Interstate Pavement Condition Sampling

Final Report

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FOREWORD

With the passing of the Moving Ahead for Progress in the 21st Century Act (MAP-21), the Federal Highway Administration (FHWA) is required to adopt a set of national pavement performance measures for evaluating the condition of the Interstate and National Highway System. In support of this legislation, FHWA considered various data sources. One of those sources was the Highway Performance Monitoring System (HPMS) data set, which is the official Federal government source of data on the extent, condition, performance, use, and operating characteristics of the nation's highways.

As a result, the FHWA decided to undertake the research effort documented in this report, whose objectives are to:

- Collect an unbiased baseline study of a statistically significant sample of the entire Interstate Highway System (IHS) and produce a report indicating the pavement condition on the IHS nationally and in each State where data were collected.
- Determine if HPMS is an unbiased representation of the pavement condition of the IHS.
- Recommend improvements to HPMS data collection and reporting that are necessary to either make HPMS unbiased or improve its precision, in regard to performance management and FHWA's use of HPMS data.

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16. Abstract

With the passing of the Moving Ahead for Progress in the 21st Century Act (MAP-21), the Federal Highway Administration (FHWA) has proposed that the Highway Performance Monitoring System (HPMS) data set is the data source for the national pavement performance measures. The objectives of this project are to: 1. Collect an unbiased baseline study of a statistically significant sample of the entire Interstate Highway System (IHS) and produce a report indicating the pavement condition on the IHS nationally and in each State where data were collected. 2. Determine if HPMS is an unbiased representation of the pavement condition of the IHS. 3. Recommend improvements to HPMS data collection and reporting that are necessary to either make HPMS unbiased or improve its precision, in regard to performance management and FHWA's use of HPMS data.

The project answers the following questions regarding HPMS data collection: Is two-way data collection necessary? Does data need to be collected in more than one lane in a direction? What is the optimum HPMS section length? Do all distress items require full extent reporting or is sampling adequate? Are protocols proposed by FHWA adequate for collecting and reporting distress or do they need improvement? This report documents the entire research effort, with particular emphasis on the data collection and data analyses activities.

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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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LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
C&P	Conditions and Performance
CRCP	Continuously Reinforced Concrete Pavement
DIM	Distress Identification Manual
DMI	Distance Measuring Instrument
DOT	Department of Transportation
FHWA	Federal Highway Administration
GPS	Global Positioning System
HERS	Highway Economics Requirements System
HPMS	Highway Performance Monitoring System
IHS	Interstate Highway System
IMU	Inertial Measurement Unit
IRI	International Roughness Index
JCP	Jointed Concrete Pavement
JPCP	Jointed Plain Concrete Pavement
JRCP	Jointed Reinforced Concrete Pavement
LCMS	Laser Crack Measurement System
LTPP	Long-Term Pavement Performance
MAP-21	Moving Ahead for Progress in the 21st Century Act
MEPDG	Mechanistic Empirical Pavement Design Guide
NAPCOM	National Pavement Cost Model
NHS	National Highway System

NPRM	Notice of Proposed Rulemaking
PCI	Pavement Condition Index
PCC	Portland Cement Concrete
PHT	Pavement Health Track
PMS	Pavement Management System
POS	Position Orientation System
PPDB	Pavement Performance Database
QA	Quality Assurance
QC	Quality Control
QM	Quality Management
RFP	Request for Proposal
ROW	Right-of-Way
RSL	Remaining Service Life
RSP	Road Surface Profilometer
SHA	State Highway Agencies
TRB	Transportation Research Board
TRIS	Transportation Research Information Service

CHAPTER 1. INTRODUCTION

1.1. BACKGROUND

With the passing of the Moving Ahead for Progress in the 21st Century Act (MAP-21), the Federal Highway Administration (FHWA) was required to adopt a set of national pavement performance measures for evaluating the condition of the Interstate and National Highway System (NHS). In support of this legislation, FHWA considered various data sources. One of those sources was the pavement management systems (PMS) developed and maintained by various State Highway Agencies (SHA); i.e., external data sources to FHWA. Another data source, an internal one, was the Highway Performance Monitoring System (HPMS) data set, which is the official Federal government source of data on the extent, condition, performance, use, and operating characteristics of the nation's highways.

HPMS data are used for assessing and reporting highway system performance under FHWA's strategic planning process. They also form the basis of analyses that support the Conditions and Performance (C&P) Report to Congress and are the source for a substantial portion of the information in the annual Highway Statistics publication and in other FHWA publications. In addition, HPMS data are widely used throughout the transportation community for research purposes, including performance measurement purposes. Accordingly, HPMS data were selected as the basis for defining the required national pavement performance measures.

In January 2015, the FHWA issued a Notice of Proposed Rulemaking (NPRM) to establish performance measures to assess the condition of the pavements on the NHS and Interstate System. (1) According to the NPRM, FHWA considered use of existing methods such as Pavement Condition Index (PCI), remaining service life (RSL) and other methods used within State Departments of Transportation (DOTs), but found nothing to be considered a national standard and that implementing such measures would be challenging and a burden. (1) This resulted in FHWA proposing four pavement performance measures to assess pavement condition as follows: (1)

- Percentage of pavements on the Interstate Highway System (IHS) in good condition.
- Percentage of pavements on the IHS in poor condition.
- Percentage of pavements on the NHS (excluding IHS) in good condition.
- Percentage of pavements on the NHS (excluding IHS) in poor condition.

In the NPRM, FHWA proposed that the performance measures used to assess pavement condition meet the following criteria and, as noted earlier, be based on data within HPMS: (1)

- Consider more than roughness.
- Utilize pavement condition attributes currently reported at a national level.

- Utilize pavement condition attributes where data collection and reporting standards exist today.

- Result in an assessment approach that is consistent with typical conceptual approaches used today by State DOTs to assess condition.

- Consider an approach that can be implemented so that State DOTs can establish targets within a 12-month time period after FHWA establishes the performance measures without introducing a considerable burden on State DOTs.

The performance measures, as proposed by FHWA, to assess the condition of the pavement are based on the percentage of pavements on both the IHS and NHS (excluding the IHS) in good and poor condition. Condition of the pavements is to be determined based on the following metrics:(1)

- International Roughness Index (IRI)

- Rutting

- Cracking percent

- Faulting

The proposed pavement condition rating thresholds are provided in table 1. (1) The overall condition of the pavement is determined based on the individual metric conditions, as follows:

- For asphalt and jointed concrete pavements, the pavement is classified as good condition if all three metrics are in good condition. The pavement is classified as poor condition if two or more of the metrics are in poor condition. All other combination of metric conditions classify a pavement as fair. (1)

- For continuously reinforced concrete pavements (CRCP), if both of the metrics are in good condition, the pavement is classified as good. The pavement is classified as poor if both of the metrics are in poor condition. All other combination of metric conditions classify the pavement as fair. (1)

Three of the four NPRM pavement condition metrics are used to determine the overall condition for asphalt and jointed concrete HPMS pavement sections, while only two pavement condition metrics are used to determine the overall condition for CRCP. The NPRM notes that each of the above pavement condition data metrics are to be collected on the full extent of the IHS in the rightmost travel lane in both directions of travel on an annual basis. (1) For the non-Interstate NHS pavements, data are to be collected for the full extent of the rightmost lane in one direction of travel on a biennial frequency. (1) Percent cracking, rutting, and faulting are not required for the full extent of the non-interstate NHS until the 2019 data collection cycle and may be reported as sampled data until that time. (1)

Table 1. Proposed pavement condition rating thresholds. [1]

Surface Type	Metric	Metric range	Rating
All Pavements	IRI	< 95 in/mi	Good
		95-170 in/mi: Areas with a population less than 100,000	Fair
		95-220 in/mi: Urbanized areas with a population of at least 1,000,000	
		> 170 in/mi: Areas with a population less than 100,000	Poor
		> 220 in/mi: Urbanized areas with a population of at least 1,000,000	
Asphalt, Jointed Concrete, and CRCP	Cracking Percent	< 5%	Good
		5 – 10%	Fair
		> 10%	Poor
Asphalt Pavement	Rutting	< 0.20	Good
		0.20 – 0.40	Fair
		> 0.40	Poor
Jointed Concrete Pavement	Faulting	< 0.05	Good
		0.05 – 0.10	Fair
		> 0.10	Poor

FHWA and other agencies have performed various studies to determine the “truth” of the data and its reliability as a tool for the measurement and reporting required by MAP-21. For example, NCHRP 20-24, Task 82, looked at this issue in a report titled, “Increasing Consistency in the Highway Performance Monitoring System for Pavement Reporting, Final Report.” [2] This report cited several findings and observations on current practice among States and made five recommendations to improve HPMS data for use as a national pavement performance management system.

At the same time, FHWA performed a study to look at similar concerns. This study resulted in a series of reports with the core title, “Improving FHWA’s Ability to Assess Highway Infrastructure Health.” (See references 3, 4, 5 and 6.) For this study, Interstate 90 through Wisconsin, Minnesota, and South Dakota was evaluated. This study resulted in several recommendations for HPMS data collection.

The above referenced reports along with various discussions with and among Transportation Research Board (TRB) and American Association of State Highway Transportation Officials (AASHTO) committees have raised concerns about the validity and availability of HPMS pavement data. However, use of HPMS data are necessary by FHWA as the agency goes through the development of regulations and policy. Additionally, FHWA and State and local agencies will use these data to set goals and measure the performance of their systems.

1.2. PROJECT OBJECTIVES

As a result of the issues summarized at the end of the previous section, the FHWA decided to undertake the research effort documented in this report. The objectives of the project were to:

- Collect an unbiased baseline data set for a statistically significant sample of the entire IHS and produce a report indicating pavement condition on the IHS nationally and in each State where data were collected.
- Determine if HPMS is an unbiased representation of pavement condition on the IHS.
- Recommend improvements to HPMS data collection and reporting necessary to either make HPMS unbiased or improve its precision, in regard to performance management and FHWA's use of HPMS data, which in turn will enable responses to questions such as:
    - Is two-way data collection necessary?
    - Does data need to be collected in more than one lane in a direction?
    - What is the optimum HPMS section length?
    - Do all distress items require full extent reporting or is sampling adequate?
    - Are protocols proposed by FHWA adequate for collecting and reporting distress or do they need improvement?

Towards successful accomplishment of the above referenced objectives, the following phases and tasks were undertaken:

- Phase 1: Development of Data Collection and Analysis Plan
    - Task 1.1 Kick-Off Meeting/Teleconference
    - Task 1.2 Literature Review
    - Task 1.3 HPMS Data for IHS Pavement Conditions
    - Task 1.4 Data Collection and Analysis Plan
    - Task 1.5 Project Update Meeting
    - Task 1.6 Draft Phase 1 Report
    - Task 1.7 Final Phase 1 Report
- Phase 2: Implementation of Data Collection and Analysis Plan
    - Task 2.1 Data Collection

- Task 2.2 Data Analysis
- Task 2.3 Progress Meetings
- Task 2.4 Draft Phase 2 Report
- Task 2.5 Final Phase 2 Report

1.3. REPORT ORGANIZATION

This report documents the entire research effort, with particular emphasis on the data collection and data analyses activities. The report chapters are summarized below along with a brief description of their contents:

1. Introduction – provides the project background, project objectives, and organization of the report.

2. Literature Review – identifies recent developments in the areas of HPMS data collection, HPMS practices and SHA practices, which provided much of the foundation for the data collection and analysis efforts presented in the next two chapters.

3. Data Collection – details the data collection effort, from the planning stages to its completion, including data processing and quality review.

4. Data Analysis – details the data analysis effort, from the planning stages to its completion, including quality review of the results and major findings.

5. Supplemental Analysis – details the supplemental analysis effort, including threshold values, impact of the section length and comparison of the HPMS and project data.

6. Conclusions and Recommendations – documents the major conclusions from the effort, including responses to the various issues pursued in the project, and recommendations for improving HPMS data collection practices.

In addition, three appendices are provided to more completely document the data collection and data analyses efforts. These appendices are as follows:

Appendix A – Data Storage and Quality Review Plan

Appendix B – Project Database Data Dictionary

Appendix C – Sample Length Graphs

CHAPTER 2. LITERATURE REVIEW

The objective of the literature review was to identify recent developments in the areas of HPMS and State DOTs data collection practices. This effort was considered important because the resulting information provided much of the foundation for the data collection and analysis efforts presented in chapters 3 through 5. Towards accomplishing this objective, the project team performed the following activities:

- Built on literature reviews and surveys recently conducted by the project team and others on the focus subject area, including the series of "Improving FHWA's Ability to Assess Highway Infrastructure Health" reports.
- Built on other recently completed and relevant literature reviews for FHWA's Long-Term Pavement Performance (LTPP) effort to develop HPMS data sets for LTPP test sections.
- Conducted searches utilizing the TRB Research in Progress database, Transportation Research Information Service (TRIS) database, FHWA information resources, online libraries, State and regional transportation agencies, industry organizations, academic institutions, military departments, and other related information sources.

The remainder of this chapter presents the results of the literature review effort – it summarizes relevant information extracted from the literature that supports accomplishment of the stated study objectives. This information is presented in two separate sections based on the reference – (1) reports and other references that resulted from the "Improving FHWA's Ability to Assess Highway Infrastructure Health" studies and (2) other reports and references.

2.1. IMPROVING FHWA'S ABILITY TO ASSESS HIGHWAY INFRASTRUCTURE HEALTH STUDIES

Over the past five years, FHWA conducted a series of studies under the "Improving FHWA's Ability to Assess Highway Infrastructure Health" effort, which led to highly relevant references for the study in question. (See references 3, 4, 5, 6, 7 and 8.) The studies were conducted under three phases. Phase I focused on defining an approach for assessing pavement and bridge condition and health. In Phase II, the approach was refined and tested via a pilot study on a sample corridor. Phase III consisted of a national meeting to review the project results with practitioners. The more relevant references associated with the Phase II and III efforts are summarized next.

This project included a pilot study conducted by FHWA aimed at enhancing FHWA's ability to assess the health of the nation's highway infrastructure. As part of this study, a section of Interstate 90 through South Dakota, Minnesota, and Wisconsin was evaluated in order to: [(3)]

- Define a consistent and reliable method of assessing infrastructure health with a focus on bridges and pavements on the IHS.
- To develop tools to provide FHWA and SHA personnel access to key information that will allow for a better and more complete view of infrastructure health nationally.

Major conclusions from the pilot study relating to the level of confidence associated with the various pavement condition measures evaluated include: (3)

- There is a high-level of confidence with IRI given the acceptable correlation found in the study between the HPMS, State DOT PMS, and field data sources.
- A medium-level of confidence exists for the rut depth data and additional investigation is required to resolve the bias issue between the HPMS or State DOT PMS data and the field data.
- For the remaining condition measures (cracking percentage, cracking length and faulting), additional work is required to standardize data collection and processing at the national level.
- Given the need for consistent, high-quality data at the national level, use of the HPMS data set to drive the good/fair/poor indicator is considered the best option at present and in the near future. However, this does not imply that improvements to the HPMS data are not possible and/or required, as discussed next. Using State DOT PMS data does not seem feasible at this time due to the differences between States. Collecting field data on the entire interstate system likewise does not appear economically justified at this time.

In turn, based on the study findings, the following list highlights some of the higher priority HPMS data improvement opportunities: (3)

- HPMS data summary lengths should be investigated to resolve the analysis bias when using variable sample lengths. At present, the summary lengths are highly variable, which can lead to pavement condition measures being either exaggerated in the case of short lengths or being lost due to averaging over long lengths.
- Incorporate additional checks in the HPMS software to flag HPMS data that are not consistent (for example sections that have a high PSR value but show high distress levels or vice versa). These checks should be applied at the State level, prior to submission of data to FHWA. Having up-to-date information on maintenance and rehabilitation is important to resolve potential issues associated with the temporal analysis of pavement condition data.
- The HPMS rut depth data collection procedure and analysis algorithm should be codified for purposes of the good/fair/poor indicator.
- HPMS cracking data collection should be better defined and a manual for its implementation prepared along with the recommended quality assurance (QA) standards.
- Faulting data should be investigated to resolve the inconsistencies in data collection and analysis. Use of the ProVAL tool to analyze faulting may be a suitable method to standardize the analysis of faulting data.

As part of the project a national meeting was conducted by FHWA, in coordination with AASHTO, to: [(4)]

- Present the results of the FHWA Highway Infrastructure Health Assessment Study.
- Solicit feedback on project findings and recommendations, with a particular focus on their benefits, potential implementation challenges, and recommendations for addressing these issues.
- Identify critical next steps for advancing national performance measures for infrastructure.

The meeting entitled "AASHTO/FHWA Workshop on the Highway Infrastructure Health Assessment Study" took place on October 13, 2011 in Detroit, Michigan. Some of the more relevant discussion points and common themes for the project in question include:

- One group urged national condition measurement should remain confined to the IHS for now.
- Some participants expressed concern over consistency with State efforts.
- There was a desire to find measures that would indicate the adequacy of condition over time or the timeframe when condition might deteriorate significantly, as opposed to a snapshot of condition at one time.
- There was general consensus that, while IRI is ready and available for use as a pavement condition rating, it does not tell the whole story of pavement condition.
- Participants felt it was important to acknowledge the limitations of the condition ratings.
- There was a general consensus on the need for better data collection standards and protocols.
- The importance of continual improvements to the national data sets, which are the foundation for all of the measures being investigated by FHWA and AASHTO.
- The importance of viewing measurement and reporting efforts from the perspective of the traveling public.

Subsequent to the pilot study, FHWA conducted two follow-up studies. The first one was intended to investigate the rutting bias issue identified during the pilot study. The objectives of this follow-up study were to: [(5)]

- Investigate the discrepancy between rutting observed from field data collection versus that retrieved from HPMS/State data to determine the cause of the bias.
- Develop data requirements and an algorithm that can be applied to rutting to produce consistent, high-quality data.

The following recommendations were made based on the study findings: [5]

- A maximum longitudinal spacing of 50 ft should be used for the collection of transverse profile data, but a 10-ft spacing provides a more optimal approach for estimating rut depth.
- A minimum of 400 data points should be used to characterize the transverse profile.
- For transverse profiles containing 1,000 points or more, a moving average of 2 inches may be used to reduce the white noise in the signal obtained during data collection.
- A lane width wireline should be used to calculate rut depth from the transverse profile.
- The gage width should be set to between 1.2 and 1.57-in. for calculating rut depth.

These requirements are similar to those in AASHTO PP 70 protocol, [9] but this protocol is based on reviewing data by lane-half and it does not address the required number of points per profile.

The second follow-up FHWA study was intended to develop a next generation pavement performance measure that (1) provided an accurate and repeatable assessment of functional condition and (2) relied solely on HPMS pavement condition data. [6] It was determined that to accomplish the stated objectives, changes to the HPMS data collection processes were required to ensure consistent and uniform data from one State to another, as well as accurate and repeatable data. It was also determined that differences exist on how State DOTs collect data for input to HPMS. Similarly, data processing can vary from one State to another. Accordingly, it was concluded that a number of data collection, processing and reporting requirements needed to be addressed.

Moreover, the focus of the study shifted from developing a single composite index to using individual distresses, which led to the development of recommendations for data collection, processing and QC/QA. Selected examples of the recommended data collection and processing requirements are provided below: [6]

- For rutting data collection, (1) the data points should cover a minimum width of 13 feet to help ensure the full width of the lane is covered and those data points should have a separation less than or equal to 0.4 inch, (2) the maximum longitudinal spacing between profiles should be 10 feet, (3) a 2-inch moving average filter should be applied to the transverse profile, (4) the wireline method is recommended for the rut depth computation, (5) a gage width of 1.2 to 1.5 inches should be used for calculating the rut depth, and (6) the base length for summarization of these data should be set to 0.1 mile.
- For ride quality data, (1) the data collection interval should be 2 inches or less and on concrete pavements where the data may be used for faulting measurement, the interval should be 0.75 inch or less, (2) a height sensor should be selected with a sufficient (2.75 inches) footprint to not be impacted by the surface texture, (3) data collection should ideally occur at the same time of day and time of year each time it is collected to minimize the impact of diurnal and seasonal variations, (4) the full extent of the system

(including bridges and pavement changes) should be included in the IRI calculation, and (5) the base length for summarization of these data should be set to 0.1 mile.

- For faulting data collection, (1) the equipment should be set to collect and store an elevation measurement every 0.75 inch, (2) the data should ideally be collected at the same time of day and time of year, (3) ProVAL version 3.3 (or later version) should be used for calculation of faulting, (4) both joints and cracks should be analyzed and reviewed for faulting on jointed concrete pavements, and (5) the base length for summarization of these data should be set to 0.1 mile.

- For cracking data collection, (1) an automated method for collection and processing of cracking is recommended, (2) a 100 percent sampling rate should be used to reduce the likelihood that outlier areas of condition will be missed in the evaluation, and (3) the base length for summarization of these data should be set to 0.1 mile.

The reader is referred to the study report for a complete list of recommendations, including quality control and storage recommendations. In addition, future research was recommended to improve current capabilities in data collection and processing, such as gaining a better understanding of the impact of changes in curling on faulting measurements, improving faulting measurements, and consideration of sealed cracks and length of ruts, which are not currently considered by the HPMS Field Manual.

Van Hecke and Ebright-McKeehan 2012, documents investigations into the completeness of IHS pavement condition data in the FHWA 2010 and 2011 HPMS databases.(7) Based on the review of five pavement condition data items – IRI, cracking, faulting, pavement serviceability rating (PSR), and rutting in the HPMS data set, several data gaps were identified. Highlights from the memorandum that are important to this project are summarized below: (7)

- The most common condition item in the 2010-2011 HPMS databases is IRI.

- Although less common than IRI, the extent to which cracking and rutting are available was a positive finding.

- Rutting data appears to have improved significantly recently.

- Despite the wide availability of some of the data items, the number of segments with multiple pavement condition items is not as comprehensive as anticipated. Two data gaps exist which contribute to the lack of completeness: horizontal gaps within individual data items and vertical gaps between data items within segments.

- Gaps often occur across State lines when one DOT reports a pavement condition attribute, but the neighboring State does not. Even within States for certain data items, data appears to have been collected or reported in a checkerboard fashion, creating gaps in the HPMS network for that particular attribute.

- Vertical gaps occur where the depth of data collection is shallow. For instance, some States may collect and submit IRI and cracking values for all of their system, but nothing else. Most interstate highway segments in the HPMS database contain attribute values for two pavement condition data items.

- The best combinations of pavement data are IRI and rutting, and IRI and cracking. However, while cracking data often appears in States where rutting data are reported, cracking data are slightly less prevalent and have more gaps.

In a follow-up effort to the previous referenced FHWA studies, an assessment of two additional corridors beyond the original pilot study was performed using the RSL concept contained in the FHWA Pavement Health Track (PHT) analysis tool using HPMS data. [8] In order to select the two corridors for assessment, an investigation into the completeness and utility of the interstate pavement condition data in the 2010 and 2011 HPMS databases was performed – this investigation was documented under the previous reference. Analysts identified several potential tri-State corridors with key HPMS data that could support the analysis. The two corridors selected were I-15 through Idaho, Utah and Arizona and I-85 through Virginia, North Carolina, and South Carolina. The health of these two corridors was assessed using the PHT analysis tool. The following observations and conclusions relevant to the project in question were derived from the assessment: [8]

- It is evident that the HPMS data set has significant data completeness issues for conducting this type (i.e., PHT) of analysis. No tri-State corridor study areas could be identified from interstate highway segments containing values for all pavement condition data elements.

- As the PHT analysis tool requires data elements only required for HPMS sample panels, only 77% of the pavement sections for I-15 and 45% of pavement sections for I-85 contained the required data elements for PHT analysis. The number of analysis sections was further reduced once a quality check on the data was conducted and sections that were missing required data elements were eliminated. Only 61% of the pavement sections for I-15 and 13% of pavement sections for I-85 contained all the required data elements.

- Given the significant data limitations and anomalies associated with the input HPMS data, the tri-State corridor analysis was somewhat limited. It can be rationally concluded that such an analysis for the entire IHS would similarly be very severely limited given current HPMS data completeness.

2.2. OTHER REFERENCES

The HPMS Field Manual provides the data collection and reporting requirement of HPMS data. [10] Although the field manual contains requirements for all 69 items contained in the HPMS data set, only the pavement condition requirements are summarized below. Differences between the 2013 HPMS Field Manual and 2014 HPMS Field Manual are also noted.

- IRI data should be collected according to AASHTO Standard R 43-07 [11] (and associated PP 69-10 [12] and PP 70-10 [9] as applicable). The 2014 HPMS Field Manual included the addition of PP 69-10 [12] and PP 70-10. [9] This addition allows for the collection of rutting data concurrent with collection of ride quality data.

- Rutting data should be collected according to AASHTO R 48-10 [13] (and associated PP 69-10 [12] and PP 70-10 [9] as applicable) specifications or the LTPP protocol.

- Faulting data should be collected according to AASHTO R 36-04 [14] or the LTPP protocol.

- Cracking percent and cracking length data should be collected according to AASHTO R 55-10 [15] (and associated PP 67-14 [16] and PP 68-10 [17] as applicable) or the LTPP Distress Identification Manual. [18]

Concurrent with FHWA studies synthesized in the previous section, the NCHRP 20-24 Task 82 effort was on-going. [2] The study in question focused on the following topics:

- Availability of comparable information in the pavement management and HPMS data sets.

- Amount of processing required for comparing HPMS and pavement management data.

- Differences in pavement conditions reported using HPMS and pavement management data.

- Impact of the reporting length (e.g., segment or route) on pavement condition statistics.

The findings from the study suggest that changes to the current HPMS requirements are needed to improve the consistency in pavement management and HPMS data. Some of the major study findings and observations are provided below: [2]

- There is a relatively high degree of confidence in the HPMS data on a State-by-State basis, but inconsistencies in how the information is collected nationwide result in a moderate to low degree of confidence in the ability to use the information to compare conditions across States.

- The HPMS pavement data requirements were implemented to populate new performance models based on the Mechanistic-Empirical Pavement Design Guide (MEPDG). However, the information needed for the models is not readily available in many States, and therefore, the States do not place a high degree of confidence in the reliability of the off-State system data.

- There are significant differences in the pavement condition information that States use to report network conditions. IRI is often a component of the overall condition, but ride is typically not a significant factor in selecting and prioritizing pavement preservation activities.

- The variability in the reported pavement conditions varies based on the method of aggregating the data; i.e., whether the data were summarized at the State, route, or segment levels.

- Over three quarters of the States responding to the study survey indicated that the methodology used in their PMS for cracking differs from the HPMS requirements for reporting cracking information. As a result, some agencies have developed equations for converting their pavement management information for HPMS purposes and other States have developed other approaches for responding to the requirement.

- The requirement to report faulting data is also problematic for some States since several States do not include faulting in their pavement management survey procedures.

- The comparison of HPMS data and pavement management data required a lot of manipulation to match sections, which illustrates the issues that would arise if the FHWA chose to develop a process for verifying the quality of the State data submitted to HPMS or if the pavement management personnel wanted to check the quality of the HPMS submittal before being sent to FHWA.

- There was no evidence that the size of the agency or the method of collecting and processing the data influenced the results of the analysis or the likelihood of finding variability in the data.

In turn, the above findings and observations led to the following recommendations for changes to the HPMS data requirements, which have been prioritized (from highest to lowest priority) based on their potential impact on the States: (2)

- Determine the appropriateness of the models being used for national performance management and the need for the level of detail currently required.

- Address the inconsistencies in the pavement management data collection activities that are impacting the ability to use HPMS data to compare pavement conditions across States.

- For pavement-related data only, require States to submit HPMS data using a consistent section length. Future research is needed to determine the appropriate length to minimize variability and processing time for reporting purposes.

- Demonstrate to States the benefits associated with the availability and use of HPMS data.

- Develop a strategy for obtaining the information necessary for evaluating or estimating the performance of the off-State system in a cost-effective manner.

Research for improving the consistency of the HPMS data was also recommended if these data are to be used to report national highway conditions, to predict future highway conditions, and to estimate the impacts of investment levels on national highway conditions, including: (2)

- The sensitivity of predicted conditions to the variables required under HPMS to better determine the impact of inaccurate or default data.

- The enforcement of a consistent HPMS reporting length that minimizes variability and reporting time.

- A suitable pavement condition metric that more closely matches State conditions reported for pavement management.

Many of the findings, conclusions and recommendations from this NCHRP study are similar to those presented earlier, under the discussion of the "Improving FHWA's Ability to Assess Highway Infrastructure Health" references.

A Practical Guide on Quality Management (QM) Procedures for network-level pavement condition data was developed under a study sponsored by FHWA. (19) The guide provides information related to the development and implementation of a QM program, incorporating proven QM practices, and showcasing examples or case studies using pavement condition data from a variety of State DOTs. Specific elements covered by the guide include:

- Location Referencing Systems – presents methods of geospatially locating the data.

- Network-Level Data Collection Background – presents an overview of the data collection process, the types of surveys conducted, data items collected, and rating protocols used.

- Principles of Data Quality Management – presents the principles, definitions, and key concepts of data QM.

- Development and Implementation of a Data Quality Management Plan – presents an overview of the key steps to develop and implement a comprehensive QM plan.

- Data Quality Standards and Acceptance Criteria – describes the process used to establish data quality standards and acceptance criteria.

- Quality Control – presents the key activities utilized for QC.

- Acceptance – describes the procedures used for acceptance.

- Quality Management Reporting – describes the procedure for documenting all phases of the QM process.

While the guide is primarily geared towards State DOT network-level pavement condition data for use in PMS analyses or treatment decisions, the same data are most often used for HPMS reporting. As such, the quality of network-level pavement condition data is vital not only for pavement management purposes, but also for other applications such as incorporation into HPMS. In turn, the ability to evaluate and determine the quality of pavement condition data is essential for establishing the accuracy and reliability of analyses made using pavement condition data.

This reference has been included because of its potential value to the project in addressing quality issues related to the collection, processing, and storage of HPMS data.

A review of the AASHTO R 43-13 [11] standard was important to compare how the test has changed from the version (R 43-07) referenced in the HPMS Field Manual. [10] Performing tests with the most recent version of the test standard maintains consistency with current technology. Based on this comparison, it was determined that changes made to the standard included reverting to only English units within the standard. Also, the 2013 version references the ProVAL software for use in calculating the IRI from longitudinal profile.

The AASHTO M 328-14 [20] standard was compared to the 2010 version similar to the comparison conducted between versions of the AASHTO R 43 standard. [11] The only change of note between the two versions was a change to the height sensor resolution. The resolution required in the 2010 version of the standard was 0.001 inch while the 2014 version requires a resolution of 0.002 inch. This revision is expected to have only a nominal impact on the collected IRI.

In a memo to FHWA, the creation of HPMS data sets from the FHWA LTPP test sections using information presently, or soon to be contained, in the LTPP pavement performance database (PPDB) was outlined. [21] The document provides for the potential use of LTPP data in support of improved, higher-quality HPMS data. The overall objective of the proposed effort is to develop data sets for the LTPP test sections that are compatible with the HPMS 2014 data format to enable the following:

- Validation and/or routine usage of national pavement analysis tools, including the Highway Economics Requirements System (HERS) models, the PHT analysis tool, and the NAtional Pavement COst Model (NAPCOM).
- Validation of the MAP-21 performance measures.
- Development and/or validation of other national, State and/or local performance measures and/or indices.

Again, the memorandum is relevant to this study because LTPP data could potentially be used in addressing various data quality aspects, which are so critical to the successful outcomes of the project, including data collection, data processing, and data storage quality issues.

2.3. SUMMARY

The information gathered as part of the literature review and summarized in this chapter built a foundation and provided direction for the conduct of the data collection and analysis efforts which are presented in the next two chapters of this report. Also, the data collection protocols that were followed in the actual data collection have been listed as part of the literature review.

CHAPTER 3. DATA COLLECTION

The objective of the data collection effort was to gather high-quality pavement condition metric data – IRI, rutting, percent cracking and faulting – and supporting information to enable successful accomplishments of the overall project objectives stated in the introductory chapter. The major steps taken to achieve this objective included:

- Review of information relating to the IHS.
- Review of 2013 HPMS data (more recent data were not available for data collection planning purposes).
- Formulation of data collection plan.
- Field data collection.
- Data processing and quality review.
- Creation of project database.

Each of these steps are detailed over the remainder of this chapter, including issues encountered during the course of the data collection effort and their resolution.

3.1. INTERSTATE HIGHWAY SYSTEM

The review of the IHS (and 2013 HPMS data in the next section) concentrated on those routes located within the contiguous 48 States and the District of Columbia.

In the fall of 2014, which is when this project was started, the IHS was estimated to incorporate over 46,000 centerline miles. This system is illustrated in figure 1. The system includes 62 two-digit routes with 29 in the primarily east-west alignment, as designated by their even-numbered route number. The other 33 odd-numbered routes predominantly follow a north-south alignment.

The 2013 HPMS data were reviewed for the distribution of the network across the US. Table 2 identifies the mileage of the IHS within each of the 48 contiguous States and the District of Columbia along with the mileage of condition data available. In addition, as part of the IHS review, a number of factors considered important in establishing the data collection plan were looked at, including:

  - Climate zone.
  - Urban / rural.
  - Surface type.

Figure 1. Map. Interstate Highway System.

Table 2. Mileage of HPMS 2013 data by State.

State	Total Miles	Miles of Condition Data			
		IRI	Rutting	Faulting	Cracking
Alabama	1,002	1,002	429	57	429
Arizona	1,169	1,166	0	0	886
Arkansas	656	628	434	0	391
California	2,453	2,368	1,181	0	1,213
Colorado	952	952	324	199	522
Connecticut	346	346	139	4	143
Delaware	41	41	18	18	18
District of Columbia	12	12	12	12	12
Florida	1,495	1,492	1,225	21	449
Georgia	1,248	1,207	196	212	445
Idaho	612	612	485	126	612
Illinois	2,185	2,185	467	62	529
Indiana	1,239	1,051	1,052	1,001	1,052
Iowa	782	721	94	94	94
Kansas	874	874	239	122	241
Kentucky	801	777	0	144	740
Louisiana	895	879	880	880	893
Maine	367	367	367	0	367
Maryland	480	480	192	0.1	180
Massachusetts	574	574	573	573	573
Michigan	1,244	1,244	339	354	692
Minnesota	914	907	433	482	911
Mississippi	700	700	423	423	421
Missouri	1,379	1,338	1,338	1,338	572
Montana	1,192	1,192	318	9	327
Nebraska	482	482	482	0	0
Nevada	596	587	205	39	168
New Hampshire	225	225	225	0	92
New Jersey	431	428	107	81	133
New Mexico	1,000	998	430	13	985
New York	1,724	1,717	894	50	714
North Carolina	1,254	1,239	1,239	104	466
North Dakota	571	571	106	164	309
Ohio	1,573	1,573	525	525	525
Oklahoma	933	933	167	0	291
Oregon	729	727	722	9	113
Pennsylvania	1,856	1,853	1,793	1,793	1,793
Rhode Island	70	70	70	0	51
South Carolina	851	851	292	45	365
South Dakota	679	679	180	482	678
Tennessee	1,104	1,086	297	8	298
Texas	3,415	3,415	615	232	846
Utah	937	937	936	930	931
Vermont	320	320	320	0	320
Virginia	1,119	1,119	987	75	1,045
Washington	764	764	440	325	764
West Virginia	555	555	392	129	520
Wisconsin	743	743	640	628	661
Wyoming	913	913	913	913	913

The intent was to identify how much of the IHS fell within the different categories associated with each of the above three factors.

Four climate zones are used within the HPMS system: wet freeze, wet no-freeze, dry freeze, and dry no-freeze. The climate zones are set by the FHWA based on a standard definition associated with the location. Figure 2 illustrates the location of the four climate zones around the contiguous US. Table 3 illustrates the quantity of the network within each climate zone as well as the quantity of pavement condition data available for each network.

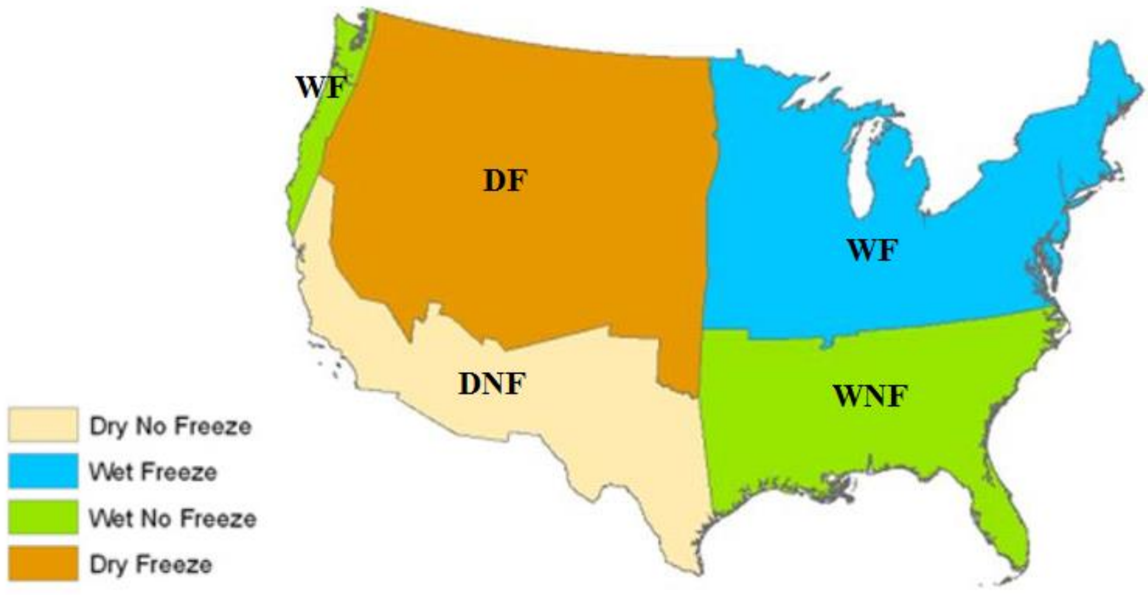

Figure 2. Illustration. Climate zones used in HPMS database.

Table 3. Mileage of IHS by climate zone in HPMS 2013.

Climate Zone	Mileage	Mileage of Condition Data			
		IRI	Rutting	Faulting	Cracking
Wet Freeze	18,954	18,645	10,974	7,361	11,734
Wet No-Freeze	11,666	11,513	6,138	2,003	4,920
Dry Freeze	9,157	9,129	4,901	3,074	5,588
Dry No-Freeze	6,684	6,613	2,139	235	3,448

From table 3, the largest percentage of the network falls within the wet freeze climate zone and the dry-no freeze contains the smallest portion. The availability of IRI data across the network was fairly consistent between the climate zones with 98 to 100 percent of the IHS having IRI data within each climate zone. There was a bit more variability in the availability of the other data from the climate zones in terms of percentage of mileage of the IHS within that area. The dry no-freeze zone has the least rutting and faulting data available. The wet no-freeze zone has the least cracking data available.

Another factor considered was whether the section fell in an urban or rural region. A section is considered urban if it falls within an area with a population of at least 5,000. More specifically, the HPMS database identifies which specific urban area the section occupies. If the section does not fall within one of the named areas, but is in an area with a population of at least 5,000, it is coded as occurring in a small urban area. All other sections are identified as rural. Table 4 identifies the total mileage within each category (urban, small urban, and rural) along with the mileage of condition data available within each category. There were approximately 32 miles of highway for which the population zone was not designated. These roadways are not included in the summations in table 4.

Table 4. Mileage of IHS by population zone in HPMS 2013.

Population Zone	Mileage	Mileage of Condition Data			
		IRI	Rutting	Faulting	Cracking
Rural	28,654	28,361	14,787	7,541	15,993
Small Urban	2,669	2,654	1,553	868	1,679
Urban	15,105	14,863	7,791	4,245	7,997

The final factor reviewed within the HPMS data is the surface type. HPMS provides eleven classifications for pavement type. Table 5 identifies the mileage of the IHS within each surface type. There were approximately 17,513 miles of the IHS for which the surface type was not identified within the HPMS. However, surface type is only required to be reported for Sample Panel sections. The HPMS Sample Panel sections represented approximately 50 percent of the interstate data within the HPMS system, or 23,588 miles. Of these miles, there were approximately 612 miles of the IHS for which surface type was not identified, or approximately 3 percent.

Table 5. Mileage of IHS by surface type in HPMS 2013.

Surface Type	Mileage	Mileage of Condition Data			
		IRI	Rutting	Faulting	Cracking
Unpaved	6	6	6	0	6
Bituminous	8,410	8,384	7,714	2,571	7,758
JPCP	4,571	4,532	2,282	3,218	3,622
JRCP	1,103	1,094	263	1,006	968
CRCP	989	984	275	627	865
AC over AC	7,265	7,215	5,237	1,347	5,884
AC over JCP	5,188	5,166	4,853	2,365	4,492
AC over CRCP	903	902	887	212	787
Unbonded PCC overlay	351	350	49	330	338
Bonded PCC overlay	69	69	45	55	67
Other	90	89	64	52	56

3.2. REVIEW OF 2013 HPMS DATA

3.2.1 Data Completeness

To obtain an accurate picture of data completeness based on each distress type, the 2013 HPMS data set mileage was subdivided based on surface type for the various distresses. That is, the total mileage for rutting and crack length is only based on mileage for surface types where rutting and crack length data are collected (e.g., bituminous), the total mileage for faulting is only based on the mileage for surface types where faulting data is collected (e.g., jointed concrete), IRI is collected on all surface types except unpaved and cracking percent is collected on all surface types except unpaved and other. Table 6 contains the mileage for each distress that data was reported, the total mileage for each distress and the percent completeness for each distress. With the exception of cracking percent, all other distress show good data completeness ranging from 74 percent to 99 percent.

Table 6. Data completeness in terms of distress type in HPMS 2013.

Distress	Distress Mileage	Total Mileage	Percentage
IRI	47,030	47,590	99%
Cracking %	24,295	47,500	51%
Rutting	19,778	22,870	86%
Faulting	5,267	7,117	74%

With the exception of IRI, all distress types are only required for Sample Panel sections. IRI is required for the Full Extent of the IHS. Therefore, the data completeness should reflect only the Sample Panel sections for all distresses besides IRI. Table 7 contains the mileage for each distress that data was reported, the total mileage for each distress and the percent completeness for each distress, based only on the Sample Panel. It should also be noted that crack length is an optional Sample Panel data item to be reported.

Table 7. Data completeness in terms of distress type based on Sample Panel in HPMS 2013.

Distress	Distress Mileage	Total Mileage	Percentage
IRI	47,030	47,590	99%
Cracking %	18,864	22,970	82%
Rutting	15,844	17,887	89%
Faulting	3,525	4,079	86%

The stratification factors considered for assessing the composition of the 2013 HPMS data set were climate zone, urban versus rural, and surface type. Table 8 through table 10 contain the mileage for each stratification factor and the percentage of the data set it represents. Table 11 contains the 2013 HPMS data set surface type distribution based on Sample Panel data.

Table 8. HPMS 2013 data set climate zone distribution.

Climate Zone	Mileage	Percentage
Wet-Freeze	18,954	41%
Wet-Non Freeze	11,666	25%
Dry-Freeze	9,157	20%
Dry-Non Freeze	6,684	14%
Total	46,460	100%

Table 9. HPMS 2013 data set urban vs. rural distribution.

Urban Code	Mileage	Percentage
Rural	28,654	62%
Small urban	2,669	6%
Urban	15,105	33%
Total	46,428	100%

Table 10. HPMS 2013 data set surface type distribution.

Surface Type		Mileage	Percentage
1	Unpaved	6	~0%
2	Bituminous	8,410	18%
3	Jointed Plain Concrete Pavement (JPCP)	4,571	10%
4	Jointed Reinforced Concrete Pavement (JRCP)	1,103	2%
5	CRCP	989	2%
6	AC Overlay over Existing AC Pavement	7,265	16%
7	AC Overlay over Existing JCP	5,188	11%
8	AC Overlay over Existing CRCP	903	2%
9	Unbonded Jointed Concrete Overlay on PCC Pavements	351	1%
10	Bonded PCC Overlays on PCC Pavements	69	~0%
11	Other	90	~0%
	No Data	17,514	38%
	Total	46,460	100%

Table 11. HPMS 2013 data set surface type distribution for Sample Panel.

Surface Type		Mileage	Percentage
1	Unpaved	6	~0%
2	Bituminous	6,760	29%
3	JPCP	2,952	3%
4	JRCP	976	4%
5	CRCP	943	4%
6	AC Overlay over Existing AC Pavement	5,986	25%
7	AC Overlay over Existing JCP	4,419	19%
8	AC Overlay over Existing CRCP	722	3%
9	Unbonded Jointed Concrete Overlay on PCC Pavements	84	~0%
10	Bonded PCC Overlays on PCC Pavements	67	~0%
11	Other	60	~0%
	No Data	612	3%
	Total	23,588	

3.2.2 Data Comparisons

As part of the review of the HPMS data, cursory checks were made comparing various data elements. In particular, the quantity of condition data by surface type was reviewed for Sample Panel data. Table 12 presents the mileage of condition data by surface type. This table shows that rutting data have been presented for approximately 1,935 miles of concrete-surfaced pavement. Further, faulting data have been presented for approximately 4,991 miles of asphalt-surfaced pavement.

The presence of condition data for inappropriate surface types suggests potential quality control issues with the HPMS data. In turn, these issues suggest that one potential improvement in HPMS data collection is a series of automated quality control checks allowing these issues to be identified quickly and the records marked for data users.

Table 12. HPMS 2013 data set condition data distribution by surface type for Sample Panel.

Surface Type	IRI, miles	Rutting, miles	Faulting, miles	Percent Cracking, miles
Unpaved	6	6	0	6
Bituminous	6,738	6,617	1,559	5,444
JPCP	2,929	1,465	2,497	2,561
JRCP	968	170	898	857
CRCP	938	238	607	845
AC over AC	5,962	4,388	1,262	4,661
AC over JCP	4,401	4,132	2,086	3,698
AC over CRCP	721	706	84	606
Unbonded PCC overlay	84	19	76	84
Bonded PCC overlay	67	43	54	65
Other	59	42	39	43

3.3. DATA COLLECTION PLAN

3.3.1 Planned Route

In light of the information gathered and reviewed, the route depicted in figure 3 was selected for data collection. The basis for selecting this route was to collect a 10,000 mile sample of the IHS that reflected the actual stratification of the overall IHS plus other considerations such as data completeness. The route covered 8,623 miles (18 percent of the total IHS centerline miles), 9 different interstates (15 percent of the total number of named routes), and 38 States and D.C. (80 percent of the States – but as noted later in this chapter data were collected in a 39th State).

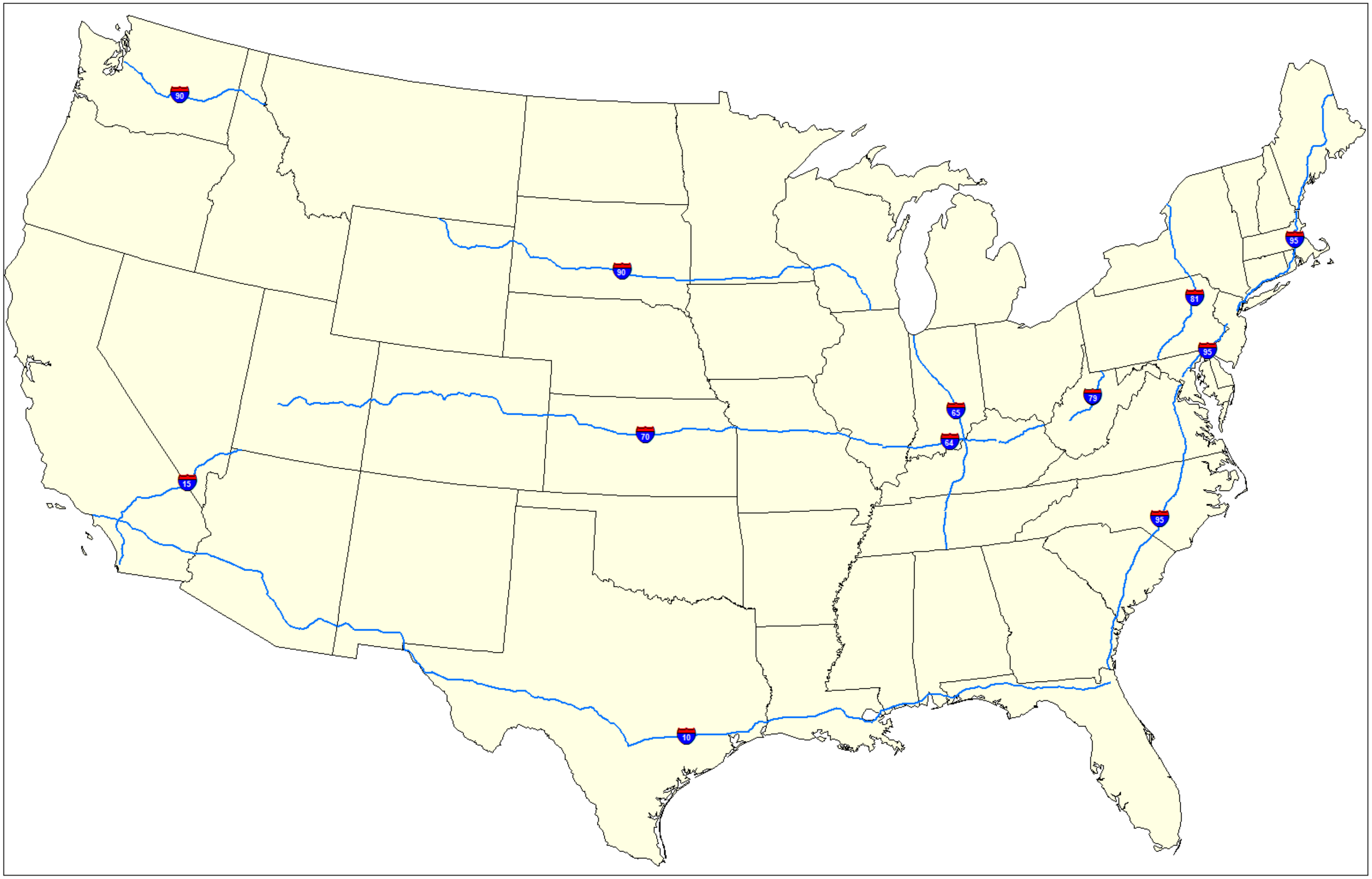

Figure 3. Map. Data collection route.

The proposed route included mileage on the following interstates along with the States covered listed next to the route:

- I-10 through California, Arizona, New Mexico, Texas, Louisiana, Mississippi, Alabama, and Florida.
- I-15 through Arizona, Nevada, and California.
- I-64 through Kentucky, Indiana, and Illinois.
- I-65 through Tennessee, Kentucky, and Indiana.
- I-70 through Utah, Colorado, Kansas, and Missouri.
- I-79 through West Virginia.
- I-81 through Pennsylvania and New York.
- I-90 through Washington, Idaho, Wyoming, South Dakota, Minnesota, and Wisconsin.
- I-95 through Georgia, South Carolina, North Carolina, Virginia, Maryland, Delaware, Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine.

Data collection on the planned route was to occur in the right most through lane in the eastbound or northbound direction along the full length of the route, except where specified otherwise, in order to match the HPMS direction of collection. In addition to those 8,623 miles, another 500 miles of data were to be collected on the inside lane, 500 miles were to be collected in the opposite direction of stated data collection, and 500 miles of data were to be collected for quality control (QC) purposes.

Table 13 summarizes the number of miles collected on each interstate by State as well as the number of miles collected in the inside lane or opposite direction and the number of miles collected for QC purposes.

To obtain an accurate picture of data completeness based on each distress type, the planned route mileage was subdivided based on surface type for the various distresses for the Sample Panel. That is, the total mileage for rutting and crack length is only based on mileage for surface types where rutting and crack length data are collected (e.g., bituminous) and the total mileage for faulting is only based on the mileage for surface types where faulting data is collected (e.g., JCP) while IRI and cracking percent are collected on all surface types and therefore are based on the total number of miles on the route. Figure 4 depicts the comparison between the data completeness for the 2013 HPMS data set and the route. The figure shows good comparison with the data completeness being slightly higher for the route than the 2013 HPMS data set with the exception of rutting. All distresses show good data completeness ranging from 79 percent to 100 percent.

Table 13. Data collection miles and direction.

Interstate	State	Miles	Direction of Data Collection	Opposing Direction, Miles/Direction	Adjacent Lane, Miles/Direction	QC Purposes, Miles and Direction
90	WA	297	East	25, West	25, East	
	ID	74	East			50, East
	WY	207	East	25, West	25, East	
	SD	412	East			
	MN	276	East			
	WI	188	East			
15	AZ	29	North	25, South	25, North	
	NV	124	North	25, South	25, North	
	CA	178	North	25, South	25, North	
10	CA	185	East			50, East
	AZ	392	East	25, West	25, East	
	NM	164	East	25, West	25, East	
	TX	881	East	25, West	25, East	
	LA	274	East	25, West	25, East	
	MS	77	East			50, East
	AL	66	East			
	FL	362	East	25, West	25, East	
70	UT	232	East	25, West	25, East	
	CO	451	East	25, West	25, East	
	KS	424	East			50, East
	MO	252	East			
95	GA	112	North	25, South	25, North	
	SC	199	North	25, South	25, North	
	NC	182	North			50, North
	VA	179	North	25, South	25, North	
	MD	110	North			
	DE	23	North			
	PA	51	North			
	NJ	98	North			
	NY	24	North			
	CT	112	North	25, South	25, North	
	RI	43	North			
	MA	92	North			50, North
	NH	16	North			
	ME	303	North	25, South	25, North	

Interstate	State	Miles	Direction of HPMS Data Collection	Opposing Direction, Miles and Direction	Adjacent Lane, Miles and Direction	QC purposes, Miles and Direction
81	PA	233	North	25, South	25, North	
	NY	184	North			50, North
79	WV	161	North			50, North
64	KY	185	East			
	IN	123	East	25, West	25, East	
	IL	128	East			50, East
65	TN	122	North	25, South	25, North	
	KY	137	North			
	IN	261	North			50, North
Total		8,623		500	500	500

In selecting the route, it was also important to have a statistically representative sample of the entire interstate system. To evaluate this, three stratification factors were considered to compare to the 2013 HPMS data set. These factors included climate zone, urban/rural, and surface type. Table 14 through table 16 show the comparison between the composition of the 2013 HPMS data set and the route for these stratification factors. Based on these comparisons, the route provides a representative sample of the entire interstate system.

The proposed route was also compared against the two freight networks that the FHWA is considering for possible adoption – the 27,000-mile and the 41,000-mile freight networks. All routes appear to be on one or both of the proposed freight networks, except for the section of I-10 in western Arizona and I-79 in West Virginia.

3.3.2 Data Collection Equipment, Protocols and Other Requirements

While definition of the data collection route was an important activity, just as important or perhaps more so was the definition of how high-quality data were to be collected, which required addressing data collection equipment, protocols and other requirements. To meet the project objectives, the equipment to be used for data collection had to meet the requirements identified in the NRPM, which included:

- AASHTO PP 68-10, "Collecting Images of Pavement Surfaces for Distress Detection."(17)
- AASHTO M 328-14, "Standard Specification for Inertial Profiler." (20)
- AASHTO PP 70-14, "Standard Practice for Collecting the Transverse Pavement Profile."(9)

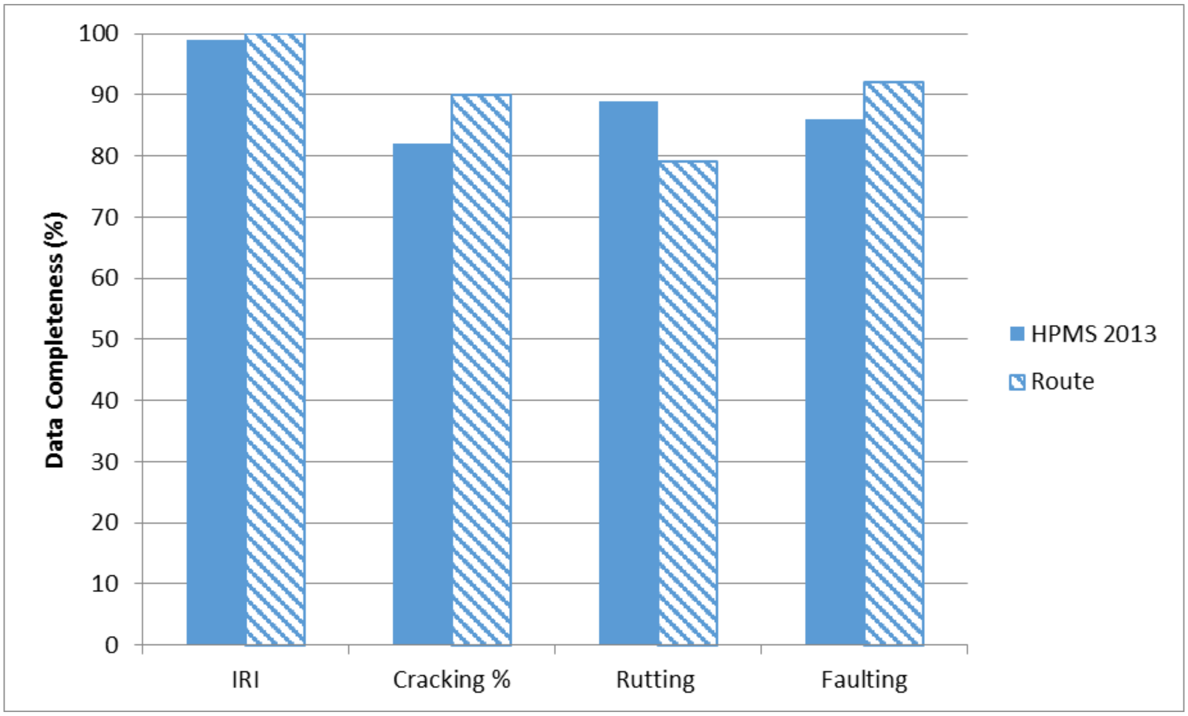

Figure 4. Chart. Data completeness comparison based on Sample Panel in HPMS 2013.

Table 14. Climate zone composition.

	2013 HPMS Data	Route
Wet Freeze	41%	35%
Wet No-Freeze	25%	18%
Dry Freeze	20%	24%
Dry No-Freeze	14%	23%

Table 15. Urban versus rural composition.

	2013 HPMS Data	Route
Rural	62%	70%
Small Urban	6%	5%
Urban	33%	25%

Table 16. Surface type composition.

	2013 HPMS Data	Route
Bituminous	18%	22%
JPCP	10%	11%
JRCP	2%	2%
CRCP	2%	3%
AC over AC	16%	15%
AC over JCP	11%	10%
AC over CRCP	2%	3%
Unbonded PCC Overlay	1%	1%
No data	38%	33%

In addition to the equipment requirements, the following specific activities were stipulated as part of the data collection plan:

- **Project Preparation:** included those items required prior to mobilization to the site – e.g., project-specific documentation, clarification of data collection, processing and/or reporting protocols, questions related to coordination and/or communications protocols, safety-related matters and other – required to ensure a successful data collection effort.

- **Calibration**: required proof of current calibration prior to mobilization to the site for data collection.

- **Data Collection**: required collection of cracking, longitudinal profile, transverse profile, and faulting data. Data collection was to be performed in the outside through lane in the eastbound or northbound direction except where specified otherwise. All raw data were to be geo-referenced. All summary data were to be referenced to a State/route number/ milepoint/direction/lane linear referencing system. If questionable data and/or improperly functioning equipment were suspected during data collection, activities were ceased immediately until the issue(s) in question were resolved.

  In addition to the above referenced calibration requirements, to ensure to the extent possible that the equipment was collecting high-quality data, repeat checks of the equipment on a monthly basis were required. These checks required the conduct of five repeat runs on a short (but no less than 1,000-ft section) pavement section and the review of those data. It was anticipated that pavement condition values resulting from the repeat runs would be within 5 percent of each other for each data collection item – IRI, cracking, rutting and/or faulting.

  The quality of the data collection was assessed after the first 250 miles of data collection and the next 500 miles of data collection by the project team. The data was processed and reviewed for quality based on the Data Storage and Quality Review Plans as contained in appendix A.

3.3.3 Data Collection Quality Requirements

While the goal behind the quality considerations presented in this section was to achieve perfect data, it was recognized that such a goal is difficult to achieve. Nonetheless, it was felt that the quality considerations identified as part of the project went a long way towards achievement of complete, high-quality data. This concentration on quality would help ensure the outcomes, conclusions, and recommendations resulting from implementation of the data collection and analysis plan were as accurate, precise, and reliable as possible. In turn, this would provide confidence that the project outcomes, conclusions, and recommendations were defensible.

The following quality-related activities were to be carried out during the data collection effort:

- Required quality considerations prior to data collection
    - Data collection plan

    - Data collection equipment and protocols in accordance with the 2014 HPMS Manual. [10]

- Required quality considerations during data collection

    - Weather considerations

    - Field data collection considerations and checks

- Required quality considerations after data collection

    - Office quality checks

On completion of planning the quality requirements, it was considered acceptable to commence data collection, but the quality mentality was to continue through the remainder of the data collection effort. An important consideration during the data collection effort was to be ambient conditions as they can significantly affect the quality of the data. For example, profiler measurements may be affected by ambient conditions. Laser height sensors can malfunction at very high and very low temperatures and begin to produce errors and/or turn off to prevent damage. Similarly, the distance measured by the Distance Measuring Instrument (DMI) is directly affected by the rolling radius of the tire, which is directly related to tire pressure which is affected by ambient conditions. In addition the interior vehicle environment is critical to the operation of on-board computers.

In addition to the equipment, ambient conditions can also affect the measurements being taken. There is, for example, the case of the self-healing hot-mix asphalt pavements in some southern US States, which show less cracking during the hot summer months. Likewise, temperature can affect the distresses visible in PCC pavement including crack and joint openings. Furthermore, rainfall prevents the collection of distress and profile data.

Accordingly, data collection personnel were required to document how ambient conditions would be addressed and, as appropriate, mitigated. It was envisioned that the planned route would help mitigate some of the ambient condition effects; e.g., data collection route starting in the southern States and moving north. Data collection personnel were asked to stop data collection immediately once ambient conditions beyond those under which the equipment sensors can properly operate occurred.

Assuming acceptable ambient conditions and once data collection began, the most critical issues to then be considered by the data collection personnel were to follow the established protocols and other stipulated requirements, and to continuously monitor the data being collected to ensure its reasonableness and that equipment was properly functioning. If questionable data and/or improperly functioning equipment were suspected, data collection personnel were to cease data collection activities immediately until the issue(s) was resolved.

In addition, because modern equipment provides software that allows for the review of the data while in the field, it was considered important that the data be checked at the end of the day to make sure things look acceptable; e.g., good images, no profile spikes, etc.

On completion of the field activities and once data were received in the office, data collection personnel were required to check those data to ensure that (1) the files were not corrupt and (2) the data collected were complete. In addition, within one week after completion of data collection for a given State-route combination, data collection personnel were to confirm that the data collected for that State-route had been reviewed and that it was either ready for processing or those data needed to be recollected.

3.4. EXECUTION OF DATA COLLECTION PLAN

3.4.1 Data Collection

On completion of the data collection plan, the project team issued a request for proposals (RFP) soliciting a vendor to perform the required data collection in accordance with the plan. The procurement process began in early February 2015 and it was completed at the end of April 2015.

With few exceptions, which are noted later in this section, data collection was completed in accordance to the plan. Actual data collection began in June 2015 after successful completion of the required equipment checks and calibrations. Prior to the start of data collection, the project team met with the data collection vendor to review, refine and finalize the data storage and quality review requirements.

Once data collection began in June 2015, the project team provided a weekly data collection status report to the FHWA. Table 17 summarizes the data collection schedule from start to end, by route and State. As shown, data collection was completed in August 2015.

Table 17. Summary of data collection schedule.

Route	State	Start Date	Completion Date
I-15	CA, NV, AZ	6/15/15	6/21/15
I-10	CA, AZ, NM, TX, LA, MS, AL, FL	6/22/15	7/9/15
I-95	GA, SC, NC, VA, MD, DE, NJ, NY, CT, RI, MA, NH, ME	7/10/15	7/28/15
I-81	PA, NY	7/29/15	8/1/15
I-79	WV	8/2/15	8/2/15
I-65	TN, KY, IN	8/3/15	8/10/15
I-70	UT, CO, KS, MO	8/11/15	8/18/15
I-64	IL, IN, KY	8/19/15	8/21/15
I-90	WA, ID, MT, WY, SD, MN, WI	8/22/15	8/31/15

A single data collection unit was used by the data collection vendor, at the request of the project team. While the data collection effort would have been completed faster with two or more units, the project team concluded that multiple units would introduce data variability and quality issues that could not be afforded on a project of this nature. The components of the equipment used by the data collection vendor are summarized below:

- **Right-of-Way Imagery**. The digital imagery system included two forward-facing cameras for the collection of right-of-way images. The cameras were capable of capturing images at a custom frame rate, and running at a minimum resolution of 3,296 x 2,472 pixels each – a capture rate of 200 frames per mile was used. The cameras automatically adjusted to changes in lighting conditions to capture images of the highest quality. Additionally, the operator was able to monitor image collection in real-time and to compensate for additional factors that could have affected the quality of the images.

- **Pavement Analysis**. A Laser Crack Measurement System (LCMS) was used for the collection of the pavement distress, rutting and faulting data. The LCMS used high-speed cameras, custom optics, and laser line projectors to acquire both 2D images and high resolution 3D profiles of the road. The LCMS allowed for the automatic extraction of distress information as well as the collection of rutting data. Other specifications of the system included:

    - Sampling rate: 5,600 profiles/s
    - Transversal field of view: 13.1 ft
    - Transversal resolution: 0.04 inch
    - Depth range of operation: 9.8 inches
    - Depth resolution: 0.02 inch

  A Mark IV Road Surface Profilometer (RSP) was used for the collection of IRI data. The RSP has two laser sensors and a Class I profiling certification to collect IRI and faulting data. System specifications include:

    - Vertical displacement measuring resolution of the laser sensors: +/- 2 mil
    - Fault/bump height detection threshold: 0.2 inch (bump heights reported to nearest 0.1 inch)
    - Number of detected fault/bumps per 0.1 mile measured and reported as "bump count"

- **Positional Information**. The Position Orientation System (POS) LV 220 was used for the collection of Global Positioning System (GPS) data. The POS collects vehicle position, velocity, attitude, track, speed, and dynamics for the collection vehicle as it travels along the roadway. It includes an Inertial Measurement Unit (IMU) and a DMI. The system is capable of providing latitude, longitude and elevation data that is accurate to within +/- 3.28 ft.

The data collection vehicle was a Ford E-350 passenger van that was outfitted with the custom hardware, cabling, and safety features required for a network-level data collection project. Figure 5 and figure 6 show the data collection vehicle that was used on the project. In addition to the technology already described, the vehicle included the following technology:

Figure 5. Photo. Data collection vehicle – rear view.

Figure 6. Photo. Data collection vehicle – side view.

- **Pavement Surface Temperature**. An infrared thermometer designed for mobile use at highway speeds was used to collect pavement surface temperature. The non-contact infrared sensor featured a robust housing and was mounted under the vehicle in order to scan the pavement surface temperature at a rate of once every 15 minutes.

- **Vehicle Tracking**. To more efficiently manage and maintain the data collection vehicle and schedule, the collection vehicle was monitored while it was in the field. The monitoring system featured a multi-network, rugged communications platform that delivered a secure, wireless wide area networking for the vehicle, which helped ensure the vehicle was on track and schedule.

As noted earlier, data collection was completed in full accordance with the protocols and requirements stipulated in the Data Collection Plan. For the most part, data collection progressed as planned, but there were issues that affected the schedule (in order to ensure the quality of the data was not affected). Those issues and their resolution are summarized below:

- **Collection vehicle overheating**. Data collection commenced in June 2015 along I-10 and I-15 in California with temperatures in excess of 100^{o}F. These high temperatures caused the collection vehicle to overheat. To resolve this issue, engine maintenance took place at a Ford Dealership in Las Vegas. Because of the excess heat, overheating was commonplace in the area and the local repair shops were inundated with vehicles, which resulted in four days lost. The heat did not affect the data collection systems.

- **Detours**. Data collection was to occur in the right most through lane in the eastbound or northbound direction along the full length of the route; i.e., 8,623 miles (remaining 1,500 miles included data collection on inside lane, in opposite direction and QC repeats). Detours were anticipated during the planning stages due to construction or other reasons, however, these detours only materialized once. In Indiana, the replacement of a bridge on I-65 prevented data collection on approximately 50 miles of that route. Given the data collection schedule constraints, the decision was made by FHWA that, instead of waiting until the bridge replacement had been completed, 50 miles of data would be collected on I-90 in Montana (thus one more State on the route, or 39 States instead of 38). Because data collection on I-90 was done from west to east, the 50 miles of data in question were collected in western Montana, starting from the border with Idaho. This was the only deviation to the data collection route.

- **Traffic delays**. Like detours, traffic delays were also anticipated during the data collection planning stages, especially in or near urban areas. Unlike the detours, however, the traffic delays did materialize, which required that data collection be delayed or postponed to ensure a minimum speed of at least 13 mph whenever possible. When the speed did drop below this threshold, IRI data collected at those speeds was excluded from the summaries. The bulk of the delays took place along the northern half of the I-95 corridor and their impact on the data collection effort was limited.

- **Rain delays**. Like traffic detours and delays, delays in the data collection effort due to weather were also anticipated. In addition to the temperature addressed above, rain also caused delays along the eastern end of the I-10 corridor and the southern end of the I-95 corridor. Fortunately, like traffic delays, the impact of rain on the data collection effort was limited.

3.4.2 Data Processing

Processing of the more than 10,000 miles worth of data was completed in accordance with the protocols and requirements specified in the data collection plan. Processing of the data was done in seven separate batches. Those batches, along with the number of miles and shipment date (to project team) are summarized in table 18. The following sections provide details on the various types of data processing.

Table 18. Summary of processed data shipments.

Shipment No.	Number of Miles	Shipment Date
1	215	June 25, 2015
2	507	July 9, 2015
3	2,105	July 27, 2015
4	1,651	August 7, 2015
5	1,376	August 17, 2015
6	2,252	September 3, 2015
7	2,021	September 21, 2015

Crack Identification

The two-dimensional intensity profiles provided by the LCMS were used to form a continuous image of the road surface. The first role of the intensity information was for the detection of road limits. This algorithm relies on the detection of the painted lines used as lane markings to determine the width and position of the road lane in order to compensate for driver wander. The lane position data was then used by the other detection algorithms to circumscribe the analysis within this region of interest in order to avoid surveying defects outside the lane.

Two separate software applications were used to analyze the collected data and automatically detect pavement distresses. The data were first run through software called RoadAnalyser, which automatically detects cracks and assigns crack width by analyzing the intensity and range data. RoadAnalyser outputs three sets of viewable images: range, intensity, and both range and intensity with detected distress overlay. The data was then run through the data collection vendor’s internally-developed classifier application which analyzed the marked cracks and classified them according to the specifications of the project. Transverse profiles were also processed and reported at the same interval as the images.

The three-dimensional data acquired by the LCMS system measures the distance from the sensor to the surface for every sampled point on the road. The lower the surface (i.e., farther from the sensor), the darker the point will be on the image. In a range image the height varies along the cross section of the road. The areas in the wheel path are usually deeper than the sides and thus appear darker, corresponding to the presence of ruts. Height variations can also be observed in the longitudinal direction due to variations in longitudinal profiles of the road causing movements in the suspension of the vehicle holding the sensors. These large-scale height variations correspond to the low-spatial frequency content of the range information in the longitudinal direction. The features that need to be detected are located in the high-spatial frequency portion of the range data.

The process of automatically detecting the cracks began by applying a threshold algorithm to the range image. The 3D profile data was detrended from the effects of rutting and vehicle movements. Once the detection operation was performed, a binary image is obtained where the remaining active pixels are potential cracks. This binary image was then filtered to remove any false detections that were caused by asperities and other features in the road surface which were not cracks on the pavement. After the detection process, the next step consisted of the characterization of the cracks. The severity level of a crack was determined by evaluating its width (opening). The cracks were also grouped into three main categories: longitudinal, transverse, and pattern cracks. Transverse cracks were divided into complete and incomplete types and joints were classified separately. Pattern cracks are groups of cracks within a close proximity to each other. Longitudinal cracks are single cracks that run parallel along the roadway.

Although data processing went as planned, a couple of issues were encountered, which required re-processing of the data. They are:

- **Sand-filled cracks**. During the data quality review process (described later in this chapter), which included a review of the right-of-way images as well as pavement images, it was discovered that cracks filled with sand (most likely due to wind) were not being properly identified by the automated crack detection software. Because the cracks were filled with sand, there was no depth to those cracks, and hence they could not be detected. Efforts to automate the detection of these cracks were unsuccessful. As a result, a significant effort was spent in (1) identifying where those cracks occurred, (2) performing manual take-offs of those cracks, and (3) integrating the resulting take-offs with the rest of the cracking data. Fortunately, the occurrence of the sand-filled cracks on the data collection route was rare, with most of it occurring along I-10 in California and Arizona as well as I-15 in California.

- **Sealed cracks**. While somewhat vague, the NPRM defers to the 2014 HPMS Guide [(10)] for the treatment of sealed cracks – sealed cracks are to be incorporated into the cracking count for purposes of estimating percent cracking. The LCMS sensor and associated processing algorithms are able to identify unsealed cracks and sealed cracks. However, when processing was initiated, the sealed crack portion of the algorithm was not initiated. Therefore, processing of data for a significant portion of the route (all but I-90 and portions of I-64), was completed without taking into account sealed cracks. Accordingly, re-processing of the data affected was complete, which required a significant effort.

  The crack identification on the PCC sections was performed manually. When the re-processing was performed, the PCC pavements were not included in that effort. A review of these sections indicated there were approximately 33 miles of PCC pavement with sealed cracks which were not re-processed amounting to approximately 0.3 percent of the collected data. In reviewing these segments, an exercise was performed to identify the impact of these data on the results. In this exercise, it was assumed that the cracking condition for all 33 miles should have been poor and the overall condition was determined using the cracking condition as poor. The condition changed for approximately 5.5 miles amounting to less than 0.1 percent of the collected data. Therefore, because the impact would have been minimal in comparison with the effort required to re-process these data, the sealed cracking on PCC pavements was omitted from consideration in these analyses.

There were portions of the route where both of the above issues occurred. In those cases, which were only a handful, the manual take-off of sand-filled cracks was done after re-processing of the data for sealed cracks had been completed.

Rutting Identification

Rutting was measured and characterized by the LCMS using more than 4,000 points, and rut depth and type (short, multiple, long radius) were evaluated. During post-processing the software retrieved the rutting information (rut depth, rut width, cross-section, etc.) for a specific road section. The rutting computation was based on the ASTM E1703 – Standard Test Method for Measuring Rut-Depth of Pavement Surfaces Using a Straightedge. [22] This method measures the depth of the rut at a chosen location in a pavement surface using a straightedge and a gauge. The LCMS processing library computes two ruts per profile, the left and right wheel paths. The number of rut measurements that were calculated per road section was 528 per 0.1-mile segment. The distance between successive rut measurements was 1 ft, the length of the straightedge used for simulating the manual rut measurement was variable depending on lane width, but never greater than 6.56 ft, and the width of the gauge utilized for rut measurement was 1.57 inches.

3.4.3 Data Quality Review

The Quality Management Plan developed for the project and approved by FHWA included the data collection daily checks and system inspections to be performed by the vendor. No precision and bias statements are available for rutting, cracking, and faulting. The checks to be performed as part of data collection included:

- Check and monitor GPS accuracy.
- Monitor images to assure collection meets specifications.
- Run internal verification program to confirm completeness of all data sets after the collection of every route.

No errors or system issues were discovered in the field.

In addition, the following weekly checks were performed.

- Inertial Profiler Repeatability
    - 10 runs of inertial profiler data have less than 5 percent standard deviation from the mean.

    - Average IRI values from the last historical validation at the validation site has less than a 10 percent standard deviation from current data.
    - Continuous IRI graph plots well.
    - Power spectral density graphs look normal.
- Rutting Repeatability
    - 10 runs of LCMS data have a standard deviation of less than 1 mm rut depth.
    - Average rutting values from the last historical validation at the validation site has less than a 0.04 inch standard deviation from current data.
- Distress Repeatability
    - 10 runs of LCMS data have a standard deviation of less than 15 percent total distress length.
    - Average distress lengths from the last historical validation at the validation site has less than a 15 percent standard deviation from current data.
- Linear Reference
    - DMI pulse counts from 5 runs have less than a 0.1 percent difference from each other.
    - Utilize validation runs to confirm proper linear reference values have been input for all collection systems.

No issues were found during the weekly repeatability tests.

The following checks were performed in the office as part of the data reduction and review.

- Daily checks
    - Use project Keyhole Markup Language (KML) files to assure 100% coverage.
    - Review sample images for clarity.
    - Review sample images for color balance.
    - Review sample images for luminance.
    - Review bounce test output in ProVAL.
    - Load inertial profiler files into ProVAL for power spectral density anomalies.
    - Process a sample of LCMS images and review for anomalies.

  - Bounce test review.
  - Block check review.

As part of these daily checks, there were 6 miles on I-15 in California that were found to have shadows on the pavement in the forward images created by the vehicle due to collection later in the day with the sun behind the vehicle. As a result, the affected mileage was recollected.

- Reduction checks
  - Review a sample of right-of-way images to assure they meet standards.
  - Utilize image enhancer program to adjust unacceptable images.
  - Check LCMS images for null rutting values.
  - Check LCMS for invalid rutting values (= 0 or > 0.75 inch).
  - Check for profile data collected outside of acceptable temperature limits (< 32 °F > 104 °F).
  - Review automated distress to assure algorithms are working appropriately.
  - Confirm placement of roadway features such as locations of bridges and pavement changes.
  - Use collected QC roadway sections to perform data set comparison.

No issues were found during the reduction checks. A number of records were identified where data was recorded outside of the acceptable temperature limits. These records were reviewed further to identify the potential for errors. The ride quality values collected at these temperatures were similar in size to other data collected in these areas. Further, the sensors used in data collection typically will automatically turnoff once an unacceptable temperature is reached. The check on data collected outside of the temperature range was performed and all data were deemed reasonable.

Prior to delivering the data, the data collection vendor reviewed the data for quality assurance in the following ways:

- Confirm completeness for all deliverables.
- Utilize outlier checks to flag improbable values for further review.

Once the data collection vendor had reviewed the data for quality assurance, the data was delivered to the project team.

As presented earlier, the data was processed in seven shipments. The data was received from the data collection vendor on hard drives. Once the data was received, the initial processing included:

- Data files scanned for viruses.
- Data were stored on the network under the Data Collection Task in the project file.
- Original data file was maintained under the data collection task.
- Copy of data then placed under Data Analysis Task in project file as working file.
- Original USB hard drive maintained until all data collection complete and received.

The data was then reviewed for quality and consistency. The review of data was performed per the requirements of the Data Storage and Quality Review Plan contained in appendix A.

Data that failed any of the above checks were flagged and reviewed by the project team. Some of these flags included exceeding the maximum IRI, cracking, rutting and faulting values, and exceeding the allowable difference between wheelpath values for IRI or rutting suggested in the Data Storage and Quality Review Plan.

The flagged data were reviewed by the QA engineer. Reviews included comparing the flagged data to the images to check for causes of being flagged. For example, for a record exceeding the maximum specified rutting value in the Data Storage and Quality Review Plan, the image at that location was reviewed to determine if the reported value was reasonable. If rutting was observable in the image, the record was considered valid.

It was through these QC reviews that both the sand-filled cracks and sealed cracks referenced earlier were found. No other systematic issues were found during the QC review process.

After the review by the QA engineer and resolution of any issues, the data was approved and included in the database.

3.4.4 Project Database

The data were exported to an Access database to be used for all analyses. The database contains both the original data provided at the 0.01-mile intervals and the computed values at 0.1-mile intervals.

The database contains seven tables: five containing the original data collected at 0.01-mile intervals; one containing data on the locations of bridges, required lane changes, and construction encountered during data collection; and one containing the data calculated at the 0.1-mile interval.

The five tables for the 0.01-mile interval data include a table for cracking on AC pavements, a table for cracking on PCC pavements, a table for IRI on all pavements, a table for rut depth on AC pavements, and a table for faulting on JPCP segments. Each of these five tables contains basic identification information including the State, route, milepost, latitude and longitude, direction, and lane of data collection. These tables all have a column identifying if the data is "QC" data or not, where QC data is repeat data collection on select segments of the route. The tables contain data regarding the details of the data collection effort including the vehicle, driver, operator, speed of travel, date, time, air temperature, surface temperature, and surface type. These tables also contain flags identifying the locations of bridges, construction, and required lane changes. These flags are intended to explain where condition data are not provided. Longitudinal profile data were collected and are provided on bridge decks but no other condition data were collected on these areas.

A complete Data Dictionary is provided in appendix B which provides definitions for each data element included in the database. A few specific definitions are provided here to provide clarity in the analysis discussed in the next chapter.

For the analysis several definitions were used for percent cracking on asphalt surfaces. This section covers these definitions and provides the names by which these values are referenced for the remainder of this report.

- AC HPMS – Total area of wheelpath cracking divided by the total lane area.

- AC Percent Wheelpath – Total area of wheelpath cracking divided by the area of the wheelpaths.

- NPRM Under – Area of affected wheelpath cracking plus the area of transverse cracking (transverse cracking length multiplied by 1 ft). The length of transverse cracking is reduced by the amount of the transverse cracking within the wheelpath. Total crack area is divided by the total lane area. This definition is illustrated in Figure 7.

- NPRM Over – Area of affected wheelpath cracking plus the area of transverse cracking (transverse cracking length multiplied by 1 ft) divided by the total lane area. This definition is illustrated in Figure 7.

- NPRM Step – The area of transverse cracking is reduced in a graduated manner based on the area of wheelpath cracking. Where the percentage of wheelpath cracking is greater than 80 percent of the total wheelpath area, the transverse cracking length is reduced by the amount of transverse cracking within the wheelpath. The full transverse cracking length is used where the percent of wheelpath cracking is less than 20 percent. If the percent of wheelpath cracking is between 20 and 40 percent, 75 percent of the transverse crack length within the wheelpath is used. If the percent of wheelpath cracking is between 40 and 60 percent, 50 percent of the transverse crack length within the wheelpath is used. Finally, if the percent of wheelpath cracking is between 60 and 80 percent, 25 percent of the transverse crack length within the wheelpath is used. The total crack area is divided by the total lane area. This definition is illustrated in figure 7.

In addition to the varying types of cracking used in analyses, there are two types of faulting reported within the database. The LCMS was used to estimate faulting at each joint as was the inertial profiler.

Two types of rutting were also provided with the data. The first is based on the transverse profile collected from the LCMS and the second is a rut depth estimate based on the 5-point method.

Comparisons between these definitions for the condition data are provided in chapter 4.

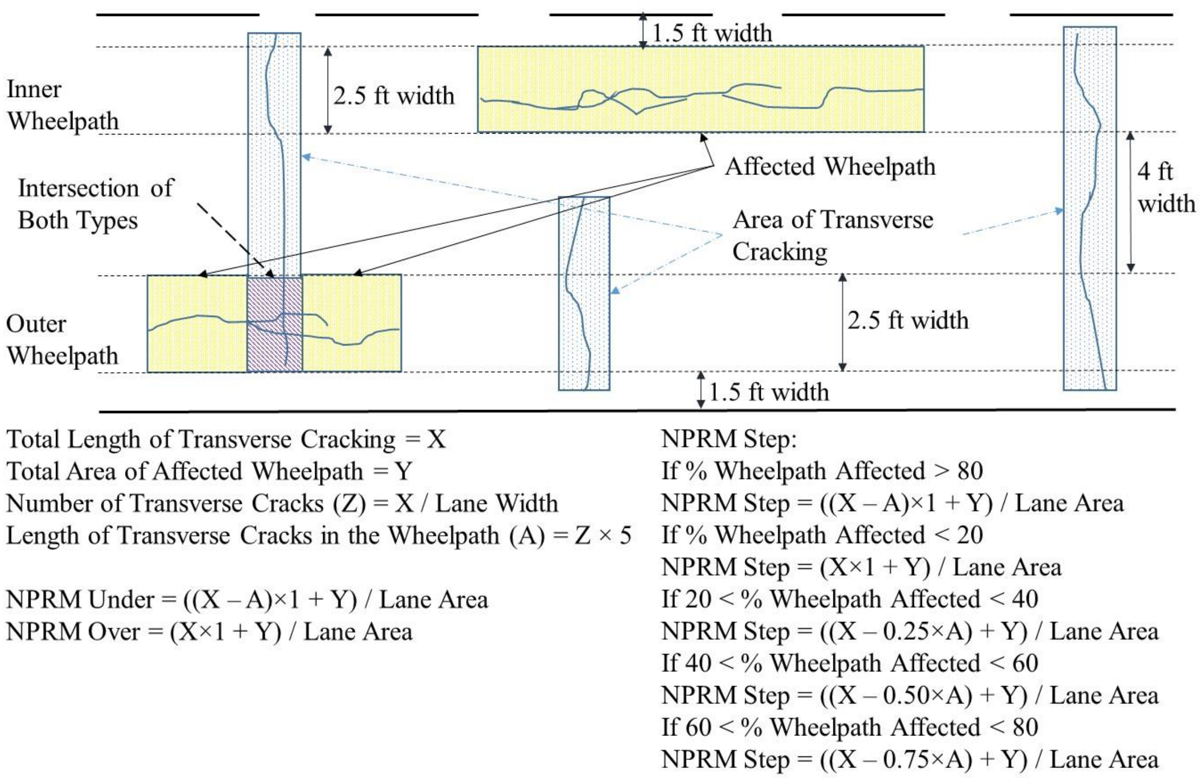

Figure 7. Sketch. Illustration of cracking definitions.

CHAPTER 4. DATA ANALYSIS

The data resulting from the effort described in the previous chapter served as the reference data for the analysis presented in this chapter. The objectives of these analyses activities, which were the same as for the project, were to:

- Produce a report indicating the pavement condition on the IHS nationally and in each State where data were collected, which was to be accomplished using project collected data.

- Determine if HPMS is an unbiased representation of the pavement condition of the IHS, which was to be accomplished by comparing project collected data with 2014 HPMS data.

- Recommend improvements to HPMS data collection and reporting that are necessary to either make HPMS unbiased or improve its precision, in regard to performance management and FHWA's use of HPMS data, which in turn would enable responses to questions such as:

    - Is two-way data collection necessary?

    - Does data need to be collected in more than one lane in a direction?

    - What is the optimum HPMS section length?

    - Do all distress items require full extent reporting or is sampling adequate?

    - Are the protocols proposed by FHWA adequate for collecting and reporting distress or do they need improvement?

To accomplish the above stated objectives, a two-pronged approach was undertaken. First, a data analysis plan was formulated, which addressed not only those analyses to be carried out, but also the quality review activities to be performed to help ensure the quality of the outcomes. Second, the implementation of the analysis plan, including issues encountered and their resolution. Both of these items are addressed, in detail, in this chapter.

4.1. DATA ANALYSIS PLAN

A detailed analysis plan was developed to identify the steps to be followed to meet the objectives as stated above. The outline of the analysis plan is as follows:

- Quality review of analyses results

    - Paired t-test of QC data collected

    - Comparison to I-90 data

- Comparison to LTPP data

- Detailed analyses
    - Distribution of condition metrics
    - Computation of overall network condition
    - Comparison of pavement condition metrics data between HPMS and project data
    - Calculation of overall condition by State
    - Comparison of overall condition between HPMS and project data
    - Paired t-tests of condition metrics to data collected in adjacent lane
    - Paired t-tests of condition metrics to data collected in opposing direction
    - Review of accumulation distance
    - Estimated sampling requirement
    - Review of impact of bridges on overall condition
    - Review of impact of equipment type on condition metrics and overall condition

The following sections will cover each of these items.

4.2. COMPARISON WITH QUALITY CONTROL DATA

Several analyses were performed as part of a check on the quality of the data collected. The first is a comparison with the QC data collected as part of the project. The second is a comparison of the data collected for this project with the data collected for the pilot project on the FHWA Study *Improving FHWA's Ability to Assess Highway Infrastructure Health - Pilot Study Report.* [3] The third comparison was with data collected for the LTPP program.

4.2.1 Comparison with Quality Control Data

The first analysis performed on the collected data was a review of these data as compared to the quality control data collected. As noted in chapter 3, approximately 500 miles of data were collected twice to provide an opportunity to review the repeatability of the data collection effort.

The comparisons were performed using the 0.01-mile interval data collected. A paired t-test was used to compare the four condition metrics from the "routine" data collection and the QC data collection. The paired t-test compares the average of the differences in the two values for each interval to zero. Table 19 provides the results of these comparisons.

The differences observed in the QC data and the routine data are small and of little importance even though the statistics indicate that they are significantly different. The statistical significance is likely due to the size of the data set. The correlation coefficients for each metric indicate that the condition metrics are quite repeatable. The comparisons indicate that the data are of good quality.

Table 19. Comparison of routine and QC data.

Element	Routine Data Average	QC Data Average	Average Difference	Correlation Coefficient	Statistical Significance
Average IRI	65 in/mile	64 in/mile	0.5 in/mile	0.92	Yes
Average Rut Depth	0.13 inch	0.14 inch	0.01 inch	0.95	Yes
AC HPMS Percent Cracking	1.8%	1.6%	0.2%	0.90	Yes
AC Percent Wheelpath	4.0%	3.6%	0.4%	0.90	Yes
AC NPRM Under	2.2%	2.0%	0.2%	0.91	Yes
AC NPRM Over	2.4%	2.2%	0.2%	0.90	Yes
AC NPRM Step	2.3%	2.1%	0.2%	0.90	Yes
PCC Cracking	2.3%	2.1%	0.2%	0.71	No
Faulting	0.03 inch	0.03 inch	0.001 inch	0.78	Yes

4.2.2 Comparison with Infrastructure Health Data

Data for the FHWA project *Improving FHWA's Ability to Assess Highway Infrastructure Health - Pilot Study Report* were collected along the I-90 corridor through South Dakota, Minnesota, and Wisconsin. [(3)] Data were collected in 2011 along the outside lane of the primary direction of travel (east). Data collected for this project included IRI, cracking, rut depth, and faulting at 0.1-mile intervals.

The first aspect of the comparison was a check on location referencing. A total of 46 locations were selected randomly along the corridor and the GPS coordinates for the milepoints identified within both data sets were used to compare how closely the data sets compared. The distance between the two points was measured in Google Earth. This measurement is not intended to have a high degree of accuracy, rather, the measurement is intended to provide a general understanding of the differences in the two data sets.

For the first 10 miles (approximately) within each of the three States, the differences in location were smaller than those at higher mileposts and were generally less than 200 ft. While after the first 10 miles, the differences were larger, the difference in milepost location did not increase with increasing milepost. In Minnesota and South Dakota, the largest differences were approximately 2,000 ft and the differences in location reached a total of approximately 3,600 ft in Wisconsin.

Table 20 provides a comparison of the total mileage for each State on the I90 corridor. Differences were observed in the total mileage for each State. However, the lengths of data collected for this project were much closer to the State published mileage than the Infrastructure

Health data. This review suggests that the location referencing for the IS Condition data is more accurate than the Infrastructure Health data.

Table 20. Comparison of mileage by State.

State	IS Condition Mileage	Infrastructure Health Mileage	State Published Mileage
MN	275.60	276.11	275.70
SD	412.75	412.47	412.76
WI	187.16	187.88	187.13

Next a comparison was made of the surface type between the two projects. The objective of this comparison is primarily to understand how the corridor changed between the two data sets rather than for quality purposes. A difference in surface type was observed for 18 percent of the I90 corridor through these three States. There is a 4-year difference in time between the two data collection efforts. The differences in surface type are expected to be caused by two factors: (1) construction that has taken place since the 2011 data collection, and (2) the shift in location referencing that occurs between the two data sets.

The next step was to compare the condition metrics between the two data sets. These results are summarized in table 21. The data were filtered such that only the portion of the corridor with the same surface in both data sets were compared. The difference in the IRI data between the two data sets was not statistically significantly different. The average value differs by 0.3 in/mile between the two data sets. Both data sets have an average of 75 in/mile.

Table 21. Comparison of condition metrics between project data and Infrastructure Health project data.

Metric	IS Condition		Infrastructure Health		Statistically Significant
	Average	Standard Deviation	Average	Standard Deviation	
IRI	75 in/mile	34 in/mile	75 in/mile	31 in/mile	No
Rut Depth	0.13 in	0.07 in	0.12 in	0.08 in	Yes
Faulting	0.03 in	0.02 in	0.08 in	0.10 in	Yes
Percent Cracking	3.6%	8.7%	4.0%	11.1%	Yes

The other three condition metrics were all statistically significant. The average rut depths are 0.13 inch for IS Condition and 0.12 inch for Infrastructure Health. So, even though the difference in these values is statistically significant, it is not significant from an engineering viewpoint. The average percent cracking is 3.6 percent for IS Condition versus 4.0 percent for Infrastructure Health; so, again, statistically significant but not from an engineering viewpoint. Last is the faulting. The difference here is much larger with an average value of 0.03 inch for IS Condition and 0.08 inch for Infrastructure Health. The larger difference in the average values is hypothesized to be a combination of factors – time and equipment. The vendor collected the faulting data using the RSP for the Infrastructure Health project. The LCMS methods for collecting faulting were not ready for general use at the time of the Infrastructure Health project and so the profiler was used for faulting for that project. A further comparison of the impact of the device is reviewed in Section 4.6.5.

A comparison was also made between the variances for each condition metric between the two data sets. Differences in variances are all identified as statistically significant. For rutting, faulting, and cracking, the Infrastructure Health data have a larger variance than the IS Condition data. For IRI, the IS data have a larger variance than the Infrastructure Health. The differences in variances for rutting, faulting, and cracking are expected to be part of a process improvement effort. In the time between the collection of the two data sets, improvements have been made in the collection of rutting, faulting, and cracking. The collection of longitudinal profile data has reached a fairly static level where little change has occurred in the last few years. Standard deviation in IRI is 33 in/mile for the IS data and 31 in/mile for the Infrastructure Health data. It is possible that the difference in length observed in the comparison of the location referencing between the two data sets contributes to the difference in variance between the two data sets. The longer length of the Infrastructure Health data allows for the variability to spread over a longer distance making the variability appear to be smaller.

The last step in the comparison was between the performance measures for each data set. Both data sets show 63 percent in good condition; although the Infrastructure Health data shows 10% poor and the IS Condition data for these three States is less than 1 percent poor. Table 22 provides the comparison of the performance measures between the two projects for the three States. While the performance measures for the three States compare well between the two data sets, a segment-by-segment comparison is not as good with differences in overall condition at the segment level ranging from 28 to 49 percent. Much of these differences are likely due to the time difference in the data sets, especially for Minnesota and Wisconsin, where overall pavement condition has clearly deteriorated from the Infrastructure Health project to the IS Condition project. Generally, segments appear to have moved from good to fair; although poor segments have also moved to either good or fair condition (likely due to maintenance of these areas).

Table 22. Comparison of performance measures.

State	Data Set	Good	Fair	Poor	Segments with Different Condition
Minnesota	Infrastructure Health	61.9%	30.6%	7.5%	41.7%
	IS Condition	55.0%	45.0%	0.0%	
South Dakota	Infrastructure Health	72.0%	21.4%	6.6%	28.2%
	IS Condition	83.9%	16.0%	0.1%	
Wisconsin	Infrastructure Health	47.1%	32.9%	20.0%	49.0%
	IS Condition	30.9%	68.0%	1.1%	
Total	Infrastructure Health	63.1%	27.1%	9.8%	37.7%
	IS Condition	63.2%	36.6%	0.2%	

The comparisons between the Infrastructure Health and IS Condition data confirm the reasonableness of the data collected for this project. These data comparisons also suggest that process improvements in data collection, particularly in reference to faulting and reference location, have made significant changes in the resulting data.

4.2.3 Comparison with LTPP Data

The third comparison for review of the quality of the data was with data from the LTPP PPDB. One-hundred sections were available for use in comparison to the data collected along this project.

The LTPP test sections are 500 ft in length; therefore, these sections were compared to data aggregated to 0.1 mile. The GPS coordinates of the LTPP section were used to identify the closest milepost along the route to the nearest 0.01 mile. In other words, the nearest 0.01-mile interval may begin at milepost 107.74 as opposed to 107.7. Condition data were then aggregated to obtain the values for the 0.1-mile beginning at that location.

The LTPP test sections are evaluated on a regular basis; therefore, multiple values are available for each condition metric with the most recent survey used. The data are stored in metric units and were converted to English units to match those of the IS Condition data. Cracking data for the LTPP test sections is collected in accordance with the LTPP DIM (18) which is much more detailed than the requirements for the NPRM. These data have been used to estimate the percent cracking on the test section in accordance with LTPP Distress Directive D-61, "Translation of LTPP Cracking Data for National Applications." (23)

Data were compared for each condition metric. The data set for each condition metric were reduced to only consider data collected within the last five years except for the rut depth comparison. Only seven test sections exist on the route in the same direction of travel with rut depth collected within the last five years; therefore, comparisons with rut depth included all data. A paired t-test was used to compare the condition metrics and these were not statistically significant for all of the condition metrics. These comparisons involved a smaller number of 0.1-mile sections than many of the other comparisons contained within this chapter; therefore, statistical significance requires a larger difference in the data. Table 23 provides the average and standard deviation for each condition metric for both data sets along with the number of sections used in that comparison.

Table 23. Average and standard deviation of each condition metric for comparison with LTPP data.

Condition Metric	IS Condition Data		LTPP Data		Number of Sections
	Average	Standard Deviation	Average	Standard Deviation	
IRI	102 in/mile	37 in/mile	100 in/mile	35 in/mile	33
Percent Cracking	23%	31%	25%	31%	32
Rut Depth	0.26 inch	0.17 inch	0.30 inch	0.17 inch	67
Faulting	0.05 inch	0.06 inch	0.03 inch	0.06 inch	25

A further review of the differences in the data between the IS Condition and LTPP data was performed. Within each condition metric, between 2 and 6 sections were identified as having a larger difference between the two data sets when compared to the other 20 plus sections reviewed for each condition metric. Six sections were identified with larger differences in rut depth between the two data sets. In all six cases, the most recent rut depth measurement was performed prior to the year 2000. The large difference in time is the cause for these differences in values.

Two sections were identified with large differences in faulting. For one of this sections, it was noted that the faulting observed on the first half of the section was larger in the project data than it was in the LTPP database, but the exact cause of this difference was not observable. The other section had several faults identified as “N/A” in the LTPP database. These joints were typically located around patches. These same joints were generally identified as having larger faults than other joints on the section.

Four sections were identified with differences in percent cracking for further review. Three of the four sections were identified as having a large quantity of map cracking. The map cracking in some areas included a crack that appeared to be deeper than just the surface from the images; however, the manual distress survey rated these areas as map cracking. It is not possible to determine from the images whether these cracks are definitely deeper than the surface. The fourth section was also a concrete pavement. On this section, there was a significant level of macrotexture observable in the images. The macrotexture appears to have masked cracking in the images that was observable to the naked eye during a manual survey.

4.2.4 Quality Control Comparison Summary

These comparisons were used to check for the quality of data collected. These comparisons illustrated that the data collection was repeatable and generally matches data collected by/for other studies in the last few years. These data suggest that process improvement practices have improved the overall capabilities of the industry to collect quality data. Further, these improvements in methods to collect quality data may be expected to have a significant impact on the performance measures.

4.3. DISTRIBUTION OF THE CONDITION METRICS

A key concern about the condition metrics is the type of distribution these data follow. Most of the standard approaches for evaluating data assume that the data follow a normal distribution. A series of reviews were conducted of the condition metrics to determine if these data follow a normal distribution. This review was performed using the data accumulated to the 0.1-mile interval.

The results of this review are provided in table 24. The table contains the mean, standard deviation, minimum, and maximum values. In addition, it also includes the skewness and kurtosis of the distribution. The skewness provides a measure of the symmetry of the distribution. A negative skewness indicates that the tail is larger on the left side of the distribution and a positive skewness indicates that the tail is larger on the right side of the distribution. The closer the value is to zero the more symmetric the distribution.

Table 24. Condition metric summary statistics.

Element	Count	Mean	Standard Deviation	Minimum	Maximum	Skewness	Kurtosis
IRI	84,837	71 in/mile	37.8 in/mile	3 in/mile	959 in/mile	2.24	11.6
Rut Depth	66,304	0.15 in.	0.10 in.	0.003 in.	1.54 in.	2.25	8.68
Fault	12,607	0.04 in.	0.04 in.	0.0 in.	0.62 in.	3.49	22.3
AC HPMS Percent Cracking	66,206	1.8%	4.9%	0%	54.1%	4.46	23.9
AC Percent Wheelpath	66,284	4.0%	10.5%	0%	99.8%	4.32	22.1
AC NPRM Under	66,206	2.1%	5.2%	0%	54.7%	4.16	20.8
AC NPRM Over	66,206	2.2%	5.3%	0%	54.7%	4.20	21.3
AC NPRM Step	66,206	2.2%	5.3%	0%	54.7%	4.02	19.5
PCC Cracking	12,618	9.2%	19.4%	0%	100%	2.56	5.96

Kurtosis is a measure of the shape of the distribution. The closer the kurtosis is to a value of 3 the more the distribution follows a normal distribution. Distributions with a kurtosis less than 3 indicate a distribution that tends to be more uniformly distributed. Distributions with a kurtosis greater than 3 tend to have a sharper peak than a true normal distribution.

Figure 8 thru figure 16 provide the cumulative distribution function of the data as compared to a true normal distribution. The distributions for cracking are the most skewed of the distributions reviewed. Generally, all of the distributions are sufficiently normal to allow for the assumption of normality in the statistical investigations and for those distributions that are not normal, comparisons using a Student’s t-test for comparison is very robust in terms of dealing with non-normal distributions. (24)

4.4. NETWORK CONDITION

The primary objective of this effort was to collect a statistically significant sample of the IHS and determine the condition of that network based on this sample. In accordance with the thresholds identified in table 1 of this report. Figure 17 presents the performance measures based on the data collected for this project as well as the condition determined from each individual metric. The figure shows that 63 percent of the network is in good condition and 1 percent of the network is in poor condition. These percentages do not reflect the 380 miles for which data could not be collected due to bridges or obstructions (construction, accident, etc.) in the primary lane.

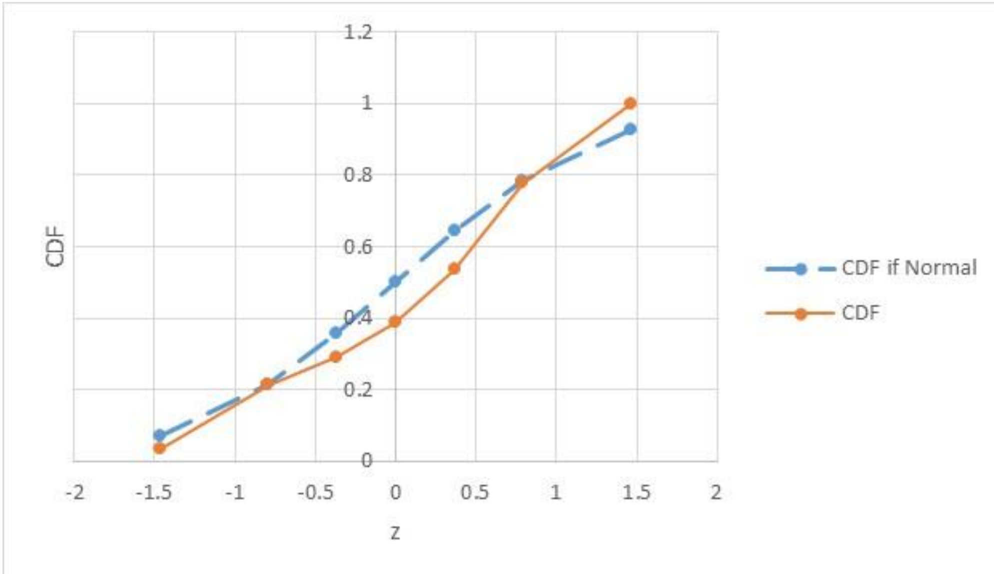

Figure 8. Graph. Distribution function of IRI.

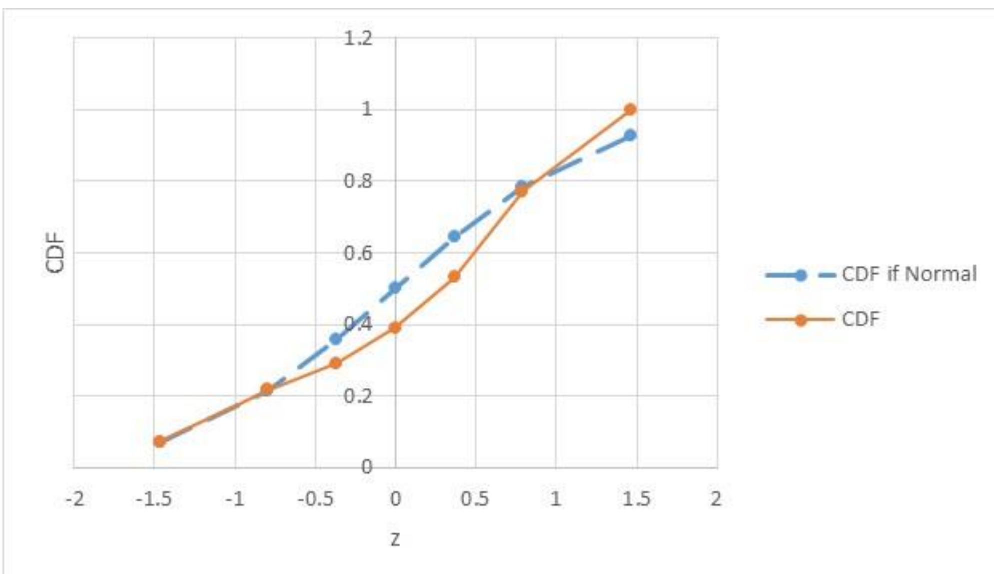

Figure 9. Graph. Distribution function of rut depth.

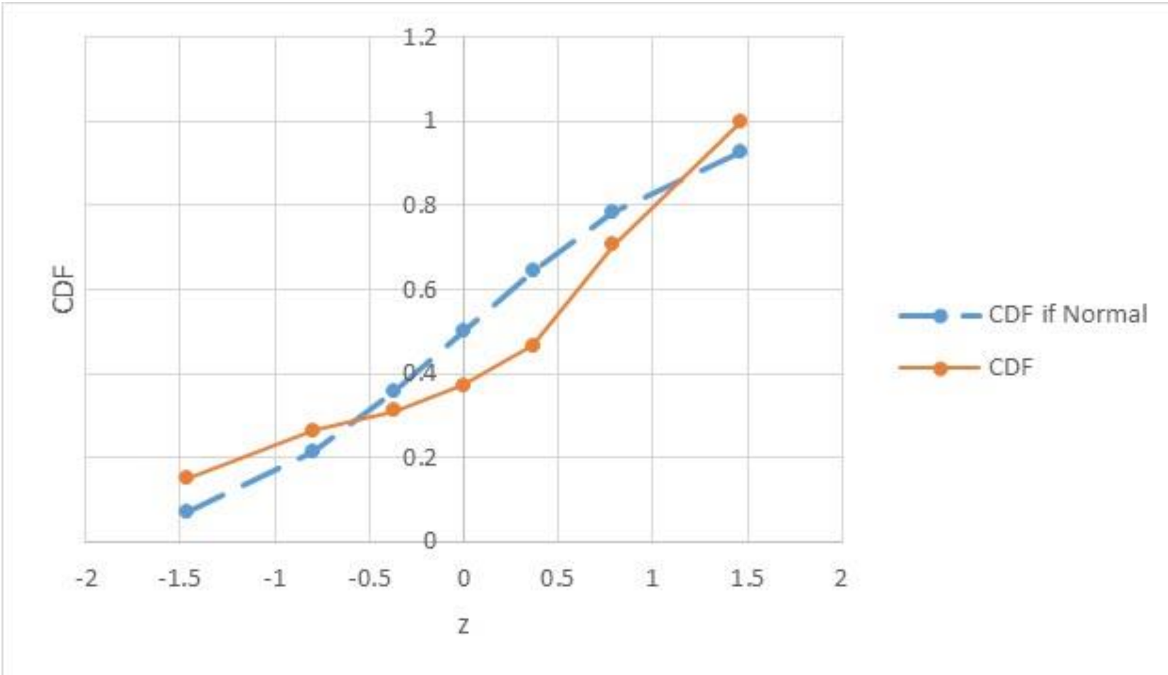

Figure 10. Graph. Distribution function of faulting.

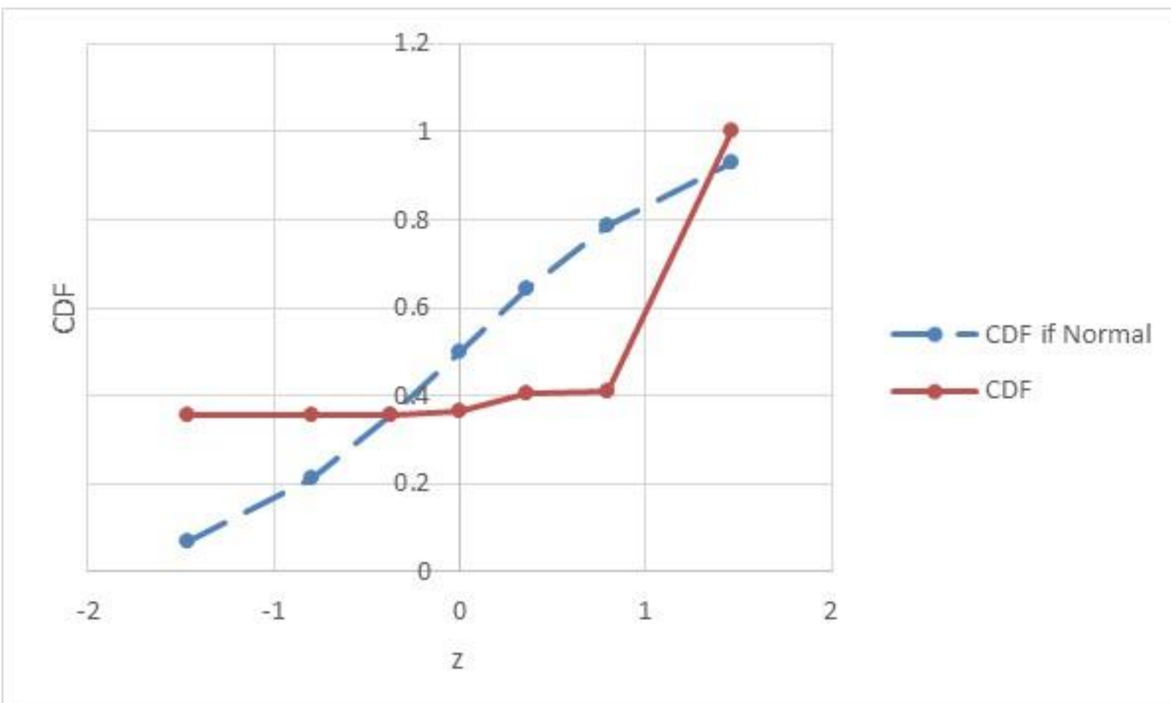

Figure 11. Graph. Distribution function of AC percent HPMS cracking.

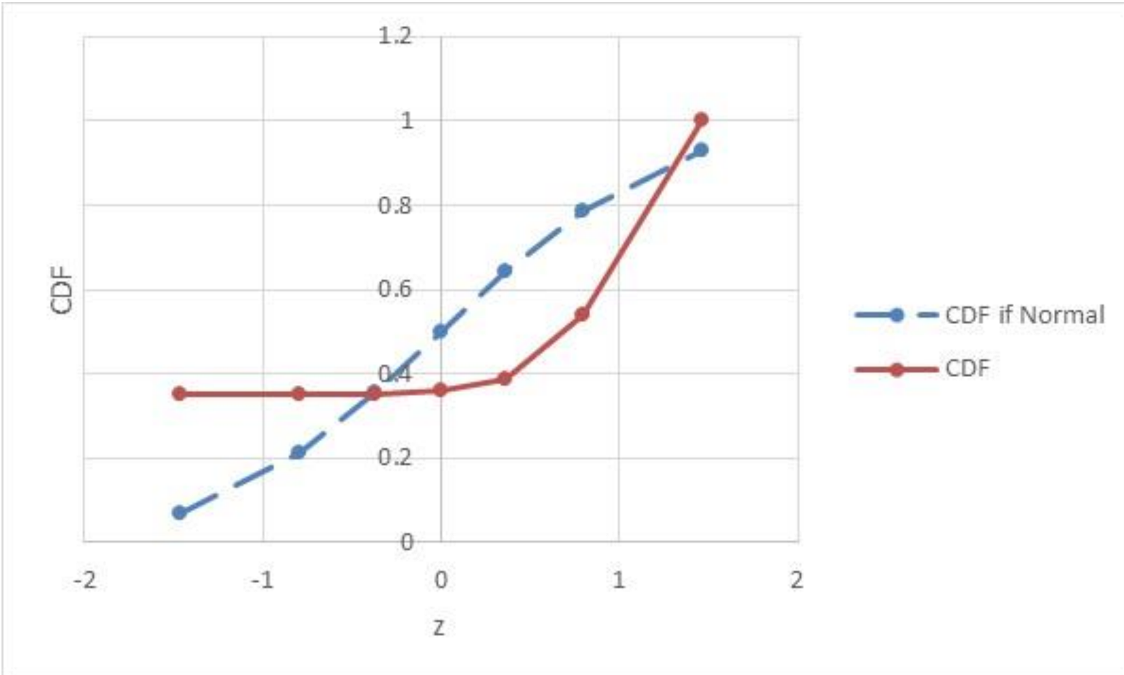

Figure 12. Graph. Distribution function of AC percent wheelpath cracking.

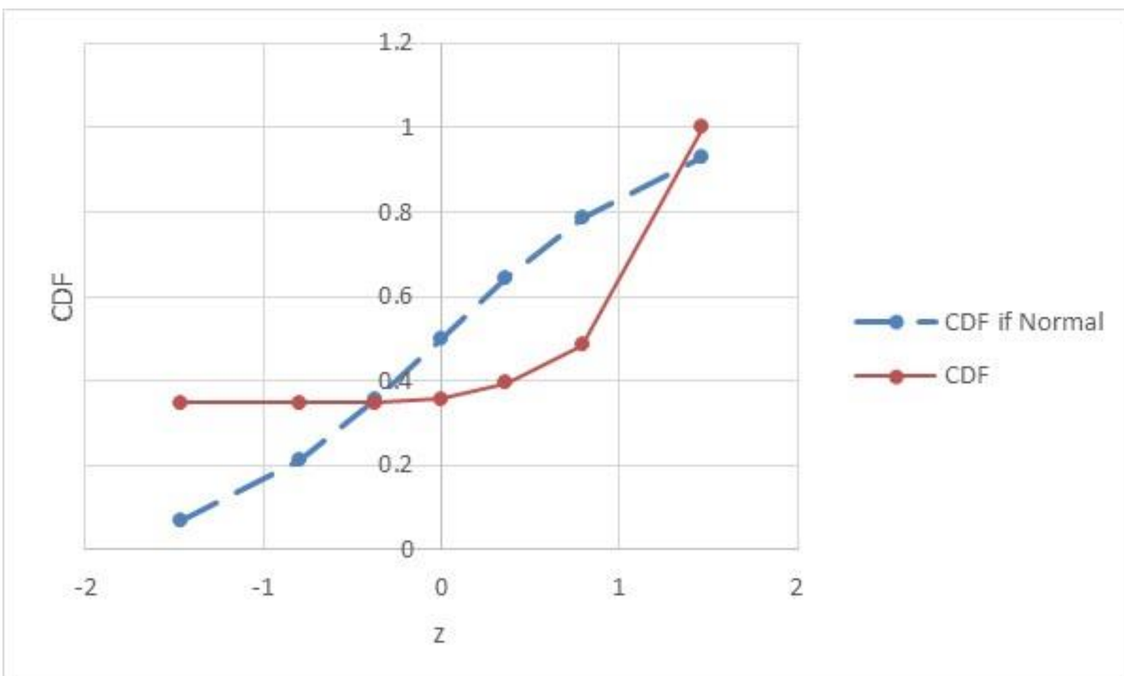

Figure 13. Graph. Distribution function of AC NPRM under.

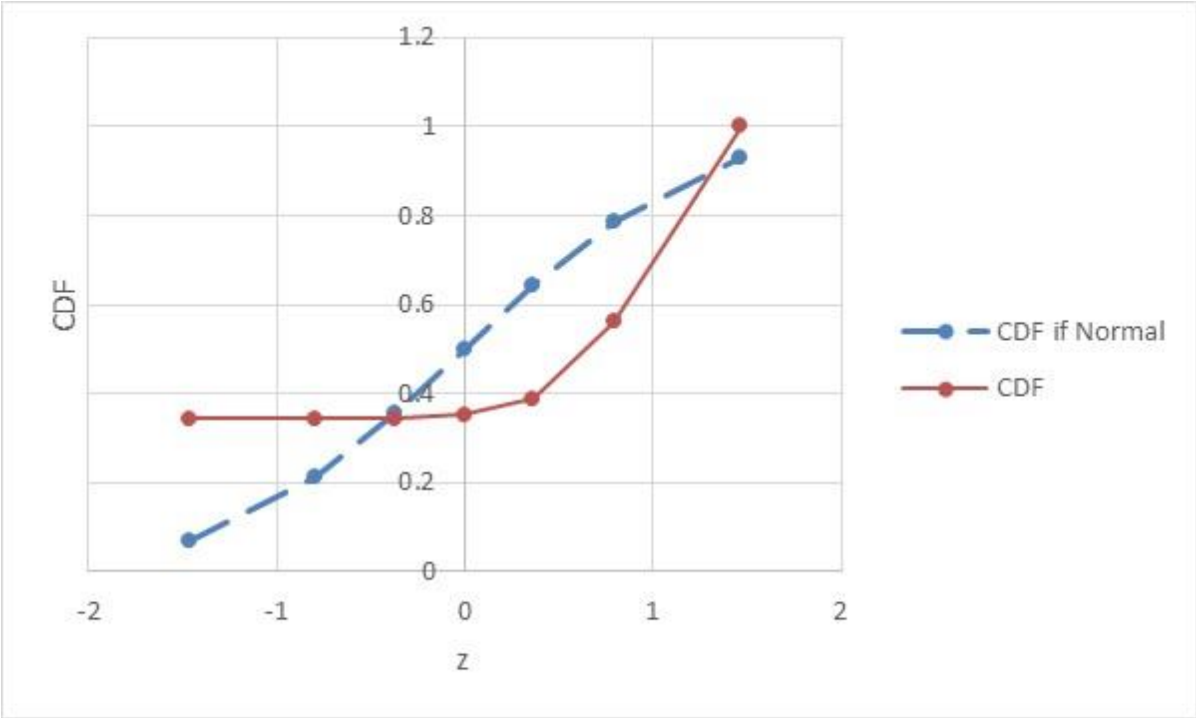

Figure 14. Graph. Distribution function of AC NPRM over.

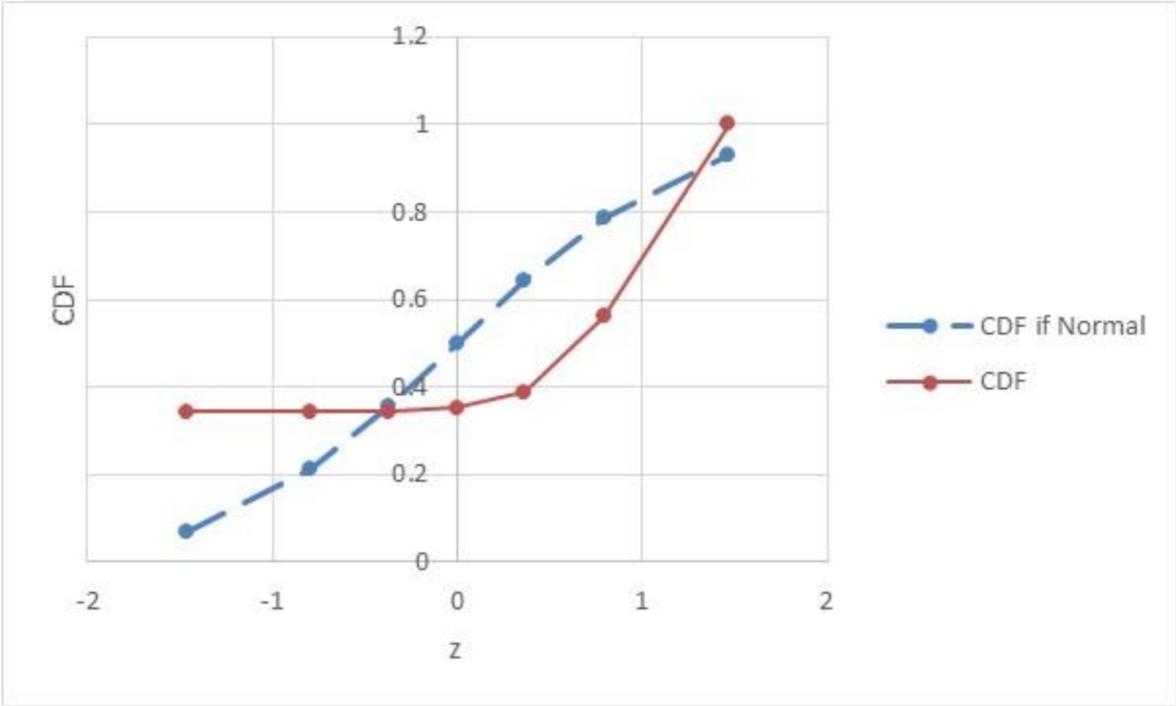

Figure 15. Graph. Distribution function of AC NPRM step.

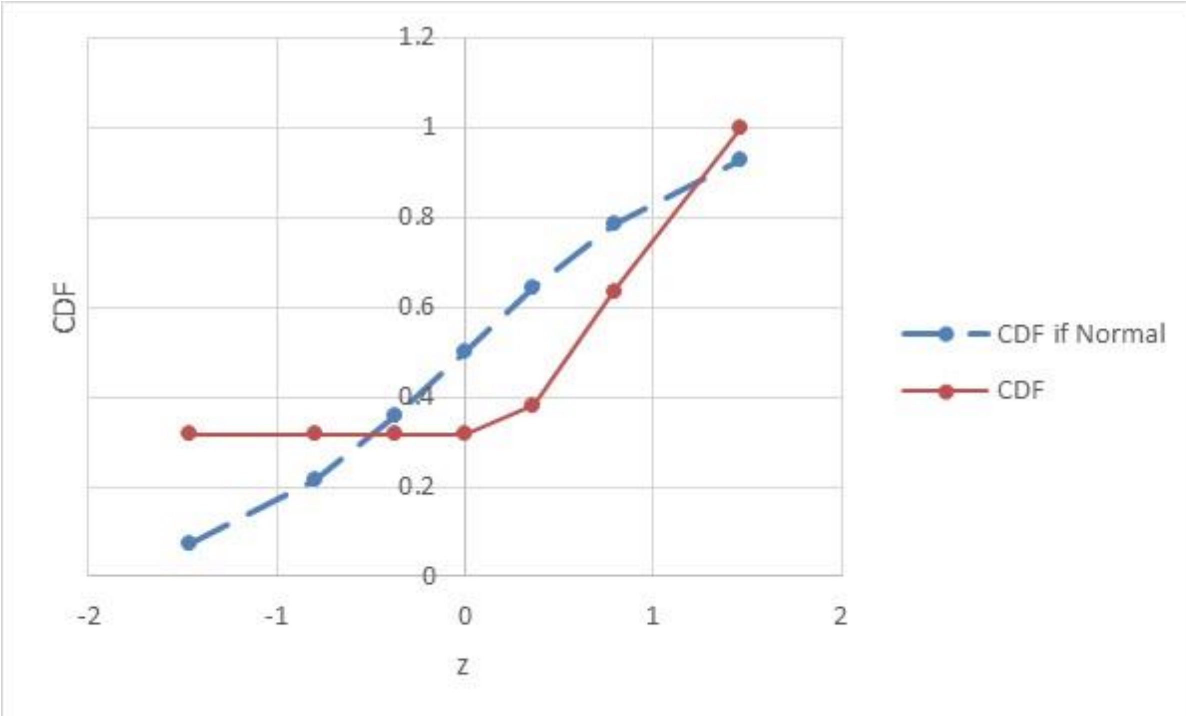

Figure 16. Graph. Distribution function of PCC cracking.

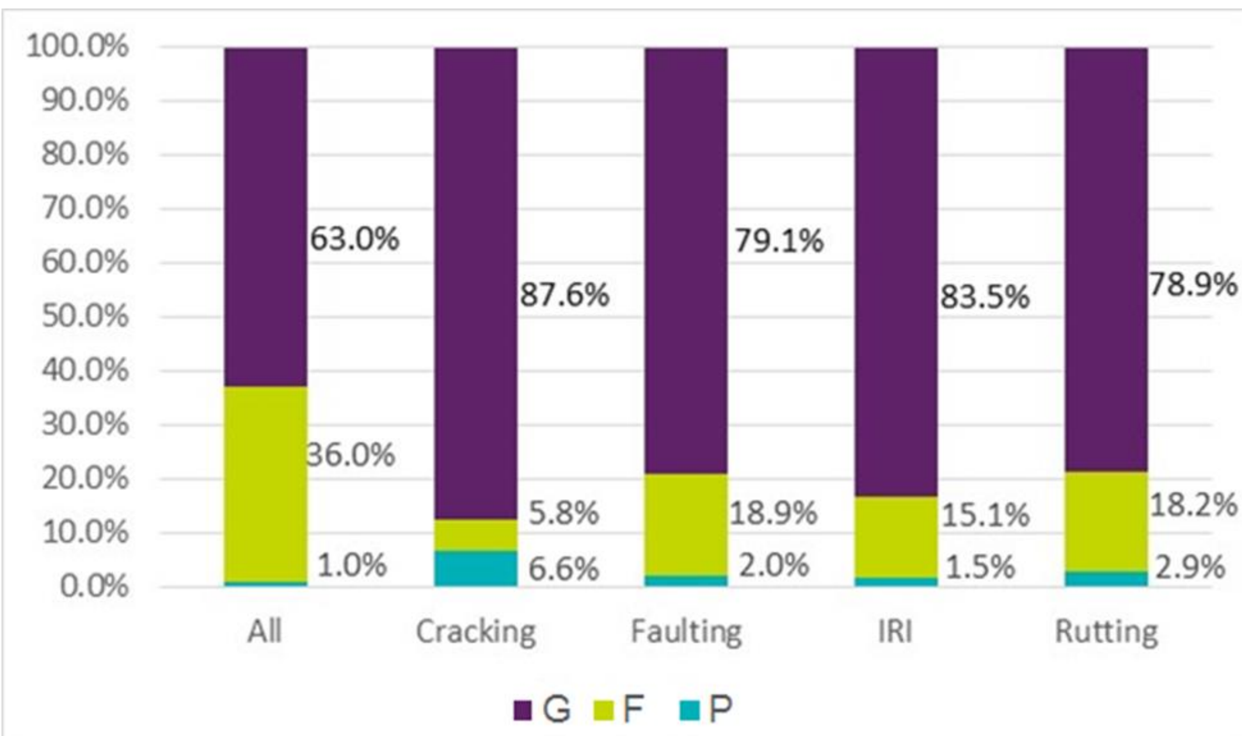

Figure 17. Chart. Condition of the IHS.

4.5. COMPARISON WITH THE HPMS

The second objective of this effort is to determine if the HPMS is an unbiased representation of IHS condition. In order to meet this objective a series of comparisons were performed between HPMS data and data collected for this project. These comparisons included comparing the condition metrics and the performance measures.

The HPMS data used for these comparisons represents condition data collected in 2014, one year prior to the data collected for this project. The condition data had not been expanded to represent the full network but were based on the sample data provided by the States. The database reviewed contained information for 47,829 miles of IHS, but only 24,149 miles contained all of the required condition metric data to identify the overall condition of the section reported. The sections of missing condition metric data are not reported as poor condition as indicated by the NPRM, rather these data are not incorporated into the statistics to allow for a comparison of the data collected rather than a comparison of data that was not collected.

A comparison of the performance measures is shown in figure 18, which shows that the HPMS data tends to rate the pavement condition as fair more frequently than the project database. Figure 19 shows the details of the HPMS condition estimate showing the Good/Fair/Poor rating for each condition metric. This figure also shows that the HPMS data tended to have less area in the good range for each condition metric as well as the overall condition.

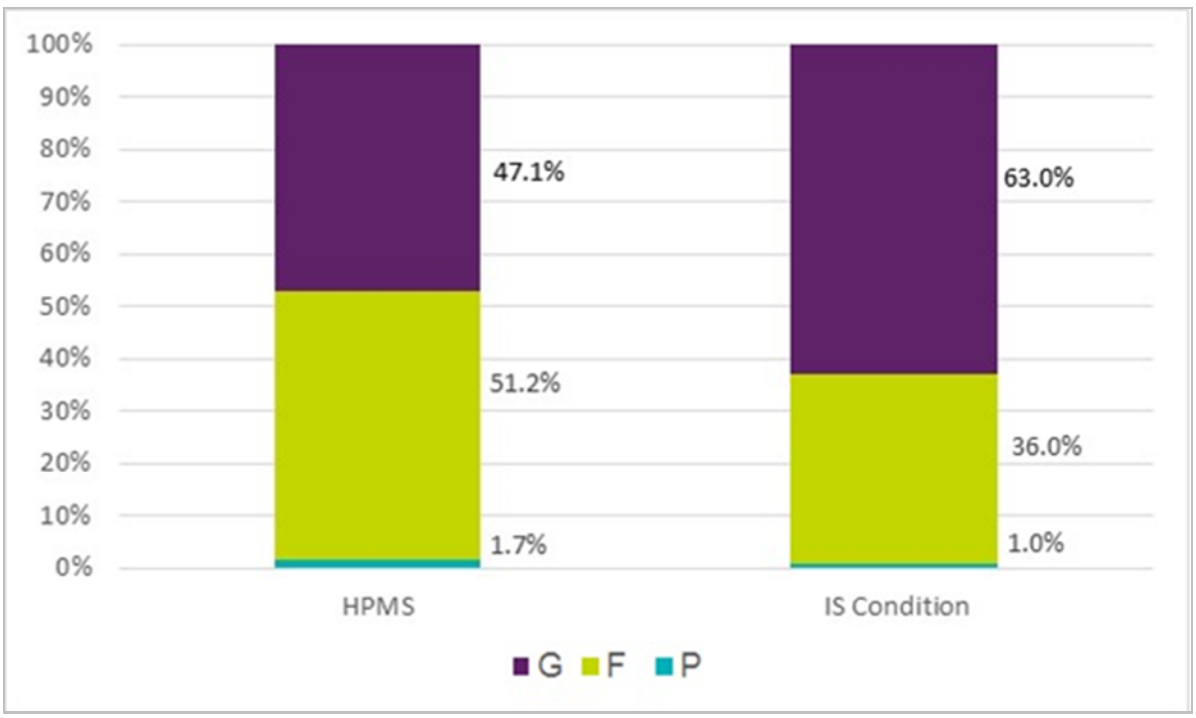

Figure 18. Chart. Comparison of performance measures.

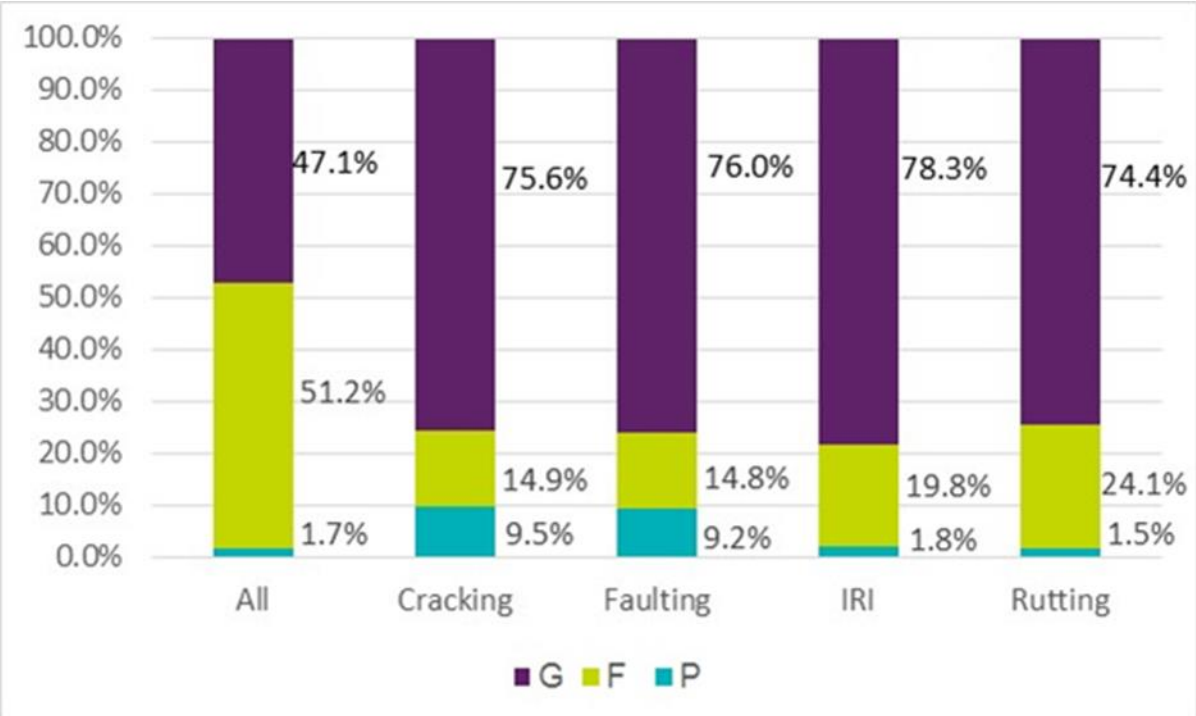

Figure 19. Chart. HPMS condition details.

Table 25 provides a comparison by State of the performance measures calculated using both the project data and the HPMS data. The table shows the overall condition has a higher percentage in Good condition for the project data than the HPMS data for the majority of the States.

The HPMS data included in the comparisons above includes all of the data collected on the IHS in the HPMS database. Therefore, additional review included removing data collected along routes other than those for which data were collected for the project. Further, the data collected for the project included ride quality on pavements as well as on bridge decks, but the data from the bridge decks were removed in developing the condition of each segment. The performance evaluation contained in table 25 does not include the bridge deck ride quality data. Last, the NPRM identifies that the segments are based on 0.1-mile intervals. Table 26 provides a comparison of the performance measures for each of these cases. The table shows that the same trend observed in the full data set is observed in the subsets.

In order to more fully understand the differences observed in the data sets, comparisons were made between the condition metrics. This comparison involved performing an F-test to compare the variances of the two data sets and then a t-test to compare the average values. Table 27 provides the results of the F-test comparisons. The HPMS data represented by the comparisons in table 27 include all of the HPMS data. The F-test suggests that the variances are not similar between the two data sets for all of the condition metrics.

Table 25. Comparison of performance measures by State.

State	Mileage, miles	HPMS 2014 Data			Mileage, miles	Project Data		
		% Good	% Fair	% Poor		% Good	% Fair	% Poor
All	23,680	47.1	51.2	1.7	8,250	63.0	36.0	1.0
Alabama	349	25.0	74.3	0.7	58	78.8	20.7	0.5
Arizona	1,068	56.9	42.8	0.3	418	69.0	30.8	0.2
California	310	52.8	45.6	1.6	356	59.1	40.1	0.8
Colorado	517	23.3	61.5	15.2	430	45.3	52.4	2.3
Connecticut	142	55.0	45.0	0.0	102	55.6	43.3	1.2
Delaware	18	35.9	64.1	0.0	22	62.7	36.8	0.5
Florida	404	58.9	41.0	0.1	356	60.4	37.3	2.3
Georgia	354	26.2	71.9	1.9	109	58.9	40.4	0.6
Idaho	610	37.3	61.6	1.1	67	35.7	60.7	3.6
Illinois	528	0.1	99.9	0.0	123	77.9	21.9	0.2
Indiana	968	71.8	28.2	0.0	308	64.5	35.2	0.3
Kansas	337	60.8	37.4	1.8	419	86.5	13.4	0.1
Kentucky	625	53.5	46.3	0.2	298	75.9	23.8	0.3
Louisiana	716	30.5	68.1	1.4	218	65.9	30.7	3.4
Maine	366	43.9	56.1	0.0	289	36.5	61.9	1.6
Maryland	185	70.7	29.3	0.0	97	81.4	18.6	0.0
Massachusetts*	0	#NA	#NA	#NA	85	83.8	16.1	0.1
Minnesota	906	58.9	39.7	1.4	252	58.0	41.9	0.1
Mississippi	416	70.1	29.3	0.6	71	69.7	29.6	0.7
Missouri	538	76.4	23.6	0.0	247	79.2	20.6	0.2
Montana	335	68.6	29.6	1.8	49	49.4	49.1	1.5
Nevada	267	62.4	37.1	0.5	124	93.0	7.0	0.0
New Hampshire	92	0.0	99.3	0.7	14	98.5	1.5	0.0
New Jersey	132	61.5	38.1	0.4	90	41.8	57.0	1.2
New Mexico	449	30.4	69.5	0.1	164	53.4	45.6	1.0
New York	216	0.0	93.7	6.3	198	70.1	29.5	0.4
North Carolina	439	60.2	39.8	0.0	181	59.7	40.2	0.1
Pennsylvania	1,798	72.0	27.9	0.1	254	51.1	47.7	1.2
Rhode Island	49	51.6	48.4	0.0	43	82.2	17.3	0.5
South Carolina	347	17.4	82.6	0.0	196	68.4	30.3	1.3
South Dakota	673	38.2	61.7	0.1	396	83.2	16.7	0.1
Tennessee	277	42.7	56.7	0.6	119	90.5	9.3	0.2
Texas	1,086	54.4	44.8	0.8	862	54.3	45.3	0.4
Utah	931	49.0	48.6	2.4	232	78.7	21.2	0.1
Virginia	1,092	39.7	58.6	1.7	174	58.7	39.2	2.1
Washington	744	34.5	61.6	3.9	285	31.4	61.6	7.0
West Virginia	544	66.9	30.0	3.1	159	75.6	24.0	0.4
Wisconsin	622	28.8	70.6	0.6	185	44.5	54.7	0.8
Wyoming	167	32.7	64.9	2.4	202	47.2	52.4	0.4

*For Massachusetts, #NA indicates that the pavement distress data was not available at the time of this report.

Table 26. Comparison of HPMS 2014 and project data performance measures.

Data Set	% Good	% Fair	% Poor
HPMS (All Interstate)	47.1	51.2	1.7
HPMS (Data Collection Route Only)	45.4	52.5	2.1
Project Data Including Bridges	61.7	37.3	1.0
Project Data Excluding Bridges	63.0	36.0	1.0
Project Data Excluding Bridges and segments less than 0.1-mile in length	63.0	35.9	1.1

Table 27. Comparison of HPMS 2014 and project data variances.

Element	HPMS Variance	Project Data Variance	Statistical Significance
IRI	1956	1433	Yes
Rut Depth	0.01	0.01	Yes
Faulting	0.02	0.001	Yes
Percent Cracking	149	84	Yes

Once the variances were compared, the next step was to compare the means of the two data sets for each condition metric. This comparison involved the use of a t-test to compare those means. Because the variances all proved to be statistically significantly different, the t-test assumed unequal variances between the data sets based upon the results presented in table 27. Table 28 provides a summary of these results. As with table 27, the HPMS data represented by the results in table 28 includes all of the HPMS data.

Table 28. Comparison of HPMS 2014 and project data condition metrics.

Data Element	HPMS Average	Project Data Average	Statistical Significance
IRI	80 in./mile	72 in./mile	Yes
Rut Depth	0.12 in.	0.15 in.	Yes
Faulting	0.05 in.	0.04 in.	Yes
Percent Cracking	4.7%	3.0%	Yes

The comparisons of the HPMS data and project data suggest that the biases in the data are insufficient to be considered important. The comparison of the variances suggests that the variance of the HPMS data is larger than the variance of the project data. Absolute differences in condition by metric is 11 percent for IRI, 20 percent for rutting, 25 percent for faulting and 57 percent for cracking. These values are large and statistically significant, but, for example, the difference in IRI would be difficult for anyone to judge given the 8 in/mile difference in the average values.

As a further review of the differences in variability between the two data sets, table 29 provides the mean, minimum, and maximum values for each of the condition metrics for the two data sets. The range in the rut depth and faulting is larger for the HPMS data than that seen from the project data. As noted previously, the cracking and IRI from the HPMS data have larger variances than those observed from the project data. These factors are believed to be the cause of the difference in the good overall condition observed.

Table 29. Comparison of HPMS 2014 and project data statistics.

Element	HPMS			Project Data		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
IRI	80 in./mile	6 in./mile	771 in./mile	72 in./mile	3 in./mile	959 in./mile
Rut Depth	0.12 in.	0 in.	1.77 in.	0.15 in.	0.0 in.	1.5 in.
Faulting	0.05 in.	0 in.	9 in.	0.04 in.	0 in.	0.6 in.
Cracking	4.7%	0%	100%	3.0%	0%	100%

The maximum values shown in table 29 illustrate that there are some unusual values contained in the HPMS data set. For example, the 9-inch value for faulting was observed in a State where other faulting values greater than 1 inch were observed. It appears that this particular State was reporting values in an incorrect unit, possibly tenths of inches. The large IRI value observed in the 2014 HPMS data is actually less than the largest value observed in the project data. These IRI values were reviewed against the images and physical features within the pavement surface were observable to explain these larger values. Similarly, the maximum values from the 2014 HPMS data for rut depth and cracking are similar to the maximum values observed in the project data set.

Three States were selected for further review of the differences in the HPMS and project data – Washington, New Hampshire, and Kentucky. The condition metrics were compared between these two data sets for each of these States, which represent three conditions of comparability between the overall conditions. Washington performance compares well between the two data sets. New Hampshire shows a poor comparison between the overall conditions from the two data sets. Kentucky has a fair comparability between the two data sets. This type of comparison will be covered in more detail in the next chapter.

Table 30 provides the results of this comparison for all three States. The condition metrics compare best for the State where the overall conditions compare well. The condition metrics do not compare well for the State where the overall condition compares poorly. The State with the fair overall condition comparison fell in the middle of the comparisons for these three States. The faulting did not compare well for either Washington or Kentucky. New Hampshire did not have concrete pavement to use for the comparison.

One additional aspect to the comparison of HPMS and the project data considered was the location of bridges. The data collection included marking bridge locations as part of that effort. Therefore a sample of data was used to compare the locations of the bridges marked by the project team and the location of the bridges identified within the HPMS.

The sample used for this comparison included I-10 in Alabama, Arizona, and California as well as I-15 in Arizona. A paired t-test was used to compare both the start location and the length of the bridges identified within both data sets. Table 31 presents the results of these comparisons. These comparisons indicate that there is a significant difference in the starting location of the bridges identified between the two data sets. Further, the project data identified 274 bridges within the sample route selected for this comparison while the HPMS data identified 586 bridges in these routes. It is likely that the large difference observed is due to the identification of box culverts and other small structures as bridges within the HPMS data. State DOTs are better able to track these smaller locations, which are not observable when driving the route.

Table 30. Comparison of the condition metrics by state.

State	Condition Metric	HPMS 2014		Project Data		Statistically Significant
		Mean	Standard Deviation	Mean	Standard Deviation	
WA	IRI	84	47	86	49	No
	Rut Depth	0.26	0.13	0.27	0.15	Yes
	Percent Cracking	4	10	4	10	No
	Faulting	0.04	0.07	0.06	0.04	Yes
NH	IRI	52	16	44	26	Yes
	Rut Depth	0.18	0.03	0.10	0.09	Yes
	Percent Cracking	11	8	1	1	Yes
KY	IRI	58	32	61	40	Yes
	Rut Depth	0.09	0.05	0.09	0.04	No
	Percent Cracking	8	12	4	13	Yes
	Faulting	0.10	0.14	0.04	0.02	Yes

Table 31. Comparison of bridge location and length.

Element	Mean Difference	Statistical Significance	Correlation Coefficient
Starting Milepost	0.132 mile	Yes	0.99999
Bridge Length	0.004 mile	No	0.94

4.6. IMPROVEMENTS TO DATA COLLECTION AND REPORTING

The third objective of the project is to recommend improvements to data collection and reporting necessary to make HPMS unbiased or improve precision of the data. The following sections discuss various aspects of the collected data to identify potential improvements in the data collection and reporting required by the NPRM.

4.6.1 Direction and Lane

As noted previously, approximately 500 miles of data were collected in the adjacent lane and in the opposing direction. These data were used to compare the condition metrics in these lanes to identify the need for data collection in additional lanes.

Data comparisons were made using the data accumulated to 0.1-mile intervals. Table 32 presents the results of these comparisons. The results show that there is little difference in the average values between the data in these other locations and the primary route data. Additionally, the table illustrates that the condition in the adjacent lane is better on average than that estimated for the primary lane.

Table 32. Comparison of adjacent lane and opposing direction with primary lane.

Element	Primary Average	Adjacent Average	Opposing Average	Statistical Significance
IRI	68 in/mile	66 in/mile	66 in/mile	Yes, Yes
Rut Depth	0.14 in.	0.11 in.	0.14 in.	Yes, Yes
Faulting	0.07 in.	0.05 in.	0.07 in.	Yes, Yes
AC HPMS Cracking	2.3%	1.6%	2.4%	Yes, No
AC % WP	4.9%	3.5%	5.2%	Yes, No
AC NPRM Under	2.5%	1.7%	2.6%	Yes, No
AC NPRM Over	2.6%	1.8%	2.6%	Yes, No
AC NPRM Step	2.5%	1.8%	2.6%	Yes, No
PCC Cracking	11.7%	7.0%	13.6%	Yes, No

The other aspect to the data in the opposing direction to consider is the comparison of the surface type. If the surface type is different in the opposing direction from the primary, it may still be important to collect data in both directions as the primary direction condition may not be expected to represent the condition in both directions. The surface type was observed to be different for approximately 3 percent of the 552 miles of data collected in the opposing direction.

Based on this analysis, the data collected in the primary direction in the outside lane is sufficient to provide an estimate of condition of the interstate system.

4.6.2 Section Length

The next aspect of the data collection reviewed is the section length used for the reporting length. The current version of the rule requires that data be reported at 0.1-mile intervals. The first step in this analysis was to use a power spectral density analysis to determine if the content of the signal identified any particular required section length. In order to perform this analysis, two sample sections were used for the analysis. The first was an asphalt-surfaced section in Arizona on I-10 from milepost 320 to milepost 356 and a jointed concrete section on I-90 in Wisconsin from milepost 61.32 to milepost 68.54. Figure 20 thru Figure 23 provide the power spectral density for the IRI and rut depth on the asphalt section and the IRI and faulting on the jointed concrete section, respectively.

The power spectral density plots demonstrate that most of the content is contained in the smaller wavelengths for IRI and rut depth. Faulting appears to be fairly random. These plots suggest that smaller section lengths are necessary to distinguish the areas of good and poor condition from areas of fair condition.

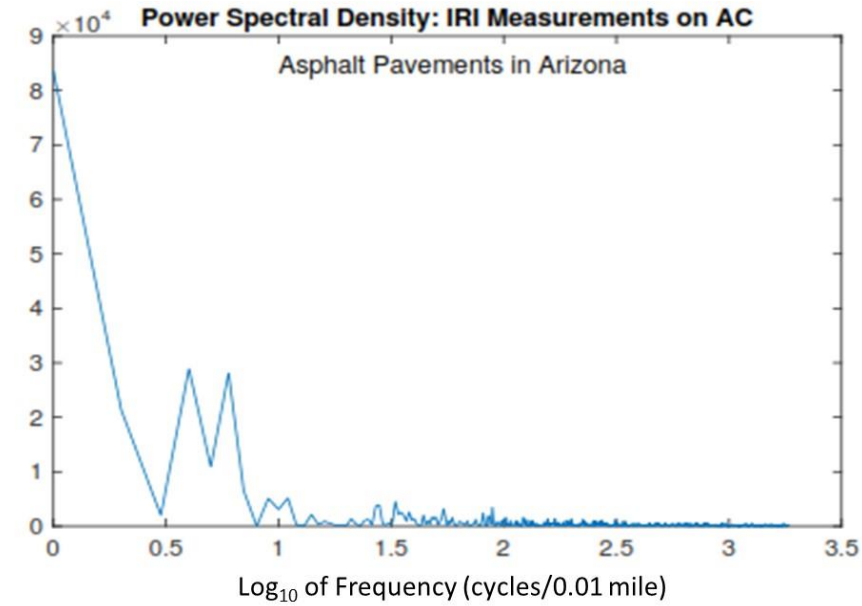

Figure 20. Graph. Power spectral density curve for IRI on asphalt section.

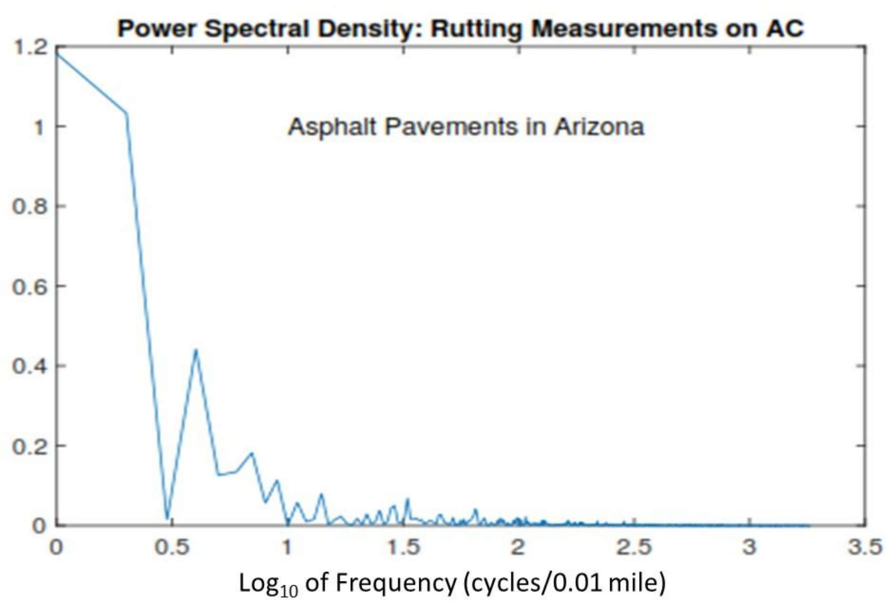

Figure 21. Graph. Power spectral density curve for rut depth on asphalt section.

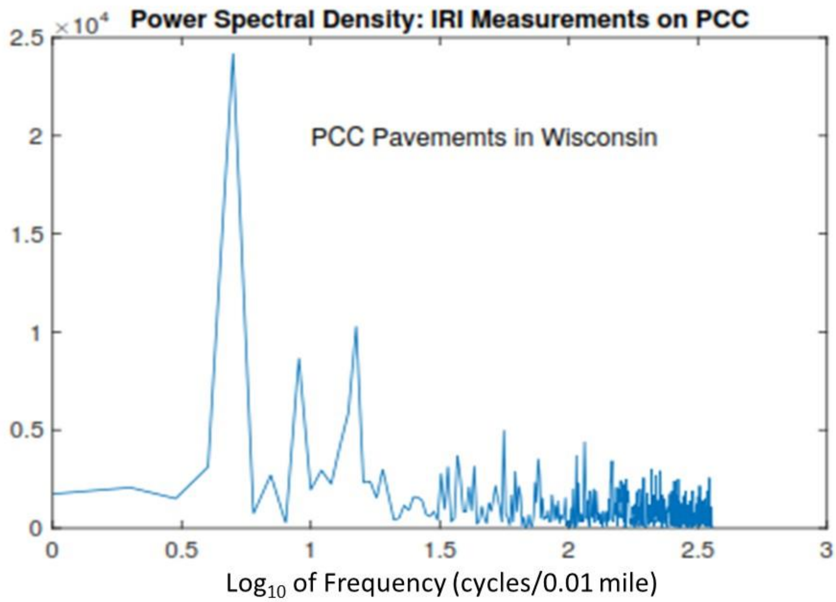

Figure 22. Graph. Power spectral density curve for IRI on jointed concrete section.

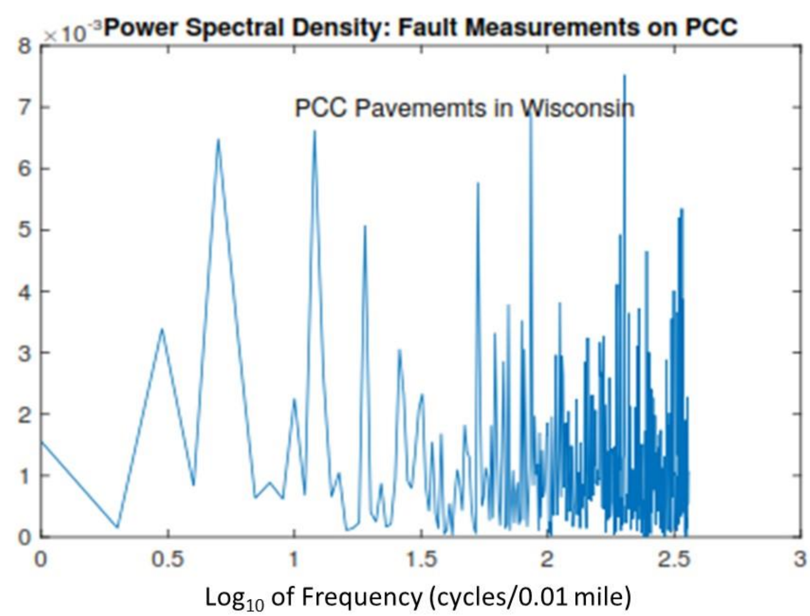

Figure 23. Graph. Power spectral density curve for faulting on jointed concrete section.

A further review of the impact of the section length on the results was performed using the section identified in Arizona. For this section, the impact of the section length was evaluated by accumulating the data at different lengths including 0.01-mile, 0.05-mile, 0.1-mile, 0.5-mile, and

1-mile. Figure 24 through figure 26 provide the samples of the results of the varying levels of accumulation for IRI, rut depth, and percent cracking on the asphalt pavement section. A full set of figures illustrating these comparisons are provided in appendix C.

The figures confirm the observation made from the power spectral density plots. The blue line that shows up in the middle of the graph representing the 1-mile section length illustrates how the maximum and minimum values are averaged out with a longer section length. Generally, the smaller the section length the simpler it becomes to distinguish between areas of good and poor condition from areas of fair condition.

The other item to consider in determining the appropriate section length is the size of the database. Smaller sections will increase the size of the database and subsequently the difficulty in transmittal and analysis of the data. Therefore, the optimal section length is a tradeoff between identifying specific locations of good and poor condition and the size of the database.

Analyses of IRI, percent cracking and rutting suggest that longer section lengths tend to mask areas of good and poor condition. Selection of section length is a matter of balancing the need to identify specific areas of good and poor condition with the increase in database size that comes with smaller sections. The 0.1-mile section length appears to be a good balance between these two needs.

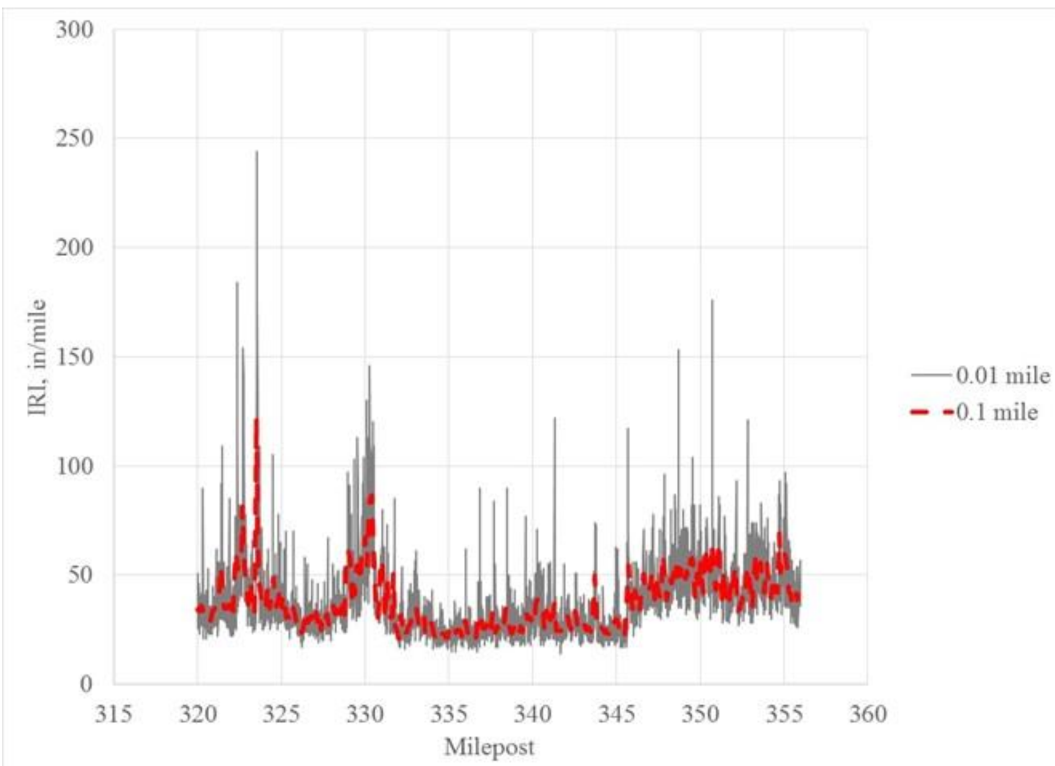

Figure 24. Graph. Impact of section length on average IRI – 0.1 vs 0.01-mile.

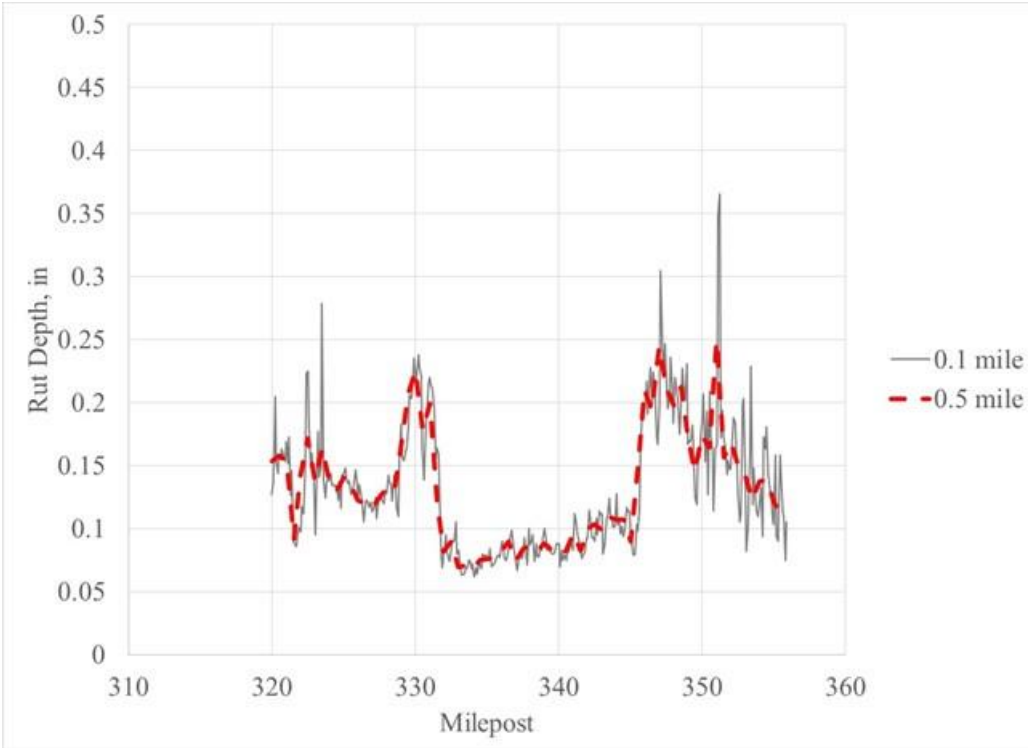

Figure 25. Graph. Impact of section length on rut depth – 0.1 vs 0.5-mile.

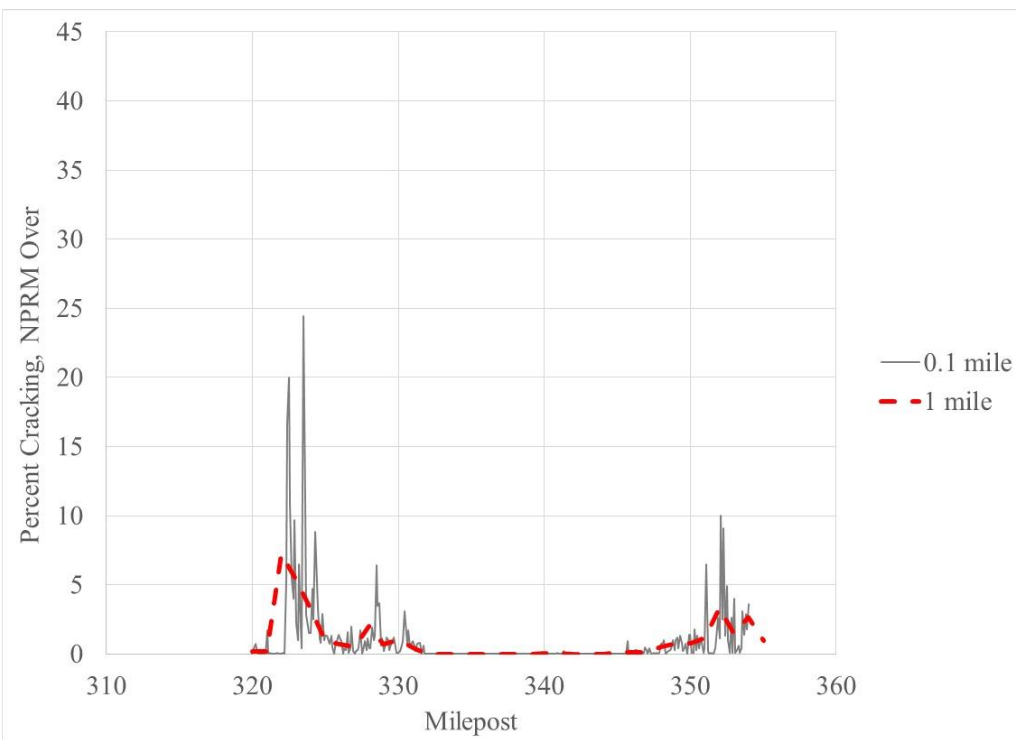

Figure 26. Graph. Impact of section length on percent cracking.

4.6.3 Sampling of the Interstate Highway System

The next question about the data collection effort reviewed was the possibility of sampling the system to determine condition. The database was used to estimate the number of samples required to estimate the mean and standard deviation of the population represented by the database to a given level of confidence and acceptable error. Three confidence levels were used in this investigation: 90 percent, 95 percent, and 99 percent. Three acceptable error levels were also used: 1 percent, 5 percent, and 10 percent. Table 33 presents the results for the full data set. The mileage shown in the table identifies the mileage of the available data used to estimate the required sample size. This full data set indicates that a minimal sample is required to estimate the condition of the network based solely on IRI with a sampling requirement of 18 percent for a 99 percent confidence limit and a 1 percent error level; however, estimating the condition of the network based on cracking will require a more substantial sample. Cracking on CRCP sections shows a sampling requirement of 97 percent to achieve a 95 percent confidence level with a 5 percent acceptable error level.

Table 33. Sampling requirements at the national level.

Element	Confidence Level	Error Level		
		1%	5%	10%
IRI (8,484 miles)	90%	8%	0.4%	0.1%
	95%	11%	1%	0.1%
	99%	18%	1%	0.2%
Rut Depth (6,630 miles)	90%	16%	1%	0.2%
	95%	21%	1%	0.3%
	99%	31%	2%	0.5%
Faulting (1,261 miles)	90%	67%	7%	2%
	95%	74%	10%	3%
	99%	83%	16%	5%
AC Cracking (6,630 miles)	90%	72%	9%	3%
	95%	78%	13%	4%
	99%	86%	20%	6%
CRCP Cracking (421 miles)	90%	100%	97%	90%
	95%	100%	98%	93%
	99%	100%	99%	96%
JPCC Cracking (1,262 miles)	90%	91%	28%	9%
	95%	93%	35%	12%
	99%	96%	49%	19%

The sample collected for this project represents an 18 percent sample of the overall IHS across the nation. Chapter 3 illustrates the efforts taken to develop a routing that encompassed a wide range of traffic, climate, and construction or maintenance practices used across the contiguous US. Table 33 illustrates that at a 95 percent level of confidence, this sample can be expected to represent average conditions across the contiguous US for IRI, rutting, and faulting. Because cracking was considered by surface type, the level of sampling identified must be reviewed by surface type. The project data set represents a 28 percent sample of the asphalt surfaced portion of the IHS, a 38 percent sample of the CRCP portion of the IHS, and a 22 percent sample of the

JPCC segments of the IHS. These percentages are based on records from 2014 HPMS providing the surface type. These percentages suggest that the project data sample is not sufficient to fully capture the condition of cracking on CRCP and JPCC pavements. The sampling of the asphalt surfaced pavements was sufficient to capture cracking condition.

Using the larger sample may result in some issues with the estimated sample requirements. The large size of the data set may mask some of the variability that is important to the FHWA to capture. Further, it is likely that data collected will be used to draw conclusions about the conditions within a particular State as opposed to only looking at the data at the national level. Therefore, the data were reviewed at the State level. Table 34 presents the minimum sampling level identified at the State level and table 35 presents the maximum sampling level identified at the State level. Table 36 presents the average of the sampling requirements at the State level. As with table 33, the mileages shown in the tables represent the mileage of the data set used for estimating the sampling requirements.

In all cases, the sampling rate required for the IRI is the lowest of the condition metrics. The sampling required for cracking is the highest of the condition metrics. In general, the sampling requirements for cracking are well over 50 percent at the State level. These sampling rates suggest that a 100 percent sampling rate is required for data collection.

Table 34. Minimum sampling requirements at the State level.

Element	Confidence Level	Error Level		
		1%	5%	10%
IRI (880 miles)	90%	39%	3%	1%
	95%	48%	4%	1%
	99%	61%	6%	2%
Rut Depth (628 miles)	90%	50%	4%	1%
	95%	58%	5%	1%
	99%	71%	9%	2%
Faulting (159 miles)	90%	88%	23%	7%
	95%	91%	30%	10%
	99%	95%	42%	15%
AC Cracking (165 miles)	90%	96%	51%	20%
	95%	97%	59%	27%
	99%	98%	72%	39%
CRCP Cracking (19 miles)	90%	99%	88%	64%
	95%	100%	91%	72%
	99%	100%	95%	81%
JPCC Cracking (120 miles)	90%	97%	55%	23%
	95%	98%	63%	30%
	99%	99%	75%	42%

Table 35. Maximum sampling requirements at the State level.

Element	Confidence Level	Error Level		
		1%	5%	10%
IRI (24 miles)	90%	97%	53%	22%
	95%	98%	61%	29%
	99%	99%	74%	41%
Rut Depth (22 miles)	90%	98%	63%	30%
	95%	99%	71%	38%
	99%	99%	81%	51%
Faulting (4 miles)	90%	100%	91%	70%
	95%	100%	93%	77%
	99%	100%	98%	86%
AC Cracking (14 miles)	90%	100%	99%	93%
	95%	100%	99%	95%
	99%	100%	99%	97%
CRCP Cracking (1 mile)	90%	100%	100%	100%
	95%	100%	100%	100%
	99%	100%	100%	100%
JPCC Cracking (4 miles)	90%	100%	100%	100%
	95%	100%	100%	100%
	99%	100%	100%	100%

Table 36. Average sampling requirements at the State level.

Element	Confidence Level	Error Level		
		1%	5%	10%
IRI	90%	77%	17%	5%
	95%	82%	21%	7%
	99%	88%	31%	12%
Rut Depth	90%	80%	19%	6%
	95%	85%	24%	8%
	99%	91%	34%	13%
Faulting	90%	96%	59%	33%
	95%	97%	66%	39%
	99%	99%	75%	50%
AC Cracking	90%	99%	79%	53%
	95%	99%	83%	60%
	99%	100%	89%	71%
CRCP Cracking	90%	100%	97%	90%
	95%	100%	98%	92%
	99%	100%	99%	95%
JPCC Cracking	90%	100%	89%	72%
	95%	100%	92%	77%
	99%	100%	95%	84%

4.6.4 Inclusion of Bridges

One additional item of interest was the impact of the inclusion of bridges within the data collection. The only condition metric collected on the bridge decks was IRI. This comparison involved comparing the overall average of the IRI with and without the bridge deck IRI using a t-test. The t-test was significant although the difference in the average IRI values was very small. The difference in the conditions due to the inclusion of the bridges in the IRI was also very small. Table 37 provides the results of the comparison illustrating that there is very little difference between the two approaches for evaluating pavement condition.

Table 37. Comparison of data with and without bridges.

Element	With Bridges	Without Bridges
Average IRI	72 in./mile	69 in./mile
Percent Good	62%	63%
Percent Fair	37%	36%
Percent Poor	1%	1%

4.6.5 Equipment Type

Faulting

Two types of faulting data were collected. The first was collected using the LCMS sensor which allows for a visual verification of the joint location. The three dimensional nature of this sensor allows for measuring the faulting at each identified joint. The joint locations were manually reviewed as part of data collection to obtain faulting from the LCMS sensor.

The second method for faulting collection was using the inertial profiler data. These data were used in accordance with AASHTO Designation R36-13, "Evaluating Faulting of Concrete Pavements" to estimate the faulting of each joint. (14)

A paired t-test was used to compare the two data sets at the 0.01-mile level. Table 38 provides the results of the comparison. The paired t-test was statistically significant. The difference in the faulting values also resulted in a small change in the overall condition for the network. The inertial profiler faulting displayed more variability than the LCMS faulting.

As part of the investigation into the differences in equipment, differences in the number of joints were observed between the two methods. These are presented in Table 38. The database also contains the number of fault measurements within each 0.01-mile section. Comparisons were made between the fault count and the joint count for each 0.01-mile section. The average number of joints within each 0.01-mile section is 3.6. The differences in all of the data sets are statistically significant; however, the LCMS fault count is much closer to the joint count with an average difference of 0.2 joints per 0.01-mile section. Table 38 illustrates that although statistically the faulting changes based on the type of sensor used for calculation, due to the nature of the condition evaluation, these differences are diminished by the categorical nature of that process.

Table 38. Comparison of faulting from LCMS and RSP.

Element	LCMS Fault	RSP Fault
Average Fault	0.04 inch	0.02 inch
Standard Deviation Fault	0.05 inch	0.06 inch
Average Number of Faults	3.4 faults	0.4 faults
Average Number of Joints	3.6 joints	
Percent Good	62%	64%
Percent Fair	37%	35%
Percent Poor	1%	1%

Rutting

Two types of rutting were considered as part of the data collection. The first is the rut depth based on the transverse profile as collected from the LCMS sensor. The second is an estimate of the rut depth that would have been measured using a 5-point laser system. Table 39 provides the results of this comparison performed using the 0.01-mile interval data.

Table 39. Comparison of rutting from LCMS and 5-point profile.

Element	LCMS Rut	5-point Rut
Average Rut Depth	0.15 inch	0.09 inch
Standard Deviation Rut	0.10 inch	0.12 inch
Percent Good	62%	64%
Percent Fair	37%	35%
Percent Poor	1%	1%

A paired t-test was used to compare the two data sets. The t-test was statistically significant and shows a large difference in the average values. Further, the standard deviations show that the values for the 5-point vary over a wider range than the rut depth determined from the LCMS transverse profile. The difference in the overall condition are due primarily to the negative rut depths observed in the 5-point rut depth values. As with the faulting, table 39 illustrates that though there are differences in the data based on the sensor type, the impact of these differences is diminished by the categorical nature of the condition evaluation.

Cracking Definition

As noted previously, several definitions for percent cracking were explored for the asphalt surfaces. These definitions have been provided in chapter 3 of this document, but are repeated here to ease understanding of the terms used in this section.

- AC HPMS – Total area of wheelpath cracking divided by the total lane area
- AC Percent Wheelpath – Total area of wheelpath cracking divided by the area of the wheelpath

- NPRM Under – Area of affected wheelpath cracking plus the area of transverse cracking (transverse cracking length multiplied by 1 ft). The length of transverse cracking is reduced by the amount of the transverse cracking within the wheelpath. Total crack area is divided by the total lane area. This definition is illustrated in Figure 7.

- NPRM Over – Area of affected wheelpath cracking plus the area of transverse cracking (transverse cracking length multiplied by 1 ft) divided by the total lane area. This definition is illustrated in Figure 7.

- NPRM Step – The area of transverse cracking is reduced in a graduated manner based on the area of wheelpath cracking. Where the percentage of wheelpath cracking is greater than 80 percent of the total wheelpath area, the transverse cracking length is reduced by the amount of transverse cracking within the wheelpath. The full transverse cracking length is used where the percent of wheelpath cracking is less than 20. If the percent of wheelpath cracking is between 20 and 40 percent, 75 percent of the transverse crack length within the wheelpath is used. If the percent of wheelpath cracking is between 40 and 60 percent, 50 percent of the transverse crack length within the wheelpath is used. Finally, if the percent of wheelpath cracking is between 60 and 80 percent, 25 percent of the transverse crack length within the wheelpath is used. The total crack area is divided by the total lane area. This definition is illustrated in Figure 7.

Comparisons were made between the results associated with these various definitions of cracking. Table 40 provides the results of these comparisons. A paired t-test was used to identify the statistical significance of the differences observed.

Table 40. Comparison of definitions of cracking on AC pavements.

Element	AC HPMS	AC % WP	NPRM Under	NPRM Over	NPRM Step
Average	1.8%	4.1%	2.1%	2.2%	2.2%
Standard Deviation	5.7%	12.1%	5.9%	5.9%	5.9%
Percent Good	64%	61%	63%	63%	63%
Percent Fair	35%	38%	36%	36%	36%
Percent Poor	1%	1%	1%	1%	1%

The results show that even though the differences were found to be statistically significant, there is very little difference in the average values with the exception of the percent wheelpath cracking. This parameter is based on a smaller area of the lane as opposed to the total lane area so the size of this value is larger (by approximately twice) than the others and has a larger variability associated with it.

Table 41 presents the correlation coefficients between the various definitions. These correlations illustrate that the data are very highly correlated and represent the same aspect of the pavement section. Based on these data, the impact of the definition is limited on the resulting overall condition.

Table 41. Correlations between cracking definitions.

	AC % WP	NPRM Under	NPRM Over	NPRM Step
AC HPMS	100%	100%	99%	99%
AC % WP		99%	99%	99%
NPRM Under			100%	100%
NPRM Over				100%

4.7. SUMMARY

The data analysis covered a series of efforts to address questions posed by the FHWA. The data collected indicate that 63 percent of the network is in good condition and 1 percent is in poor condition. The HPMS data indicate that 47 percent of the network is in good condition and 2 percent is in poor condition. Comparisons with the condition metrics indicate that there is no significant bias between the two data sets.

The primary difference in the two data sets is primarily due to differences in variability. The comparison of the collected data with the quality control data, Infrastructure Health data, and LTPP data suggest that the data collected for this project are of good quality. Further these comparisons suggest that attention to quality of the data is more important than the frequency of data collection. This observation is supported by the comparisons with the LTPP data which were not statistically significant even though the difference in time was as much as 5 years for comparisons with IRI, percent cracking, and faulting and larger for comparisons with rut depth.

Data collection included sufficient data to review the need to collect data in multiple lanes and directions. Comparisons with these data suggest that there are not significant differences in data collected in different directions of travel where the surface type was the same. The surface type was the same for 97 percent of the mileage where data was collected in both directions. Data collected in adjacent lanes suggested that the differences were not significant and the condition reported for the outside lane is worse than the adjacent lane. These analyses indicate that data collection may be limited to one lane and one direction of travel.

Analyses were performed to identify the appropriate section length and sampling rate of the network. In particular, analyses of IRI, percent cracking and rutting suggest that longer section lengths tend to mask areas of good and poor condition. Selection of section length is a matter of balancing the need to identify specific areas of good and poor condition with the increase in database size that comes with smaller sections. The 0.1-mile section length appears to be a good balance between these two needs.

A study of the sampling rate suggests that if all review of the data would be performed at the national level, less than 100 percent of the Interstate system could be assessed. Further, the size of the full data set may mask some of the variability in the data. Sampling requirements at the State level suggest that a 100 percent sample is required.

Analyses indicate that there is little difference in the overall condition when the ride quality measured on the bridges is included. Further, the average IRI changed very little when the bridges were included. The bridges had very little impact on the network level ride quality analysis. For ease of collection, our recommendation is to collect ride quality on bridges.

The faulting protocols allow for use of several different types of devices. The faulting data collected for this project included data from both an inertial profiler and from the LCMS sensor. The faulting from the LCMS sensor appears to be more reliable than that from the inertial profiler. The inertial profiler occasionally missed joints so it was difficult to make sure that all zero faulting was included in the average values. Additionally, the inertial profiler occasionally identified a crack as a joint.

As with the faulting, the protocols designated for rutting allow the use of at least two different devices. Rut depths were collected using the LCMS sensor and a 5-point rut depth was estimated. Comparisons between these two data sets indicated that the 5-point rut depth is not a reliable measure of rutting on pavements. This method of data collection yields negative rut depths and may miss the maximum rut depth due to vehicle wander. However, the differences in the two methods of data collection exhibited by the overall condition is limited since the data are being categorized.

The various definitions of cracking made very little difference in the overall condition. The various definitions resulted in very similar values of cracking with one exception, percent wheelpath cracking. The percent wheelpath definition provides the percentage of the wheelpath with cracking on the basis of the area of the wheelpaths. Therefore the percent wheelpath cracking was approximately twice the value for other types of cracking.

CHAPTER 5. SUPPLEMENTAL ANALYSIS

Subsequent to the completion of the planned analyses, which were presented in the previous chapter, a series of supplemental analyses were conducted at the request of FHWA. These analyses were pursued to answer specific questions raised related to the impact of the threshold values for each condition metric, the impact of the section length on the assessed condition metrics, and direct comparisons of the HPMS and project data. This chapter presents the results of these analyses.

5.1. THRESHOLD ANALYSIS

An analysis of particular interest to the FHWA involved reviewing the impact of alternate threshold levels on the individual condition metrics, overall pavement condition and proposed performance measures. Table 42 provides a comparison of the thresholds indicated in the NPRM to the alternate thresholds of interest to the FHWA.

Table 42. Comparison of NPRM and revised thresholds.

Condition Metric	Performance Level	Threshold	
		NPRM	Alternate
IRI	Good	<95	<95
	Fair	95 – 170	95 – 170
	Poor	>170: Areas with a population less than 1,000,000 >220: Areas with a population of at least 1,000,000	>170
Percent Cracking, AC	Good	<5%	<5%
	Fair	5 – 10%	5 – 20%
	Poor	>10%	>20%
Percent Cracking, CRCP	Good	<5%	<5%
	Fair	5 – 10%	5 – 10%
	Poor	>10%	>10%
Percent Cracking, JPCC	Good	<5%	<5%
	Fair	5 – 10%	5 – 15%
	Poor	>10%	>15%
Rutting	Good	<0.20	<0.20
	Fair	0.20 – 0.40	0.20 – 0.40
	Poor	>0.40	>0.40
Faulting	Good	<0.05	<0.10
	Fair	0.05-0.15	0.10 – 0.15
	Poor	>0.15	>0.15

The alternate thresholds result in 62.0% of the pavement in good condition and 0.7% with poor condition. These values are slightly different from the performance identified with the threshold levels indicated in the NPRM. There are, however, some differences in the percentages at the individual condition levels. Figure 27 illustrates the comparison of the percentages for the full data set and each condition metric.

The largest differences are seen in the faulting metric, with the percentage of good condition changing from 79.1 percent to 93.8 percent when moving from the NPRM thresholds to the alternate ones. The percent cracking also showed a fairly significant change in the percentage of poor segments, moving from 7.9 percent to 4.3 percent.

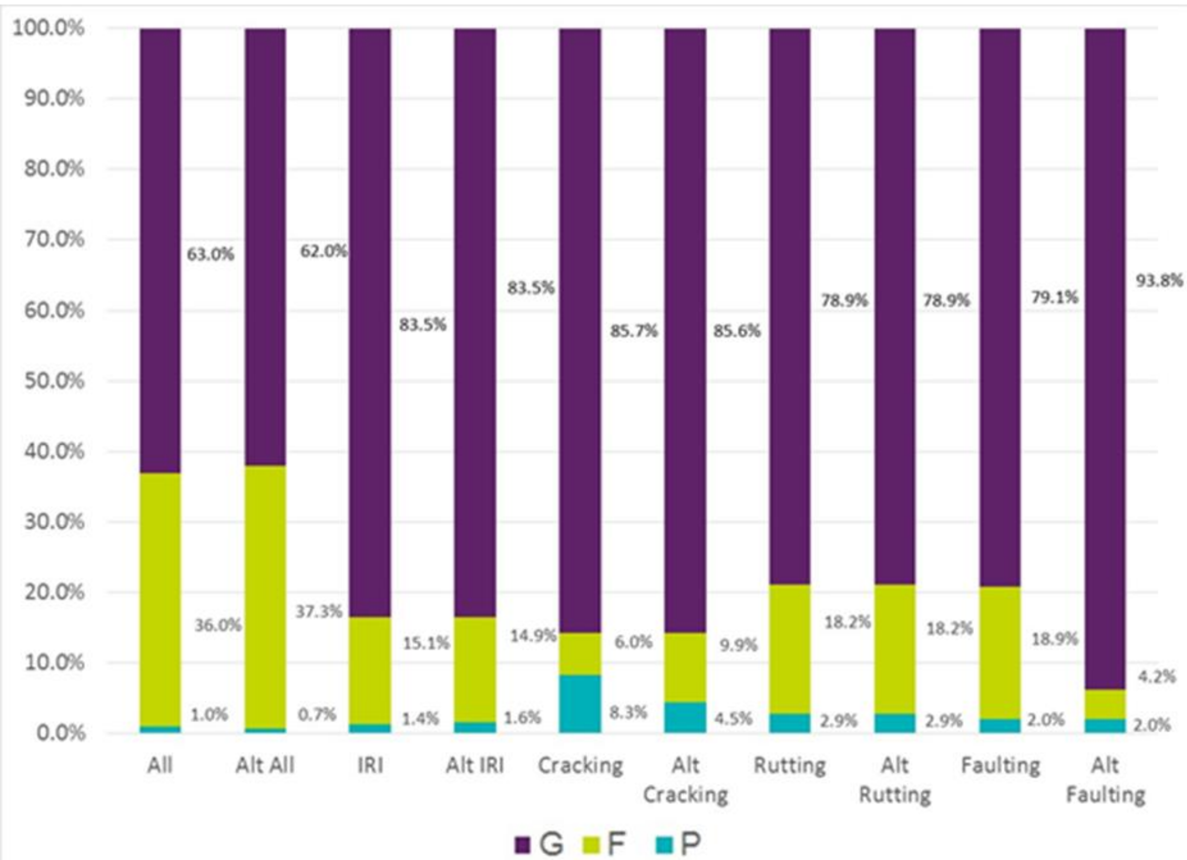

Figure 27. Chart. Comparison of condition metrics.

Table 43 provides a comparison by State of the performance measures as determined using both sets of thresholds. Comparisons were also made for each section to determine if the performance changed for each individual section. Differences were observed for approximately 177 miles of the total 8,627 miles of routine data collection. Those States that show a difference in percentages of good, fair and poor overall condition between the two sets of threshold values generally have at least 1 percent of the mileage in that State that shows a difference in comparison results for individual sections.

Table 43. Comparison of performance measures from project data using different thresholds by State.

State	Mileage, miles	NRPM Thresholds			Alternate Thresholds		
		% Good	% Fair	% Poor	% Good	% Fair	% Poor
All	8,250	63.0	36.0	1.0	62.0	37.3	0.7
Alabama	58	78.8	20.7	0.5	77.2	22.8	0.0
Arizona	418	69.0	30.8	0.2	68.5	31.4	0.1
California	356	59.1	40.1	0.8	57.7	41.2	1.1
Colorado	430	45.3	52.4	2.3	44.3	54.4	1.2
Connecticut	102	55.6	43.2	1.2	55.2	43.9	0.9
Delaware	22	62.7	36.8	0.5	60.5	39.5	0.0
Florida	356	60.4	37.3	2.3	58.8	39.7	1.5
Georgia	109	58.9	40.4	0.7	57.9	41.7	0.4
Idaho	67	35.7	60.7	3.6	34.5	63.1	2.4
Illinois	123	77.9	21.9	0.2	75.9	23.8	0.3
Indiana	308	64.5	35.2	0.3	63.6	36.0	0.4
Kansas	419	86.5	13.4	0.1	84.8	15.1	0.1
Kentucky	298	75.9	23.8	0.3	74.0	25.8	0.2
Louisiana	218	65.9	30.7	3.4	64.0	33.0	3.0
Maine	289	36.5	61.9	1.6	36.1	63.2	0.7
Maryland	97	81.4	18.6	0.0	78.5	21.4	0.1
Massachusetts	85	83.8	16.1	0.1	81.9	18.0	0.1
Minnesota	252	58.0	41.9	0.1	58.4	41.6	0.0
Missouri	247	79.2	20.6	0.2	78.5	21.4	0.1
Mississippi	71	69.7	29.6	0.7	68.1	31.6	0.3
Montana	49	49.4	49.1	1.6	49.0	50.3	0.7
Nevada	124	93.0	7.0	0.0	92.9	7.0	0.1
New Hampshire	14	98.5	1.5	0.0	98.5	1.5	0.0
New Jersey	90	41.8	57.0	1.2	39.0	60.0	1.0
New Mexico	164	53.4	45.6	1.0	53.0	46.4	0.6
New York	198	70.1	29.5	0.4	69.3	30.1	0.6
North Carolina	181	59.7	40.2	0.1	59.0	40.9	0.1
Pennsylvania	254	51.1	47.7	1.2	50.8	48.1	1.1
Rhode Island	43	82.2	17.3	0.5	80.3	19.7	0.0
South Carolina	196	68.4	30.3	1.3	68.4	30.6	1.0
South Dakota	396	83.2	16.7	0.1	83.1	16.8	0.1
Tennessee	119	90.5	9.3	0.2	89.4	10.4	0.2
Texas	862	54.3	45.3	0.4	53.0	46.7	0.3
Utah	232	78.6	21.3	0.1	80.8	19.2	0.0
Virginia	174	58.7	39.2	2.1	56.6	41.5	1.9
Washington	285	31.4	61.6	7.0	31.8	63.7	4.5
West Virginia	159	75.6	24.0	0.4	73.5	26.4	0.1
Wisconsin	185	44.5	54.7	0.8	44.1	55.4	0.5
Wyoming	202	47.2	52.4	0.4	48.3	51.5	0.2

The same comparison was performed for the data obtained from the HPMS database. The data used for this analysis were based on HPMS sample data. Figure 28 provides a comparison of these results, while Table 44 provides a comparison of the results by State for data from the HPMS database.

Generally, the differences in the performance measures by State for the HPMS data are similar to those observed in the project data with one exception. The percent poor for Colorado differed by 10 percentage points. In looking at the individual condition metrics, the cracking and IRI both showed changes in condition, but neither had a difference of 10 percent. A direct comparison at each location where data were available revealed that approximately 11 percent of the distance had a change in condition based on the alternate threshold levels.

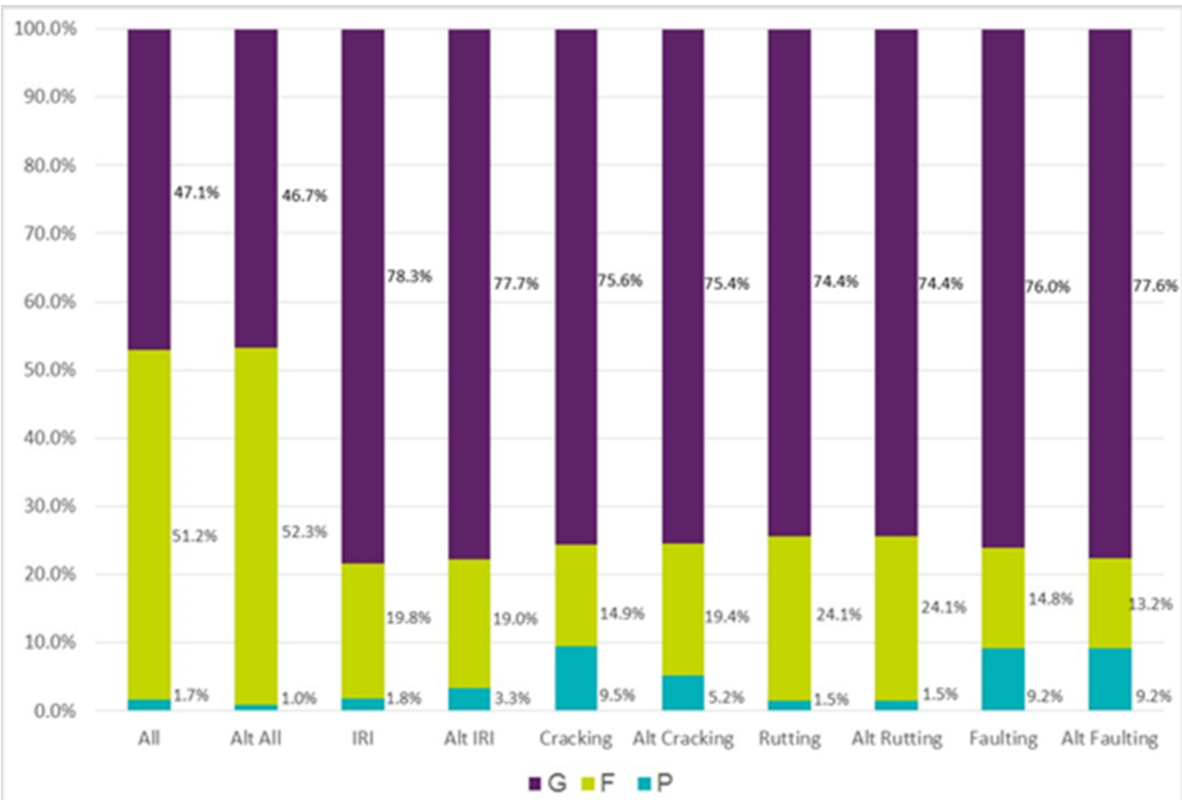

Figure 28. Chart. Comparison of condition metrics for HPMS data.

In the HPMS data, the State of Delaware showed an increase in the percentage of poor condition. The mileage from this State is small, plus a significant portion of the mileage is located within the Philadelphia urban area. This is important because pavement condition in this area, in terms of IRI, contains sufficient data within the 170 in/mile to 220 in/mile range to cause the decrease in performance from fair to poor.

Overall, the threshold analysis results suggest that very little difference is observed as a result of the change in the threshold levels. Larger differences may be observed when reviewing smaller subsets of the data, as was the case with the changes in the State data.

Table 44. Comparison of HPMS 2014 performance using different thresholds by State.

State	Mileage, miles	NRPM Thresholds			Alternate Thresholds		
		% Good	% Fair	% Poor	% Good	% Fair	% Poor
All	23,680	47.1	51.2	1.7	46.7	52.3	1.0
Alabama	353	25.0	74.3	0.7	24.7	74.5	0.8
Arizona	1,069	56.9	42.8	0.3	56.9	42.9	0.2
California	336	52.8	45.6	1.6	46.1	51.2	2.7
Colorado	519	23.3	61.5	15.2	23.2	71.8	5.0
Connecticut	146	55.0	45.0	0.0	53.2	46.6	0.2
Delaware	18	35.9	64.1	0.0	35.9	61.1	3.0
Florida	404	58.9	41.0	0.1	58.9	41.1	0.0
Georgia	355	26.2	71.9	1.9	25.9	73.0	1.1
Idaho	611	37.3	61.6	1.1	37.2	61.4	1.4
Illinois	528	0.1	99.9	0.0	0.1	99.9	0.0
Indiana	968	71.8	28.2	0.0	69.8	30.1	0.1
Kansas	336	60.8	37.4	1.8	61.4	37.5	1.1
Kentucky	626	53.5	46.3	0.2	53.4	46.4	0.2
Louisiana	738	30.5	68.1	1.4	29.6	66.6	3.8
Maine	366	43.9	56.1	0.0	43.9	56.1	0.0
Maryland	186	70.7	29.3	0.0	70.2	29.8	0.0
Massachusetts*	0	#NA	#NA	#NA	#NA	#NA	#NA
Minnesota	906	58.9	39.7	1.4	58.0	41.5	0.5
Missouri	541	76.4	23.6	0.0	75.9	24.1	0.0
Mississippi	420	70.1	29.3	0.6	69.5	30.0	0.5
Montana	335	68.6	29.6	1.8	68.4	30.9	0.7
Nevada	267	62.4	37.1	0.5	62.4	37.5	0.1
New Hampshire	244	0.0	99.3	0.7	0.0	99.5	0.5
New Jersey	133	61.5	38.1	0.4	61.3	38.3	0.4
New Mexico	449	30.4	69.5	0.1	30.3	69.6	0.1
New York	223	0.0	93.7	6.3	0.0	97.4	2.6
North Carolina	439	60.2	39.8	0.0	60.0	39.8	0.2
Pennsylvania	1803	72.0	27.9	0.1	71.6	28.2	0.2
Rhode Island	49	51.6	48.4	0.0	51.1	48.9	0.0
South Carolina	347	17.4	82.6	0.0	17.4	82.6	0.0
South Dakota	673	38.2	61.7	0.1	42.2	57.7	0.1
Tennessee	277	42.7	56.7	0.6	42.6	56.7	0.7
Texas	1093	54.4	44.8	0.8	54.0	45.6	0.4
Utah	931	49.0	48.6	2.4	49.0	50.0	1.0
Virginia	1098	39.7	58.6	1.7	39.5	59.9	0.6
Washington	745	34.5	61.6	3.9	35.9	61.6	2.5
West Virginia	545	66.9	30.0	3.1	66.7	33.3	0.0
Wisconsin	622	28.8	70.6	0.6	28.8	70.4	0.8
Wyoming	166	32.7	64.9	2.4	29.3	66.4	4.3

*For Massachusetts, #NA indicates that the pavement distress data was not available at the time of this report

5.2. IMPACT OF SECTION LENGTH

In a more extensive review of the section length (as compared to that presented in the previous chapter), the case study data, as identified in Section 4.6.2, were used to review the impact of data summarized to 0.2-mile intervals, 0.3-mile intervals, and 0.4-mile intervals. All comparisons were to the data accumulated to 0.1-mile sections as required by the NPRM. The graphs shown in figure 29 through figure 31 illustrate the impact of the section length on the average pavement condition values – percent cracking, IRI, and rut depth, respectively. The complete set of section length-pavement condition figures is provided in appendix C.

Figure 29 through figure 31 clearly show that there is a definite reduction in the peaks with the longer section lengths. This finding further confirms that the longer section lengths tend to diminish the ability to discern areas of good and poor condition. To further illustrate this point, figure 32 through figure 34 were prepared to show the change in the standard deviation with the increasing section length for percent cracking, IRI, and rut depth, respectively; specifically, data presented in figure 32 through figure 34 are based on section lengths of 0.01 mile, 0.05 mile, 0.1 mile, 0.2 mile, 0.3 mile, 0.4 mile, 0.5 mile, and 1 mile.

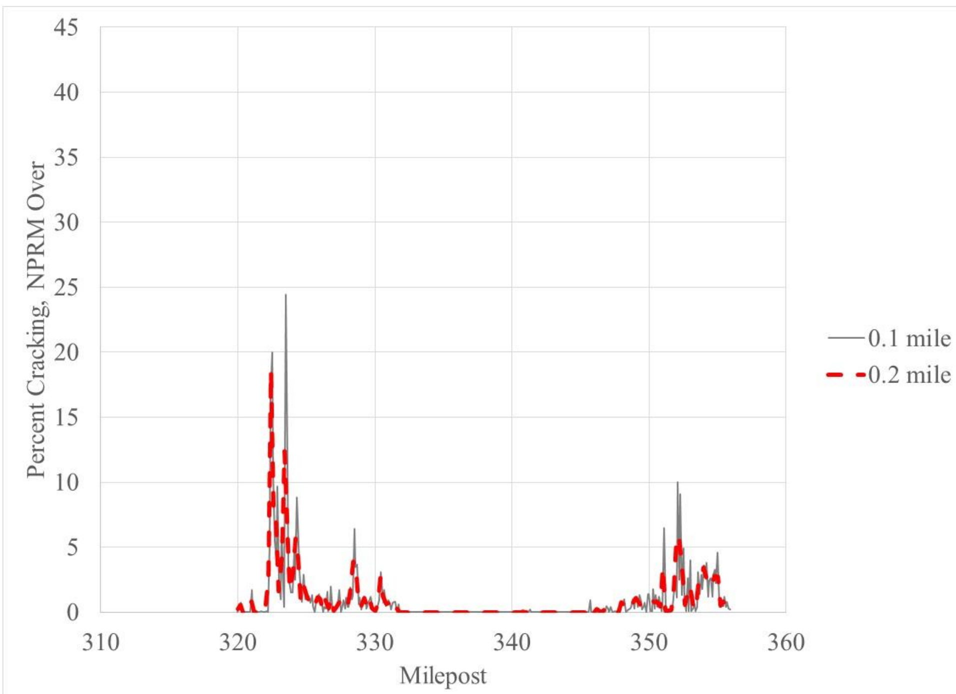

Figure 29. Graph. Impact of section length on percent cracking.

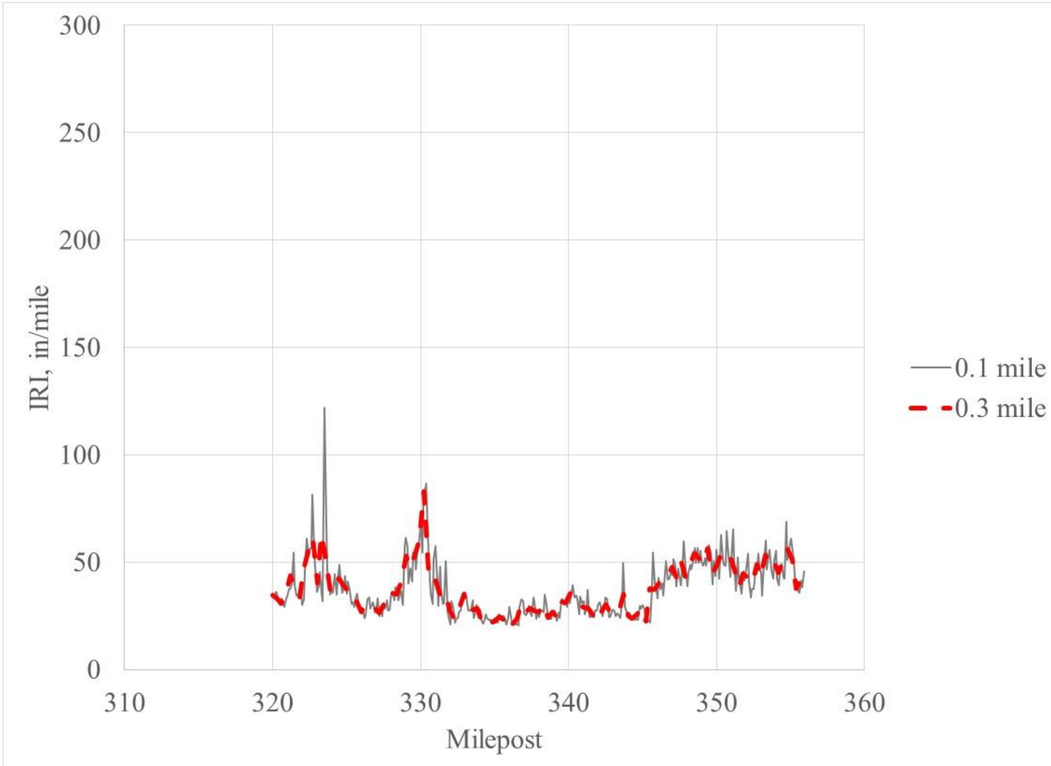

Figure 30. Graph. Impact of section length on IRI.

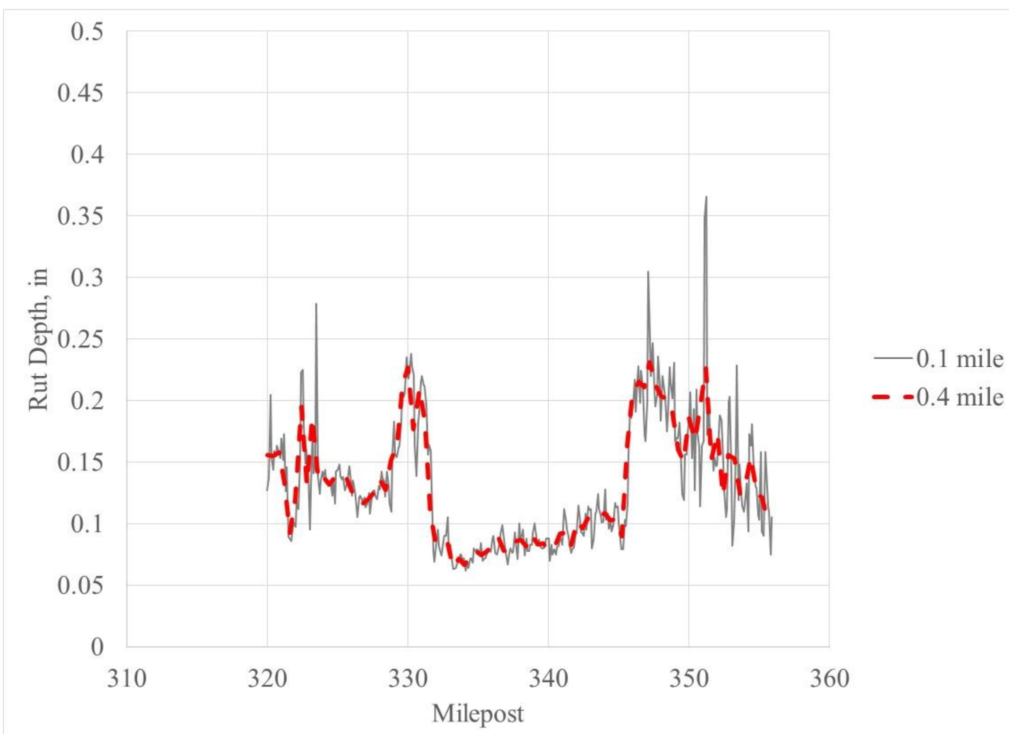

Figure 31. Graph. Impact of section length on rut depth.

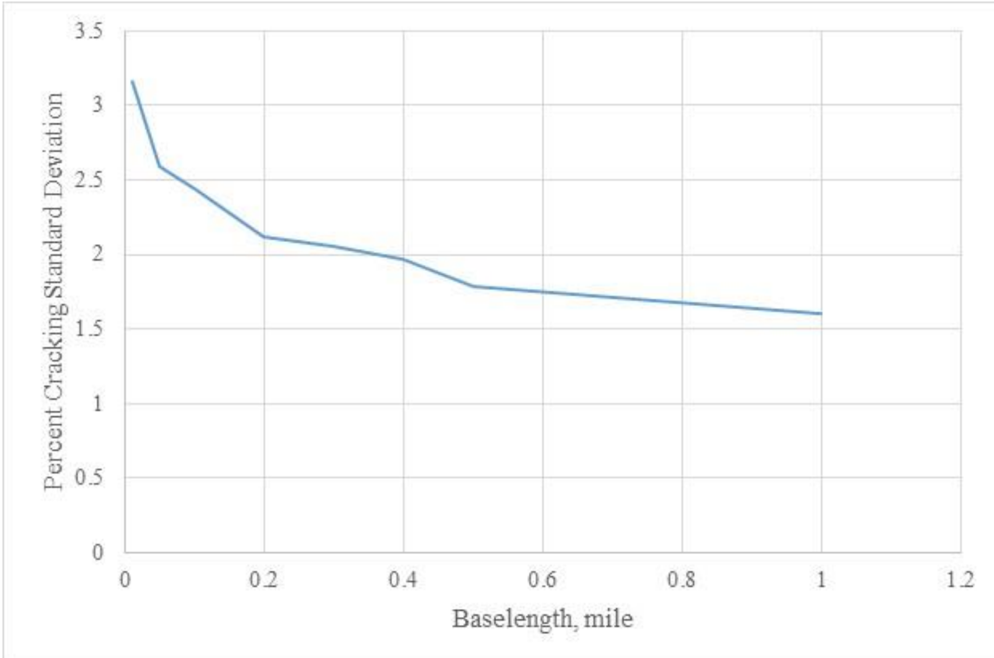

Figure 32. Graph. Change in standard deviation of percent cracking by section length.

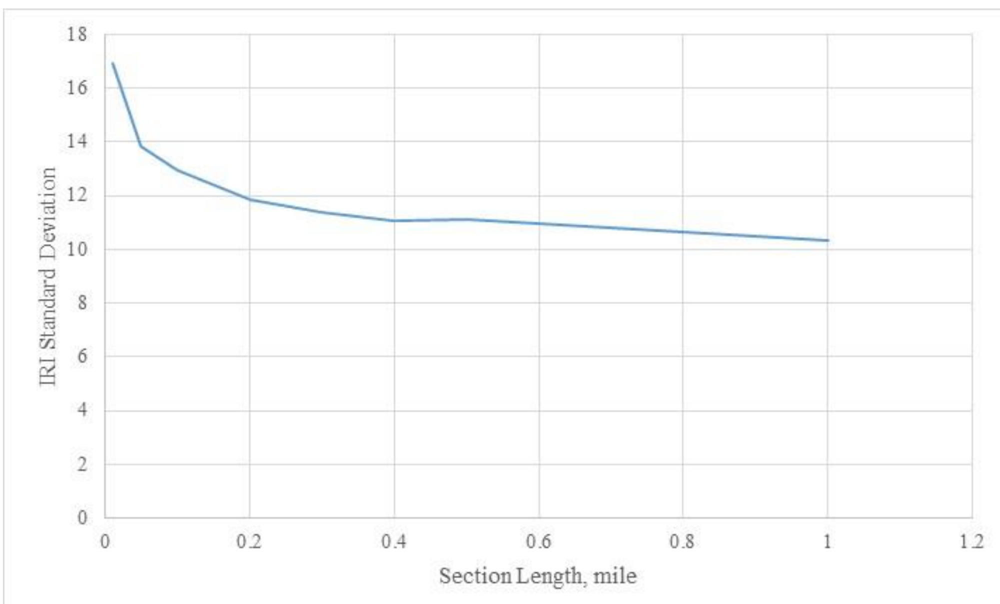

Figure 33. Graph. Change in standard deviation of IRI by section length.

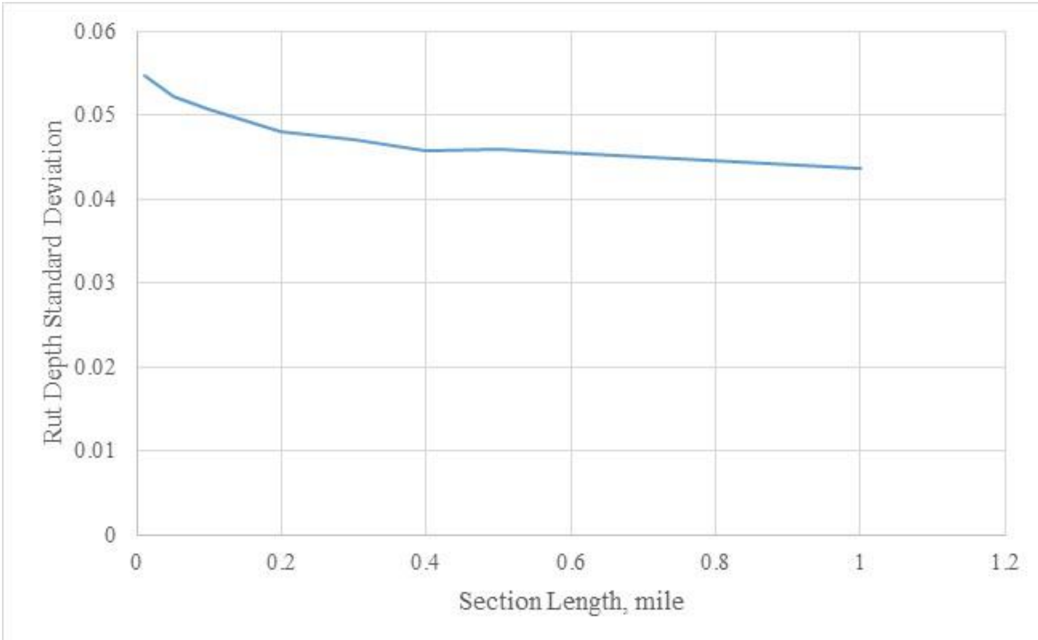

Figure 34. Graph. Change in standard deviation of rut depth by section length.

Figure 32 through figure 34 show that the standard deviation decreases with longer section lengths. In turn, the decrease in standard deviation indicates that the maximum values are reduced and the minimum values are increased with the longer section lengths. IRI is the pavement condition metric most impacted by the change in section length, but rut depth and cracking also are impacted by the reduced section length.

These data were then used to review the impact of the section length on the overall condition. Figure 35 provides the results of those calculations. These results do not indicate the anticipated trend of increasing percent fair. Although it is difficult to observe, the quantity of poor performance does decrease with increasing section length as might be expected.

5.3. POINT-BY-POINT COMPARISON

A more detailed, point-by-point comparison was conducted to review the differences, if any, between the project-gathered data in 2015 and the 2014 HPMS data. Towards this end, a series of maps were prepared to illustrate the condition by location for both the project data and the HPMS data. Subsequently, a series of maps were prepared to illustrate how the data compared at each location.

Figure 36 through figure 38 illustrate the range of comparisons observed in the data. Figure 36 illustrates a State where the results compared well, figure 37 illustrates a State with poor comparability between the two data sets, and figure 38 illustrates a mixed result in the comparability between the two data sets. These figures are intended to demonstrate that for some States the performance determined from the HPMS and project data were very comparable, for some States the data do not compare well, and for some States the result is mixed. Table 45 summarize the results of the comparisons for each of the 39 States where both data sets were available.

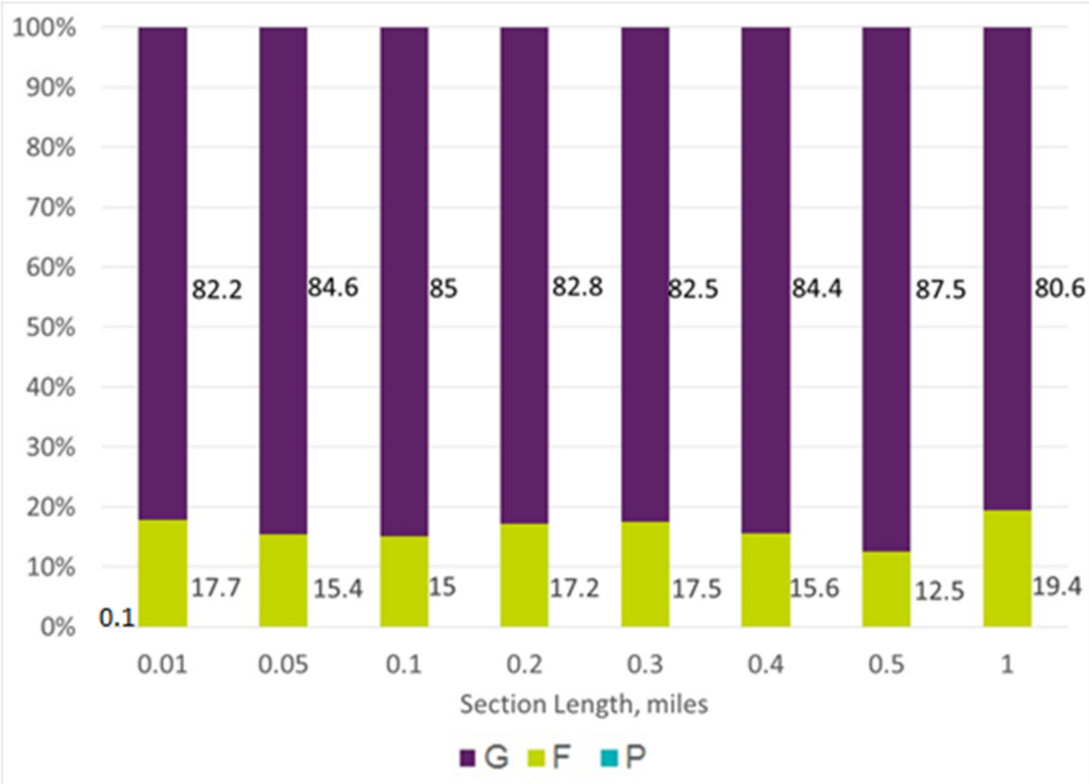

Figure 35. Performance comparison by section length.

It is important to emphasize that the HPMS data used in this analysis, as has been the case for all analyses discussed in this report, were the sample data. Therefore, the column identified as "No HPMS Data" does not indicate where States are failing to report data, but rather, it is an indication of how much sampling is being conducted on the Interstate(s) included in the data collection for this project.

A range of conditions were observed in this comparison with some of the States showing good comparability between the two data sets and some showing poor comparability between States.

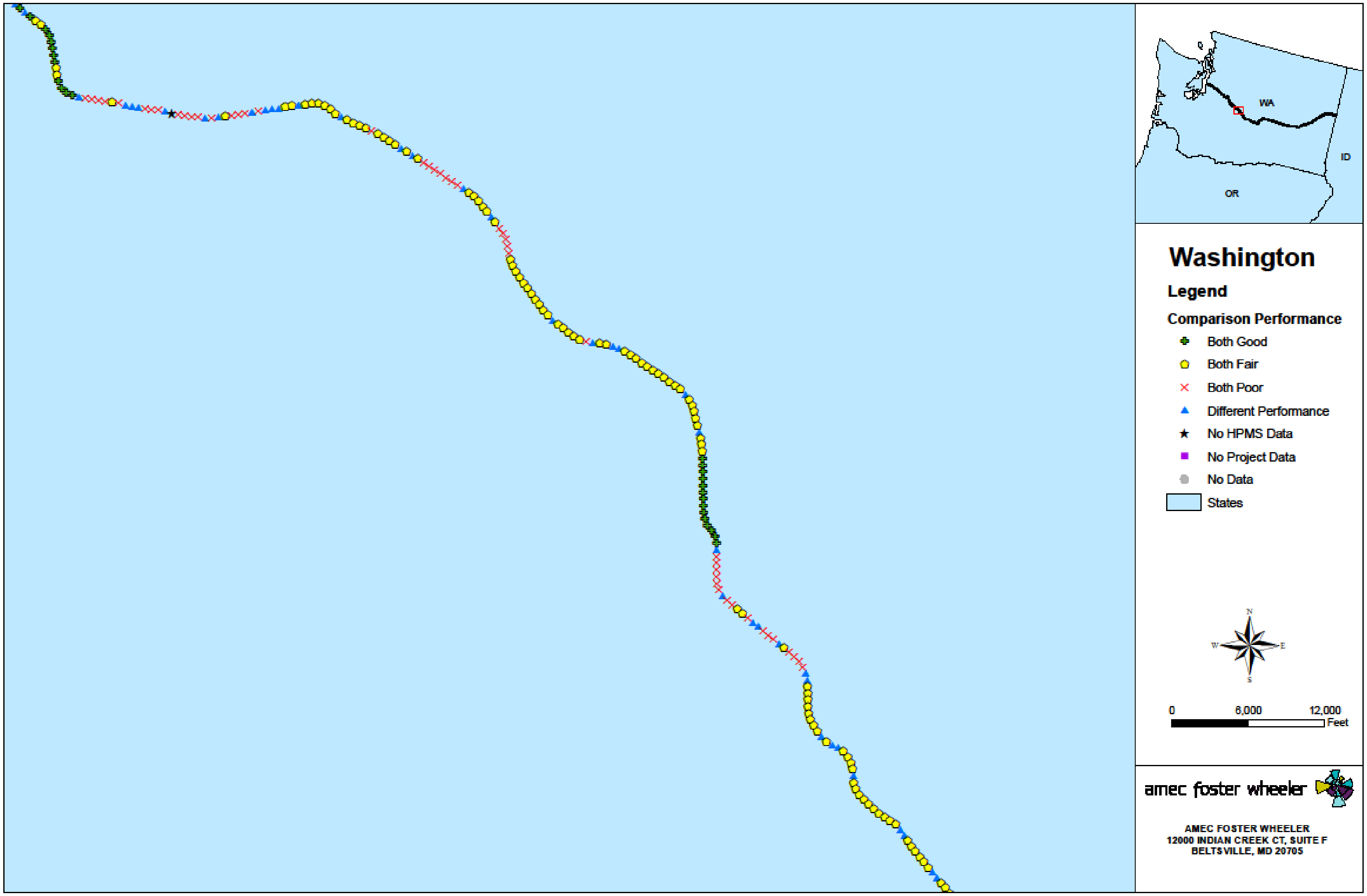

Figure 36. Map. Example of good point-by-point comparison.

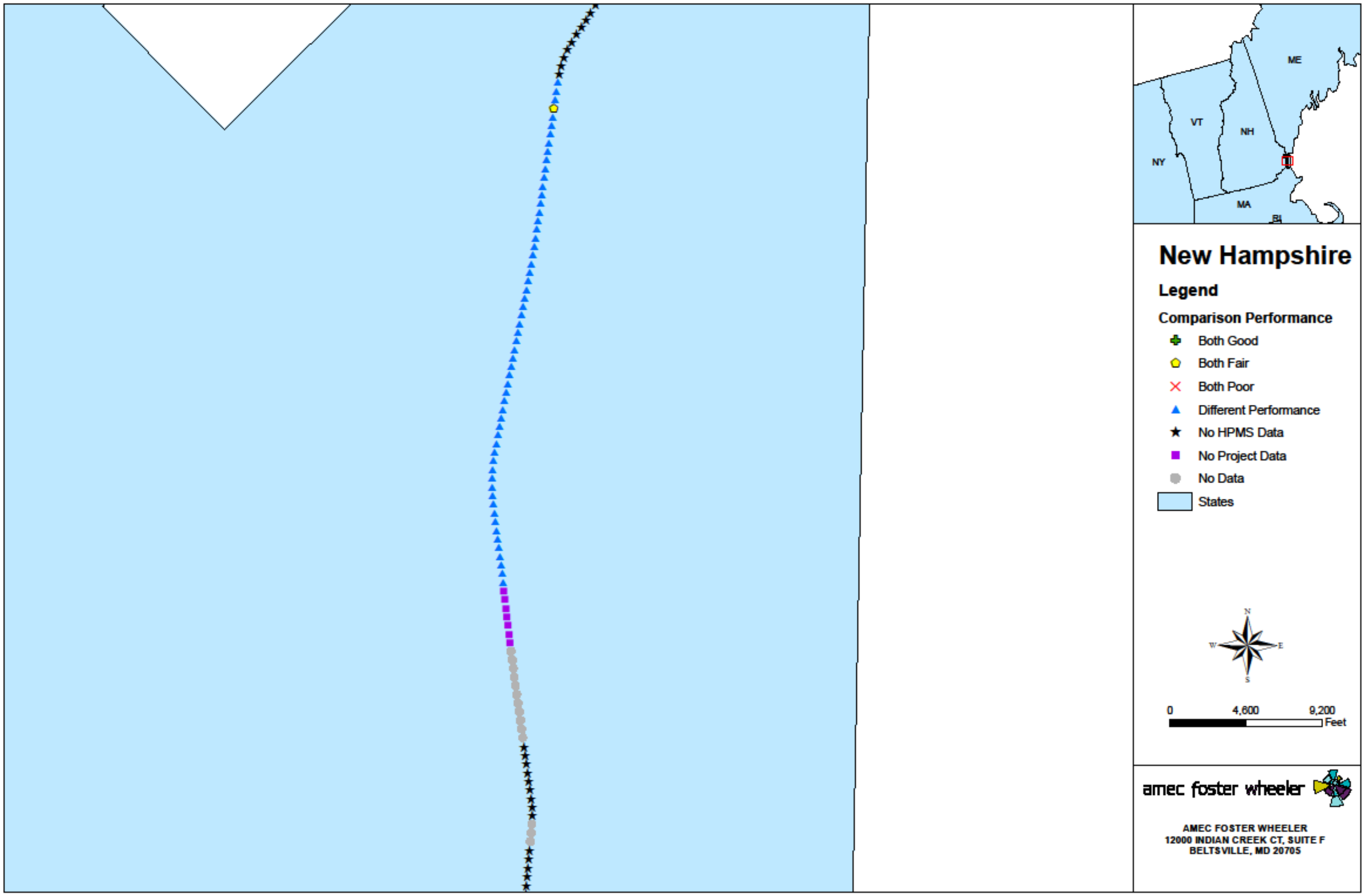

Figure 37. Map. Example of poor point-by-point comparison.

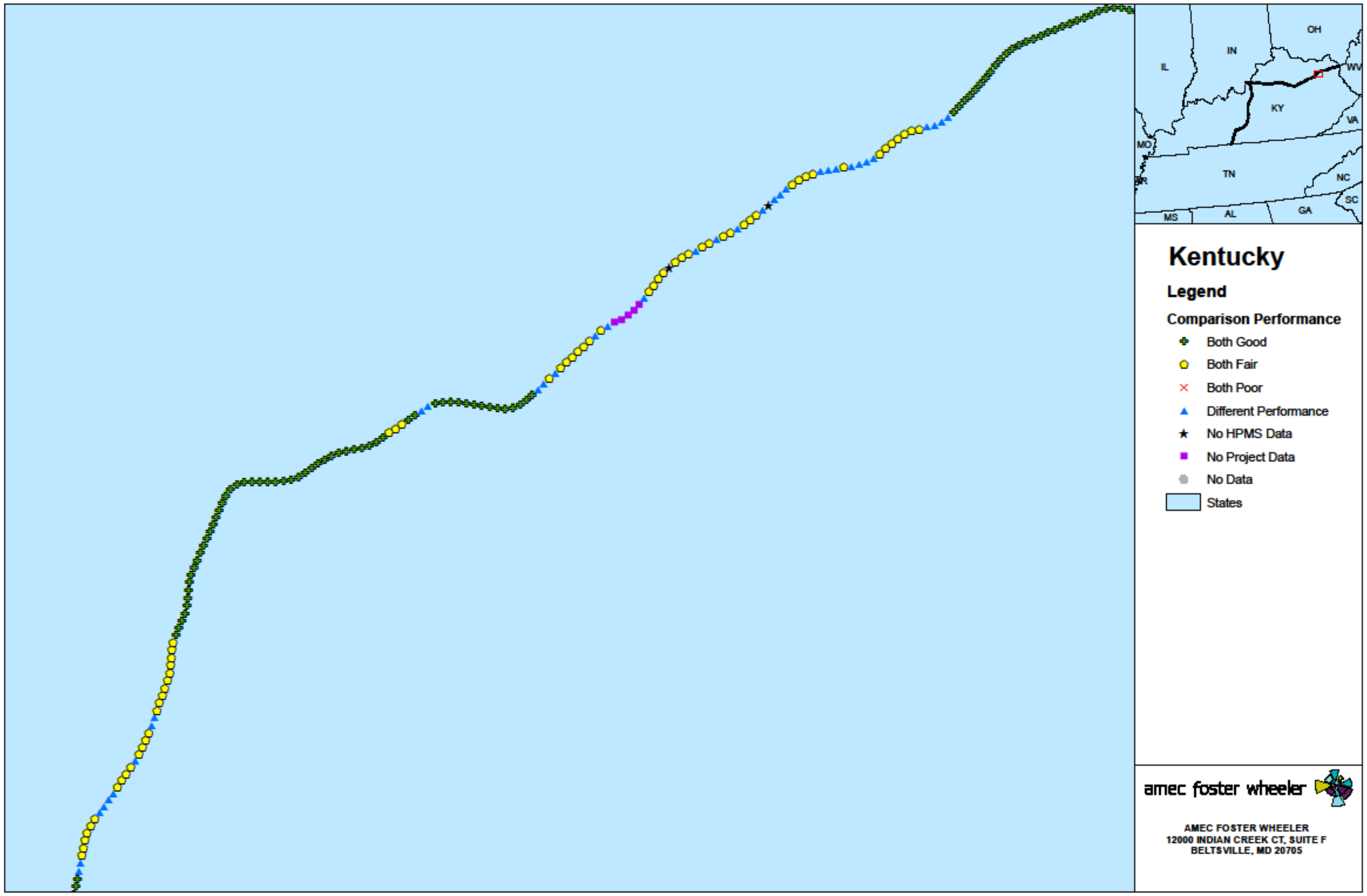

Figure 38. Map. Example of mixed point-by-point comparison.

Table 45. Mileage by comparison category.

State	Same Performance	Different Performance	No HPMS Data	No Project Data	No Data	Total Mileage
Alabama	15%	32%	41%	0%	12%	66
Arizona	63%	24%	12%	1%	0%	421
California	9%	2%	86%	0%	3%	369
Colorado	24%	24%	47%	3%	2%	450
Connecticut	20%	9%	63%	2%	6%	112
Delaware	28%	24%	43%	1%	4%	23
Florida	20%	7%	71%	0%	2%	361
Georgia	7%	5%	85%	0%	3%	112
Idaho	67%	22%	0%	10%	1%	74
Illinois	8%	28%	59%	1%	4%	128
Indiana	65%	17%	10%	7%	1%	333
Kansas	25%	7%	67%	0%	1%	424
Kentucky	36%	19%	36%	4%	5%	329
Louisiana	40%	29%	11%	6%	14%	274
Maine	77%	17%	0%	5%	1%	303
Maryland	21%	5%	63%	4%	7%	108
Massachusetts*	0%	0%	93%	0%	7%	91
Minnesota	69%	22%	0%	9%	0%	276
Mississippi	68%	16%	8%	7%	1%	77
Missouri	25%	8%	66%	0%	1%	251
Montana	1%	14%	78%	0%	6%	50
Nevada	59%	11%	30%	0%	0%	124
New Hampshire	1%	43%	41%	4%	11%	16
New Jersey	22%	8%	62%	2%	6%	99
New Mexico	25%	28%	47%	0%	0%	164
New York	5%	7%	84%	0%	4%	206
North Carolina	26%	6%	68%	0%	0%	181
Pennsylvania	65%	24%	0%	7%	4%	284
Rhode Island	35%	29%	35%	0%	1%	43
South Carolina	16%	16%	67%	0%	1%	199
South Dakota	55%	40%	1%	4%	0%	413
Tennessee	23%	5%	68%	2%	2%	122
Texas	24%	16%	58%	0%	2%	881
Utah	73%	27%	0%	0%	0%	232
Virginia	65%	32%	1%	1%	1%	178
Washington	83%	12%	1%	2%	2%	297
West Virginia	59%	39%	1%	1%	0%	160
Wisconsin	32%	21%	46%	0%	1%	187
Wyoming	6%	2%	88%	0%	4%	209

*For Massachusetts, #NA indicates that the pavement distress data was not available at the time of this report.

5.4. SUMMARY

Supplemental analyses were performed at the request of FHWA to further investigate specific issues related to the data requirements presented in the NPRM and how the project data compare to the HPMS.

The following conclusions were drawn from these analyses:

- Revision of the threshold values has a limited impact on the resulting overall condition. The overall condition identified from the individual condition metrics is impacted, but the combination of the metric-based condition into the overall condition results in very little change.

- Any change in section length to a value longer than 0.1-mile will result in loss of detail in terms of identifying specific areas of good and poor performance. As noted in chapter 4, the appropriate section length for reporting of condition is a balance of the size of the database being requested and the detail of the information obtained.

- When comparing the data from the HPMS database with the data collected for the project, no significant biases were observed. Some States provided data that were more comparable to the project data than others.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

This chapter provides the conclusions and recommendations resulting from the project. The project was conducted to meet three objectives as follows:

- Collect an unbiased baseline data for statistically significant sample of the entire IHS and produce a report indicating pavement condition on the IHS nationally and in each State where data were collected.
- Determine if HPMS is an unbiased representation of pavement condition on the IHS.
- Recommend improvements to HPMS data collection and reporting necessary to either make HPMS unbiased or improve its precision, in regard to performance management and FHWA's use of HPMS data, which in turn will enable responses to questions such as:
    - Is two-way data collection necessary?
    - Does data need to be collected in more than one lane in a direction?
    - What is the optimum HPMS section length?
    - Do all distress items require full extent reporting or is sampling adequate?
    - Are protocols proposed by FHWA adequate for collecting and reporting distress or do they need improvement?

In order to meet these objects, approximately 10,000 miles of data were collected on the IHS which consists of almost 20 percent of the IHS. Data were collected on nine interstates in 39 States. Of the mileage collected, approximately 8,624 miles were collected in the primary direction of travel in the primary lane. Approximately 500 miles were collected in the adjacent lane, approximately 500 miles were collected in the opposing direction, and repeat data collection was performed on approximately 500 miles.

The following statements provide the conclusions observed from this study:

- 62 percent of the IHS is in good condition and 1 percent is in poor condition.
- No significant bias was observed between the HPMS and the IS Condition data collected for this project.
- Attention to data quality has more impact on the data and subsequent conclusions than frequency of data collection.
- Data collected in opposing directions are very similar and the surface was the same for approximately 97 percent of the distance over which data were collected in both directions of travel.

- Data collected in the adjacent lane are very similar to those collected in the primary (outside) lane of travel. Although overall, the condition metrics indicate that the adjacent lane is in slightly better condition than the primary lane.

- Selection of the section length is a tradeoff between detail of information and database size. With longer section lengths, the IRI, cracking, and rutting condition metrics will tend toward a fair condition resulting in more of the network appearing as fair condition. With shorter section lengths, the database will become larger and more difficult to handle.

- Further analysis of section length confirms that even a small change in section length can reduce the impact of small areas of good and poor condition.

- Review of statistically-based sampling requirements suggests that for conclusions drawn only on data at the national level, a 50 percent or smaller sample may be acceptable for data collection. For conclusions drawn on State-level data sets, sampling will not provide sufficient data to estimate condition.

- Ride quality data collected on the bridge decks made very little difference on the overall condition. Other analyses indicated that it is very difficult for the data collection crew to identify where all bridge decks are especially since HPMS identifies pavement over box culverts as a bridge. These observations suggest that third party data collectors should not be relied upon for exclusion of data on bridges.

- A comparison between faulting data collected using the LCMS system and the inertial profiler indicates that these two systems do not collect the same data. Review of the number of faults identified by these two systems suggests that the LCMS provides a more reliable evaluation of the average faulting in a section as the inertial profiler may not accurately identify all joints within a section.

- Rut depth values were provided from both the LCMS sensor and an estimated 5-point rut depth. Comparisons between these two values illustrates that the LCMS sensor provides a more reliable rut depth as the 5-point value may result in a negative rut depth.

- Several different definitions of percent cracking on asphalt pavements were reviewed using the data collected. Percent wheelpath cracking was the only definition which used some basis other than full section area by using only the area of the wheelpaths. The percent wheelpath cracking was approximately twice the value of the other definitions of percent cracking and resulted in a small difference in the percent good overall condition with no difference in the percent poor overall condition.

- Changes in threshold values investigated have limited impact on the performance measures developed from the data for the national data. Some of the measures at the State level are impacted by these changes in the threshold values. Of note is that removing the provisions for urban populations related to IRI may increase the percentage of fair and poor performance more than the increase in good performance by the increase in the threshold values for the faulting and percent cracking.

- Comparisons of the good/fair/poor condition at the location level further illustrate the variability of the data in the HPMS database. The HPMS and project data compare well for some States and for others the data do not compare well. In some cases, the sampling rate of the data used by the State for submittal to the HPMS is clearly visible. In other cases the use of a reporting interval larger than the 0.1-mile interval required by the NPRM.

Based on the analyses conducted the following recommendations are made for data collection:

- Pavement metrics
    - A data collection quality control plan should be provided by each State for data submitted for the HPMS.
    - Condition data should be collected for the full extent of the outside lane in the primary direction of travel to estimate the performance of the network.
    - Condition data reported for segments of 0.1-mile in length provides a good tradeoff between detail of information and database size.
    - Ride quality data should be collected on bridge decks.
- The data collection effort was not arranged to directly validate the protocols; however, several recommendations may be made with regard to the protocols used.
    - Rut depth data collected using a 5-point system should not be used for estimating the performance of asphalt surfaced pavements.
    - Improvements in collection of faulting data will be required.
    - Clarification in the data collection guidelines should identify the preference for sealed cracks.
    - Protocols should identify how to address the quantification of cracking in areas where transverse cracks cross areas of wheelpath cracking.
- The following recommendations are for future research to be pursued:
    - Improvements are required for measurement of faulting. Further review should be undertaken of automated methods for collection of faulting data and how to collect reliable and repeatable data.

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APPENDIX A. DATA STORAGE AND QUALITY REVIEW PLAN

The objective of this document is to provide the storage and review process to be used for the data collected as part of the Interstate Pavement Condition Sampling project. The document provides a layout of the project database to be used for storage of the project data. The document also provides a step-by-step listing of the quality review to be conducted on the data as they are submitted.

1. Set up database

   Database to be set up in MS Access to provide primary storage for data to be used in the project analyses. This database is a project deliverable. The database has the table structure as indicated below.

   a. ID table – basic identification data for every 0.01-mile segment for which data are collected
      i. State (Character, 2)
      ii. Route (Character, 3)
      iii. Begin Milepost (Numeric, 4,2)
      iv. End Milepost (Numeric, 4,2)
      v. Latitude (Numeric, 3,5)
      vi. Longitude (Numeric, 3,5)
      vii. Elevation (Numeric, 4,2)
      viii. Date of data collection (Date – mm/dd/yyyy hh:mm:ss)
      ix. Lane of data collection (Numeric, 1,0) – 1 indicated for primary outside lane for data collection, 2 for adjacent lane
      x. Direction of travel (Character, 1 – N,S,E,W)
      xi. QC Data (Character, 1 – Y or N)
      xii. Climate zone (Character, 3 – WF, WNF, DF, DNF)
      xiii. Surface (Numeric, 1,0)
      xiv. Urban/Rural – from HPMS data (Numeric, 5,0)
      xv. Driver (Character, 3)
      xvi. Operator (Character, 3)
      xvii. Air Temperature (Numeric, 3,1)
      xviii. Pavement Surface Temperature (Numeric, 3,1)
      xix. Speed of Data Collection (Numeric 2,1)
      xx. Vehicle ID (Character, 6)
      xxi. Comments
   b. Event table – identifies location of bridges, construction, and pavement change
      i. State (Character, 2)
      ii. Route (Character, 3)
      iii. Date of data collection (Date – dd/mm/yyyy)
      iv. Milepost (Numeric, 3,2)

v. Event (Note field) – field should identify bridge begin/end, construction begin/end, pavement change

c. 0.01-mile IRI – provides IRI data at the 0.01-mile increment for primary route data collection
   i. State (Character, 2)
   ii. Route (Character, 3)
   iii. Date of data collection (Date – dd/mm/yyyy)
   iv. Begin milepost (Numeric, 3,2)
   v. End milepost (Numeric, 3,2)
   vi. Left IRI (Numeric, 3,0)
   vii. Right IRI (Numeric, 3,0)
   viii. Avg IRI (Numeric, 3,0)
   ix. Processor (Character, 3)
   x. QC Reviewer (Character, 3) – in all cases, this is the subcontractor personnel in charge of reviewing the data prior to submission
   xi. QA Reviewer (Character, 3)

d. 0.01-mile Rutting – provides rutting data at the 0.01-mile increment for primary route data collection
   i. State (Character, 2)
   ii. Route (Character, 3)
   iii. Date of data collection (Date – dd/mm/yyyy)
   iv. Begin milepost (Numeric, 3,2)
   v. End milepost (Numeric, 3,2)
   vi. Left Rut Depth (Numeric, 1,2)
   vii. Right Rut Depth (Numeric 1,2)
   viii. Avg Rut Depth (Numeric 1,2)
   ix. Processor (Character, 3)
   x. QC Reviewer (Character, 3)
   xi. QA Reviewer (Character, 3)

e. 0.01-mile Faulting – provides faulting data at the 0.01-mile increment for primary route data collection. Faults measured as 0 inch will be recorded as 0 inch.
   i. State (Character, 2)
   ii. Route (Character, 3)
   iii. Date of data collection (Date – dd/mm/yyyy)
   iv. Begin milepost (Numeric, 3,2)
   v. End milepost (Numeric 3,2)
   vi. Average Fault (Numeric 1,2)
   vii. Standard Deviation Fault (Numeric 1,2)
   viii. Minimum Fault (Numeric 1,2)
   ix. Maximum Fault (Numeric 1,2)
   x. Processor (Character, 3)
   xi. QC Reviewer (Character, 3)
   xii. QA Reviewer (Character, 3)

f. 0.01-mile Percent Cracking – provides percent cracking at the 0.01-mile increment for primary route data collection
    i. State (Character 2)
    ii. Route (Character, 3)
    iii. Date of data collection (Date – dd/mm/yyyy)
    iv. Begin milepost (Numeric 3,2)
    v. End milepost (Numeric 3,2)
    vi. Percent Cracking HPMS (Numeric 3,0)
    vii. Percent Cracking Wheelpath (Numeric 3,0 – AC only)
    viii. Processor (Character, 3)
    ix. QC Reviewer (Character, 3)
    x. QA Reviewer (Character, 3)

g. Condition (0.1-mile intervals) – provides the condition metrics and the performance management measures at the 0.1-mile increment for performance management measures.
    i. State (Character, 2)
    ii. Route (Character, 3)
    iii. Date of data collection (Date – dd/mm/yyyy)
    iv. Begin milepost (Numeric 3,2)
    v. End milepost (Numeric 3,2)
    vi. Avg IRI (Numeric 3,0)
    vii. Percent Cracking Wheelpath (Numeric 3,0)
    viii. Avg Rutting (Numeric 1,2)
    ix. Avg Faulting (Numeric 1,2)
    x. IRI Condition (Character, 1 – G/F/P)
    xi. Cracking Condition (Character, 1 – G/F/P)
    xii. Rut Condition (Character, 1 – G/F/P)
    xiii. Fault Condition (Character, 1 – G/F/P)
    xiv. Overall Condition (Character, 1 – G/F/P)
    xv. Note for Missing Data (Note) Field will contain explanations/reasons for data that are missing – e.g., missing data due to bridge, construction event, data quality issue or other reason.

h. 0.01-mile IRI – Additional IRI data collected at 0.01-mile increments as part of adjacent lane, opposing direction, or quality control
    i. State (Character, 2)
    ii. Route (Character, 3)
    iii. Date of data collection (Date – dd/mm/yyyy)
    iv. Lane of data collection (Numeric, 1,0) – 1 indicated for primary outside lane for data collection, 2 for adjacent lane
    v. Direction (Character, 1 – N,S,E,W)
    vi. QC (Y or N)
    vii. Begin milepost (Numeric 3,2)
    viii. End milepost (Numeric 3,2)

ix. Left IRI (Numeric 3,0)
x. Right IRI (Numeric 3,0)
xi. Avg IRI (Numeric 3,0)
xii. Processor (Character, 3)
xiii. QC Reviewer (Character, 3)
xiv. QA Reviewer (Character, 3)

i. 0.1-mile IRI – Additional IRI data collected at 0.1-mile increments as part of adjacent lane, opposing direction or quality control. Note that primary data collection IRI at 0.1-mile intervals will be stored in the condition table above.
    i. State (Character, 2)
    ii. Route (Character, 3)
    iii. Date of data collection (Date – dd/mm/yyyy)
    iv. Lane (Character, 1 – P = primary, A = adjacent, O = opposing direction primary lane)
    v. Direction (Character, 1 – N,S,E,W)
    vi. QC (Y or N)
    vii. Begin milepost (Numeric 3,2)
    viii. End milepost (Numeric 3,2)
    ix. Left IRI (Numeric 3,0)
    x. Right IRI (Numeric 3,0)
    xi. Avg IRI (Numeric 3,0)
    xii. Processor (Character, 3)
    xiii. QC Reviewer (Character, 3)
    xiv. QA Reviewer (Character, 3)

j. 0.01-mile Rutting – Additional rut data collected at 0.01-mile increments as part of adjacent lane, opposing direction or quality control
    i. State (Character, 2)
    ii. Route (Character, 3)
    iii. Date of data collection (Date – dd/mm/yyyy)
    iv. Lane (Character, 1 – P = primary, A = adjacent, O = opposing direction primary lane)
    v. Direction (Character, 1 – N,S,E,W)
    vi. QC (Y or N)
    vii. Begin milepost (Numeric 3,2)
    viii. End milepost (Numeric 3,2)
    ix. Left Rut Depth (Numeric 1,2)
    x. Right Rut Depth (Numeric 1,2)
    xi. Avg Rut Depth (Numeric 1,2)
    xii. Processor (Character, 3)
    xiii. QC Reviewer (Character, 3)
    xiv. QA Reviewer (Character, 3)

k. 0.01-mile Faulting – Additional faulting data collected at 0.01-mile increments as part of adjacent lane, opposing direction or quality control

i. State (Character, 2)
ii. Route (Character, 3)
iii. Date of data collection (Date – dd/mm/yyyy)
iv. Lane (Character, 1 – P = primary, A = adjacent, O = opposing direction primary lane)
v. Direction (Character, 1 – N,S,E,W)
vi. QC (Y or N)
vii. Begin milepost (Numeric 3,2)
viii. End milepost (Numeric 3,2)
ix. Average Fault (Numeric 1,2)
x. Standard Deviation Fault (Numeric 1,2)
xi. Minimum Fault (Numeric 1,2)
xii. Maximum Fault (Numeric 1,2)
xiii. Processor (Character, 3)
xiv. QC Reviewer (Character, 3)
xv. QA Reviewer (Character, 3)

l. 0.01-mile Percent Cracking – Additional cracking data collected at 0.01-mile increments as part of adjacent lane, opposing direction or quality control
    i. State (Character, 2)
    ii. Route (Character, 3)
    iii. Date of data collection (Date – dd/mm/yyyy)
    iv. Lane (Character, 1 – P = primary, A = adjacent, O = opposing direction primary lane)
    v. Direction (Character, 1 – N,S,E,W)
    vi. QC (Y or N)
    vii. Begin milepost (Numeric 3,2)
    viii. End milepost (Numeric 3,2)
    ix. Percent Cracking HPMS (Numeric 3,0)
    x. Percent Cracking Wheelpath (Numeric 3,0 – AC only)
    xi. Processor (Character, 3)
    xii. QC Reviewer (Character, 3)
    xiii. QA Reviewer (Character, 3)

2. Data received for completed State-route combination.

Data was received from the data collection vendor at the completion of collection on each State-route combination. Data have been submitted on a USB drive and the original USB drive containing each submittal was maintained until data collection was completed and the data received were reviewed. Each submittal received a review in accordance with the following steps.

a. Data files scanned for viruses
b. Data stored on network under Data Collection Task in project file
c. Original data file to be maintained under the data collection task

d. Copy of data then placed under Data Analysis Task in project file as working file
e. Original USB hard drive maintained until all data collection complete and has been received

3. Data were reviewed for quality and consistency.

   These checks performed on the data will be a review of the data against itself. These basic checks will be completed using the data as received. Portions of the checks will be automated over the course of the project, but initially checks will be conducted manually or with the use of features in Excel.

   a. Initial checks
      i. Data is for State-route combination identified in submittal
      ii. QC, adjacent lane, and opposing direction data labeled
      iii. Data submittal contains all required elements
         1. Data needed to complete database
         2. Check that all required data elements were included in the data set
      iv. ROW images provided
      v. Identify if rain was falling in general vicinity of data collection vehicle using website such as www.wunderground.com which stores historic weather information
      vi. Data collection vendor equipment daily and weekly checks
      vii. Once these items verified, log data submittal showing date of submittal. Use log form as attached.
   b. Check following for completeness
      i. Roughness
      ii. Percent cracking
      iii. Faulting for all records with a surface type of 3 or 4
      iv. Rutting for all records with a surface type of 2 or 5
      v. Surface type
      vi. Location information
      vii. Event data
   c. Check for range
      i. Roughness – 40 to 250 in/mile
      ii. Percent Cracking – less than 100%
      iii. Rutting – less than 1 inch
      iv. Faulting – less than 1 inch
      v. Surface type – no unpaved surfaces. Surface type should be 2, 3, or 5
      vi. Air Temperature – 40 to 100°F
      vii. Pavement Surface Temperature – 20 to 130°F
      viii. Speed – 40 to 65 mph
   d. Data consistency
      i. Faulting data should not be provided on a surface type of 2 or 5

ii. Compare slab length to surface type. Typically, a slab length of 25 ft or greater will be a JRCP (Surface type 4). The data collection vendor will be instructed to default to surface type 3 (JPCP) if unsure whether surface is 3 or 4.
iii. Rutting data should not be provided on a surface type of 3 or 5
iv. Difference in rut depth between wheelpath values at the same location ≥ 0.25 inch. (Based on LTPP data which have average difference less than 0.1 inch and a standard deviation of approximately 0.1 inch.)
v. Both values of percent cracking complete for surface types of 2
vi. Have record for every 0.01-mile increment
vii. Have record for IRI calculated at 0.1-mile increments
viii. Difference in IRI between wheelpath values at the same location ≥ 50 in/mile (As with rut depth, based on LTPP data which have average difference of 13 in/mile and standard deviation in difference of 16 in/mile)
ix. For every begin event marker, there is an ending event marker
x. Same data collection vehicle used for all data in a single submittal
xi. Data collection vehicle matches prior data collection vehicle, unless communication provided indicating otherwise

e. Review ROW images
    i. Are images clear? Review images from various times of day (morning, noon, and late afternoon).
        1. Determine the total mileage collected for the day. Divide this mileage by 4.
        2. Review images for 5 miles at each of the following:
            a. First mileage of the day
            b. At a quarter of the mileage collected
            c. At half of the mileage collected
            d. At three-quarters of the mileage collected
            e. Last 5 miles of the day
    ii. Compare 5% of event markers to ROW images – do they match?
    iii. Compare areas of cracking with ROW images – can cracks be observed? Complete this check for a minimum of 10 locations. Lack of visible cracking does not necessarily indicate a problem with the data but this check is to be used in concert with the other checks to review quality of submittal.

f. Review downward/pavement images
    i. Are images clear?
    ii. Compare marked images to quantity reported for minimum 10 locations – are these consistent?

g. Flag data failing any of the checks identified under items a through f above.
    i. Any data failing these checks, notify project team (Rada, Groeger, Simpson, Visintine)

    ii. Team will make decision regarding flagged data, i.e., data failing checks in items a through f above.
        1. If data appears to be outlying record, data will be maintained and stored in database
        2. If data appears to be part of persistent issue (more than 4 records flagged for a day for the same reason), subcontractor will be notified.
        3. If more than 10 records flagged for same issue, a stop work order will be issued to subcontractor to sort out problem and correct any equipment issues.
  - h. In instances where QC data are provided.
    - i. Compare QC data to original data
    - ii. Identify segments that differ by more than 5%
    - iii. Share list of segments with project team (Rada, Groeger, Simpson, Visintine)
    - iv. If more than 10% of repeat data are flagged, stop work order will be issued to subcontractor for them to investigate potential equipment issue.

4. After review, data passing QC review will be filtered into project database as identified under item 1.

5. After data has been added to database, perform the following additional QC reviews based on consistency comparisons with other data sets.

  - a. Compare to I-90 pilot study data
    - i. Data collected along I-90 through SD, MN, and WI
    - ii. Perform one-to-one comparison with data collected on I-90 corridor for Infrastructure Health project
    - iii. Flag data based on any of the following deviations:
        1. IRI increase > 10 in/mile per year or decrease > 5 in/mile
        2. Rut depth increase > 0.1 inch/year or decrease > 0.05 inch
        3. Faulting increase > 0.08 in/year or decrease > 0.04 inch
        4. Percent cracking > 10% / year or decrease > 5%
  - b. LTPP Data
    - i. Identify segments along data collection route matching LTPP test sections
    - ii. Compare data from that segment to most recent LTPP performance data for matching test section

6. Once all reviews have been completed, the QA Reviewer will add their initials to the database tables in that field.

The compilation of these records represents the project database used to perform the analyses required to accomplish project objectives.

Table 46. Data submittal log.

State	Route	Data Received	Review Completed	Date Notify Data Collection Vendor	Date Resubmittal, if needed
WA	I90				
ID	I90				
WY	I90				
SD	I90				
MN	I90				
WI	I90				
AZ	I15				
NV	I15				
CA	I15				
CA	I10				
AZ	I10				
NM	I10				
TX	I10				
LA	I10				
MS	I10				
AL	I10				
FL	I10				
UT	I70				
CO	I70				
KS	I70				
MO	I70				
GA	I95				
SC	I95				
NC	I95				
VA	I95				
MD	I95				
DE	I95				
PA	I95				
NJ	I95				
NY	I95				
CT	I95				
RI	I95				
MA	I95				
NH	I95				
ME	I95				
PA	I81				
NY	I81				
WV	I79				

State	Route	Data Received	Review Completed	Date Notify Data Collection Vendor	Date Resubmittal, if needed
KY	I64				
IN	I64				
IL	I64				
TN	I65				
KY	I65				
IN	I65				

APPENDIX B. PROJECT DATABASE DATA DICTIONARY

The IHS pavement condition sampling database consists of eight tables. These tables are detailed here. At the top of each table, the table name (in bold) from the database file is provided, and the table name is followed by a brief description of the table contents. The table then describes each of the data elements within the table, including attribute, data type, description and notes.

Table 47 is cracking data for asphalt concrete pavements at 0.01-mile interval.

Table 47. 0.01mile_Crack_AC.

Attribute	**Data Type**	**Description**	**Notes**
Session_Name	Text 14	Collected file name used by data collection subcontractor	*SSRN*MP*###DL* SS – State RN – Route Number ### - Milepost at beginning of the file D – Direction L – Lane Suffix QC added if QC data
State	Text 2	2 character postal code for State	
Route_Number	Text 3	I for Interstate followed by two-digit route number	
Direction	Text 1	N = North S = South E = East W = West	
Lane	Number 1	1 = Primary Lane 2 = Adjacent Lane	
Begin_Milepost	Number 8,4	Milepost of summary section start	Miles
End_Milepost	Number 8,4	Milepost of summary section end	Miles
Section_Length	Number 8,4	Driven distance in the summary section	Miles
Begin_Latitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Longitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Elevation	Number 5,2	GPS location of summary section start	Height above Ellipsoid in Feet – WGS84
End_Latitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Longitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Elevation	Number 5,2	GPS location of summary section end	High above Ellipsoid in Feet – WGS84
QC_Data	Text 1	Y = repeat quality control collection segment N = not quality control collection segment	
Vehicle_ID	Text 3	ID of collection vehicle	
Driver	Text 3	Initials of driver	

Attribute	Data Type	Description	Notes
Operator	Text 3	Initials of operator	
Speed	Number 2	Speed of vehicle at summary section start	MPH
Collection_Date	Date	Date of data collection	MM/DD/YYYY
Collection_Time	Time	Time of data collection	HH:MM:SS
Air_Temperature	Number 3	Ambient air temperature	Degrees Fahrenheit
Surface_Temperature	Number 3	Temperature of pavement surface	Degrees Fahrenheit
Surface_Type	Text 4	Surface Type of pavement	AC = asphalt concrete CRCP = continuously reinforced concrete pavement JPCP = jointed concrete pavement
Bridge_Flag	Text 4	True = Bridge deck located within the summary section Blank = No bridge deck within the summary section	
Lane_Deviation_Flag	Text 4	True = Segment contains a lane deviation Blank = no deviation contained within the segment	
Construction_Flag	Text 4	True = Segment contains construction Blank = no construction contained within the segment	
Percent_Cracking_HPMS	Number 3,1	Area of affected wheelpath divided by area of lane	%
Percent_Cracking_Wheelpath	Number 3,1	Area of affected wheelpath divided by the total area of the wheelpath	%
Percent_Cracking_NPRM_Under	Number 3,1	Area of affected wheelpath plus area of transverse cracking not in the wheelpath divided by area of lane	%
Percent_Cracking_NPRM_Over	Number 3,1	Area of affected wheelpath plus area of transverse cracking divided by area of lane	%
Percent_Cracking_NPRM_Step	Number 3,1	Area of affected wheelpath plus area of transverse cracking not in the wheelpath with addition of transverse cracking in the wheelpath based on percentage of wheelpath cracking (none if more than 80% wheelpath, 25% if between 60 and 80% wheelpath, 50% if between 40 and 60% wheelpath, 75% if between 20 and 40% wheelpath, and 100% if less than 20% wheelpath) divided by area of lane	%
Length	Number 3,1	Length of segment considered in accumulating traffic data	Feet

Attribute	**Data Type**	**Description**	**Notes**
Lane_Width	Number 4,2	Average width of lane for the segment of cracking data	Feet
Num_Transverse	Number 3,2	Transverse cracking length divided by lane width	
Wheelpath_Length	Number 5,2	Length of affected wheelpath	Feet
Affected_Wheelpath_Area	Number 5	Area of affected wheelpath	Square Feet
Wheelpath_Area	Number 5	Area of wheelpath	Square Feet
Fatigue_Area	Number 5	Area of fatigue present in entire lane	Square Feet
Transverse_Crack_Length	Number 5	Length of transverse cracks in segment	Feet
Lane_Area	Number 5	Area of lane in segment	Square Feet

Table 48 is cracking data for continuously-reinforced concrete pavement and jointed concrete pavement for 0.01-mile segments.

Table 48. 0.01mile_Crack_PCC.

Attribute	**Data Type**	**Description**	**Notes**
Session_Name	Text 14	Collected file name used by data collection subcontractor	*SSRN*MP*###DL* SS – State RN – Route Number ### - Milepost at beginning of the file D – Direction L – Lane Suffix QC added if QC data
State	Text 2	2 character postal code for State	
Route_Number	Text 3	I for Interstate followed by two-digit route number	
Direction	Text 1	N = North S = South E = East W = West	
Lane	Number 1	1 = Primary Lane 2 = Adjacent Lane	
Begin_Milepost	Number 8,4	Milepost of summary section start	Miles
End_Milepost	Number 8,4	Milepost of summary section end	Miles
Section_Length	Number 8,4	Driven distance in the summary section	Miles
Begin_Latitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Longitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Elevation	Number 5,2	GPS location of summary section start	Height above Ellipsoid in Feet – WGS84
End_Latitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Longitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Elevation	Number 5,2	GPS location of summary section end	High above Ellipsoid in Feet – WGS84
QC_Data	Text 1	Y = repeat quality control collection segment N = not quality control collection segment	
Vehicle_ID	Text 3	ID of collection vehicle	
Driver	Text 3	Initials of driver	
Operator	Text 3	Initials of operator	
Speed	Number 2	Speed of vehicle at summary section start	MPH
Collection_Date	Date	Date of data collection	MM/DD/YYYY
Collection_Time	Time	Time of data collection	HH:MM:SS
Air_Temperature	Number 3	Ambient air temperature	Degrees Fahrenheit
Surface_Temperature	Number 3	Temperature of pavement surface	Degrees Fahrenheit

Attribute	Data Type	Description	Notes
Surface_Type	Text 4	Surface Type of pavement	AC = asphalt concrete CRCP = continuously reinforced concrete pavement JPCP = jointed concrete pavement
Bridge_Flag	Text 4	True = Bridge deck located within summary section Blank = No bridge deck within the summary section	
Lane_Deviation_Flag	Text 4	True = Segment contains a lane deviation Blank = no deviation contained within the segment	
Construction_Flag	Text 4	True = Segment contains construction Blank = no construction contained within the segment	
HPMS_Cracking_Percent	Number 3	CRCP – Area of punchouts and patching divided by area of lane JPCP – Number of cracked slabs divided by total number of slabs	%
Transverse_Cracked_Slab_Count	Number 3	Total count of transversely cracked slabs in segment	Count
Longitudinal_Cracked_Slab_Count	Number 3	Total count of longitudinally cracked slabs in segment	Count
Combination_Cracked_Slab_Count	Number 3	Total count of slabs containing both longitudinal and transverse cracks in segment	Count
Joint_Count	Number 2	Total count of joints in segment	Count
Punchout_Area	Number 5	Area of all punchouts in segment	Square Feet
Patching_Area	Number 5	Area of all patches in segment	Square Feet
Lane_Area	Number 5	Area of lane in segment	Square Feet

Table 49 is faulting data collected for 0.01-mile segments of jointed concrete surfaces.

Table 49. 0.01mile_Fault.

Attribute	Data Type	Description	Notes
Session_Name	Text 14	Collected file name used by data collection subcontractor	*SSRN*MP*###DL* SS – State RN – Route Number ### - Milepost at beginning of the file D – Direction L – Lane Suffix QC added if QC data
State	Text 2	2 character postal code for State	
Route_Number	Text 3	I for Interstate followed by two-digit route number	
Direction	Text 1	N = North S = South E = East W = West	
Lane	Number 1	1 = Primary Lane 2 = Adjacent Lane	
Begin_Milepost	Number 8,4	Milepost of summary section start	Miles
End_Milepost	Number 8,4	Milepost of summary section end	Miles
Section_Length	Number 8,4	Driven distance in the summary section	Miles
Begin_Latitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Longitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Elevation	Number 5,2	GPS location of summary section start	Height above Ellipsoid in Feet – WGS84
End_Latitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Longitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Elevation	Number 5,2	GPS location of summary section end	High above Ellipsoid in Feet – WGS84
QC_Data	Text 1	Y = repeat quality control collection segment N = not quality control collection segment	
Vehicle_ID	Text 3	ID of collection vehicle	
Driver	Text 3	Initials of driver	
Operator	Text 3	Initials of operator	
Speed	Number 2	Speed of vehicle at summary section start	MPH
Collection_Date	Date	Date of data collection	MM/DD/YYYY
Collection_Time	Time	Time of data collection	HH:MM:SS
Air_Temperature	Number 3	Ambient air temperature	Degrees Fahrenheit
Surface_Temperature	Number 3	Temperature of pavement surface	Degrees Fahrenheit

Attribute	Data Type	Description	Notes
Surface_Type	Text 4	Surface Type of pavement	AC = asphalt concrete CRCP = continuously reinforced concrete pavement JPCP = jointed concrete pavement
Bridge_Flag	Yes/No	Yes = Bridge deck located within summary section No = No bridge deck within the summary section	
Lane_Deviation_Flag	Text 4	True = Segment contains a lane deviation Blank = no deviation contained within the segment	
Construction_Flag	Text 4	True = Segment contains construction Blank = no construction contained within the segment	
LCMS_Faulting_Average	Number 4,2	Average fault height derived from LCMS adjusted to account for undetected joints	Inches
LCMS_Fault_Count	Number 2	Number of faults detected by LCMS	Count
LCMS_Faulting_Standard_Deviation	Number 4,2	Standard deviation of faults measured with LCMS and added zero values	Inches
LCMS_Faulting_Minimum	Number 4,2	Minimum fault height included in average from LCMS including added zero values	Inches
LCMS_Faulting_Maximum	Number 4,2	Maximum fault height included in average from LCMS	Inches
RSP_Faulting_Average	Number 4,2	Average fault height derived from RSP adjusted to account for undetected joints	Inches
RSP_Fault_Count	Number 2	Number of faults detected by RSP	Count
RSP_Faulting_Standard_Deviation	Number 4,2	Standard deviation of faults measured with RSP and added zero values	Inches
RSP_Faulting_Minimum	Number 4,2	Minimum fault height included in average from RSP including added zero values	Inches
RSP_Faulting_Maximum	Number 4,2	Maximum fault height included in average from RSP	Inches
Joint_Count	Number 2	Number of joints detected by LCMS supplemented by manual detection	Count

Table 50 is IRI data for the 0.01-mile segment. These data were collected on all surface types.

Table 50. 0.01mile_IRI.

Attribute	Data Type	Description	Notes
Session_Name	Text 14	Collected file name used by data collection subcontractor	*SSRN*MP*###DL* SS – State RN – Route Number ### - Milepost at beginning of the file D – Direction L – Lane Suffix QC added if QC data
State	Text 2	2 character postal code for State	
Route_Number	Text 3	I for Interstate followed by two-digit route number	
Direction	Text 1	N = North S = South E = East W = West	
Lane	Number 1	1 = Primary Lane 2 = Adjacent Lane	
Begin_Milepost	Number 8,4	Milepost of summary section start	Miles
End_Milepost	Number 8,4	Milepost of summary section end	Miles
Section_Length	Number 8,4	Driven distance in the summary section	Miles
Begin_Latitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Longitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Elevation	Number 5,2	GPS location of summary section start	Height above Ellipsoid in Feet – WGS84
End_Latitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Longitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Elevation	Number 5,2	GPS location of summary section end	High above Ellipsoid in Feet – WGS84
QC_Data	Text 1	Y = repeat quality control collection segment N = not quality control collection segment	
Vehicle_ID	Text 3	ID of collection vehicle	
Driver	Text 3	Initials of driver	
Operator	Text 3	Initials of operator	
Speed	Number 2	Speed of vehicle at summary section start	MPH
Collection_Date	Date	Date of data collection	MM/DD/YYYY
Collection_Time	Time	Time of data collection	HH:MM:SS
Air_Temperature	Number 3	Ambient air temperature	Degrees Fahrenheit
Surface_Temperature	Number 3	Temperature of pavement surface	Degrees Fahrenheit
Surface_Type	Text 4	Surface Type of pavement	AC = asphalt concrete CRCP = continuously reinforced concrete pavement JPCP = jointed concrete pavement

Attribute	Data Type	Description	Notes
Bridge_Flag	Yes/No	Yes = Bridge deck located within summary section No = No bridge deck within the summary section	
Lane_Deviation_Flag	Text 4	True = Segment contains a lane deviation Blank = no deviation contained within the segment	
Construction_Flag	Text 4	True = Segment contains construction Blank = no construction contained within the segment	
IRI	Number 3	Average IRI	in/mile
IRI_Left	Number 3	Left wheelpath IRI	in/mile
IRI_Right	Number 3	Right wheelpath IRI	in/mile

Table 51 is rut depth data collected for 0.01-mile segments with asphalt concrete surfaces.

Table 51. 0.01mile_Rut.

Attribute	Data Type	Description	Notes
Session_Name	Text 14	Collected file name used by data collection subcontractor	*SSRN*MP*###DL* SS – State RN – Route Number ### - Milepost at beginning of the file D – Direction L – Lane Suffix QC added if QC data
State	Text 2	2 character postal code for State	
Route_Number	Text 3	I for Interstate followed by two-digit route number	
Direction	Text 1	N = North S = South E = East W = West	
Lane	Number 1	1 = Primary Lane 2 = Adjacent Lane	
Begin_Milepost	Number 8,4	Milepost of summary section start	Miles
End_Milepost	Number 8,4	Milepost of summary section end	Miles
Section_Length	Number 8,4	Driven distance in the summary section	Miles
Begin_Latitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Longitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Elevation	Number 5,2	GPS location of summary section start	Height above Ellipsoid in Feet – WGS84
End_Latitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Longitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Elevation	Number 5,2	GPS location of summary section end	High above Ellipsoid in Feet – WGS84
QC_Data	Text 1	Y = repeat quality control collection segment N = not quality control collection segment	
Vehicle_ID	Text 3	ID of collection vehicle	
Driver	Text 3	Initials of driver	
Operator	Text 3	Initials of operator	
Speed	Number 2	Speed of vehicle at summary section start	MPH
Collection_Date	Date	Date of data collection	MM/DD/YYYY
Collection_Time	Time	Time of data collection	HH:MM:SS
Air_Temperature	Number 3	Ambient air temperature	Degrees Fahrenheit
Surface_Temperature	Number 3	Temperature of pavement surface	Degrees Fahrenheit
Surface_Type	Text 4	Surface Type of pavement	AC = asphalt concrete CRCP = continuously reinforced concrete pavement JPCP = jointed concrete pavement

Attribute	Data Type	Description	Notes
Bridge_Flag	Yes/No	Yes = Bridge deck located within summary section No = No bridge deck within the summary section	
Lane_Deviation_Flag	Text 4	True = Segment contains a lane deviation Blank = no deviation contained within the segment	
Construction_Flag	Text 4	True = Segment contains construction Blank = no construction contained within the segment	
Rutting_Average	Number 4,2	Average of left and right rut depth values	Inches
Rutting_Left	Number 4,2	Left wheelpath rut depth	Inches
Rutting_Right	Number 4,2	Right wheelpath rut depth	Inches
5pt_Rutting_Average	Number 4,2	Average of left and right rut depths based on 5-pt simulation	Inches
5pt_Rutting_Left	Number 4,2	Left wheelpath rut depth based on 5-pt simulation	Inches
5pt_Rutting_Right	Number 4,2	Right wheelpath rut depth based on 5-pt simulation	Inches

Table 52 is location of features impacting data collection.

Table 52. Event_Table.

Attribute	Data Type	Description	Notes
Session_Name	Text 14	Collected file name used by data collection subcontractor	*SSRN*MP*###DL* SS – State RN – Route Number ### - Milepost at beginning of the file D – Direction L – Lane Suffix QC added if QC data
Route	Text 6	Route description	*SSRNDL* *SS* – State *RN* – Route Number *D* – Direction *L* - Lane
Begin_Milepost	Number 8,4	Measured distance at start of feature	Miles
End_Milepost	Number 8,4	Measured distance at end of feature	Miles
Feature_Type	Text 14	Feature type that exists at referenced location	Bridge Construction Lane Deviation

Table 53 is location of changes in pavement type.

Table 53. Pavement_Change.

Attribute	Data Type	Description	Notes
Session_Name	Text 14	Collected file name used by data collection subcontractor	*SSRN*MP*###DL* SS – State RN – Route Number ### - Milepost at beginning of the file D – Direction L – Lane Suffix QC added if QC data
State	Text 2	2 character postal code for State	
Route_Number	Text 3	I for Interstate followed by two-digit route number	
Direction	Text 1	N = North S = South E = East W = West	
Lane	Number 1	1 = Primary Lane 2 = Adjacent Lane	
QC_Data	Text 1	Y = repeat quality control collection segment N = not quality control collection segment	
Milepost	Number 8,4	Measured distance at pavement change	Miles
Pavement Type	Text 4	Pavement type that begins at referenced location	AC CRCP JPCP

Table 54 is data accumulated to the 0.1-mile segment. Shorter segments are used where a pavement change occurs.

Table 54. Tenth_Mile_Data.

Attribute	Data Type	Description	Notes
Session_Name	Text 14	Collected file name used by data collection subcontractor	*SSRN*MP*###DL* SS – State RN – Route Number ### - Milepost at beginning of the file D – Direction L – Lane Suffix QC added if QC data
State	Text 2	2 character postal code for State	
Route_Number	Text 3	I for Interstate followed by two-digit route number	
Direction	Text 1	N = North S = South E = East W = West	
Lane	Number 1	1 = Primary Lane 2 = Adjacent Lane	
Begin_Milepost	Number 8,4	Mile point of summary section start	Miles
End_Milepost	Number 8,4	Mile point of summary section end	Miles

Attribute	Data Type	Description	Notes
Section_Length	Number 8,4	Driven distance in the summary section	Miles
Begin_Latitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Longitude	Number 12,8	GPS location of summary section start	Decimal Degrees WGS84
Begin_Elevation	Number 5,2	GPS location of summary section start	Height above Ellipsoid in Feet – WGS84
End_Latitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Longitude	Number 12,8	GPS location of summary section end	Decimal Degrees – WGS84
End_Elevation	Number 5,2	GPS location of summary section end	High above Ellipsoid in Feet – WGS84
Vehicle_ID	Text 3	ID of collection vehicle	
Driver	Text 3	Initials of driver	
Operator	Text 3	Initials of operator	
Collection_Date	Date	Date of data collection	MM/DD/YYYY
Surface_Type	Text 4	Surface type of pavement	AC = asphalt concrete CRCP = continuously reinforced concrete pavement JPCP = jointed concrete pavement
IRI with Bridge	Number 4,1	IRI for the segment including data collected on bridge decks	in/mile
IRI No Bridge	Number 4,1	IRI for the segment excluding data collected on bridge decks identified by the data collection crew	in/mile
Avg_Rutting	Number 4,3	Average rut depth for the segment	Inches
Avg_5pt_Rut	Number 4,3	Average rut depth for the segment based on 5-point simulation	Inches
Avg_LCMS_Fault	Number 4,3	Average fault for the segment derived from LCMS	Inches
Avg_RSP_Fault	Number 4,3	Average fault for the segment derived from RSP	Inches
Percent Cracking HPMS PCC	Number 3,1	Percent cracking for the segment CRCP – Area of punchouts and patching divided by area of lane JPCP – Number of cracked slabs divided by total number of slabs	%
Percent Cracking Over	Number 3,1	Area of affected wheelpath plus area of transverse cracking divided by area of lane	%
Percent Cracking Step	Number 3,1	Area of affected wheelpath plus area of transverse cracking not in the wheelpath with addition of transverse cracking in the wheelpath based on percentage of wheelpath cracking (none if more than 80% wheelpath, 25% if between 60 and 80% wheelpath, 50% if between 40 and 60% wheelpath, 75% if between 20 and 40% wheelpath, and 100% if less than 20% wheelpath) divided by area of lane	%
Percent Cracking HPMS AC	Number 3,1	Area of affected wheelpath divided by area of lane	%
Percent Cracking Under	Number 3,1	Area of affected wheelpath plus area of transverse cracking not in the wheelpath	%

Attribute	Data Type	Description	Notes
		divided by area of lane	
Percent Cracking %WP	Number 3,1	Area of affected wheelpath divided by the total area of the wheelpath	%
IRI Perf	Text 1	Pavement condition based solely on IRI including IRI collected on bridge decks	G / F / P
NB IRI Perf	Text 1	Pavement condition based solely on IRI excluding IRI collected on bridge decks	G / F / P
NB IRI with no short segments Perf	Text 1	Pavement condition based solely on IRI excluding IRI collected on bridge decks or for segments shorter than 0.1-mile	G / F / P
IRI Alt Perf	Text 1	Pavement condition based solely on IRI including IRI collected on bridge decks using alternate thresholds	G / F / P
NB IRI Alt Perf	Text 1	Pavement condition based solely on IRI excluding IRI collected on bridge decks using alternate thresholds	G / F / P
Rutting Perf	Text 1	Pavement condition based solely on average rut depth	G / F / P
5pt Rut Perf	Text 1	Pavement condition based solely on average rut depth from 5-point simulation	G / F / P
Faulting Perf	Text 1	Pavement condition based solely on faulting derived from LCMS	G / F / P
RSP Fault Perf	Text 1	Pavement condition based solely on faulting derived from RSP	G / F / P
Alt Faulting Perf	Text 1	Pavement condition based solely on faulting derived from LCMS using alternate threshold values	G / F / P
PCC Crack Perf	Text 1	Pavement condition based solely on percent cracking (CRCP and JPCP only)	G / F / P
Alt PCC Crack Perf	Text 1	Pavement condition based solely on percent cracking (CRCP and JPCP only) using alternate threshold values	G / F / P
Over Cracking Perf	Text 1	Pavement condition based solely on percent cracking over (AC only)	G / F / P
Alt Over Cracking Perf	Text 1	Pavement condition based solely on percent cracking over (AC only) using alternate threshold values	G / F / P
Step Crack Perf	Text 1	Pavement condition based solely on percent cracking step (AC only)	G / F / P
HPMS Perf	Text 1	Pavement condition based solely on HPMS percent cracking (AC only)	G / F / P
Under Perf	Text 1	Pavement condition based solely on percent cracking under (AC only)	G / F / P
%WP Perf	Text 1	Pavement condition based solely on percent wheelpath cracking (AC only)	G / F / P
Performance	Text 1	Pavement performance using IRI Perf, Rutting Perf, Faulting Perf, PCC Crack Perf, and Over Cracking Perf	G / F / P
Alt Performance	Text 1	Pavement performance using IRI Alt Perf, Rutting Perf, Alt Faulting Perf, Alt PCC Crack Perf, and Alt Over Cracking Perf	G / F / P
No Bridge Performance	Text 1	Pavement performance using NB IRI Perf, Rutting Perf, Faulting Perf, PCC Crack Perf, and Over Cracking Perf	G / F / P

Attribute	Data Type	Description	Notes
Alt No Bridge Performance	Text 1	Pavement performance using NB IRI Alt Perf, Rutting Perf, Alt Faulting Perf, Alt PCC Crack Perf, and Alt Over Cracking Perf	G / F / P
Performance no short segments	Text 1	Pavement performance using NB IRI with no short segments Perf, Rutting Perf, Faulting Perf, PCC Crack Perf, and Over Cracking Perf	G / F / P
Performance w RSP Fault	Text 1	Pavement performance using IRI Perf, Rutting Perf, RSP Fault Perf, PCC Crack Perf, and Over Cracking Perf	G / F / P
Performance w 5pt rut	Text 1	Pavement performance using IRI Perf, 5pt Rut Perf, Faulting Perf, PCC Crack Perf, and Over Cracking Perf	G / F / P
Performance with Step	Text 1	Pavement performance using IRI Perf, Rutting Perf, Faulting Perf, PCC Crack Perf, and Step Crack Perf	G / F / P
Performance w HPMS	Text 1	Pavement performance using IRI Perf, Rutting Perf, Faulting Perf, PCC Crack Perf, and HPMS Perf	G / F / P
Performance w Under	Text 1	Pavement performance using IRI Perf, Rutting Perf, Faulting Perf, PCC Crack Perf, and Under Perf	G / F / P
Performance w %WP	Text 1	Pavement performance using IRI Perf, Rutting Perf, Faulting Perf, PCC Crack Perf, and %WP Perf	G / F / P

APPENDIX C. SAMPLE LENGTH PLOTS

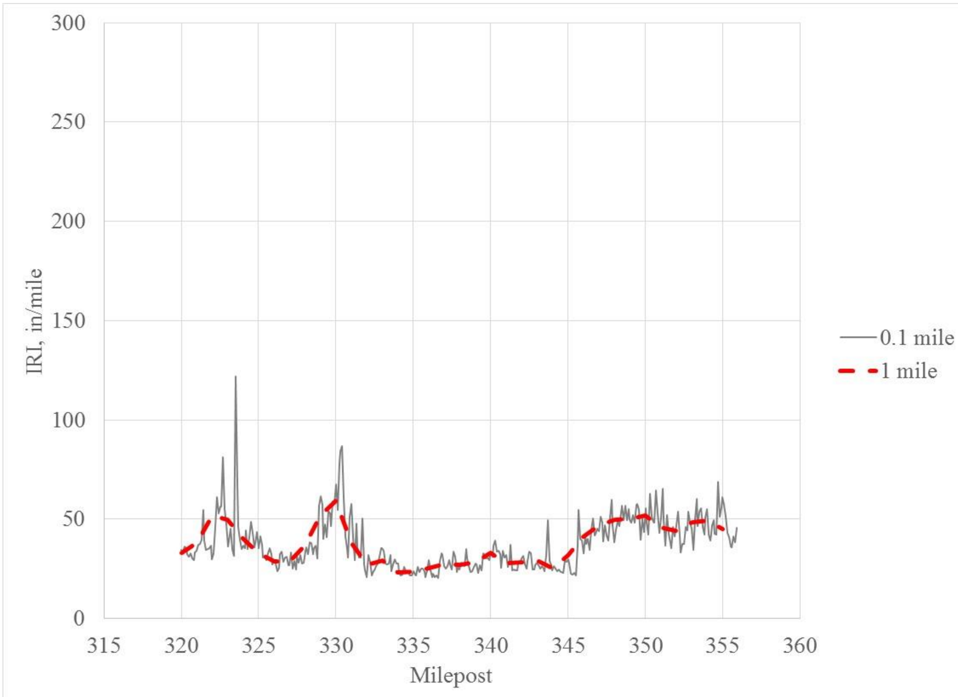

Figure 39. Graph. Comparison of IRI at 1-mile section length to 0.1-mile section length.

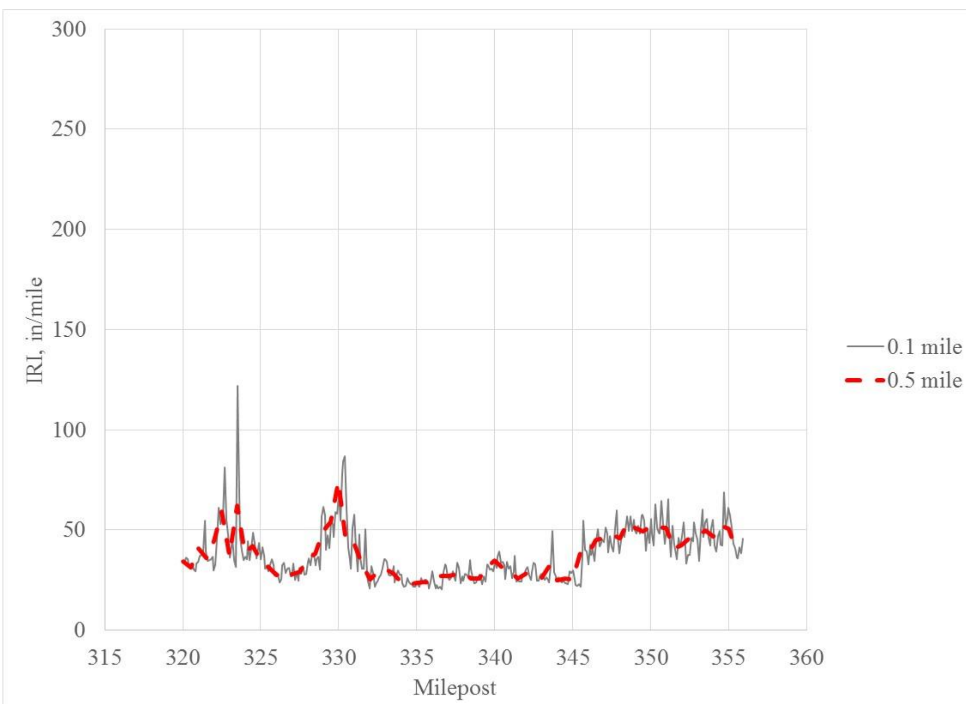

Figure 40. Graph. Comparison of IRI at 0.5-mile section length to 0.1-mile section length.

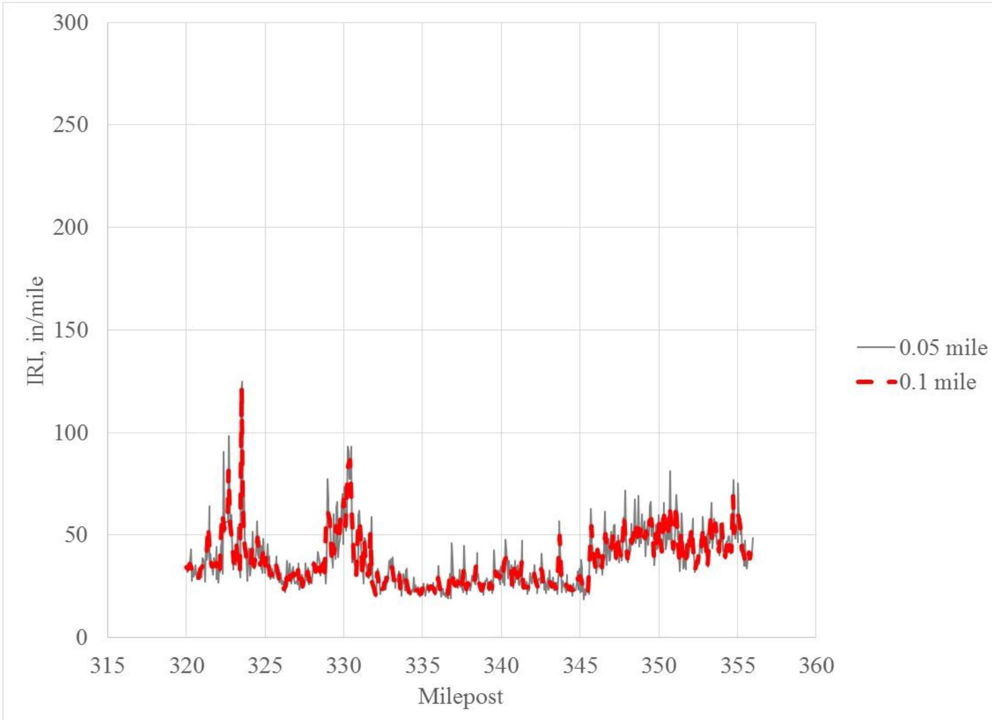

Figure 41. Graph. Comparison of IRI at 0.05-mile section length to 0.1-mile section length.

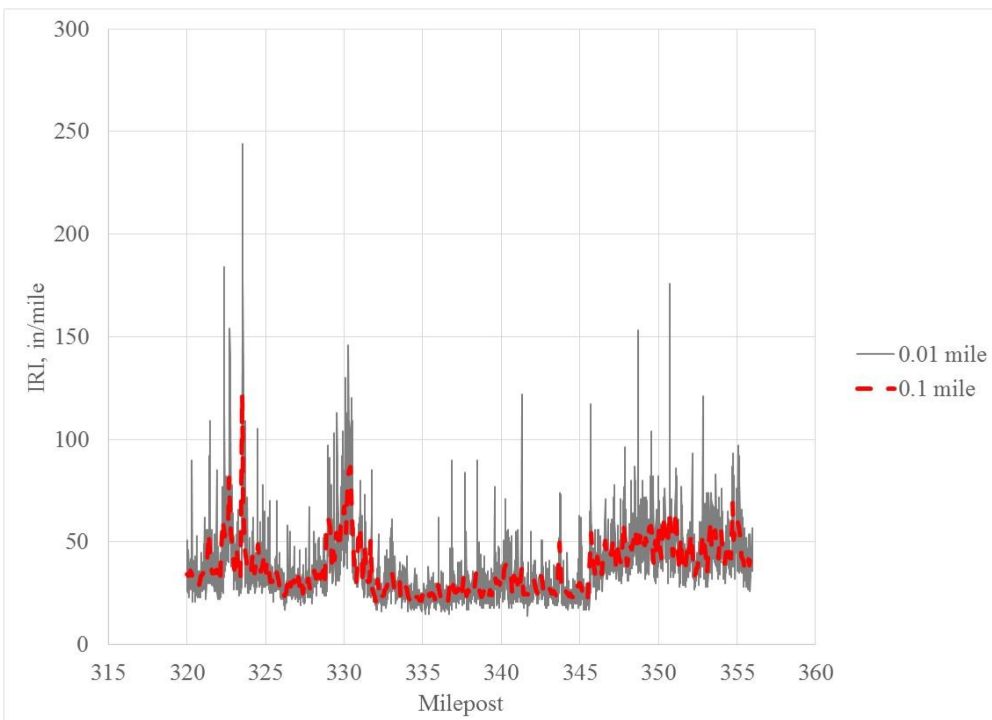

Figure 42. Graph. Comparison of IRI at 0.01-mile section length to 0.1-mile section length.

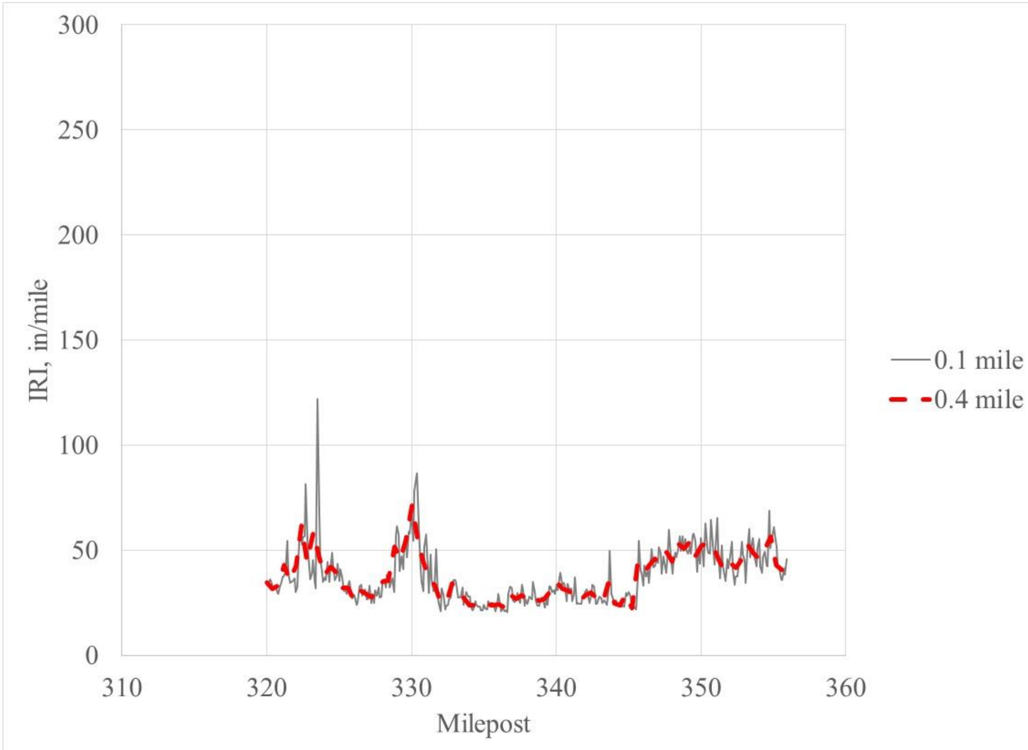

Figure 43. Graph. Comparison of IRI at 0.4-mile section length to 0.1-mile section length.

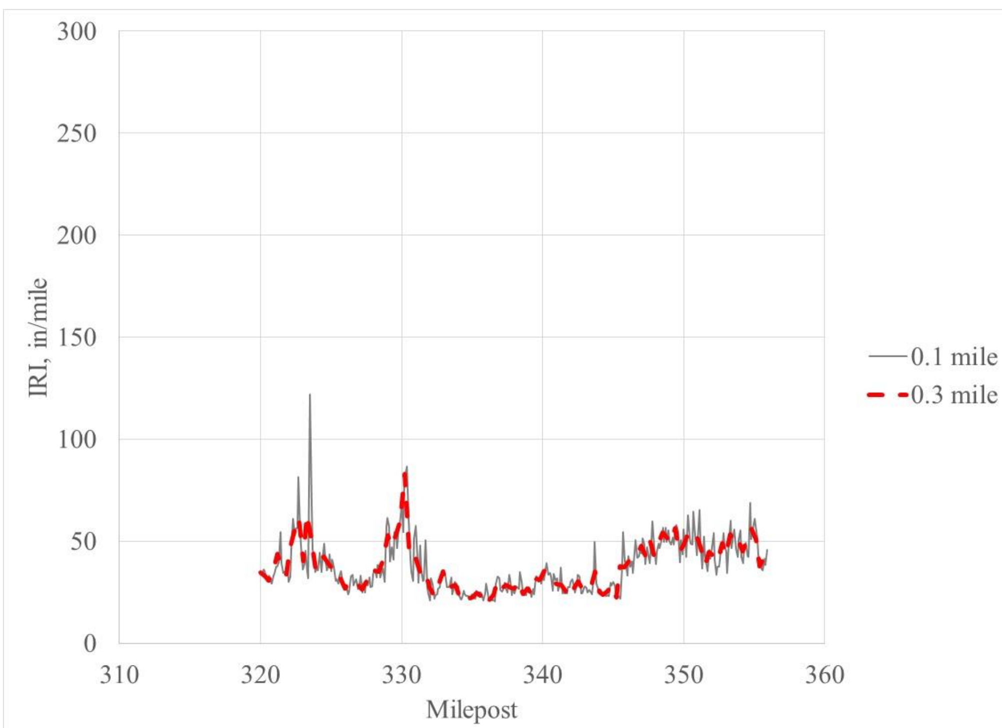

Figure 44. Graph. Comparison of IRI at 0.3-mile section length to 0.1-mile section length.

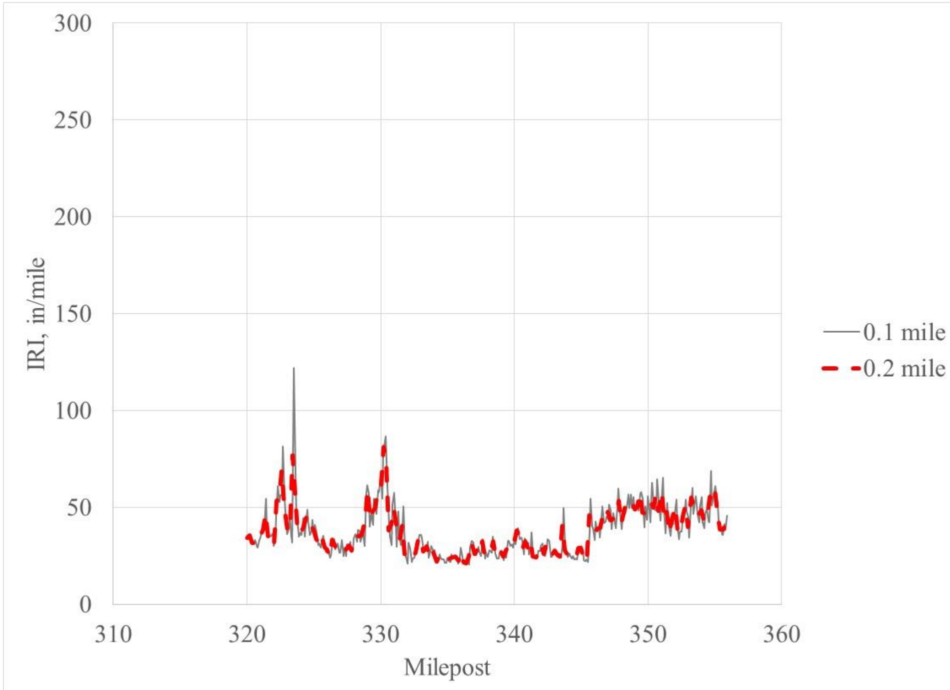

Figure 45. Graph. Comparison of IRI at 0.2-mile section length to 0.1-mile section length.

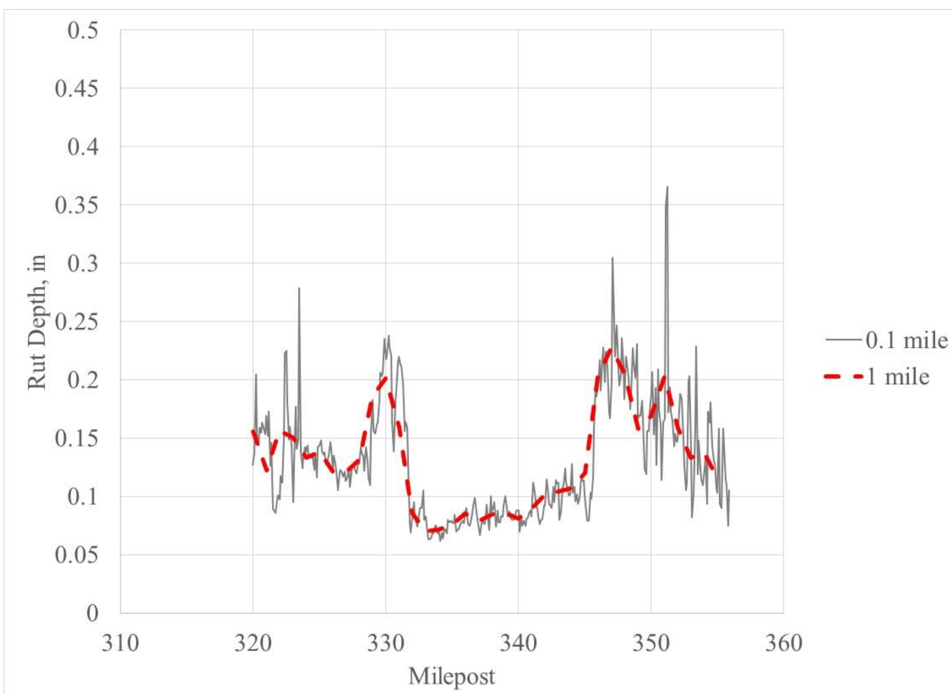

Figure 46. Graph. Comparison of rut depth at 1-mile section length to 0.1-mile section length.

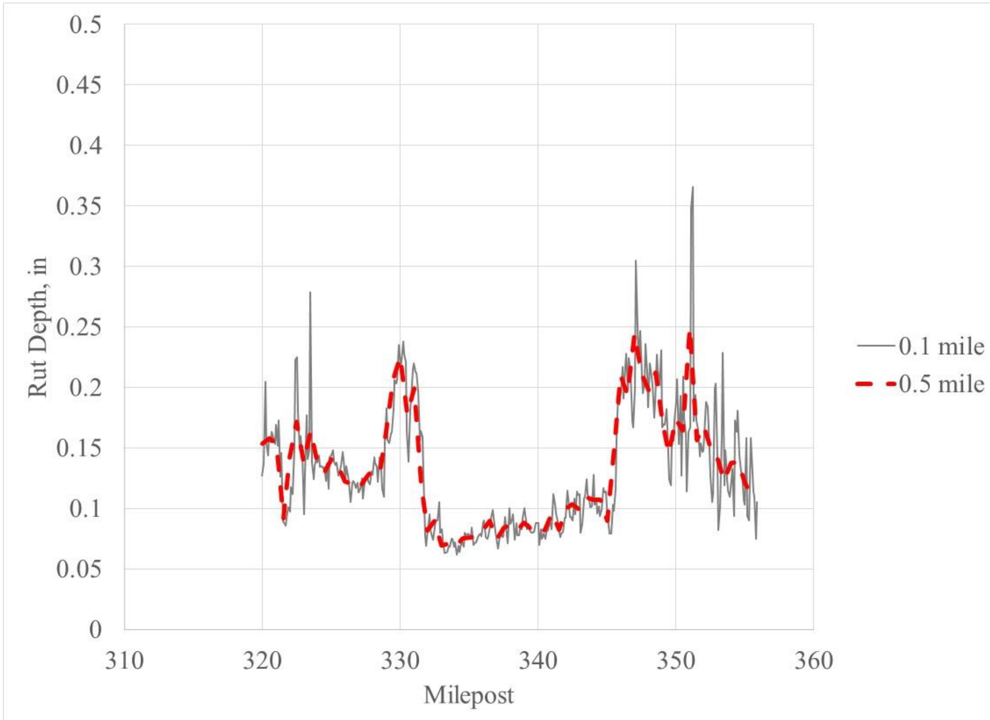

Figure 47. Graph. Comparison of rut depth at 0.5-mile section length to 0.1-mile section length.

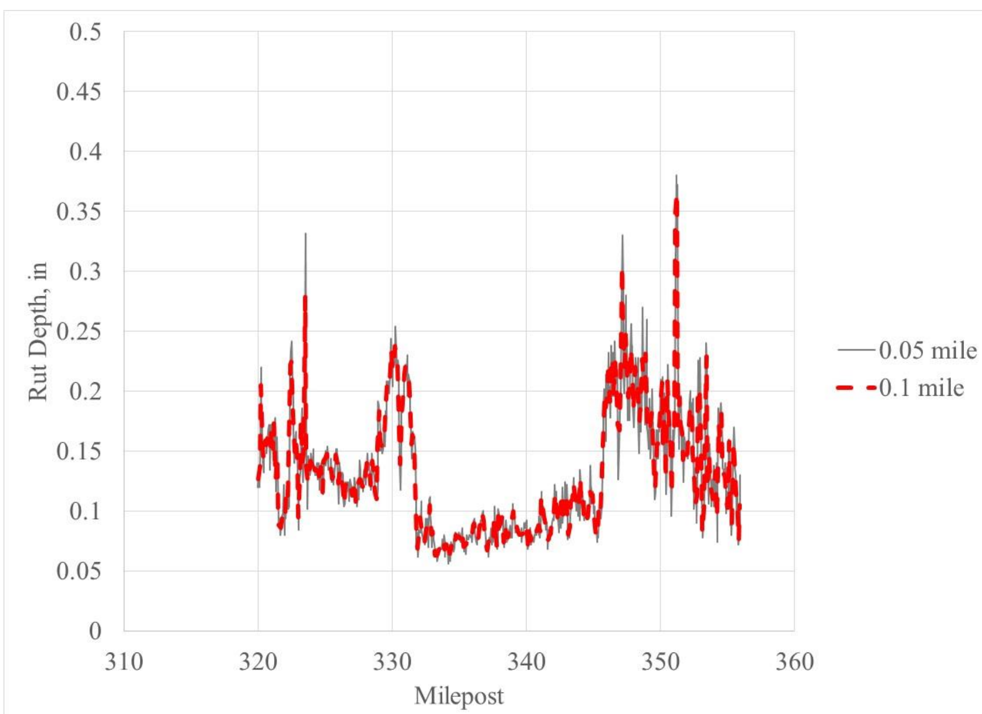

Figure 48. Graph. Comparison of rut depth at 0.05-mile section length to 0.1-mile section length.

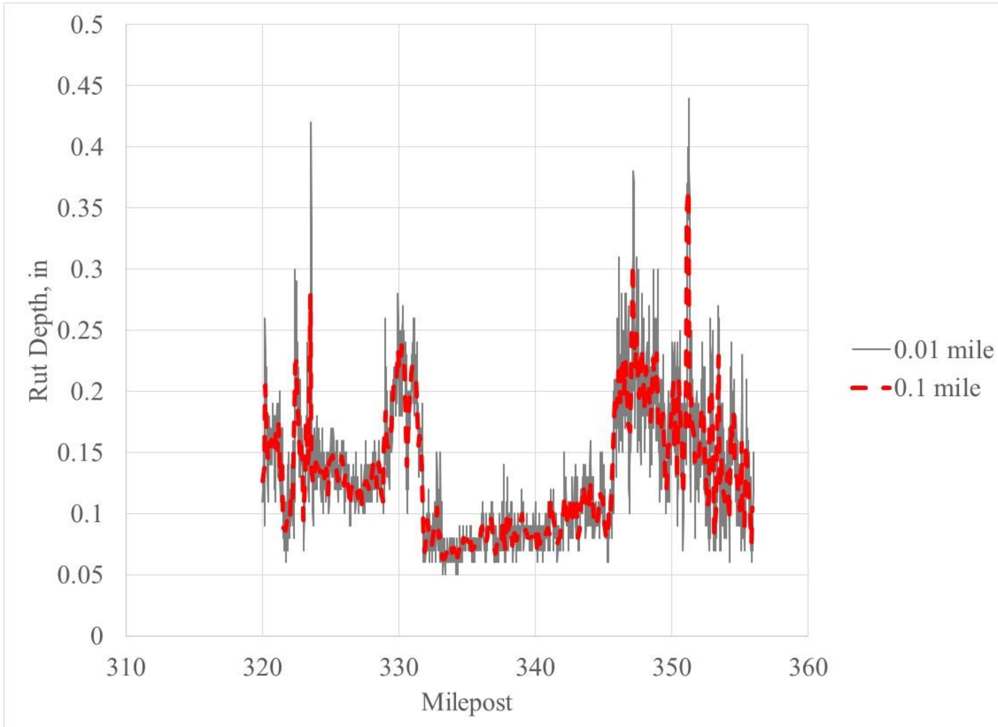

Figure 49. Graph. Comparison of rut depth at 0.01-mile section length to 0.1-mile section length.

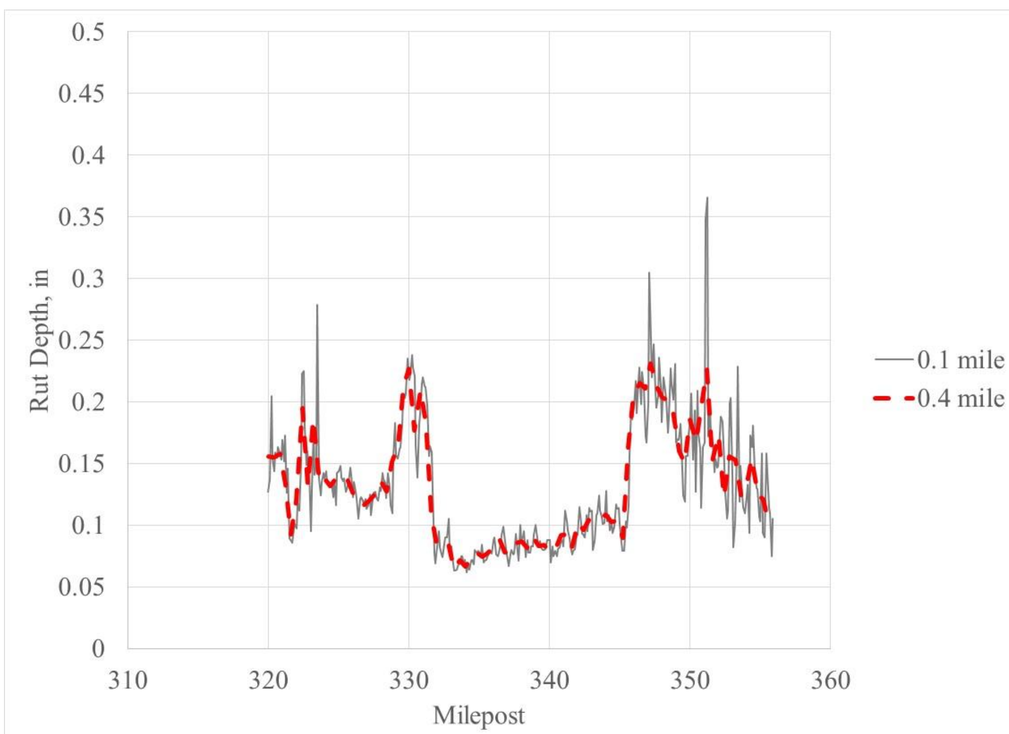

Figure 50. Graph. Comparison of rut depth at 0.4-mile section length to 0.1-mile section length.

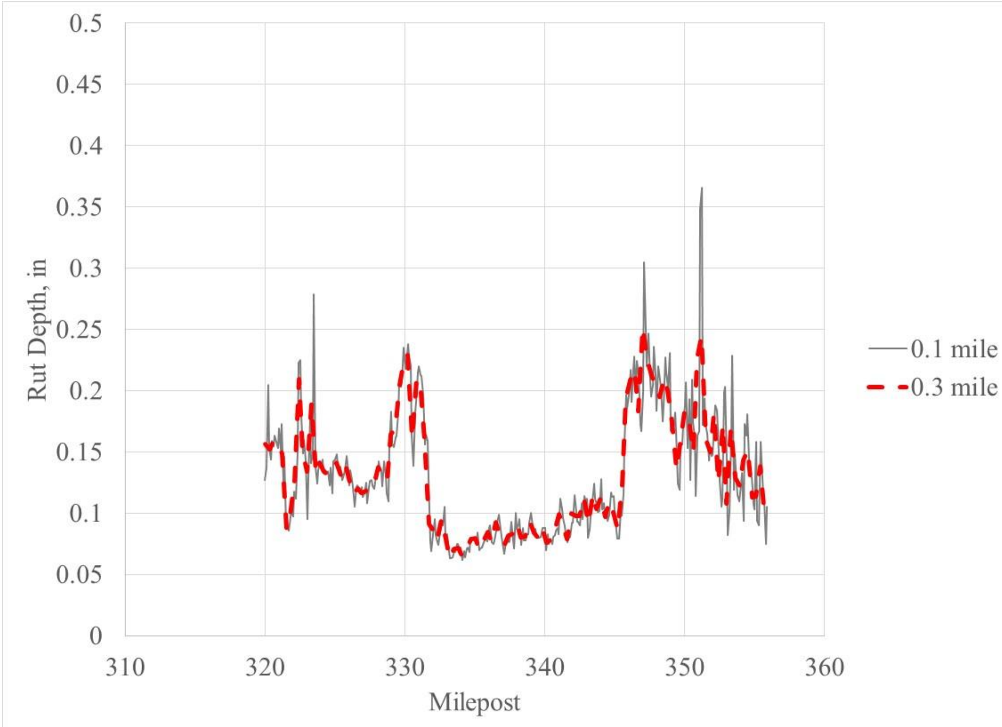

Figure 51. Graph. Comparison of rut depth at 0.3-mile section length to 0.1-mile section length.

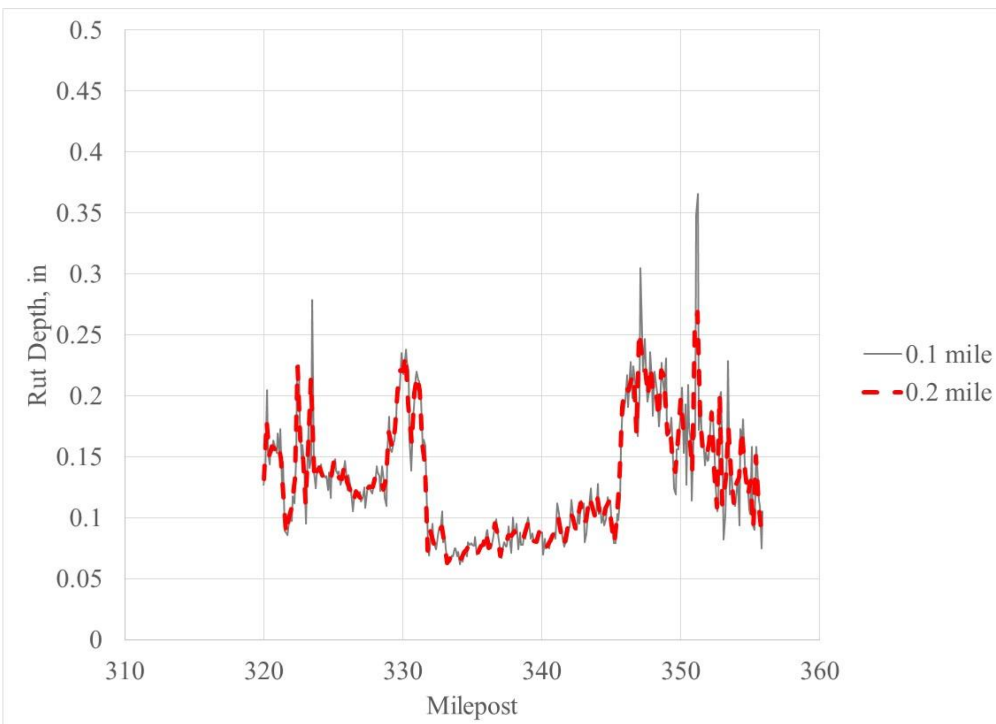

Figure 52. Graph. Comparison of rut depth at 0.2-mile section length to 0.1-mile section length.

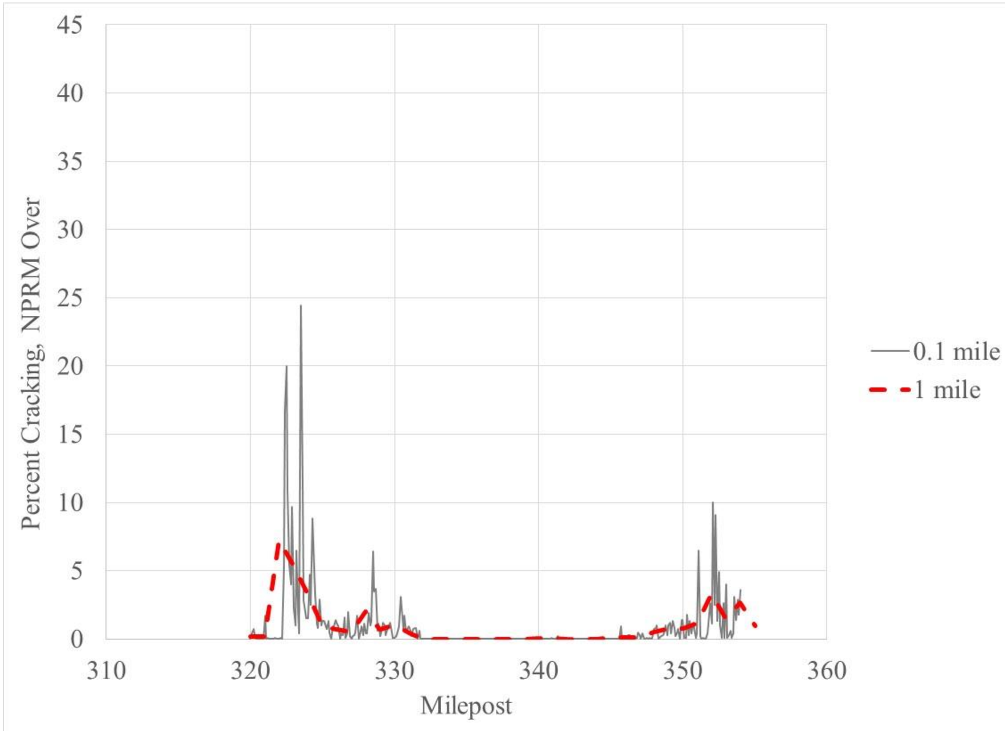

Figure 53. Graph. Comparison of percent cracking at 1-mile section length to 0.1-mile section length.

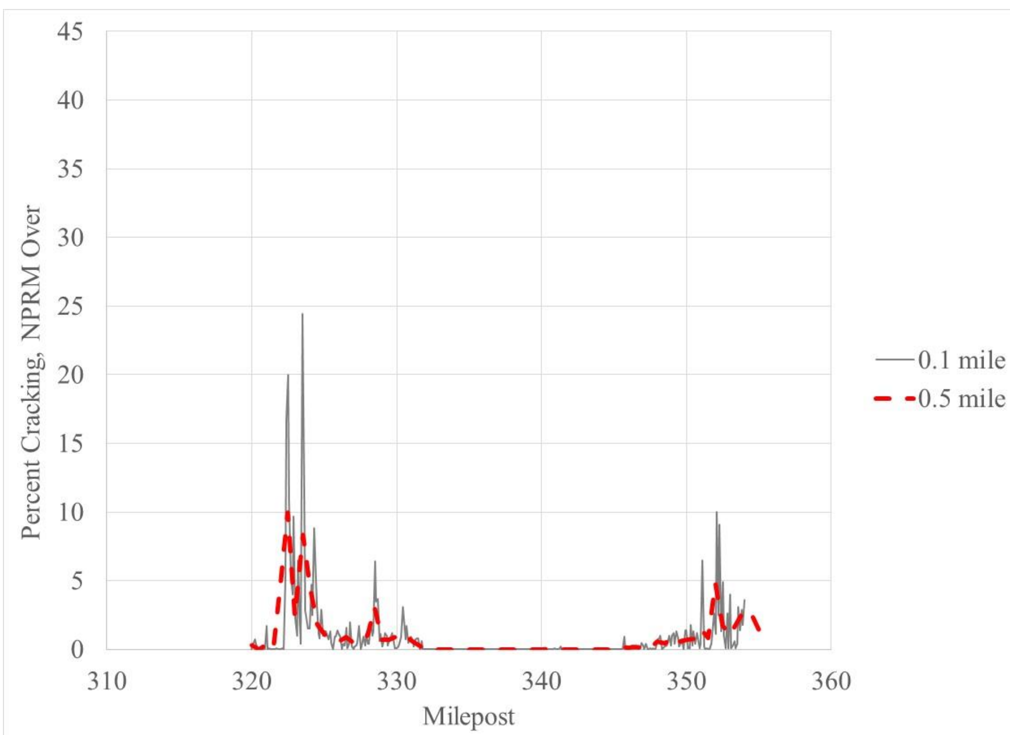

Figure 54. Graph. Comparison of percent cracking at 0.5 mile section length to 0.1-mile section length.

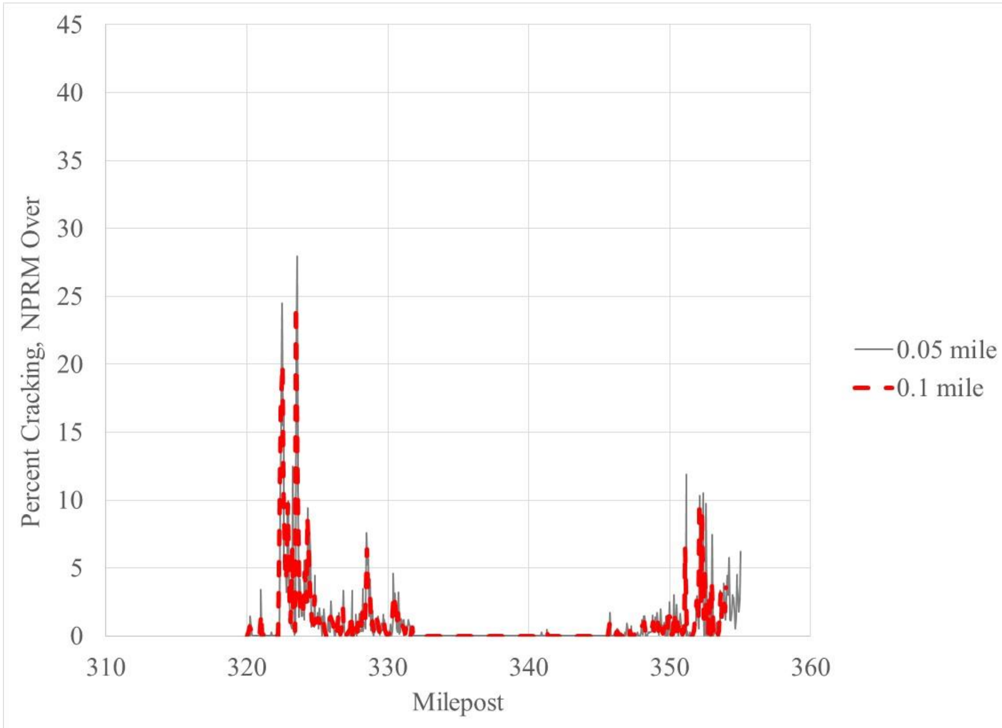

Figure 55. Graph. Comparison of percent cracking at 0.05-mile section length to 0.1-mile section length.

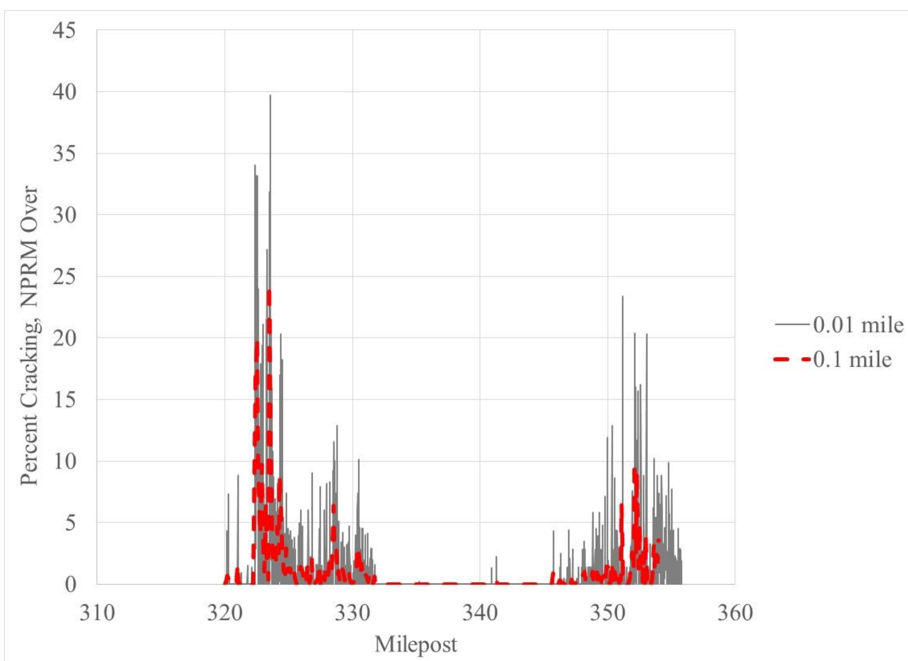

Figure 56. Graph. Comparison of percent cracking at 0.01-mile section length to 0.1-mile section length.

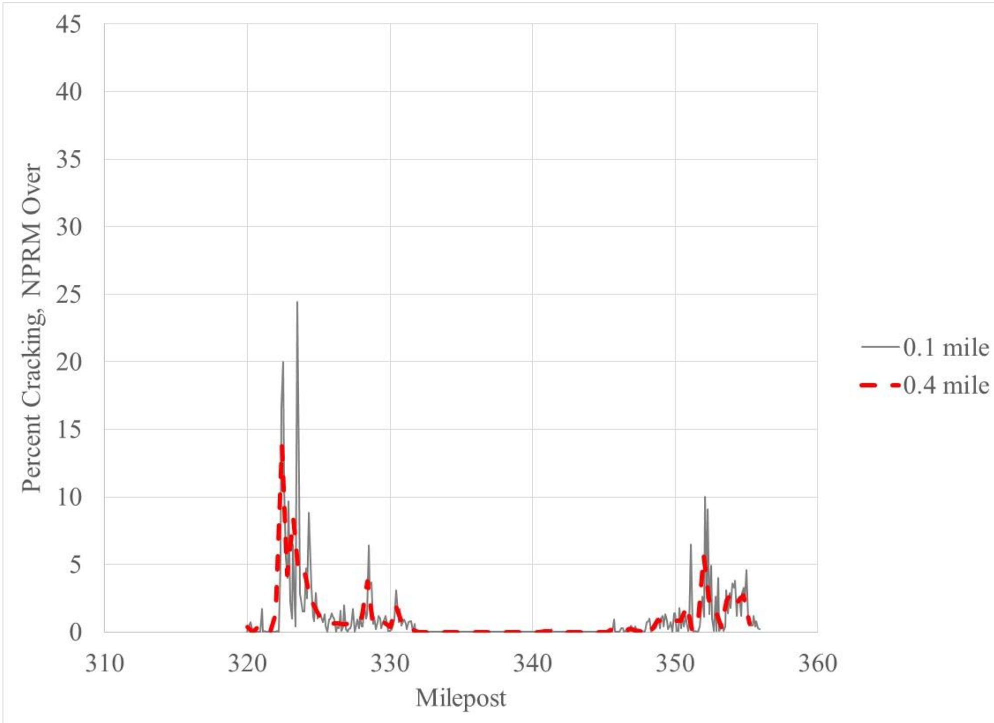

Figure 57. Graph. Comparison of percent cracking at 0.4-mile section length to 0.1-mile section length.

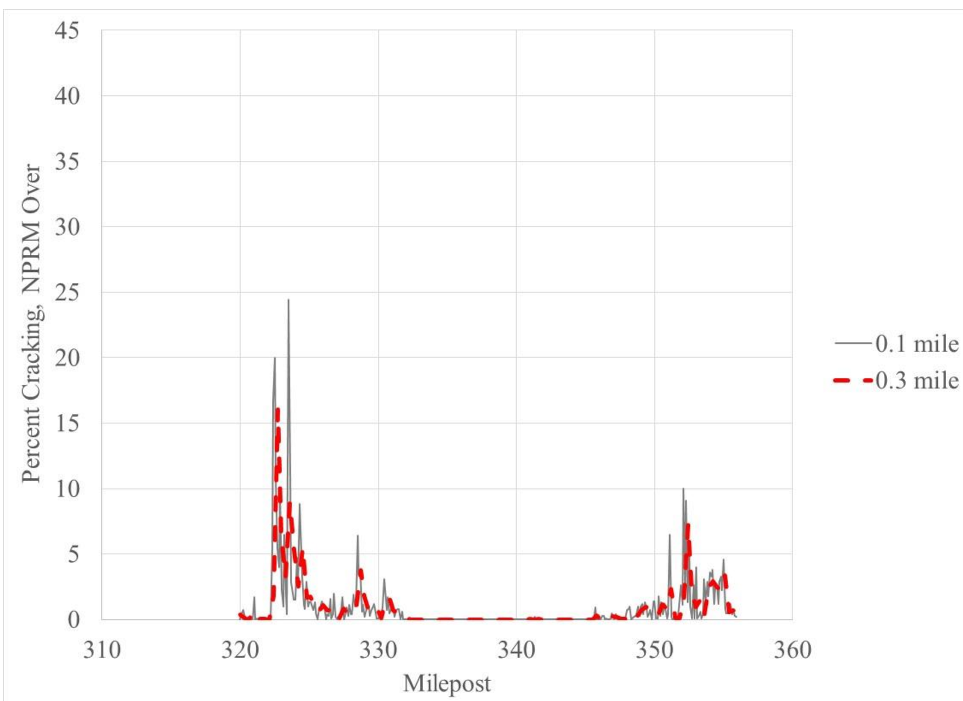

Figure 58. Graph. Comparison of percent cracking at 0.3-mile section length to 0.1-mile section length.

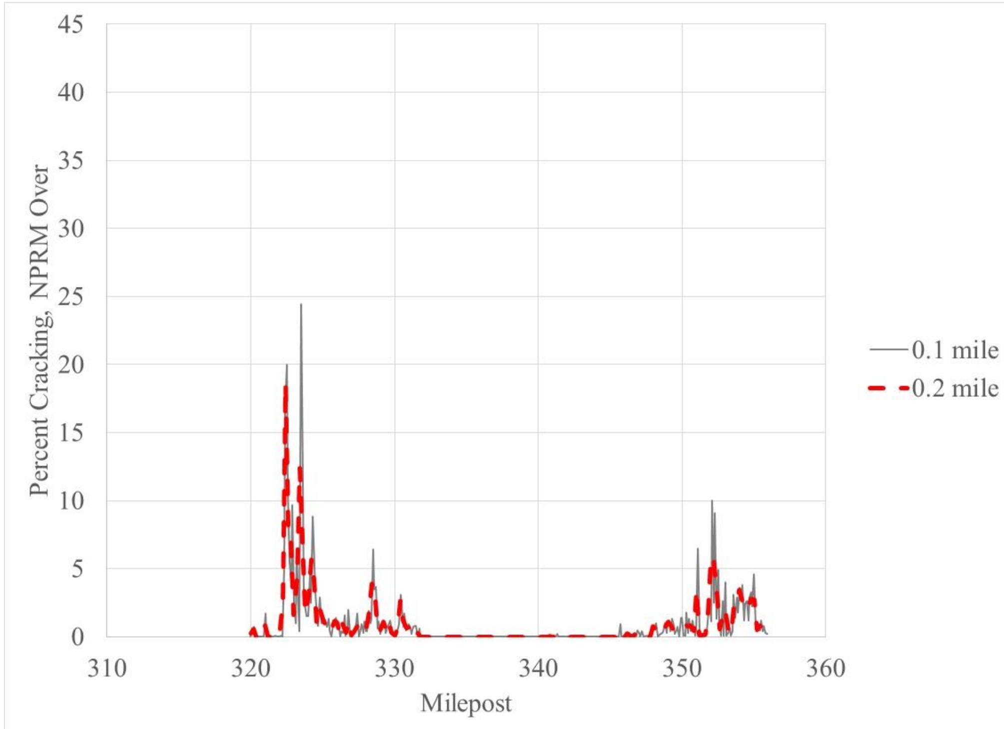

Figure 59. Graph. Comparison of percent cracking at 0.2-mile section length to 0.1-mile section length.