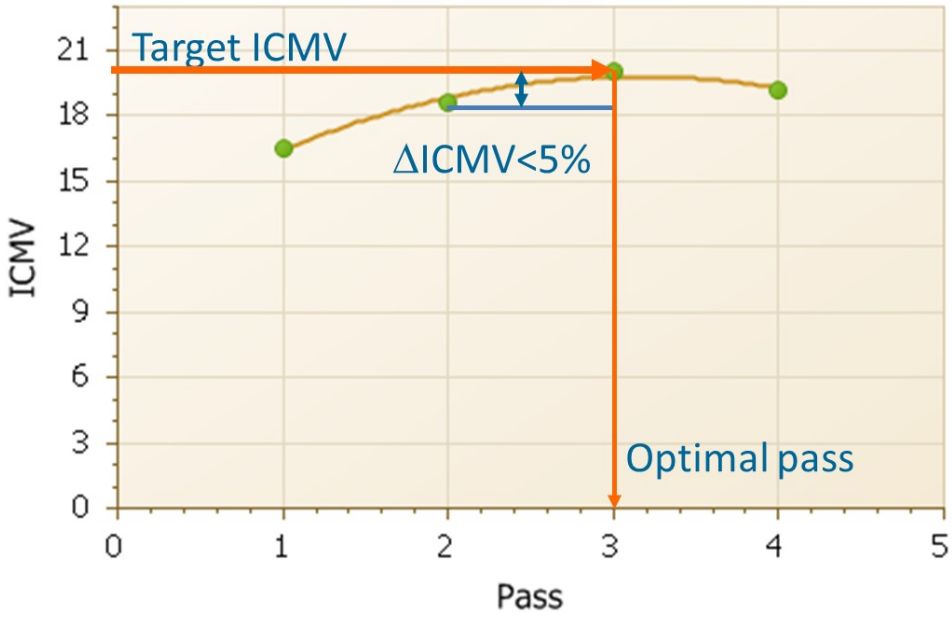


Figure 25: Target ICMV determined by an ICMV Compaction Curve when Acceptance Spot Tests from Trial Section Data are Not Available.

The target ICMV coverage was based on MoDOT IC specification, as shown in Table 7.

Table 7. MoDOT Target ICMV Coverage Classification.

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

Based on MoDOT Specification Section 403.15 (Figure 26), 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.

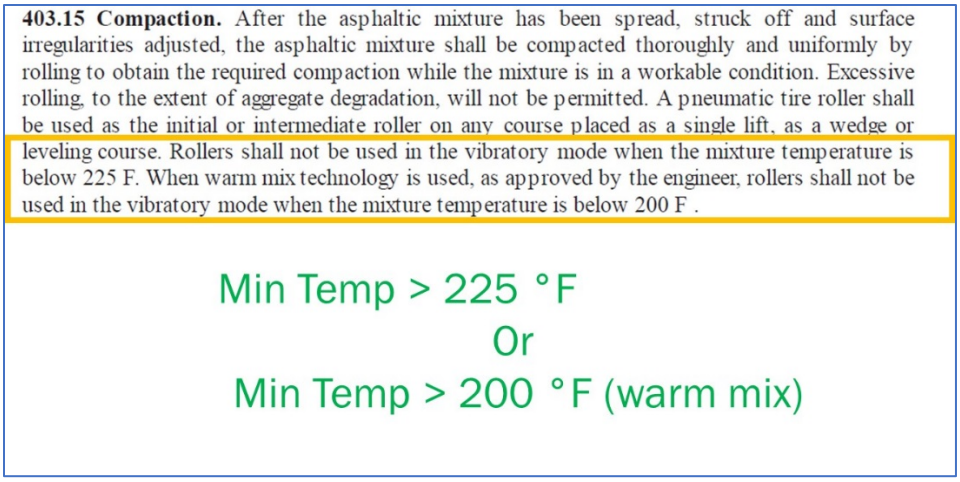


Figure 26: MODOT Requirement for Mat Temperatures during vibratory compaction.

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 27). While as demonstrated in Figure 27, 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.

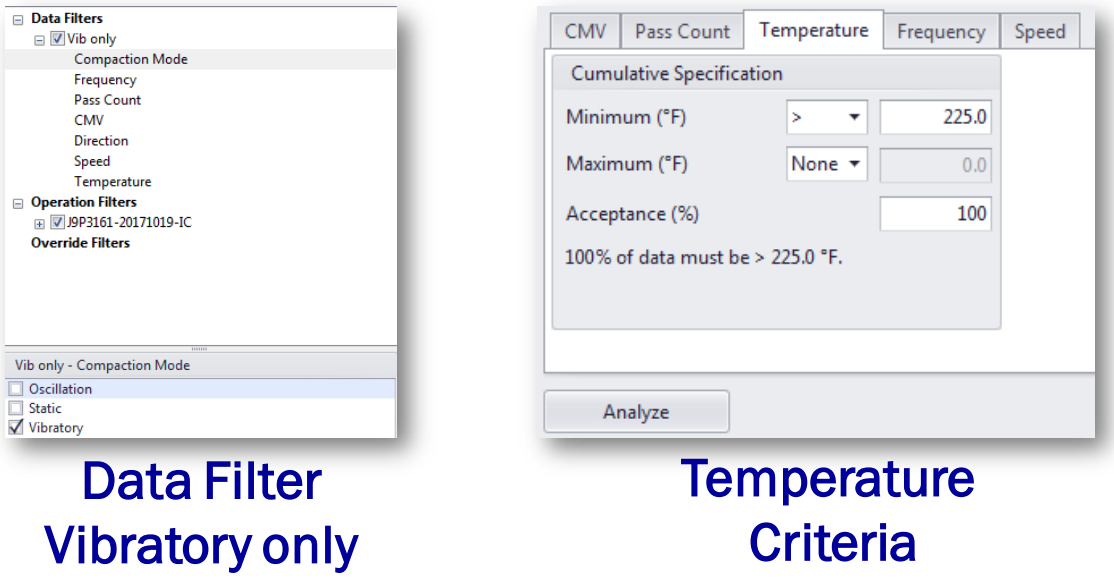


Figure 27: Veta Data Filter and Analysis Setup for MODOT Requirement for Mat Temperatures during vibratory compaction.

Analysis Example

An example of a complete IC analysis is presented below for the J5S3207 RT 54 project on October 22, 2018.

Import the TOPCON all-passes data (PLN) files from the two IC rollers to Veta 5.2 and save as J5S3207-20181022-IC.vetaproj. Based on the Trial Section NDG compaction curve and information provided by the contractor, the target is 5 vibratory passes.

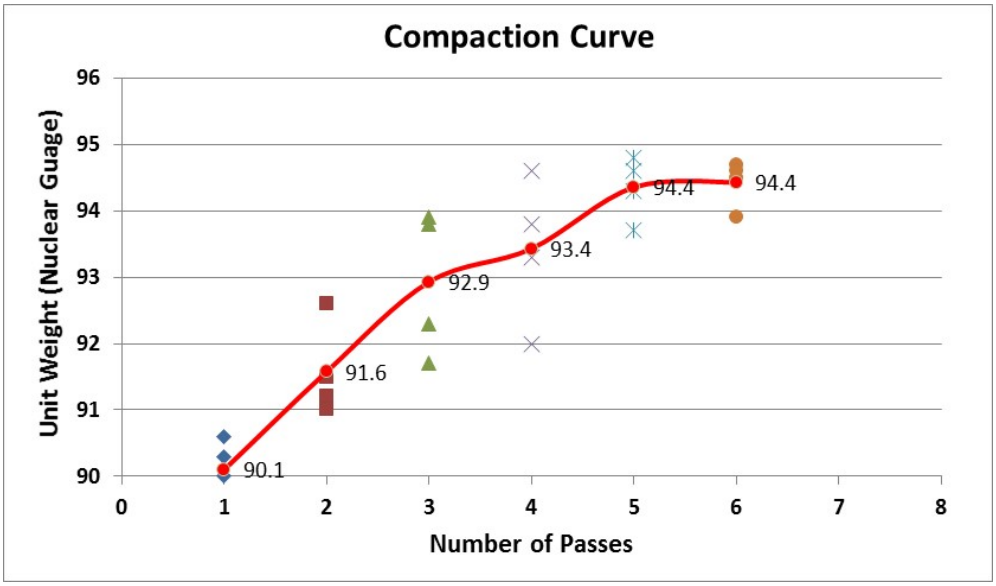


Figure 28: Density Compaction Curve based on the Trial Section Data (J5S3207 RT 54).

Therefore, adjust the color palette for pass count map as follows:

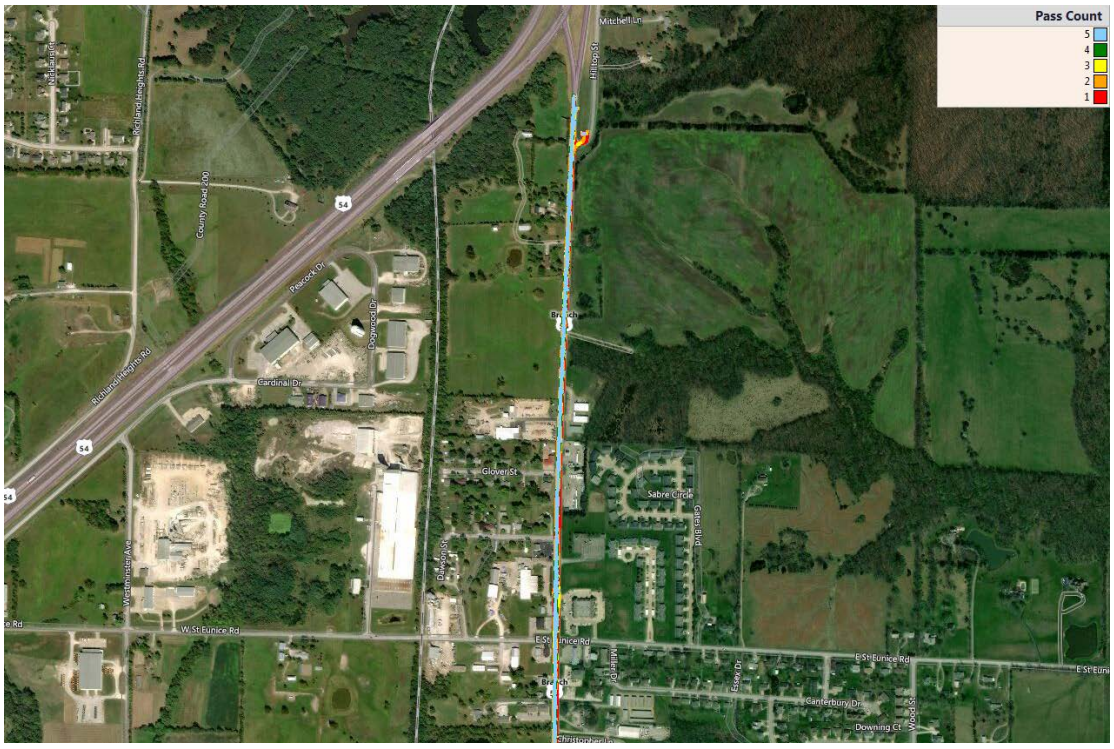


Figure 29: Veta Pass Count Screen of IC Data Analysis (J5S3207 RT 54).

Setup a filter group J5S3207-20181022-IC. Add an operation filter J5S3207-20181022-IC. Add a data filter to use vibratory passes only.

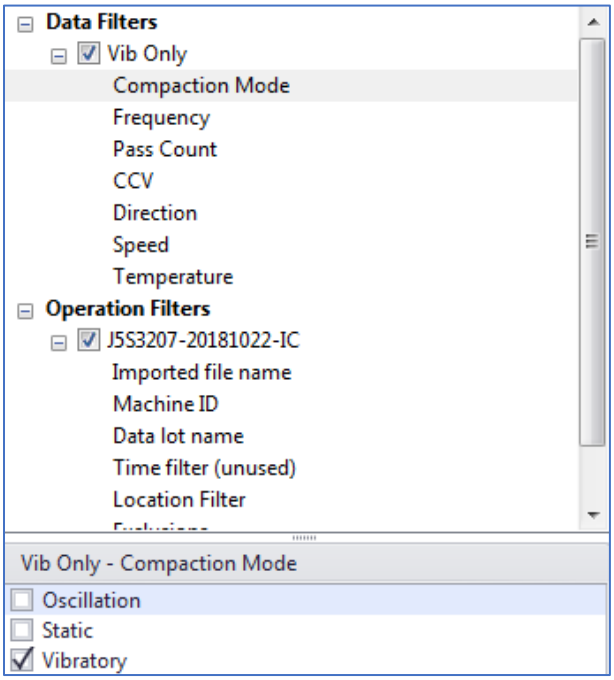


Figure 30: Veta Pass Count Screen of IC Data Analysis (J5S3207 RT 54).

Add a Location filter and define the paving boundary with the GPS boundary file.

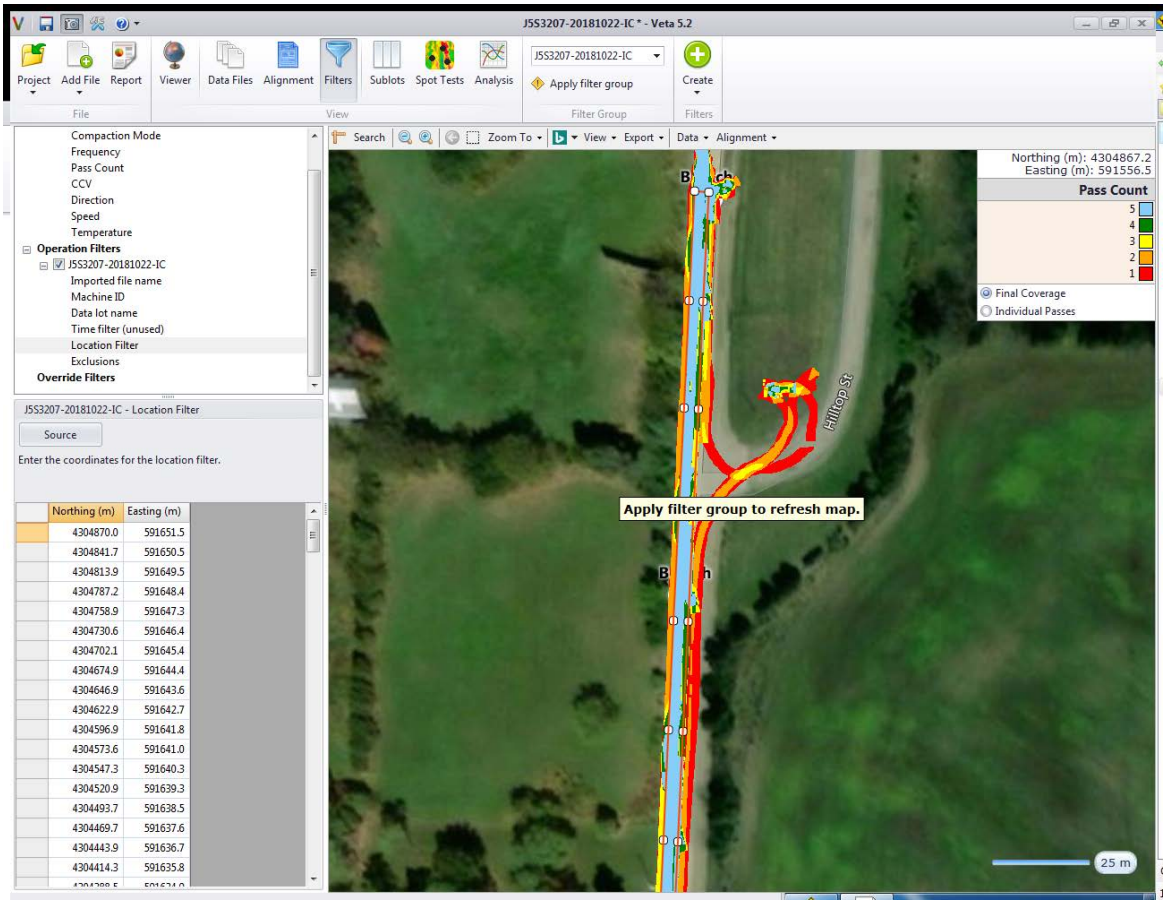


Figure 31: Veta Filter Group Screen of IC Data Analysis (J5S3207 RT 54).

Before filtering:

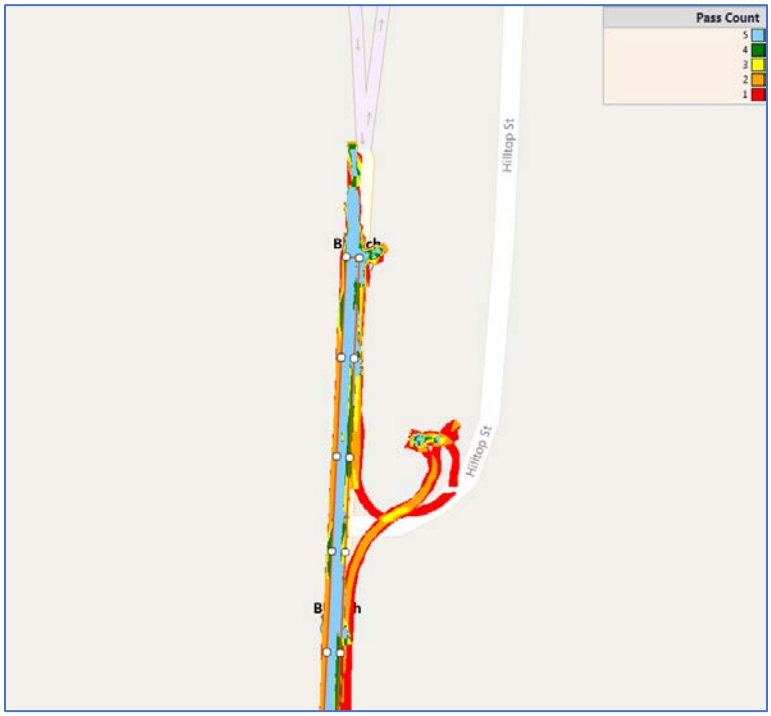


Figure 32: Veta Filter Group Screen of IC Data Analysis: Before Filtering (J5S3207 RT 54).

After filtering:

Figure 33: Veta Filter Group Screen of IC Data Analysis: After Filtering (J5S3207 RT 54).

Setup 1000-ft sublots.

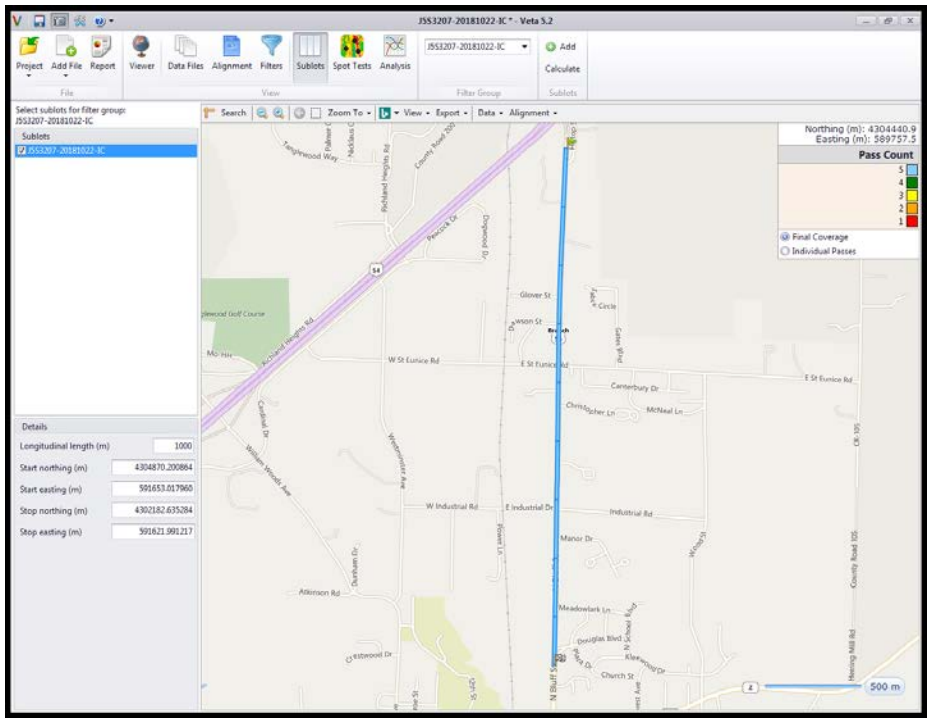


Figure 34: Veta Sublot Screen of IC Data Analysis (J5S3207 RT 54).

The core density data and GPS data are copied and pasted to the Spot Test.

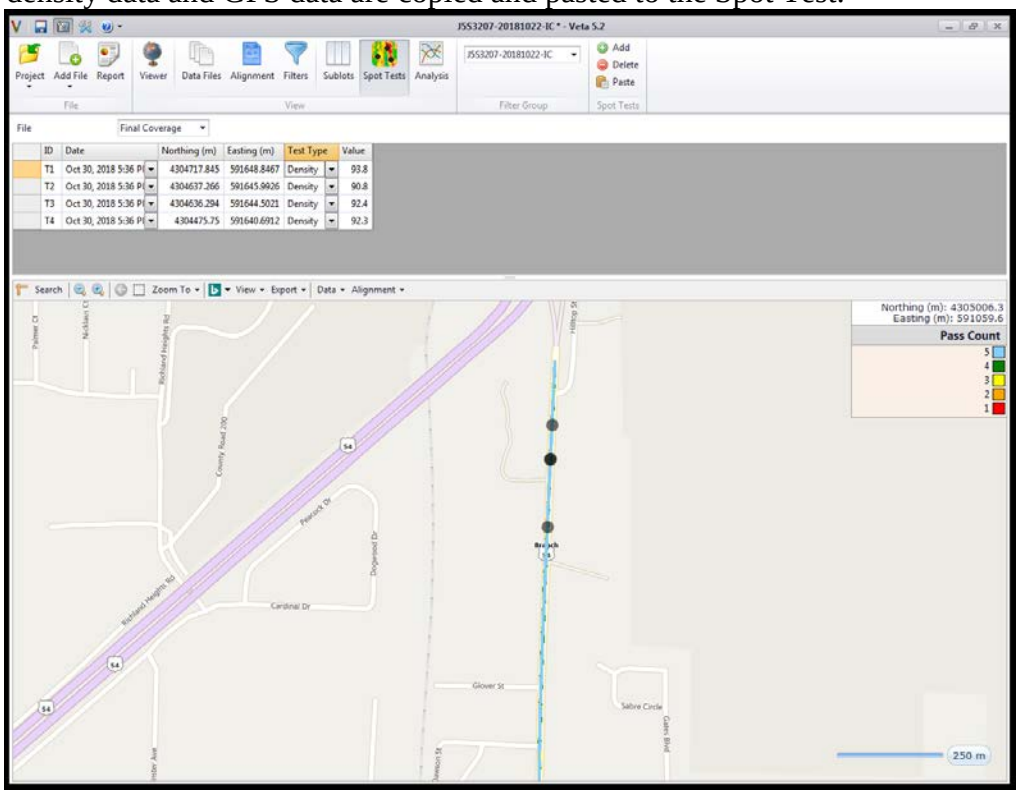


Figure 35: Veta Spot Test Screen of IC Data Analysis (J5S3207 RT 54).

Run the first-round analysis:
The Final Coverage CCV correlation with the core density is not good.

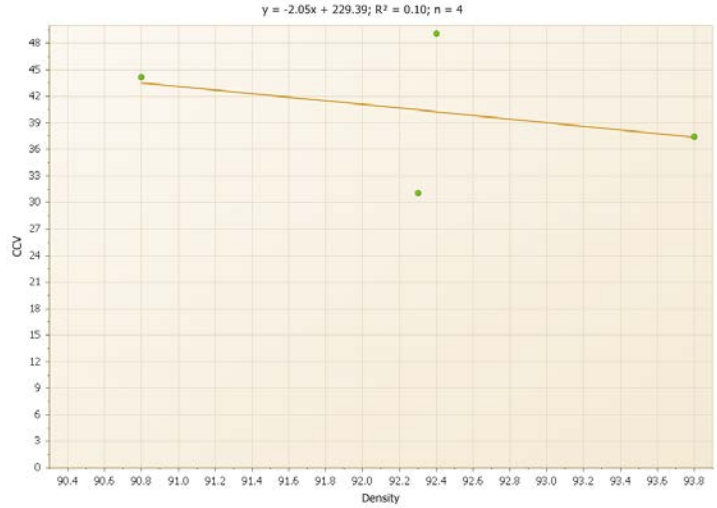


Figure 36: Veta Correlation Analysis Screen of IC Data Analysis (J5S3207 RT 54).

The All-passes CCV compaction curve (focusing on the first 5-7 passes), CCV does plateau around 5 passes.

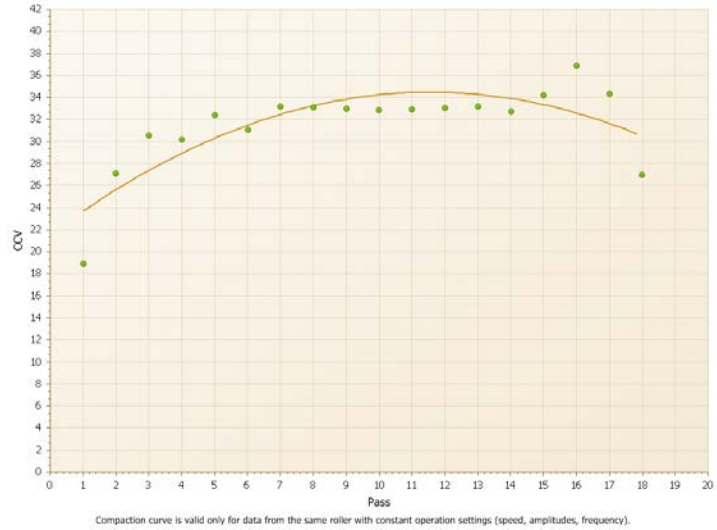


Figure 37: Veta Compaction Curve Screen of IC Data Analysis (J5S3207 RT 54).

Therefore, the target ICMV can be set at 32.

Setup target CCV and target temperature for the analysis:

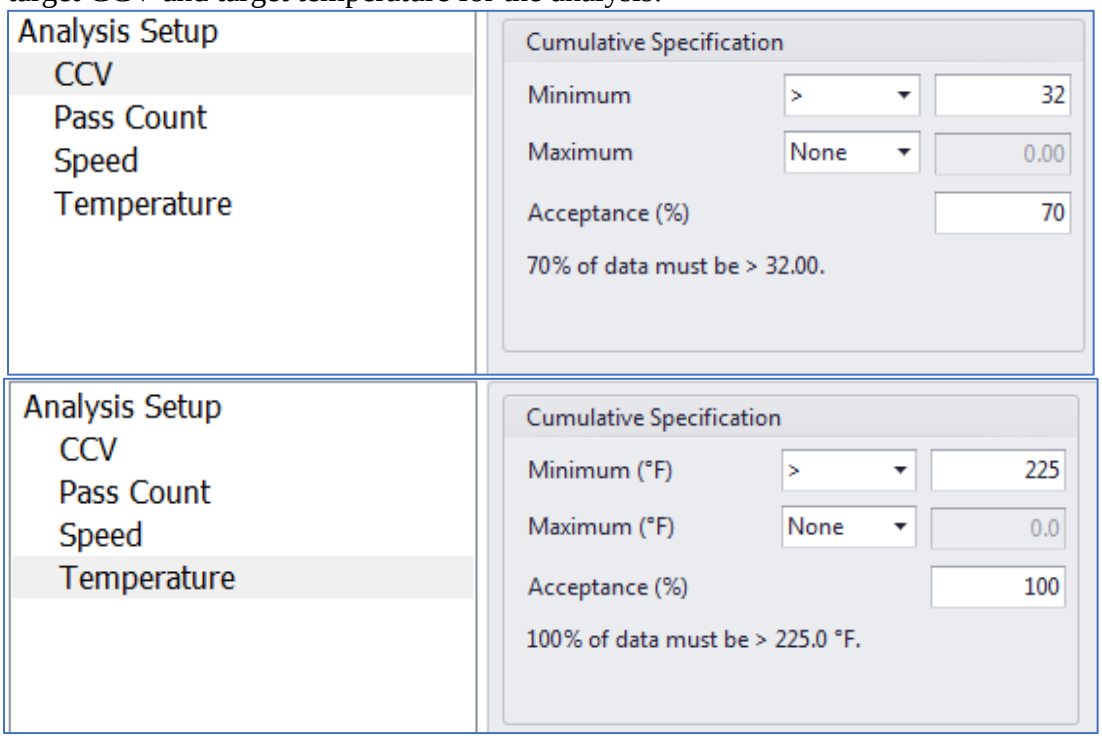


Figure 38: Veta Spot Test Screen of IC Data Analysis (J5S3207 RT 54).

The overall pass count coverage is 59.5% that meet the target passes – just barely passing 70% requirement.

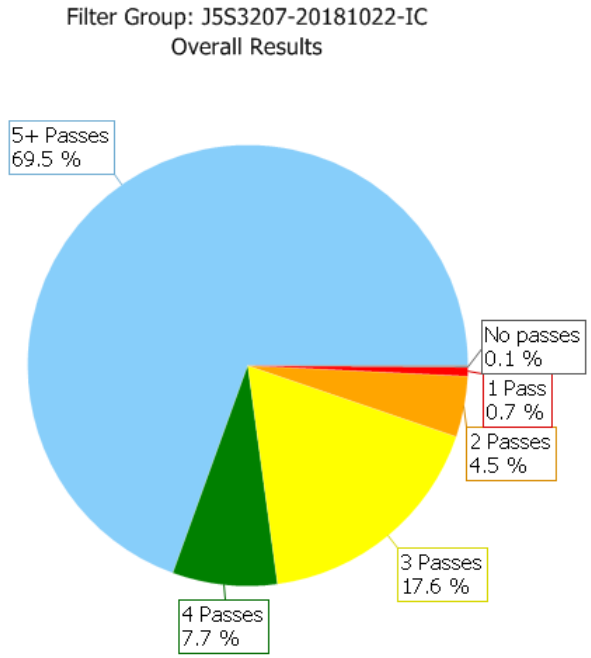


Figure 39: Veta Pass Count Coverage Screen of IC Data Analysis (J5S3207 RT 54).

The target ICMV coverage is 49.75% which is less than the 70% requirement. However, due to the poor correlation between CCV and core density, this CCV data set is not recommended to be used for such analysis.

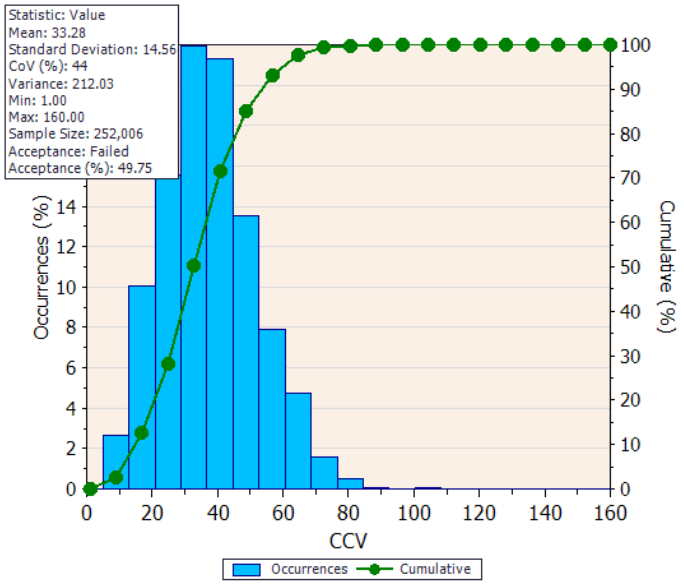


Figure 40: Veta CCV Statistics Screen of IC Data Analysis (J5S3207 RT 54).

The target temperature coverage is 38.68%. It does not meet the MODOT's minimum temperature requirement of 225F.

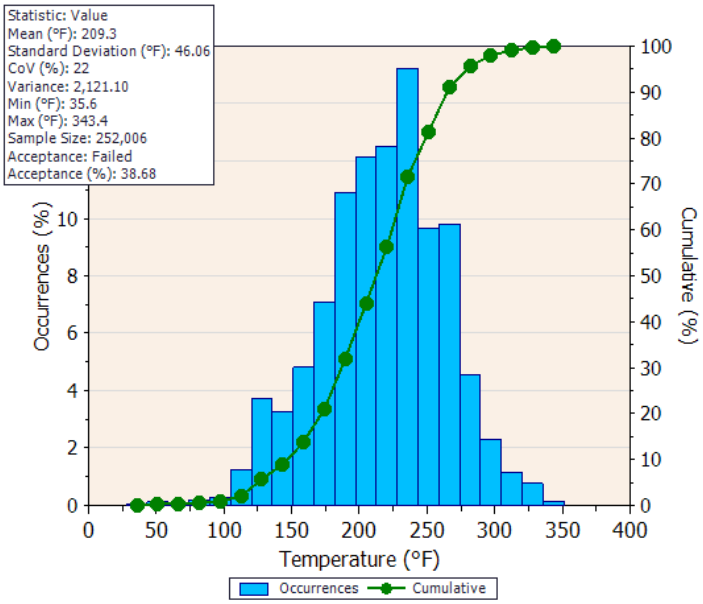


Figure 41: Veta Temperature Statistics Screen of IC Data Analysis (J5S3207 RT 54).

The 1000-ft sublot results for pass count coverage is as follows.

Distribution | Mean | Acceptance

Location (m)	Length (m)	Acceptance	Acceptance (%)	Min	Mean	Max	Standard Deviation	Variance	CoV (%)	Sample Size
0	305	Failed	65.6	2	6	15	3	7.44	46	28,653
305	305	Failed	67.9	2	6	14	3	7.17	45	28,742
610	305	Failed	64.9	1	6	15	3	6.44	44	27,602
914	305	Failed	65.6	1	6	17	3	7.89	48	29,501
1,219	305	Failed	64.2	1	6	15	3	6.87	46	29,267
1,524	305	Passed	70.6	1	7	20	3	10.41	48	28,670
1,829	305	Passed	87.6	1	8	20	3	9.40	39	28,667
2,134	305	Passed	74.9	1	7	17	3	9.57	45	28,198
2,438	250	Failed	63.6	1	6	13	2	5.85	42	22,706

Figure 42: Veta Sublot Statistics Report Screen of IC Data Analysis (J5S3207 RT 54).

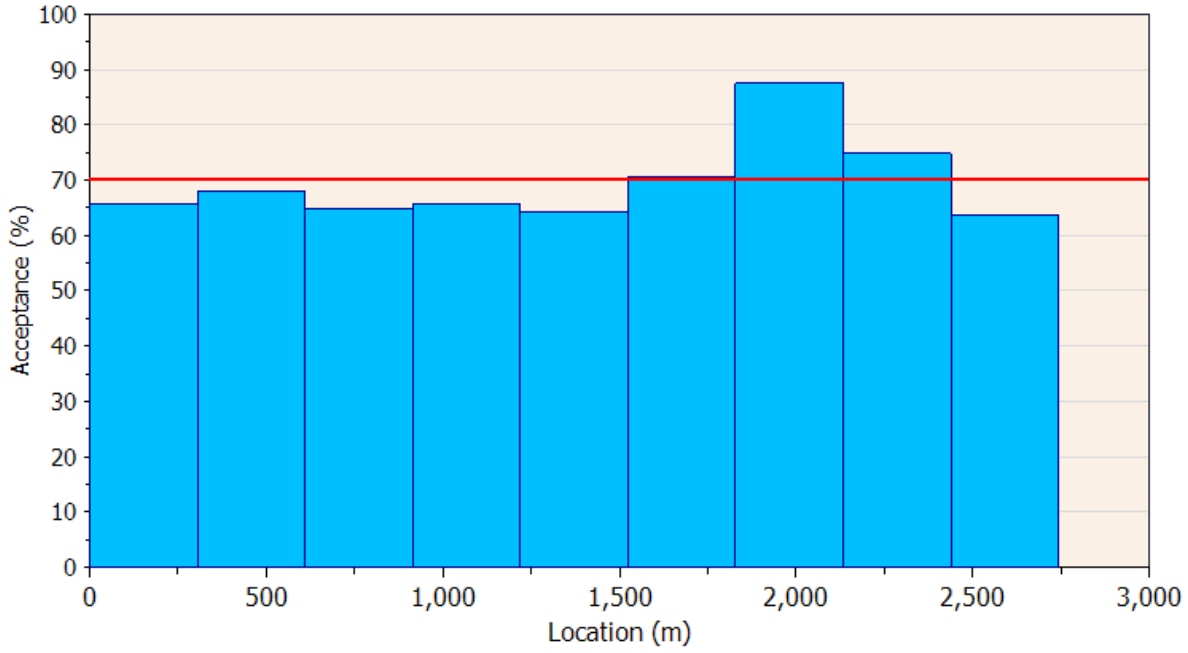


Figure 43: Veta Sublot Statistics Report Plot Screen of IC Data Analysis (J5S3207 RT 54).

Summary of Results

Project No. 1 - J 4S3153, RT 71

Trial Section (5/8/2018)
Optimum Rolling Pattern: The trial section data were provided by the contractor, but no compaction curve is provided. The rolling pattern established was 7 vibratory passes with the one double drum roller.

A summary of IR results are shown as follows. Most of the temperature segregation was in the "no segregation" and "moderate segregation" categories.

Table 8: Summary of IR Results (Project No. 1 - J 4S3153, RT 71)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	5/8/2018	24	*75*	7	*22*	1	*3*	18	*56*	11	*34*	3	*9*
2	5/9/2018	46	*82*	8	*14*	2	*4*	32	*63*	15	*29*	4	*8*
3	5/10/2018	62	*79*	10	*13*	6	*8*	59	*76*	16	*21*	3	*4*
4	5/11/2018	57	*74*	17	*22*	3	*4*	49	*65*	25	*33*	1	*1*
5	5/15/2018	50	*74*	17	*25*	1	*1*	36	*53*	28	*41*	4	*6*
6	5/17/2018	63	*73*	19	*22*	4	*5*	45	*52*	33	*38*	8	*9*
Notes:	The contracors produce MOBA PPM thermal segregation report. The research team produce the reports with Veta.												

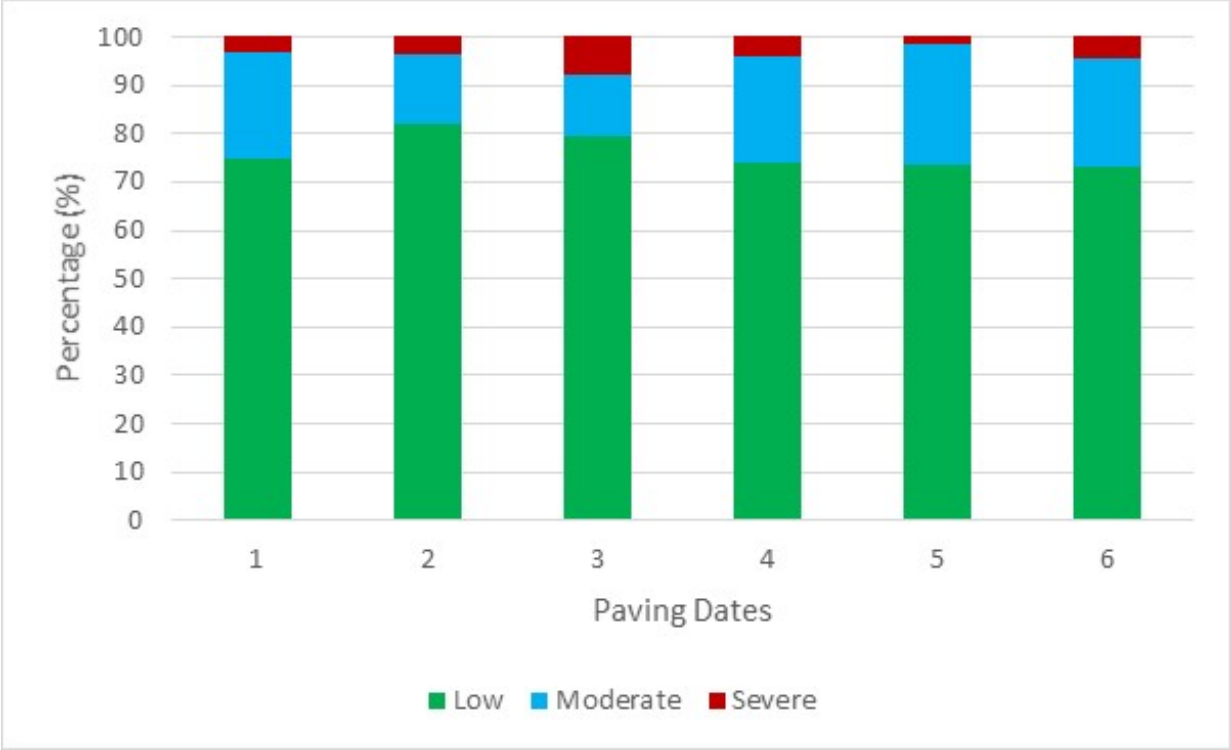


Figure 44: Summary of MOBA PPM Temperature Segregation Report (Project No. 1 - J 4S3153, RT 71).

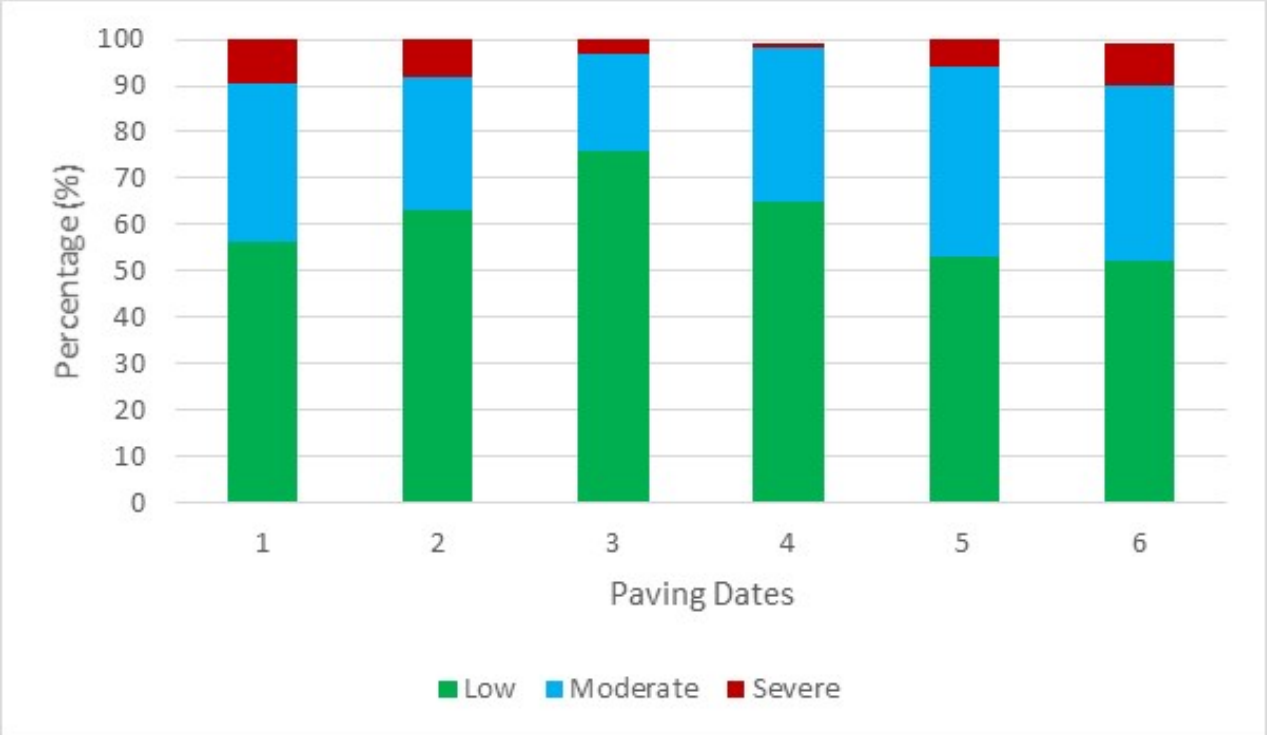


Figure 45: Summary of Veta Temperature Segregation Report (Project No. 1 - J 4S3153, RT 71).

Note that the roller coverage reports are missing for Day 1 due to malfunctioning of the IC system. The roller coverage results were mixed without apparent trends of improvement.

Table 9: Summary of IC Results (Project No. 1 - J 4S3153, RT 71)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	5/8/2018	0	Failed	NA	NA	NA	NA
2	5/9/2018	87	Moderate	NA	NA	NA	NA
3	5/10/2018	87	Moderate	NA	NA	NA	NA
4	5/11/2018	90	Moderate	NA	NA	NA	NA
5	5/15/2018	60	Failed	NA	NA	NA	NA
6	5/17/2018	60	Failed	NA	NA	NA	NA

Notes:
The IC data is missing on 2018-05-08.
The contractor used the 1000-ft sublot results.
The research use the averaged overall results instead to view the trend.
The contractor did not use the Target ICMVanalysis.
The conrtactor use the target 175F of 70% compacted area for target temperature.

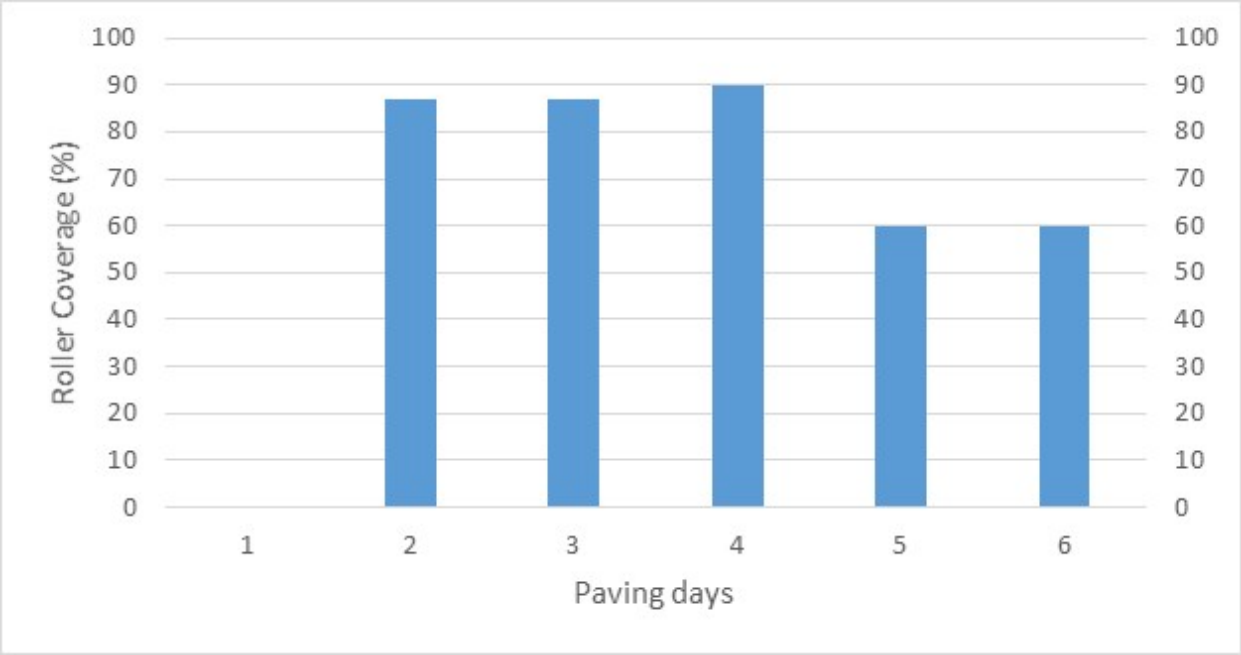


Figure 46: Summary of Roller Coverage Report (Project No. 1 - J 4S3153, RT 71).

Project No. 2 - J1L1800B, RT 139

No trial section tests were conducted due to the use of surface leveling course.

A summary of IR results is shown as follows. Note that the contractors did not perform MOBA PPM analysis. There was moderate temperature segregation with limited severe segregation, except for Day No. 8.

Table 10: Summary of IR Results (Project No. 2 - J1L1800B, RT 139)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	10/17/2018							69	*81*	13	*15*	3	*4*
2	10/18/2018							88	*73*	24	*20*	8	*7*
3	10/19/2018							91	*66*	34	*25*	13	*9*
4	10/20/2018							101	*71*	28	*20*	13	*9*
5	10/22/2018							43	*75*	9	*16*	5	*9*
6	10/23/2018							112	*73*	29	*19*	12	*8*
7	10/24/2018							76	*60*	41	*32*	10	*8*
8	10/25/2018							0	*0*	4	*67*	2	*33*
9	10/27/2018							83	*66*	31	*25*	11	*9*
10	10/29/2018							112	*77*	27	*19*	6	*4*
11	10/30/2018							60	*77*	14	*18*	4	*5*
12	10/31/2018							99	*73*	26	*19*	10	*7*
13	11/1/2018							65	*47*	53	*38*	21	*15*
14	11/6/2018							31	*57*	19	*35*	4	*7*
Notes:	* No MOBA PPM results. Veta results are used. * All contractors Veta PDF reports consist of no temperature segregation results. * The research team has data QA on 20181017, 20181018, 20181019. The research team has re-run all analysis with contractor's Veta files and provide the results.												

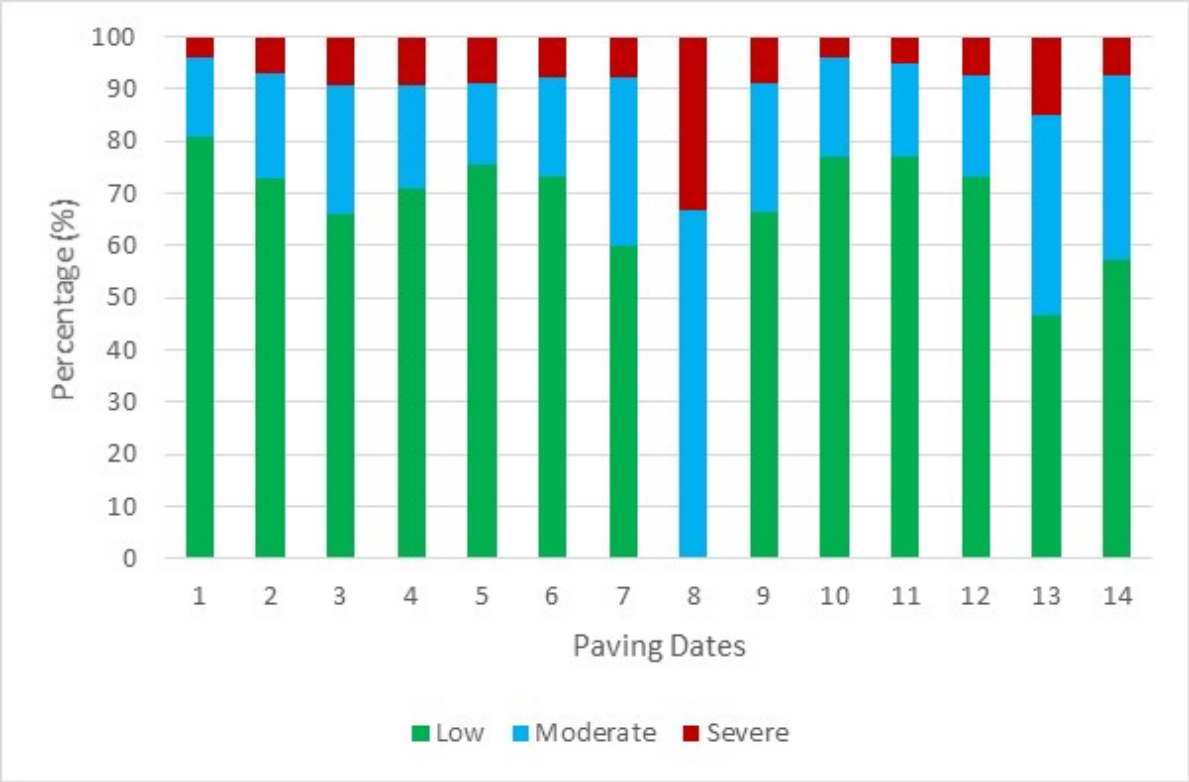


Figure 47: Summary of Veta Temperature Segregation Report (Project No. 2 - J1L1800B, RT 139).

The followings provide a summary of the roller coverage results. There were missing data for Day No. 10 and 11 due to malfunctioning of the IC system. The roller coverage results were generally good except for Fay No. 3.

Table 11: Summary of IC Results (Project No. 2 - J1L1800B, RT 139)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	10/17/2018	98.6	Passed	NA	NA	NA	NA
2	10/18/2018	83	Moderate	NA	NA	NA	NA
3	10/19/2018	64	Failed	NA	NA	NA	NA
4	10/20/2018	87.5	Moderate	NA	NA	NA	NA
5	10/22/2018	94	Passed	NA	NA	NA	NA
6	10/23/2018	90.8	Passed	NA	NA	NA	NA
7	10/24/2018	93.4	Passed	NA	NA	NA	NA
8	10/25/2018	88.8	Moderate	NA	NA	NA	NA
9	10/27/2018	85.5	Moderate	NA	NA	NA	NA
10	10/29/2018	0	Failed	NA	NA	NA	NA
11	10/30/2018	0	Failed	NA	NA	NA	NA
12	10/31/2018	94	Passed	NA	NA	NA	NA
13	11/1/2018	93.9	Passed	NA	NA	NA	NA
14	11/6/2018	94.5	Passed	NA	NA	NA	NA

Notes: Since only static passes are used, there are no analysis on Target ICMV and Temperature for Virbratory Passes.
The research team has data QA on 20181017, 20181018, 20181019, 20181020, 20181029 (no data), 20181030 (no data).
Where there is no data, 0% coverage is used.

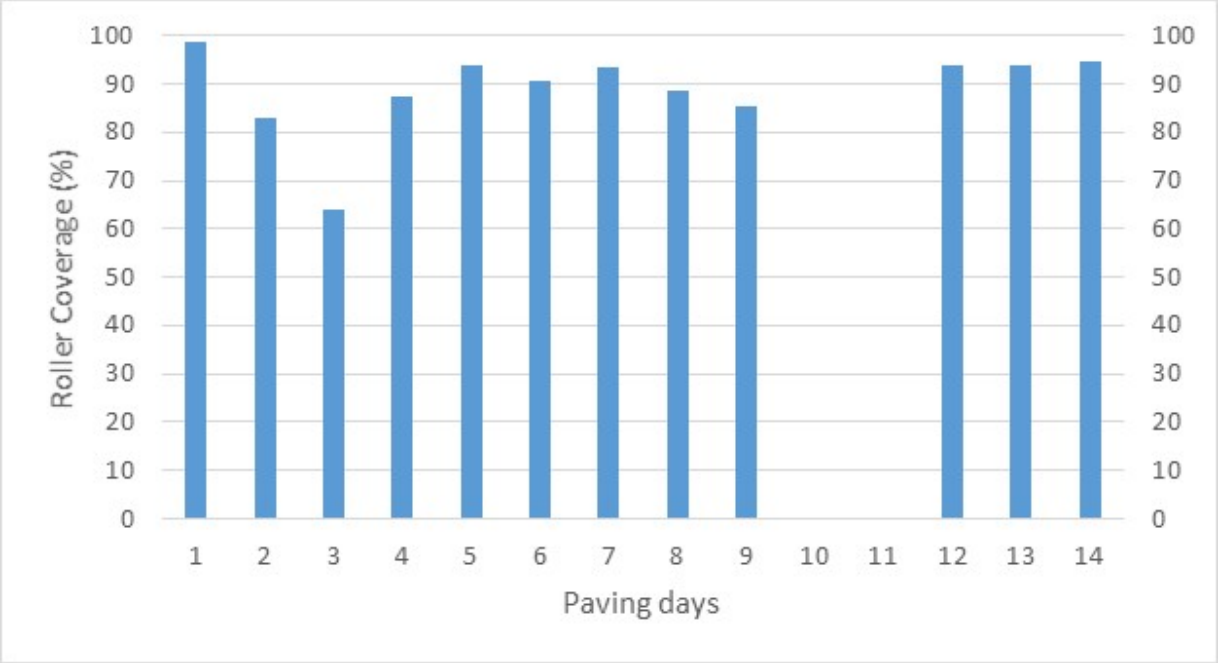


Figure 48: Summary of Roller Coverage Report (Project No. 2 - J1L1800B, RT 139).

Project No. 3 - J1I3169, I-35

Trial Section (10/11/2018)
Optimum Rolling Pattern: The compaction curve is shown in **Error! Reference source not found.**. The rolling pattern established was 5 vibratory passes with two breakdown IC rollers.

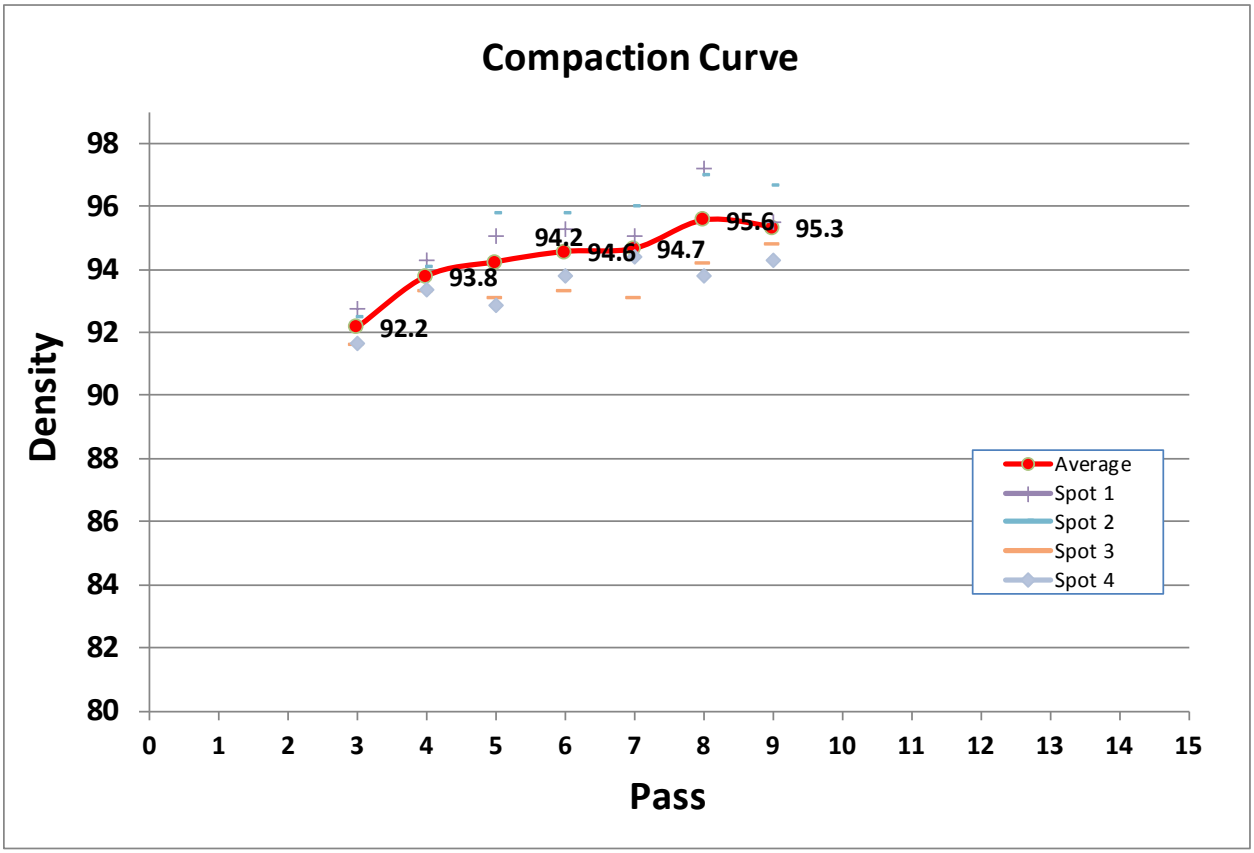


Figure 49: Density Compaction Curve from the Trial Section on 10/11/2018 (Project No. 3 - J1I3169, I-35)

A summary of IR results is shown as follows. Day 11's IR data is missing.

Table 12: Summary of IR Results (Project No. 3 - J1I3169, I-35)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	10/11/2018	4	*23*	11	*65*	2	*12*	5	*31*	9	*56*	2	*13*
2	10/13/2018	8	*36*	11	*50*	3	*14*	26	*51*	18	*35*	7	*14*
3	10/15/2018	18	*62*	11	*38*	0	*0*	47	*72*	14	*22*	4	*6*
4	10/16/2018	62	*68*	29	*32*	0	*0*	69	*74*	23	*25*	1	*1*
5	10/17/2018	7	*41*	8	*47*	2	*12*	7	*44*	7	*44*	2	*13*
6	10/18/2018	62	*72*	24	*28*	0	*0*	66	*78*	19	*22*	0	*0*
7	10/19/2018	40	*45*	22	*25*	26	*30*	50	*51*	40	*41*	8	*8*
8	10/20/2018	9	*12*	25	*35*	38	*53*	32	*45*	33	*46*	6	*8*
9	10/22/2018	14	*54*	12	*46*	0	*0*	12	*46*	13	*50*	1	*4*
10	10/26/2018	4	*50*	3	*38*	1	*12*	8	*40*	9	*45*	3	*15*
11	10/31/2018												
12	11/1/2018	28	*59*	17	*35*	3	*6*	61	*73*	19	*23*	3	*4*
13	11/2/2018	62	*82*	14	*18*	0	*0*	49	*65*	23	*31*	3	*4*
14	11/6/2018	49	*59*	34	*41*	0	*0*	22	*27*	56	*68*	4	*5*
Notes:	*. Missing most of the IR Veta project results. The research team re-run all Veta analysis to obtain results. *. Both the PPM report and Veta files are missing for 2018-10-31												

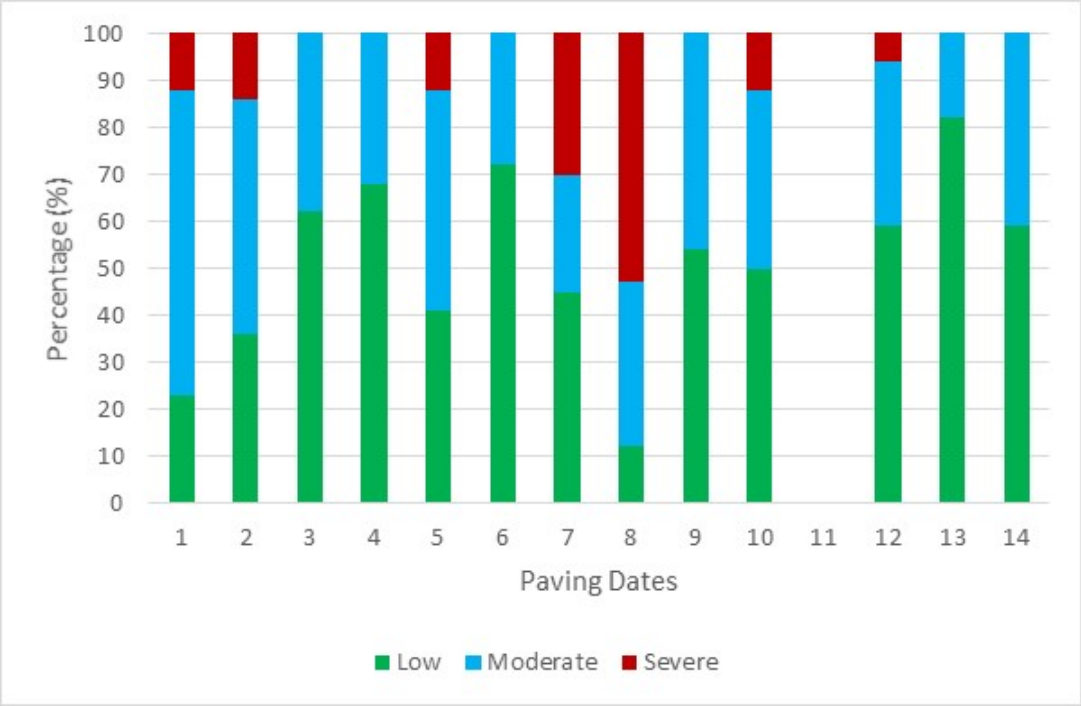


Figure 50: Summary of MOBA PPM Temperature Segregation Report (Project No. 3 - J1I3169, I-35).

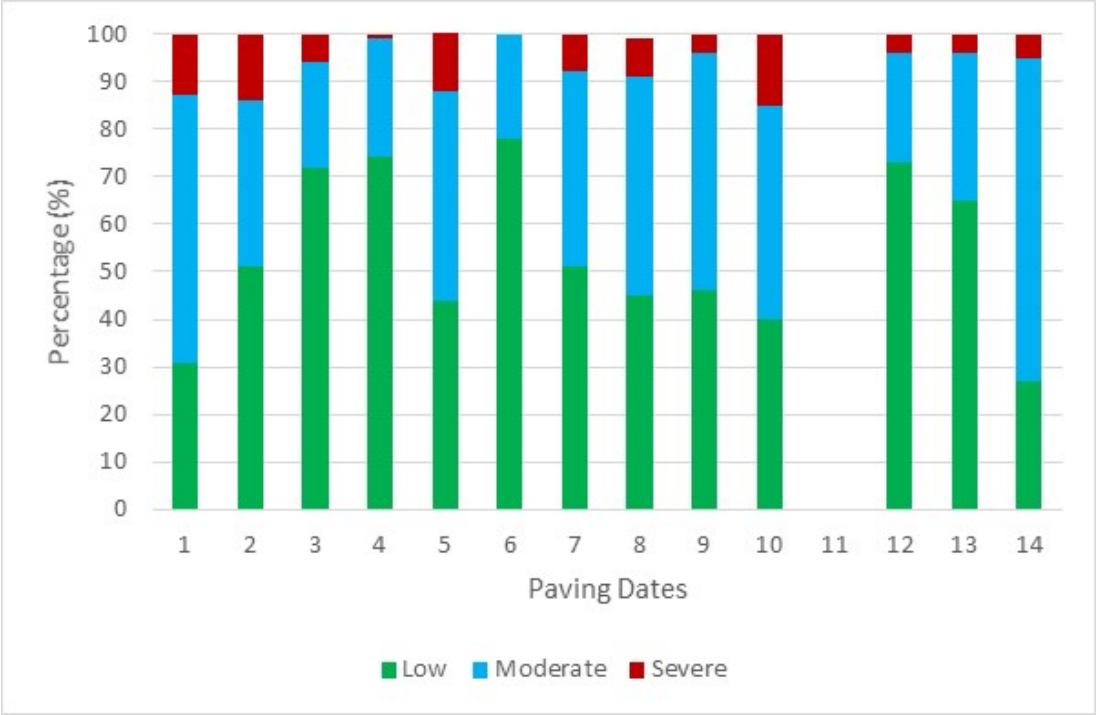


Figure 51: Summary of Veta Temperature Segregation Report (Project No. 3 - J1I3169, I-35). (Missing results)

The followings provide a summary of the roller coverage results. Day No. 3 data is missing.

Table 13: Summary of IC Results (Project No. 3 - J1I3169, I-35)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	10/11/2018	99	Passed	NA	NA	NA	NA
2	10/13/2018	83	Moderate	NA	NA	NA	NA
3	10/15/2018		Failed	NA	NA	NA	NA
4	10/16/2018	60	Failed	NA	NA	NA	NA
5	10/17/2018	76	Moderate	NA	NA	NA	NA
6	10/18/2018	86	Moderate	NA	NA	NA	NA
7	10/19/2018	59	Failed	NA	NA	NA	NA
8	10/20/2018	64	Failed	NA	NA	NA	NA
9	10/22/2018	63	Failed	NA	NA	NA	NA
10	10/26/2018	48	Failed	NA	NA	NA	NA
11	10/31/2018	86	Moderate	NA	NA	NA	NA
12	11/1/2018	86	Moderate	NA	NA	NA	NA
13	11/2/2018	62	Failed	NA	NA	NA	NA
14	11/6/2018	63	Failed	NA	NA	NA	NA

Notes: *Missing IC Veta file for 2018-10-15

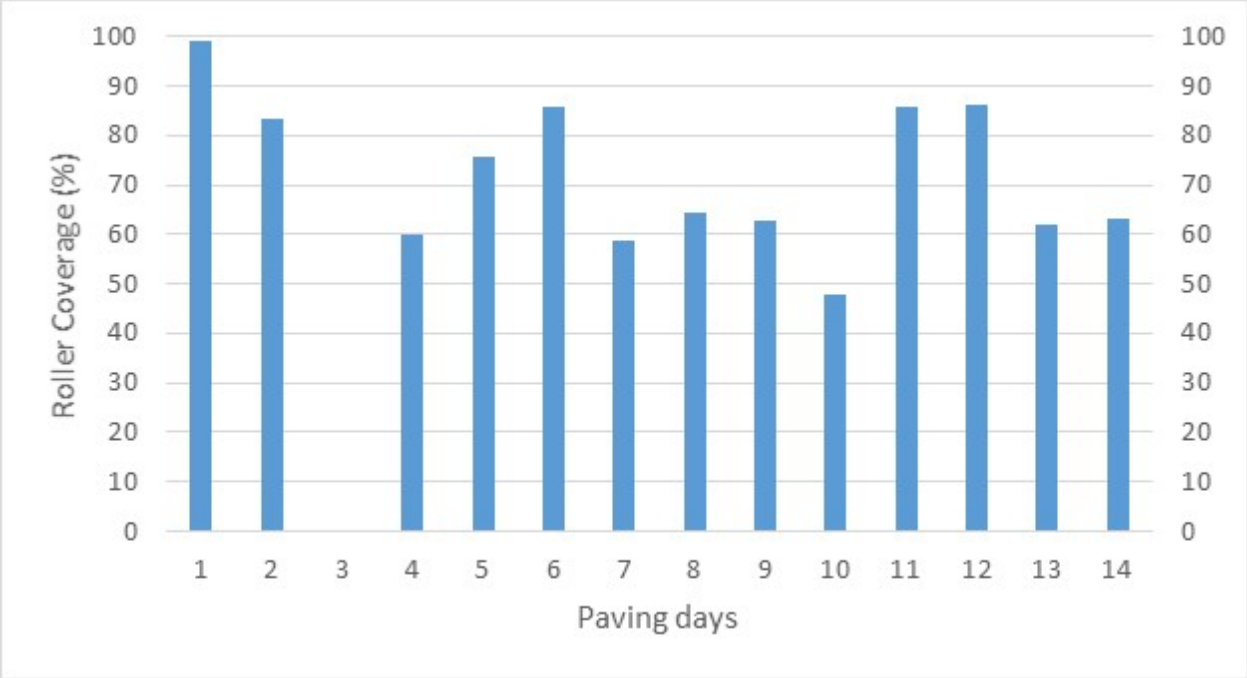


Figure 52: Summary of Roller Coverage Report. (Project No. 3 - J1I3169, I-35)

Project No. 4 - J9P3295, RT 160

Trial Section (9/4/2018)
Optimum Rolling Pattern: Based on the compaction curve of trial section data, the rolling patter is set to be 3 vibratory passes.

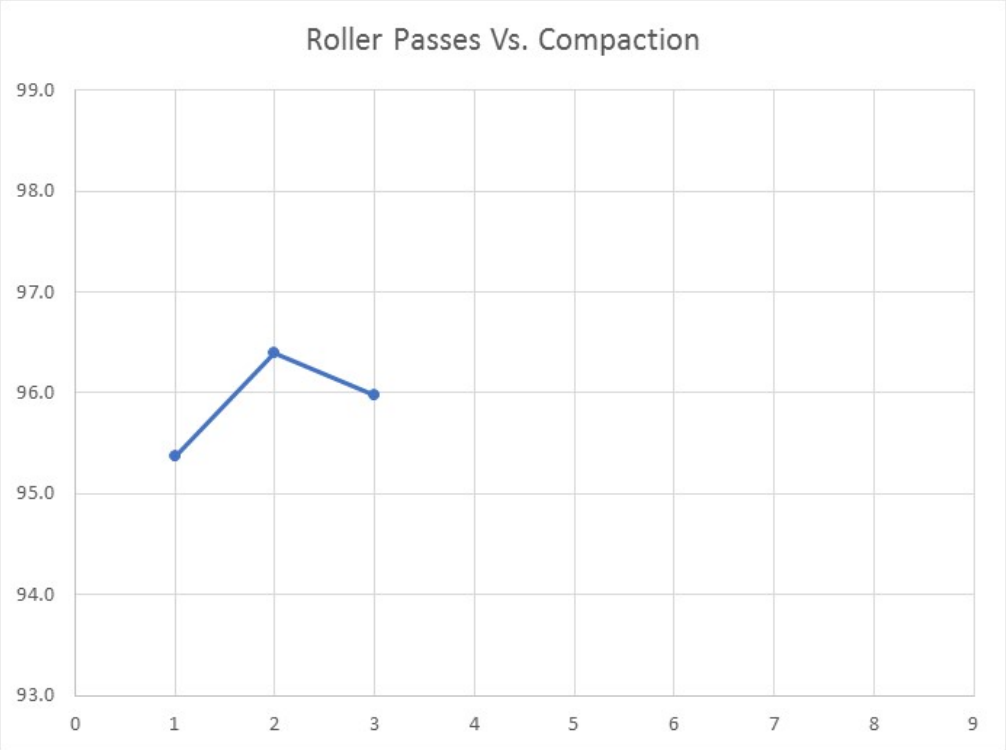


Figure 53: Density Compaction Curve from Trial Section 2018-09-04 (Project No. 4 - J9P3295, RT 160).

A summary of IR results is shown as follows. The temperature segregation was mostly in "No Segregation" and "Moderate Segregation" categories with very limited severe temperature segregation.

Table 14: Summary of IR Results (Project No. 4 - J9P3295, RT 160)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	9/4/2018							25	*20*	87	*69*	15	*12*
2	9/5/2018							31	*26*	72	*62*	14	*12*
3	9/6/2018							26	*22*	57	*49*	33	*28*
4	9/10/2018							27	*17*	101	*65*	27	*17*
5	9/11/2018							64	*42*	67	*44*	20	*13*
6	9/12/2018							73	*48*	59	*39*	19	*13*
7	9/13/2018							57	*35*	82	*50*	26	*16*
8	9/14/2018							65	*39*	79	*47*	24	*14*
9	9/15/2018							53	*40*	56	*42*	23	*17*
10	9/17/2018							74	*43*	75	*44*	22	*13*
11	9/18/2018							67	*44*	66	*43*	19	*13*
12	9/19/2018							28	*31*	42	*47*	20	*22*
Notes:	*There are no MOBA PPM report.												

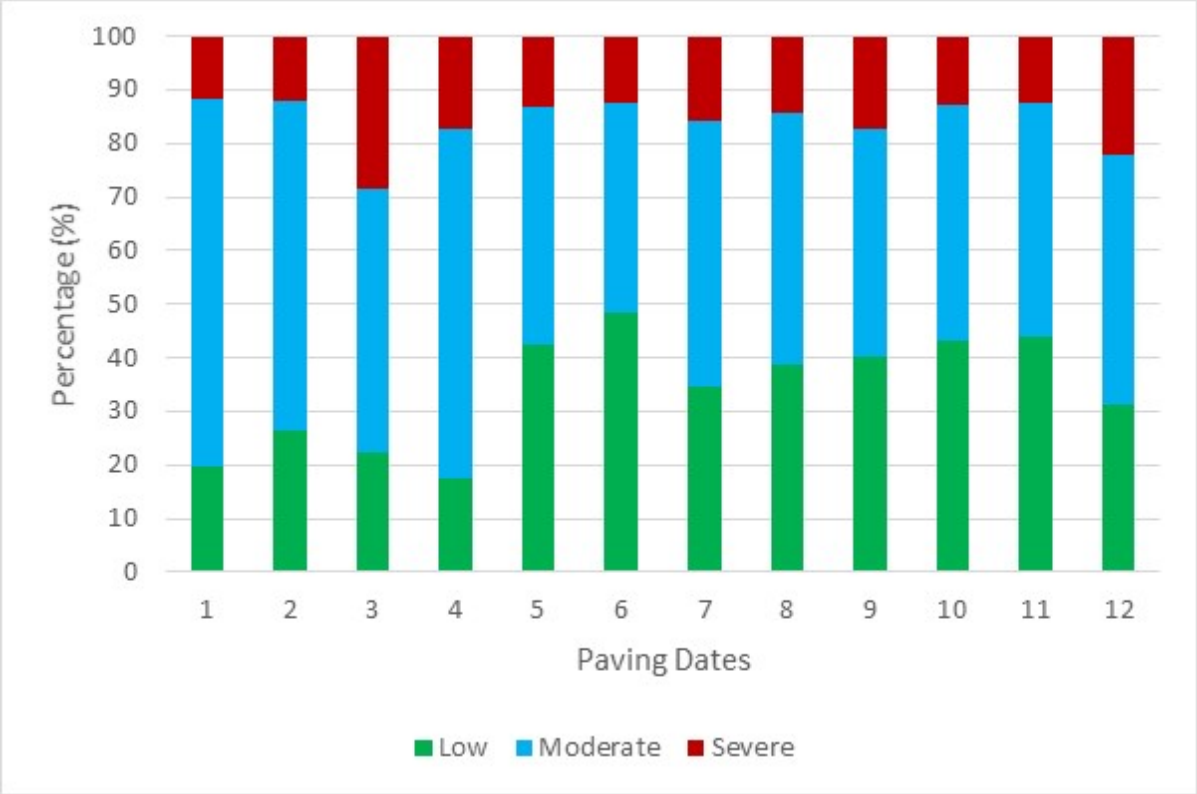


Figure 54: Summary of Veta Temperature Segregation Report (Project No. 4 - J9P3295, RT 160).

The followings provide a summary of the IC results. The roller coverage results were excellent.

Table 15: Summary of IC Results (Project No. 4 - J9P3295, RT 160)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	9/4/2018	90.17	Passed	NA	NA	NA	NA
2	9/5/2018	88.6	Moderate	NA	NA	NA	NA
3	9/6/2018	88.2	Moderate	NA	NA	NA	NA
4	9/10/2018	92.28	Passed	NA	NA	NA	NA
5	9/11/2018	91.04	Passed	NA	NA	NA	NA
6	9/12/2018	95.64	Passed	NA	NA	NA	NA
7	9/13/2018	93.74	Passed	NA	NA	NA	NA
8	9/14/2018	95.72	Passed	NA	NA	NA	NA
9	9/15/2018	97.86	Passed	NA	NA	NA	NA
10	9/17/2018	96.88	Passed	NA	NA	NA	NA
11	9/18/2018	94.53	Passed	NA	NA	NA	NA
12	9/19/2018	88.31	Moderate	NA	NA	NA	NA

Notes: The contractor used 1000-ft sublot reports.
The research team used overal coverage reports for viewing the data trend.

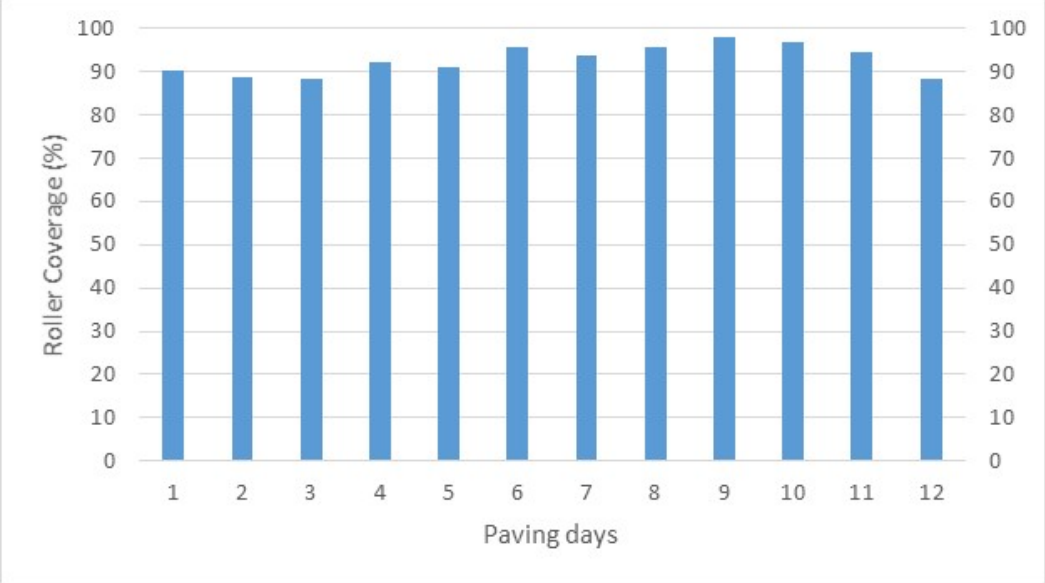


Figure 55: Summary of Roller Coverage Report (Project No. 4 - J9P3295, RT 160).

Project No. 5 - J9P3187, RT 61

Trial Section (9/19/2018)
Optimum Rolling Pattern: Based on the density compaction of the trial section data, the rolling pattern is determined to be 5 vibratory passes with two breakdown rollers.

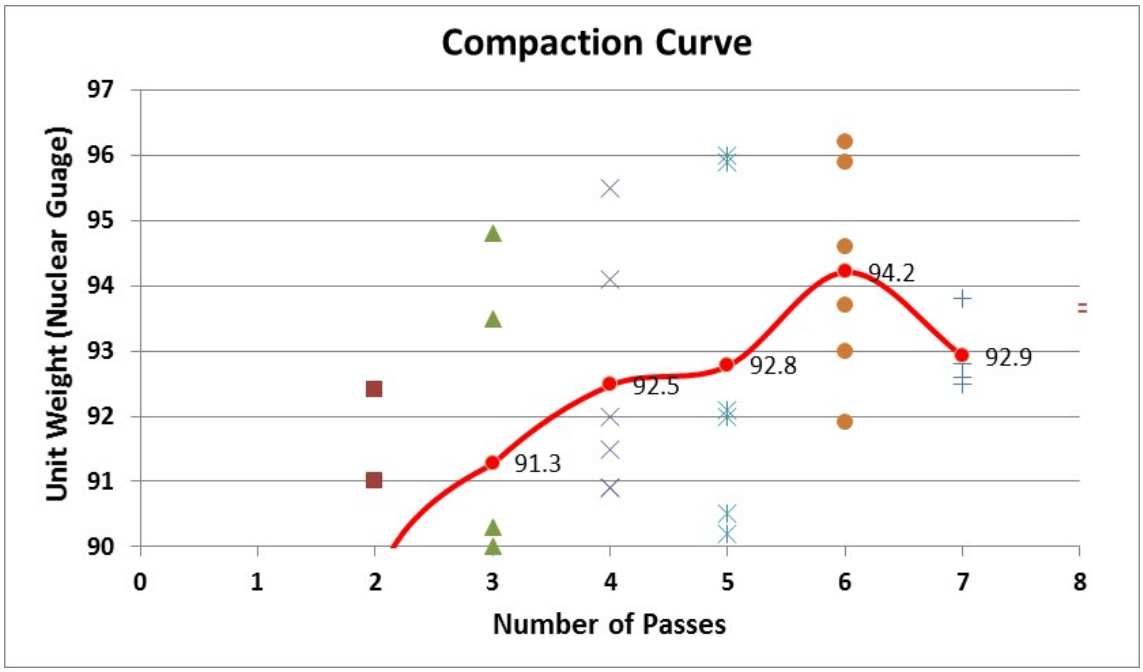


Figure 56: Density Compaction Curve of the Trial Section 2018-09-19 (Project No. 5 - J2P3100, RT 36).

A summary of IR results is shown as follows. The Day No. 13 IR data is missing. The temperature segregation was mixed with the worst results for Day No. 11 and 14.

Table 16: Summary of IR Results (Project No. 5 - J9P3187, RT 61)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	9/19/2018	21	*62*	11	*32*	2	*6*	23	*70*	10	*30*	0	*0*
2	9/20/2018	48	*75*	9	*14*	7	*11*	39	*57*	20	*29*	9	*13*
3	9/25/2018	52	*59*	34	*39*	2	*2*	42	*49*	38	*44*	6	*7*
4	9/26/2018	72	*69*	31	*30*	1	*1*	64	*63*	36	*35*	2	*2*
5	9/27/2018	28	*53*	19	*36*	6	*11*	14	*27*	33	*63*	5	*10*
6	9/28/2018	34	*58*	20	*34*	5	*8*	35	*59*	20	*34*	4	*7*
7	9/29/2018	47	*62*	23	*30*	6	*8*	14	*30*	20	*43*	13	*28*
8	10/1/2018	22	*50*	18	*41*	4	*9*	9	*33*	7	*26*	11	*41*
9	10/2/2018	4	*57*	3	*43*	0	*0*	2	*50*	1	*25*	1	*25*
10	10/3/2018	20	*77*	6	*23*	0	*0*	26	*51*	16	*31*	9	*18*
11	10/4/2018	4	*24*	4	*24*	9	*53*	1	*6*	4	*22*	13	*72*
12	10/5/2018	72	*81*	14	*16*	3	*3*	37	*70*	14	*26*	2	*4*
13	10/6/2018												
14	10/8/2018	10	*26*	11	*29*	17	*45*	10	*26*	18	*47*	10	*26*
15	10/9/2018	20	*43*	13	*28*	14	*30*	18	*44*	9	*22*	14	*34*
16	10/18/2018	26	*37*	26	*37*	19	*27*	10	*77*	2	*15*	1	*8*
17	10/19/2018	39	*65*	18	*30*	3	*5*	37	*62*	22	*37*	1	*2*
18	10/20/2018	8	*15*	25	*45*	22	*40*	12	*22*	21	*39*	21	*39*
19	10/23/2018	23	*59*	10	*26*	6	*15*	25	*57*	9	*20*	10	*23*
20	10/24/2018	30	*59*	14	*27*	7	*14*	32	*62*	11	*21*	9	*17*
21	10/26/2018	8	*15*	30	*58*	14	*27*	16	*32*	27	*54*	7	*14*
22	10/27/2018	11	*21*	25	*47*	17	*32*	23	*44*	22	*42*	7	*13*
23	10/29/2018	36	*56*	21	*33*	7	*11*	39	*59*	20	*30*	7	*11*
24	10/30/2018	2	*40*	1	*20*	2	*40*	3	*75*	1	*25*	0	*0*
25	11/2/2018	16	*31*	27	*52*	9	*17*	20	*38*	21	*40*	12	*23*
26	11/3/2018	8	*19*	27	*63*	8	*19*	16	*31*	29	*56*	7	*13*
Notes:	* Veta results are for information only. * The Veta project files submitted by the contractor use incorrect filters. * The research re-run all Veta analysis to obtain the results. *. Most of the Veta IC analysis has combined all lanes paved within the same day. *. 2018-10-18 Veta analysis uses only SBDL data since the NBDL raw data is missing.												

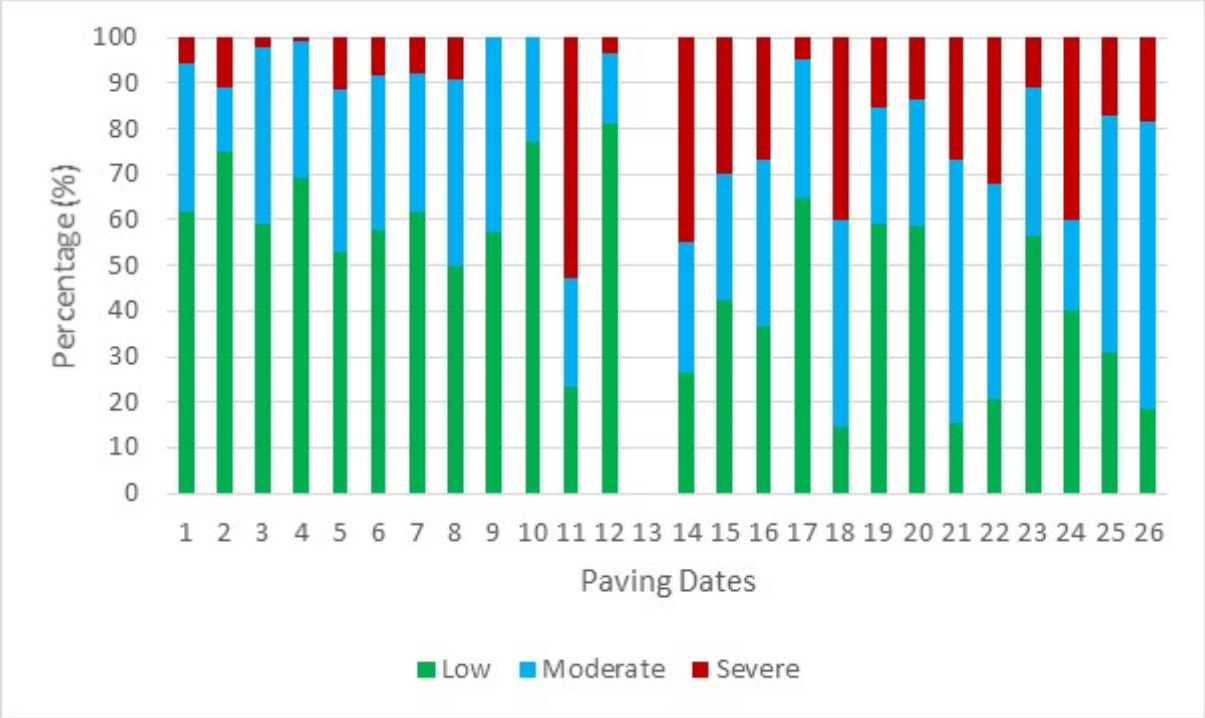


Figure 57: Summary of MOBA PPM Temperature Segregation Report (Project No. 5 - J9P3187, RT 61).

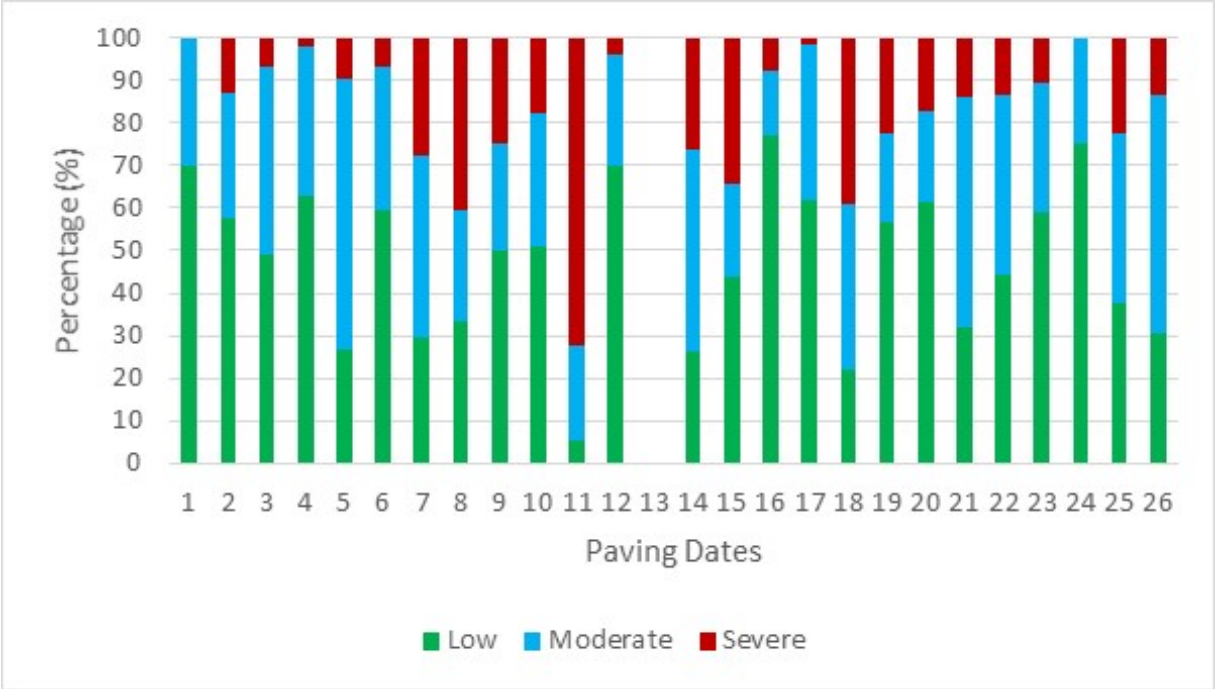


Figure 58: Summary of Veta Temperature Segregation Report (Project No. 5 - J9P3187, RT 61).

The following provide a summary of the IC results. The roller coverage results were mixed without apparent trends for improvements. There were low coverages on multiple days.

Table 17: Summary of IC Results (Project No. 5 - J9P3187, RT 61)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverag	Classification
1	9/19/2018	86	Moderate	52	Failed	7	Failed
2	9/20/2018	49	Failed	51	Failed	17	Failed
3	9/25/2018	83	Moderate	37	Failed	13	Failed
4	9/26/2018	79	Moderate	43	Failed	11	Failed
5	9/27/2018	60	Failed	28	Failed	9	Failed
6	9/28/2018	59	Failed	13	Failed	19	Failed
7	9/29/2018	49	Failed	14	Failed	50	Failed
8	10/1/2018	68	Failed	9	Failed	25	Failed
9	10/2/2018	86	Moderate	13	Failed	20	Failed
10	10/3/2018	88	Moderate	16	Failed	13	Failed
11	10/4/2018	81	Moderate	15	Failed	2	Failed
12	10/5/2018	79	Moderate	37	Failed	10	Failed
13	10/6/2018	79	Moderate	14	Failed	21	Failed
14	10/8/2018	44	Failed	54	Failed	1	Failed
15	10/9/2018	44	Failed	54	Failed	1	Failed
16	10/18/2018	87	Moderate	25	Failed	1	Failed
17	10/19/2018	83	Moderate	21	Failed	0	Failed
18	10/20/2018	80	Moderate	24	Failed	1	Failed
19	10/23/2018	88	Moderate	66	Failed	54	Failed
20	10/24/2018	90	Moderate	34	Failed	0	Failed
21	10/26/2018	84	Moderate	30	Failed	0	Failed
22	10/27/2018	56	Failed	34	Failed	1	Failed
23	10/29/2018	51	Failed	26	Failed	1	Failed
24	10/30/2018	36	Failed	18	Failed	0	Failed
25	11/2/2018	46	Failed	44	Failed	2	Failed
26	11/3/2018	64	Failed	34	Failed	4	Failed

Notes:

*The contractor submitted the data files to the Shared Point in incorrect folders.
*There are no IC summary results (e.g., roller overage) provided by the contractor.
The research team have to re-run all Veta analysis to obtain the summary results.
*The target passes are 7 vibratory passes with 3 rollers.
*The target EDV is 60 for 70% of the compacted areas.
*The minimum temperature is 225F for the vibratory passes.
* 2018-10-20 only NBDL2-3 data is analyzed due to missing data.
*. 2018-10-29 IC coverage has issues due to incorrect boundary files for NBPL.
*. The low compaction temperature data need to be investigated for Days 11,15-18, 20-26

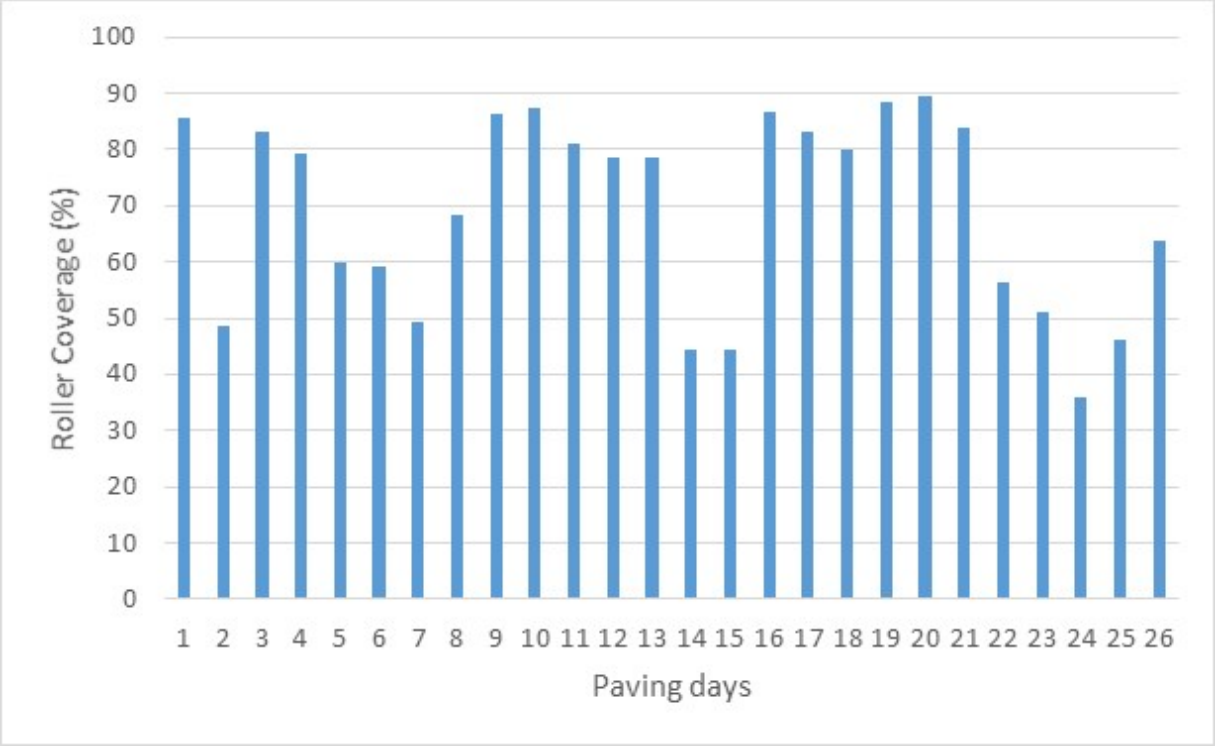


Figure 59: Summary of Roller Coverage Report (Project No. 5 - J9P3187, RT 61).

Project No. 6 - J8S3074, RT CC

Trial Section (7/26/2018)
Optimum Rolling Pattern: The density compaction curve was not provided by the contractor, though the trial section data exist. The rolling pattern is set to 7 vibratory passes with two breakdown rollers.

A summary of IR results is shown as follows. There were no MOBA PPM reports. The Day No. 1 IR data is missing.

Table 18: Summary of IR Results (Project No. 6 - J8S3074, RT CC)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	8/1/2018												
2	8/2/2018							42	*55*	18	*24*	16	*21*
3	8/3/2018							46	*62*	18	*24*	10	*14*
4	8/6/2018							34	*72*	10	*21*	3	*6*
5	8/7/2018							20	*57*	13	*37*	2	*6*
Notes:	*. Veta results are for information only. * No MOBA PPM results												

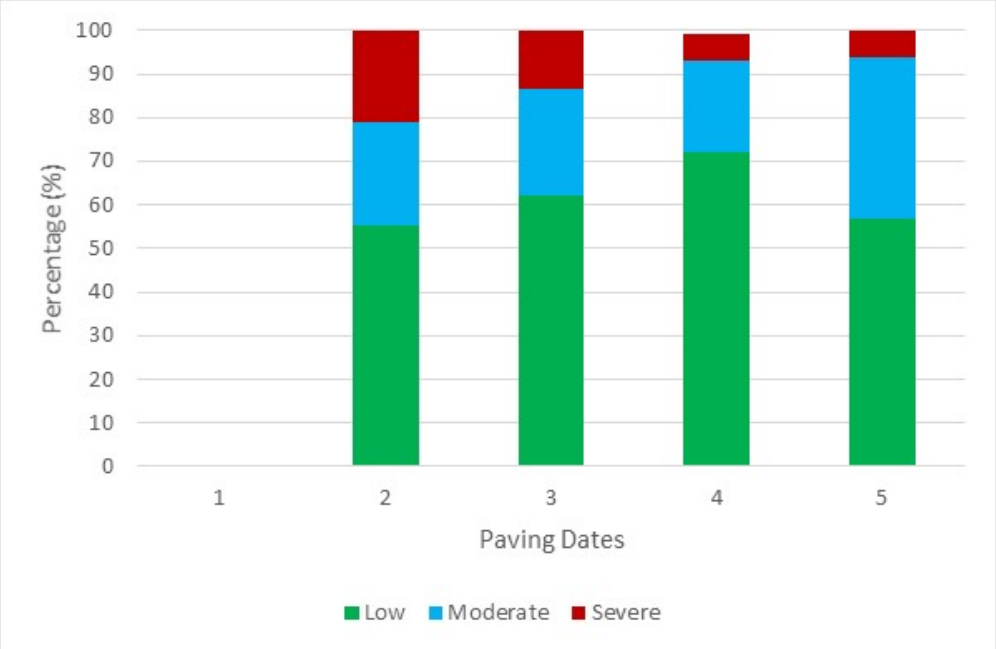


Figure 60: Summary of Veta Temperature Segregation Report (Project No. 6 - J8S3074, RT CC).

The followings provide a summary of the roller coverage results. The roller coverage is extremely poor.

Table 19: Summary of IC Results (Project No. 6 - J8S3074, RT CC)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	8/1/2018	0	Failed	NA	NA	0	Failed
2	8/2/2018	15.6	Failed	NA	NA	18	Failed
3	8/3/2018	25.5	Failed	NA	NA	14	Failed
4	8/6/2018	12	Failed	NA	NA	23	Failed
5	8/7/2018	93	Passed	NA	NA	32	Failed

Minimum temperature for the vibratory pass is 225F.

Notes: 8/1/2018 missing results.

* one of the roller temperature gauge is not functioning.

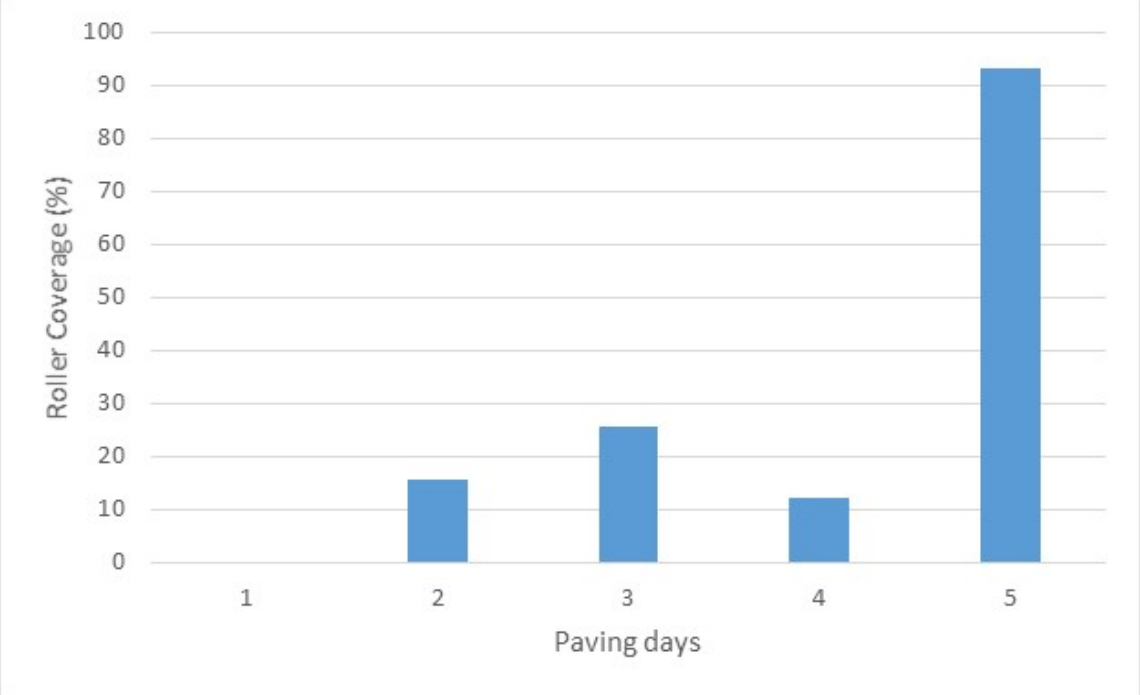


Figure 61: Summary of Roller Coverage Reports (Project No. 6 - J8S3074, RT CC.

Project No. 7 - J8S3075, RT M

Optimum Rolling Pattern: No compaction curve is provided. The rolling pattern is 7 vibratory passes with two breakdown rollers.

A summary of IR results is shown as follows.

Table 20: Summary of IR Results (Project No. 7 - J8S3075, RT M)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	8/8/2018	0	0	0	0	0	0	29	71	8	20	4	10
2	8/9/2018	0	0	0	0	0	0	42	55	18	24	16	21
Notes:	*. Veta results are for information only. * No MOBA PPM results												

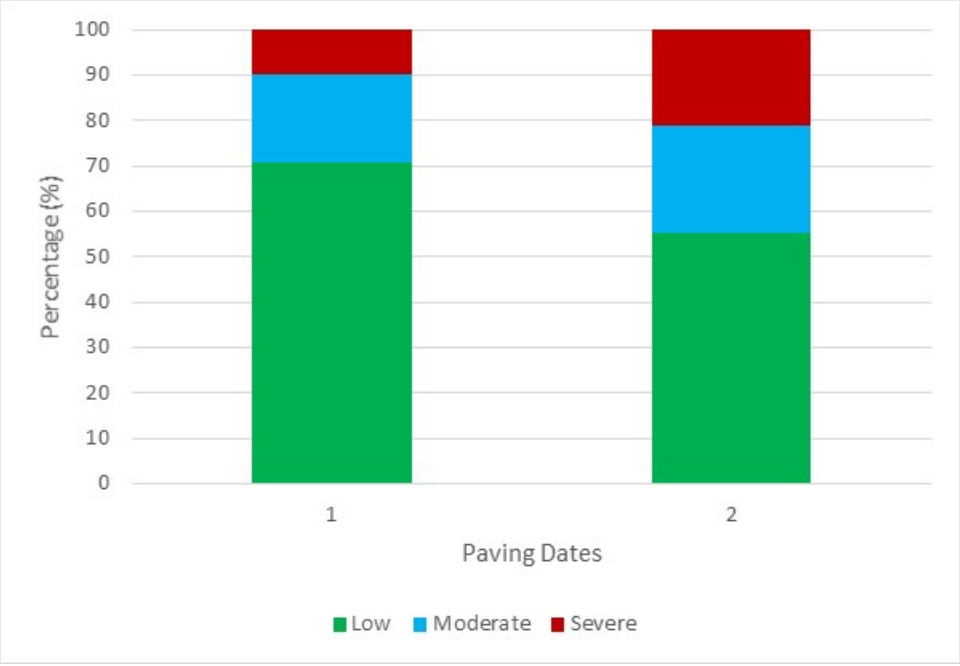


Figure 62: Summary of Veta Temperature Segregation Report (Project No. 7 - J8S3075, RT M).

The followings provide a summary of the IC results. The roller passes coverage is either missing or extremely poor.

Table 21: Summary of IC Results (Project No. 7 - J8S3075, RT M)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	8/8/2018	0	Failed	NA	NA	0	Failed
2	8/9/2018	15.6	Failed	NA	NA	18	Failed
Notes:		Minimum temperature for the vibratory pass is 225F. 8/1/2018 missing results. * one of the roller temperature gauge is not functioning.					

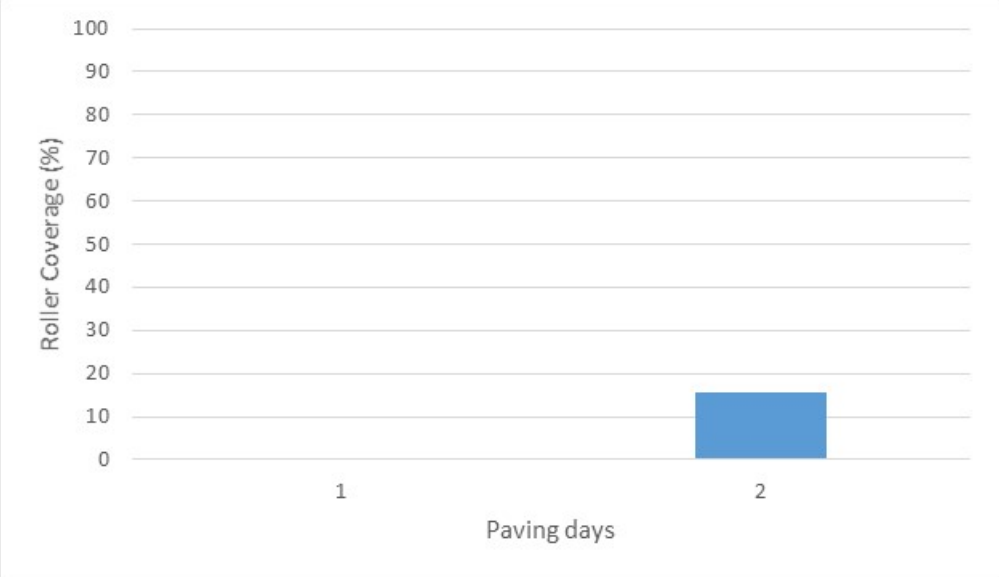


Figure 63: Summary of Roller Coverage Report (Project No. 7 - J8S3075, RT M).

Project No. 8 - J 8P3051B, RT 160

Trial Section (7/26/2018)
Optimum Rolling Pattern: The compaction curve was plotted based on the trial section data as follows. The rolling pattern is 7 vibratory passes with tow breakdown rollers.

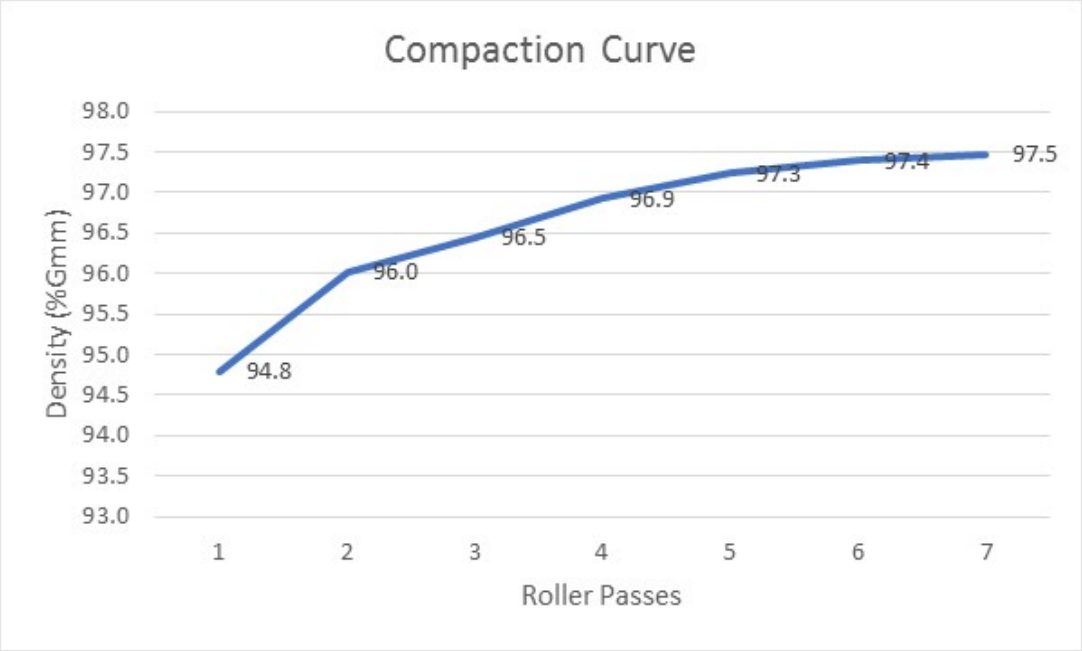


Figure 64: Compaction Curve from the Trial Section on 7/26/2018 (Project No. 8 - J 8P3051B, RT 160).

A summary of IR results is shown as follows. There were missing IR results or poor results.

Table 22: Summary of IR Results (Project No. 8 - J 8P3051B, RT 160)

Day	Date	MOBA PPM						Veta*					
		Low		Moderate		Severe		Low		Moderate		Severe	
		#	%	#	%	#	%	#	%	#	%	#	%
1	7/26/2018	5	*56*	3	*33*	1	*11*	5	*56*	3	*33*	1	*11*
2	7/27/2018	0	*0*	0	*0*	17	*100*	0	*0*	0	*0*	17	*100*
3	7/31/2018	0	*0*	0	*0*	0	*0*	33	*79*	4	*10*	5	*12*
Notes:	*. Veta results are for information only. *7/27/2018 missing data counted as failed. *7/31/2018 Missing MOBA PPM report.												

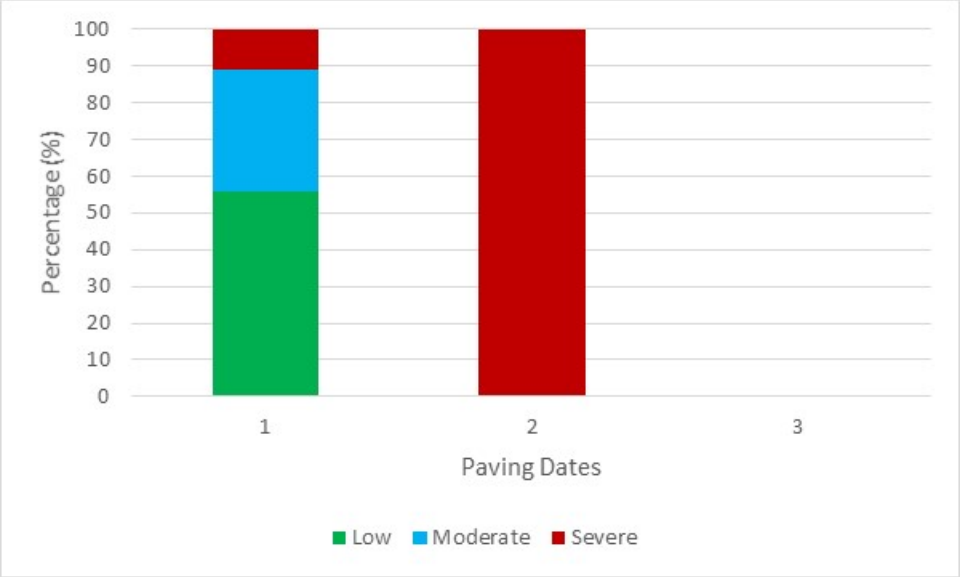


Figure 65: Summary of MOBA PPM Temperature Segregation Report (Project No. 8 - J 8P3051B, RT 160).

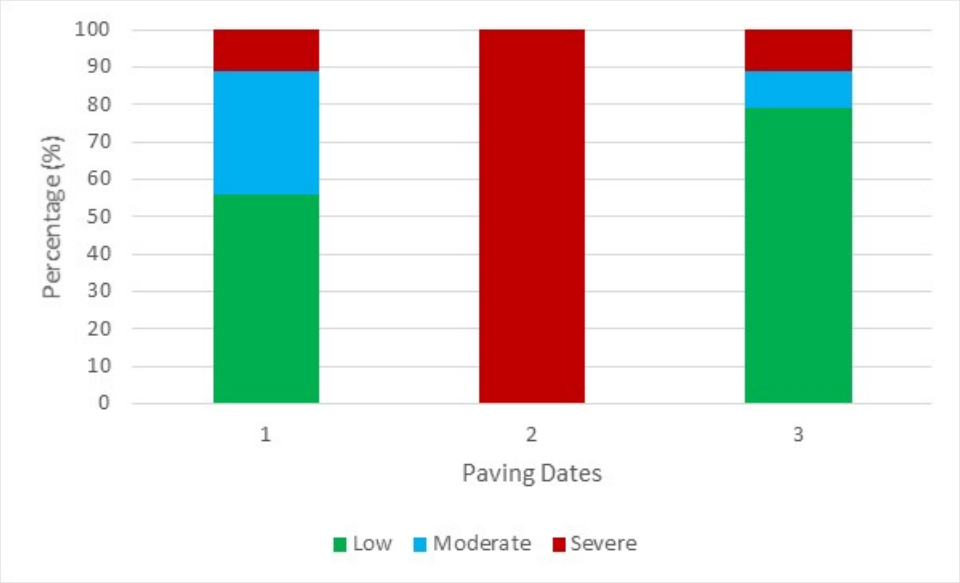


Figure 66: Summary of Veta Temperature Segregation Report (Project No. 8 - J 8P3051B, RT 160).

The followings provide a summary of the roller coverage results. The roller coverage results were inconsistent.

Table 23: Summary of IC Results (Project No. 8 - J 8P3051B, RT 160).

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	7/26/2018	54.7	Failed	NA	NA	34	Failed
2	7/27/2018	98.3	Passed	NA	NA	27.1	Failed
3	7/31/2018	18.7	Failed	NA	NA	3.9	Failed

Notes:

Minimum temperature for the vibratory pass is 225F

*. 7/31/2018 Roller 1197 operates mostly in static mode.

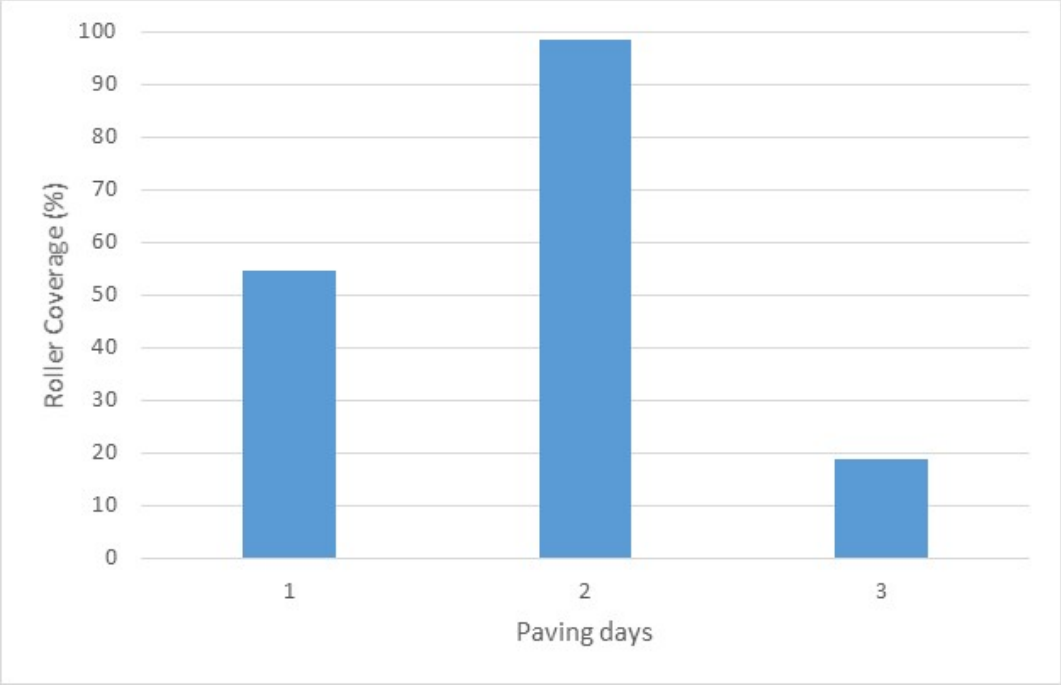


Figure 67: Summary of Roller Coverage Report (Project No. 8 - J 8P3051B, RT 160).

Project No. 9 - J5S3207, RT 54

Trial Section (10/22/2018)

Optimum Rolling Pattern: The compaction curve is shown as follows based on the trial section data. The rolling pattern established was 5 vibratory passes with two breakdown rollers.

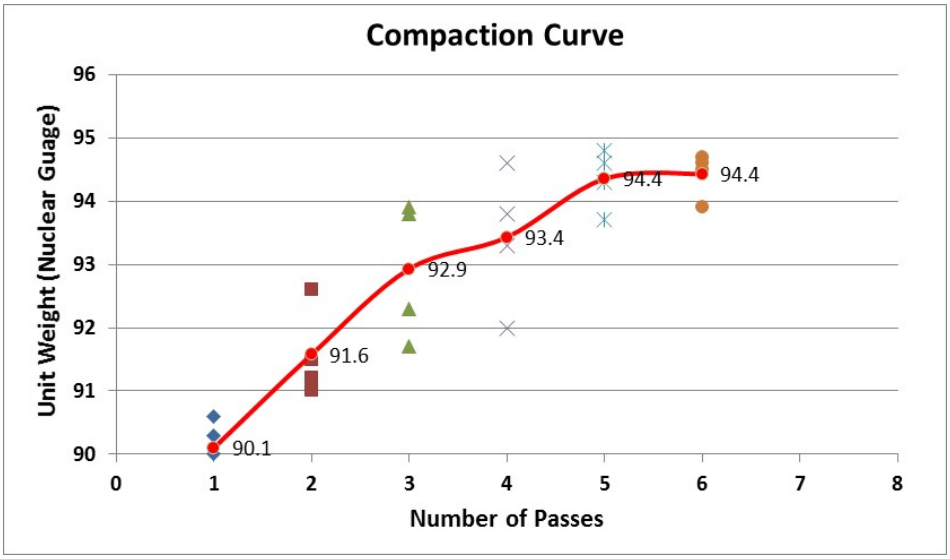


Figure 68 Compaction Curve– Trial Section (10/22/2018) (Project No. 9 - J5S3207, RT 54)

A summary of IR results is shown as follows. There was inconsistent result between MOBA PPM and Veta for Day No. 4. Further investigation is warranted.

Table 24: Summary of IR Results (Project No. 9 - J5S3207, RT 54)

Day	*Date*	*MOBA PPM*						*Veta**					
		Low		*Moderate*		*Severe*		*Low*		*Moderate*		*Severe*	
		#	*%*	*#*	*%*	*#*	*%*	*#*	*%*	*#*	*%*	*#*	*%*
1	10/22/2018	22	*37*	35	*58*	3	*5*	19	*33*	32	*55*	17	*12*
2	10/23/2018	6	*18*	26	*79*	1	*3*	2	*6*	27	*87*	2	*6*
3	10/24/2018**	1	*2*	31	*76*	9	*22*	2	*5*	20	*51*	17	*44*
4	10/29/2018	1	*8*	10	*77*	2	*15*	0	*0*	1	*8*	11	*93*
5	11/2/2018	4	*15*	8	*31*	14	*54*	4	*16*	7	*28*	14	*56*
6	11/7/2018	2	*4*	42	*84*	6	*12*	3	*6*	39	*80*	7	*14*
	Totals	36		152		35		30		126		68	
Notes:	*Veta results are for information only. **Pavement too wide to pave in one pass, MOBA was not stopped/halted during backing up periods on 20181024. There are discrapancy between the MOBA and Veta results from 20181029. The contractor's IR Veta file doesn't not chekc the data lot name for the filter group. The research team corrected the filter and re-run the analysis to obtain the results. It was observed that there are a lot of cold treaks in the thermal profiles. Further investigation is waranted. Contractor's IR Veta file on 20181102 does not check the "Remove paver stop areas from analysis". The research team has re-run the analysis and produce the above results.												

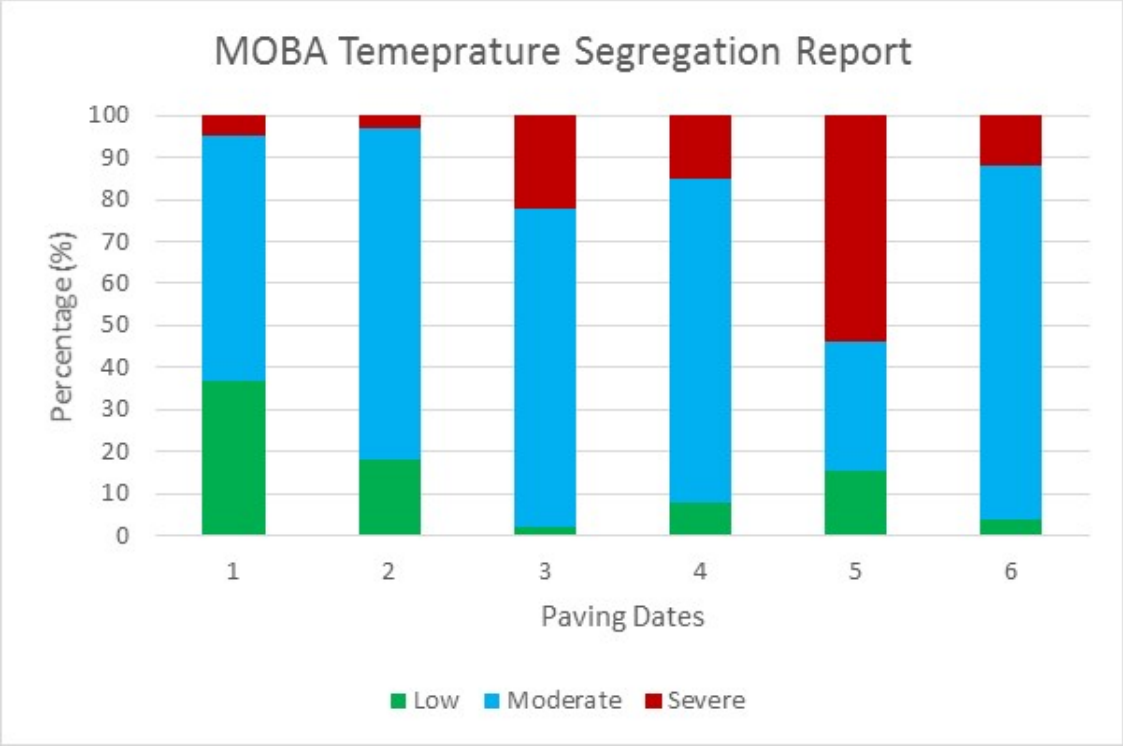


Figure 69: Summary of MOBA PPM Temperature Segregation Report (Project No. 9 - J5S3207, RT 54).

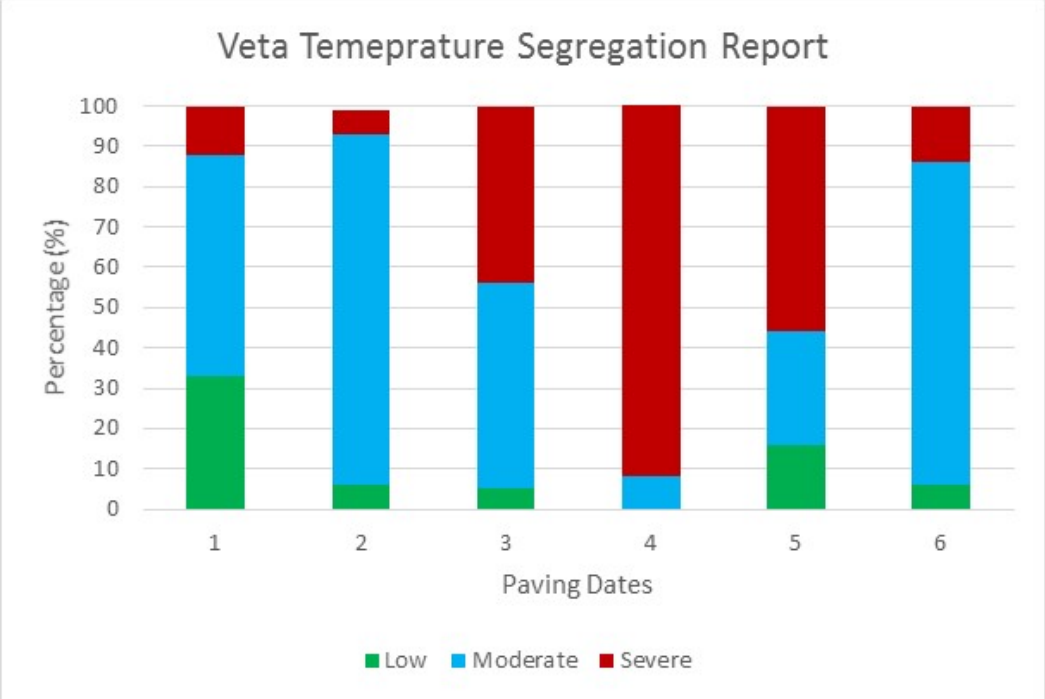


Figure 70: Summary of Veta Temperature Segregation Report (Project No. 9 - J5S3207, RT 54).

The followings provide a summary of the IC results. The roller coverages were poor for Day No. 4, 5, and 6.

Table 25: Summary of IC Results (Project No. 9 - J5S3207, RT 54)

No.	*Date*	*Target Passes*		*Target ICMV*		*Temperature for vibratory passes*	
		% Coverage	Classification	% Coverage	Classification	% Coverage	Classification
1	10/22/2018	69.5	Failed	49.75	Failed	38.68	Failed
2	10/23/2018	72	Moderate	48.38	Failed	63.87	Failed
3	10/24/2018	80.3	Moderate	28.9	Failed	42.79	Failed
4	10/29/2018	13.4	Failed	43.07	Failed	58.23	Failed
5	11/2/2018	29.1	Failed	24	Failed	90.31	Failed
6	11/7/2018	60.8	Failed	28.6	Failed	90.14	Failed
Notes:	*Data from Roller 2 was not recorded for 20181029 nor 20181102. The contractor's IC Veta files fail to use "vib only" data filter. The reseach team performed data QA on the IC data analysis from all days.						

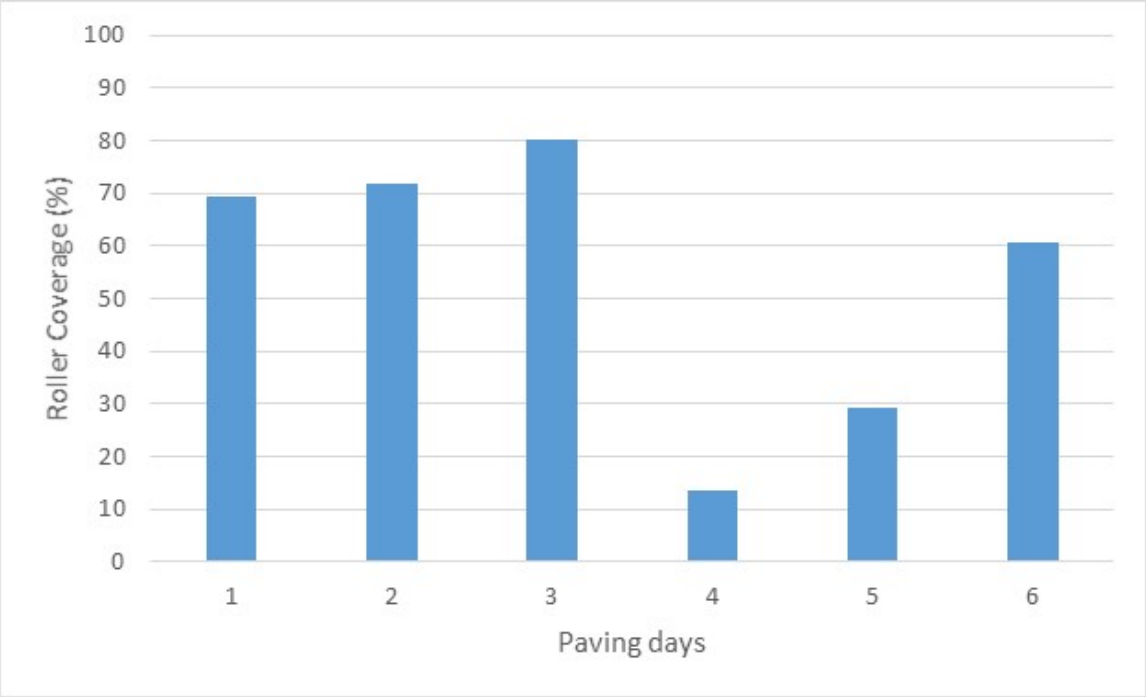


Figure 71: Summary of Roller Coverage Report (Project No. 9 - J5S3207, RT 54).

Comparison of IC-IR Results

The comparison of the IR results for all projects is as follows.

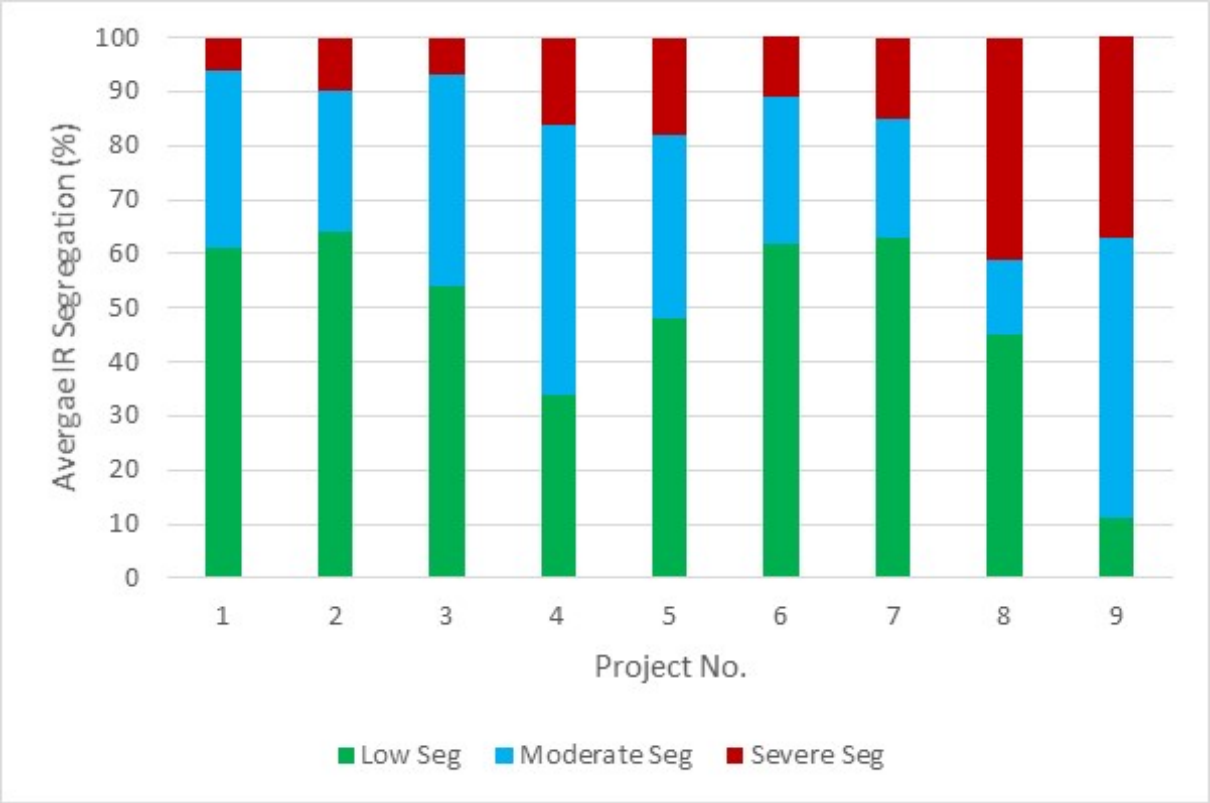


Figure 72: Comparison of IR Segregation for all projects.

The comparison of the IR results for all contractors is as follows.

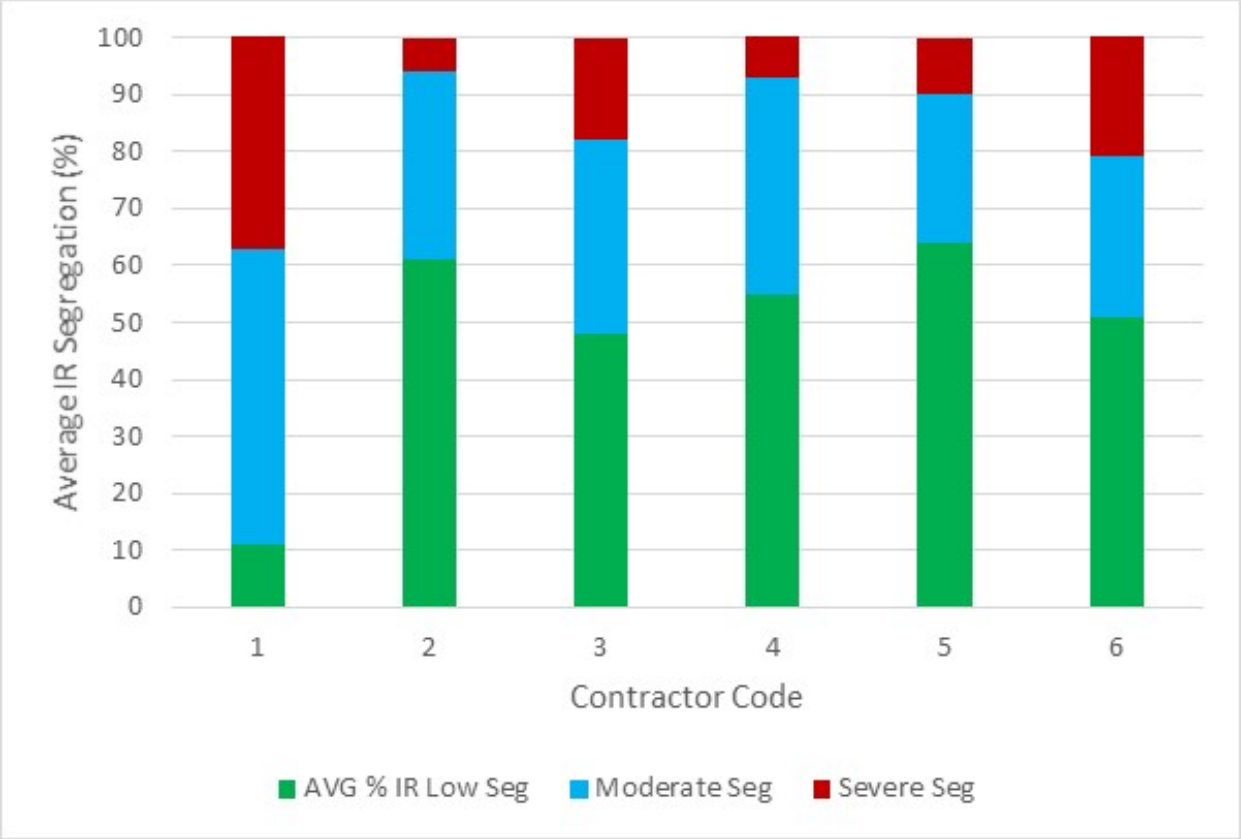


Figure 73: Comparison of IR Segregation for projects by coded contractors.

The comparison of the IC results for all projects is as follows.

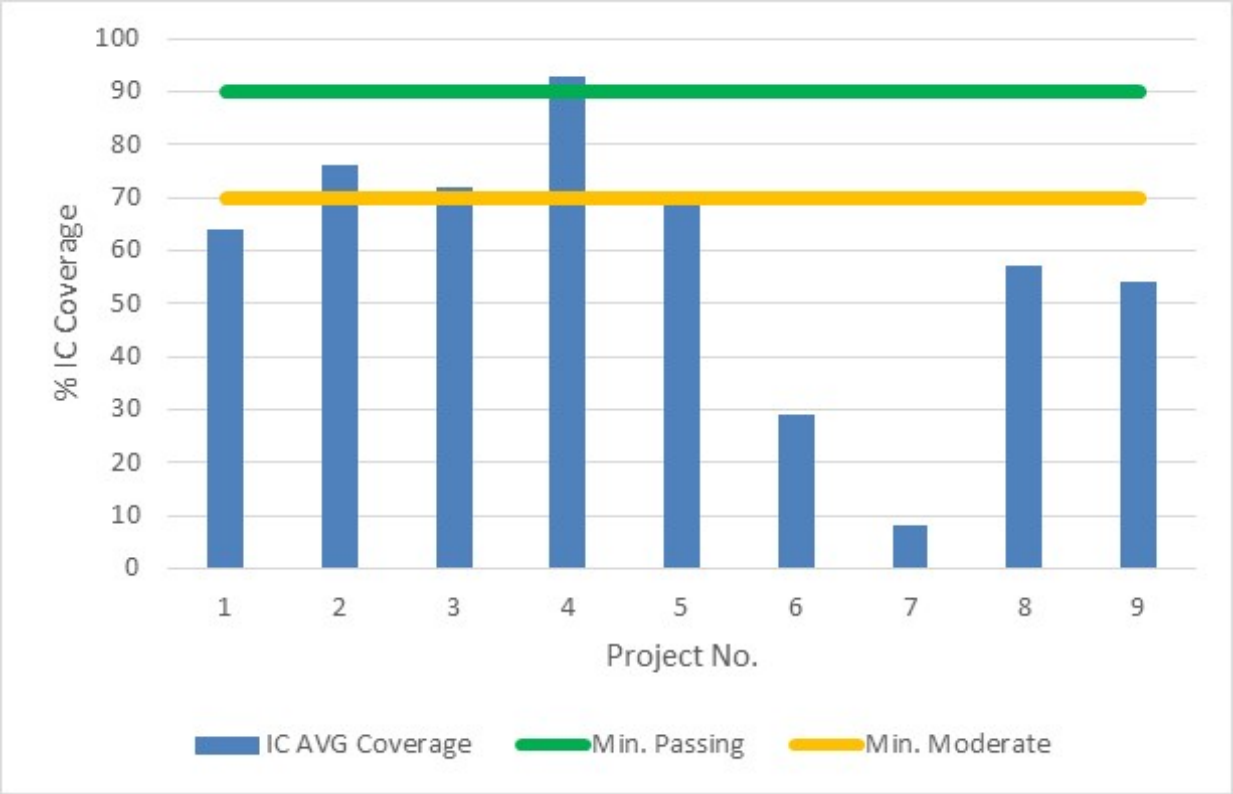


Figure 74: Comparison of IC Coverage for all projects.

The comparison of the IC results for all contractors is as follows.

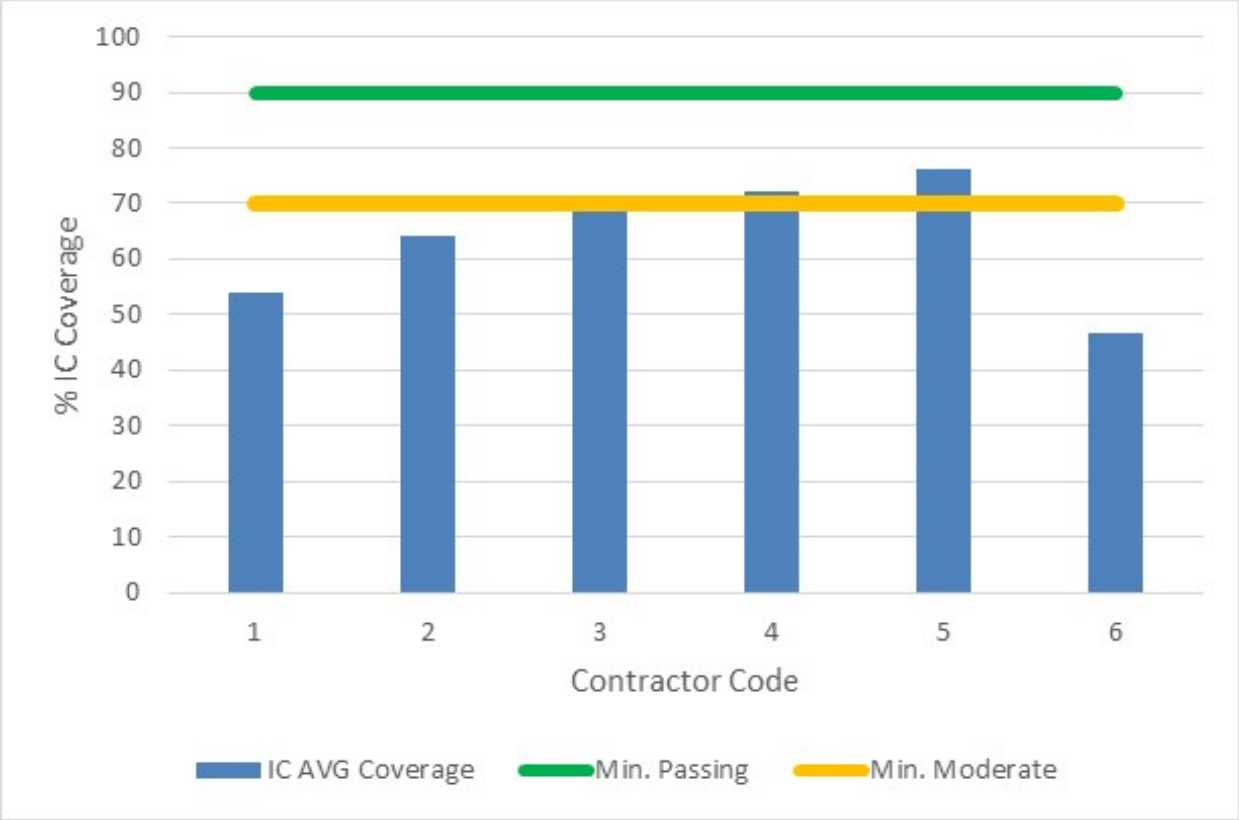


Figure 75: Comparison of IC Coverage for projects by coded contractors.

Project Evaluation

The field projects were evaluated on various aspects as follow.

GPS Verification

- GPS verification and record keeping has mostly been done by contractors.

GPS and Cellular Signal Coverage

- GPS and cellular signal coverage have not been serious issues.

Functioning of IC Equipment and System

- 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. The roller pass count coverage has been satisfactory to poor.

Functioning of IR Equipment and System

- Similar to those in 2017, there was only one IR system used for these projects (i.e., MOBA). It is expected to have more other IR systems available in 2019.
- There were still issues regarding lack of technical training and support from vendors' dealers. Several system malfunctioning occurred.

Paving Boundary Measurements

- The paving boundary measurements were still using hand-held GPS rover which is time consuming and labor intensive.
- There were several occasions when contractors' make errors for the GPS boundary measurements and record keeping.

IC Data Collection and Submission

- Most IC data collection were conducted properly.
- The data submission to the MODOT SharePoint has been issues when contractors uploaded to incorrect folders. The research team had to spend a lot of time and efforts to re-organize the data files and rename them according to the naming convention in the MoDOT IC-IR Protocol.

IR Data Collection and Submission

- Most IR data collection were conducted properly.
- The data submission to the MODOT SharePoint has been issues when contractors uploaded to incorrect folders. The research team had to spend a lot of time and efforts to re-organize the data files and rename them according to the naming convention in the MoDOT IC-IR Protocol.

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

- Trial section data were mostly recorded for these projects.

Completion of Check list

- Contractor's check list is mostly completed which is the biggest improvement from those in 2017.
- RE's check list and diary are still missing.
- The daily paving records were only provided by several contractors.

Utilization of Full Capabilities of IC and IR Systems

- Based on the roller coverage reports, most contractors' roller operators have not paid a lot of attention to achieve required roller passes. It is a step back from those in 2017.

IC-IR Training Workshops

- There was only one IC-PMTP training has been conducted during the 2018 construction season.
- Most the contractors who have been trained in 2017 have mostly forgotten the knowledge. It took them awhile to get familiar with IC, PMTP and Veta again.
- It is recommended to conduct refresh classes for contractors in 2019.

IC-IR Data Completion

There are missing IR data at several projects which may due to malfunctioning of the PMTP systems.
There are also several missing IC data due to missing files and malfunctioning sensors (such as: temperature sensors).

Table 26. Completion of IC-IR Data Collection.

Project No.	Job No.	District	County	Route	Trial Section Data	IR Data	IC Data	GPS Data
1	4S3153	KC	Jackson	71	Y	Y	P	Y
2	1L1800B	NW	Putnam	139	Y	Y	Y	Y
3	1I3169	NW	Harrison	35	Y	P	P	Y
4	9P3295	SE	Ozark	160	Y	P	Y	Y
5	9P3187	SE	Cape Girar	61	Y	P	P	Y
6	8S3074	SW	Christian	CC	Y	P	Y	Y
7	8S3075	SW	Christian	M	Y	P	Y	Y
8	8P3051B	SW	Greene	160	Y	P	Y	Y
9	J5S3207	CD	Callaway	54	Y	Y	P	Y

IC-IR Check List and Form Completion

Most Res have not submitted check list and diary.
Most contractors have performed their analyses. Though they still make errors in analysis steps and settings, this is encouraging.

Table 27. 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	2	4S3153	KC	Jackson	71	N	N	Y	N	N
2	9	1L1800B	NW	Putnam	139	Y	Y	Y	P	P
3	7	1I3169	NW	Harrison	35	Y	Y	Y	Y	P
4	10	9P3295	SE	Ozark	160	Y	Y	Y	N	N
5	3	9P3187	SE	Cape Girar	61	N	N	P	N	N
6	10	8S3074	SW	Christian	CC	Y	Y	Y	N	N
7	10	8S3075	SW	Christian	M	Y	Y	Y	N	N
8	10	8P3051B	SW	Greene	160	P	P	Y	N	N
9	1	J5S3207	CD	Callaway	54	P	P	Y	N	N

Chapter 5 – Summary and Recommendations

This is the second year 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 still to explore the full capacity of the IC and IR technology to improve QC and QA for asphalt paving projects – which is still room for improvements. 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 2018 can be considered a success in terms of building up experiences for both MoDOT personnel and contractors.
- There was only one IC-PMTP training workshop during the 2018 construction season.
- There was field technical support for only two projects.
- Due to lack of refresher training course, most contractors have not followed the MoDOT IC-IR Protocol to properly manage IC and PMTP data, file naming convention, and submit data to the correct folders in SharePoint.
- There are still occasions for PMTP system malfunctioning and/or missing files.
- There are still occasions for IC system malfunctioning and/or missing files.
- There were issues with IC roller calibration that requires better vendor's training to overcome (e.g., Volvo's EDV system).
- There was still a lack of submission of check lists, forms, and paving records to the SharePoint site.
- There are surprisingly low IC roller pass coverages at many projects. Training and education for the roller operators are key to correct that.

Recommendations

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

- It is recommended to conduct more (refresher) training courses at the beginning of the construction season. The (refresher) training courses should stress on the MoDOT IC-IR Protocol for data management and Veta analysis. Most importantly, the contractors should be educated to fully utilize the IC and PMTP systems to improve roller passes coverage, compaction temperatures, and temperature segregation.
- The PMTP technical support from vendors should be stressed to correct numerous malfunctioning issues in 2018.
- It is also recommended to encourage healthy competition for the IC-IR industry to allow all technology solutions. More pilots of innovative technologies described in this report are recommended. The goal is to improve those technologies (including various new and improved solutions of IC and PMTP) for contractors.

- 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.
- It is recommended to continue the research study to gather evidence and proof for the benefits of using the IC and PMTP technologies.