MEASURING PERFORMANCE AMONG STATE DOTS: SHARING GOOD PRACTICES – PAVEMENT STRUCTURAL HEALTH

Prepared for:

American Association of State Highway
and Transportation Officials (AASHTO)

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Table of Contents

List of Tables

List of Figures

Executive Summary

Background

This report presents the results of the latest in a series of “comparative performance” studies undertaken in support of the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Performance Management (SCOPM). Each comparative performance study focuses on a particular area of state Department of Transportation (DOT) performance and explores the possibility of moving towards common yardsticks of performance across states. The intended purpose of standard measures of performance is to enable individual states to put their own performance in the context of that of comparable peer states. The ability to identify states that have achieved a higher level of condition or performance with similar operating conditions and funding levels can lead to important discoveries about successful practices for planning, design, construction, maintenance and operations.

The current study concerns pavement structural health, complementing an earlier comparative study of pavement smoothness (based on the International Roughness Index or IRI). This performance measure study was undertaken because of the recognition that smoothness tells only part of the story about pavement condition. Relying on smoothness alone may not be the best way to understand the overall health of the pavement network – with respect to remaining life, ability to carry anticipated loads, and backlog of rehabilitation needs.

Most state DOTs do, in fact, rely on an array of data on pavement cracking and other distresses in conjunction with IRI to characterize the condition of the pavement network, set performance targets and anticipate future rehabilitation needs. The challenge is that each agency has developed their own procedures and methods for pavement condition measurement and reporting, making comparisons across peer states difficult.

Study Tasks and Key Findings

The study involved the following activities:

- **Literature Review** - A literature review to understand and characterize the state of the practice with respect to pavement condition assessment and reporting;
- **Potential Measure Identification** - Identification of potential network-level measures of pavement structural health that could serve as common yardsticks across states;
- **Measure Selection** - Selection of a set of measures with the greatest promise for near term (1-3 year) implementation;
- **Data Analysis -** Compilation and analysis of sample data from a group of volunteer states;
- **Practice Review** - Interviews with the participating states to identify notable practices for collection, reporting and use of pavement structural health measures; and
- **Implementation Options and Actions** - Identification of future options and required actions to implement common measures of pavement structural health.

Literature Review

The literature review confirmed the diversity of practices and measures in place at state DOTs, and identified several recent closely related efforts to develop a standard structural health measure. Of particular note, a recent study entitled "Improving FHWA's Ability to Assess Highway Infrastructure Health: Development of Next Generation Pavement Performance Measures" (1) presents a detailed assessment of measures for characterizing pavements as "good, fair or poor" based on data from Highway Performance Monitoring System (HPMS), and provides specific recommendations for improving data reliability and consistency. A second recent study: "Increasing Consistency in the Highway Performance Monitoring System for Pavement Reporting" (2) involved a detailed comparison of state pavement management system data against reported Highway Performance Monitoring System (HPMS) data to understand sources of inconsistency.

Potential Measure Identification

Candidate measures for characterizing structural health include those based on observation of pavement distress and damage (cracking, rutting and faulting) and those based on deflection testing. Many past efforts have developed health or condition indexes or remaining life estimates based on distress or deflection measures, but no single measure or index has been widely adopted.

Measure Selection

Measures selected for this study are those which characterize pavement structural health based on:

- Fatigue cracking - percent of cracked slabs for concrete pavements; percent of area for asphalt pavements;
- Average joint faulting (concrete pavements) and
- Average rut depth (asphalt pavements).

These items are currently required for the Federal HPMS, and can be obtained using currently available and widely used methods for automated pavement data collection. Because there is stillwork to be done to ensure standard definition and consistent measurements for these individual distresses, it is premature to move forward with developing a single structural health index that combines these multiple measures. Candidate measures based on deflection data were examined but not considered feasible for implementation across all states in the near term given the current costs of network-level deflection data collection.

Data Analysis

Sample data for the selected measures were compiled from 12 states. States were also asked to provide roughness (IRI) data. Each state provided data for sample Interstate and non-Interstate National Highway System (NHS) corridors. The sample data set from the 12 states consists of data for 23 Interstate corridors representing 349 centerline miles and 25 non-Interstate NHS corridors representing roughly 362 centerline miles. States were requested to provide a mix of asphalt, concrete and composite (concrete overlaid with asphalt) pavement types, but the sample was dominated by data for asphalt and composite pavements.

States were asked to provide data from their pavement management system used to calculate HPMS-required measures, and the resulting measures as provided in the State HPMS data set. This information allowed the research team to understand potential sources of inconsistency in measure calculation across states.

Comparison of data across states was a useful exercise for understanding relationships across different measures. It also showed how measure definition and selection would impact perceived state network structural condition across states. Specific findings of note included the following:

- Different condition measures are sometimes correlated, and sometimes not. For example, the data submitted by one of the participating agencies showed greater deterioration of structural condition than any other peer agency on all of the calculated measures (based on cracking, rutting and IRI). On the other hand, results for another agency showed one of the higher average rut depths but cracking and IRI values that were similar to those of other agencies;
- For at least one agency, fatigue cracking and IRI showed little correlation, but this was likely because of the presence of other types of cracking not classified as fatigue cracking (e.g. transverse cracking outside of the wheelpaths, and longitudinal cracking) and
- Measures calculated based on *average values* of cracking, rutting and faulting measures tell a different story than measures based on the *percentage* of lane-miles by condition category (e.g. good-fair-poor). For example, two of the agencies had nearly identical rut depths for their reported asphalt /composite pavements, but very different percentages of “good” condition pavements based on rutting.

Review of Current Practice

A review was conducted of practices used by state highway agencies for quantifying network-level pavement structural health. Specific practices of interest include how pavement structural condition data are collected, summarized, and used within the context of pavement management, asset management, and broader performance management activities. This review was based on a brief web survey and follow up interviews with three states.

Findings were consistent with the results of the literature review. The follow-up interviews provided three detailed examples of how individual states have established robust pavement data collection and management programs over time that support internal performance management efforts. Findings of note from the review of practices were:

- **Structural health measures in use.** Most agencies are using a surrogate measure for structural health based on pavement distress (e.g., cracking, patching, rutting, faulting), Remaining Service Life (RSL) or both;
- **Lack of consensus on a single comparative national measure.** Agencies have differing opinions about what measures would be both suitable for comparing structural health across states and feasible given current data collection practices. Suggestions from agencies contacted included IRI, cracking, rutting, faulting, percent good-fair-poor, structural number based on deflection data, and RSL;
- **Applications of structural health measures.** Agencies are using structural health information to report overall network condition, set network performance targets, identify appropriate treatments for assignment by Pavement Management System (PMS) decision trees, prioritize locations for funding, and forecast future rehabilitation needs and

- **Limited short-term use of network-level deflection testing.** Three agencies indicated the use of network-level pavement deflection testing. These were generally one time or infrequent efforts, and information was used primarily to support appropriate treatment selection rather than to characterize structural health at the network level. Agencies interviewed felt that while network-level deflection data could be useful, they do not believe that implementation of a high-speed network-level pavement deflection survey is possible within the next five years.

Implementation Options and Actions

Options for moving forward with a comparative measure of pavement structural health were developed with the following principles:

- **Recognize Existing State Pavement Performance Monitoring Processes.** State DOTs generally have established processes for measuring, reporting and utilizing pavement condition and performance data, which are meeting existing agency needs. This affects agencies' ability and willingness to make substantial changes in practices.
- **Clarify Use of National Measures for Structural Health.** Some of the lack of consensus about suitable comparable performance measures is based on the fact that performance measures may be used for multiple purposes. A measure that is suitable for one purpose (e.g. reporting to Congress on the state of the Interstate Highway System) may not be suitable for another purpose (agency selection and prioritization of specific road sections for rehabilitation). It will be difficult to achieve consensus about structural health measures unless there is clarity about how these measures will be used.
- **Build on Existing HPMS Reporting.** Future national reporting of pavement structural health should build on existing data standards and processes for HPMS reporting. This approach will minimize additional burdens on state DOTs. It also supports current efforts to improve HPMS data quality and value added for both state and national use.
- **Allow for Future Evolution.** Given advances in technology for automated pavement condition assessment, performance measures should be established that allow for the underlying basis for measure calculation to change over time. For example, measures based on a condition category (e.g. "good-fair-poor") or need category (e.g. "maintain-renew-reconstruct) can be established to be stable over time even as the basis for determining condition or need category changes.

Short-term options for national structural health reporting would utilize cracking, rutting and faulting data currently reported for HPMS. Specific measures for reporting could include:

- Average values for cracking, rutting and faulting – summarized by pavement type for Interstate and NHS systems (these could also be summarized by 0.1 mile section, pavement management section, and route/corridor);
- Percent of system lane-miles by condition category (e.g. good-fair-poor) defined with respect to cracking, rutting and faulting;
- Percent of system lane-miles by need category (e.g. routine maintenance, corrective maintenance, rehabilitation/reconstruction) defined with respect to cracking, rutting and faulting;

- Percent of system lane-miles by RSL category (e.g. < 2 years, 3-10 years, 11+ years) defined with respect to cracking, rutting and faulting; or
- Percent of system lane-miles by condition, need or RSL category defined based on the combination of values for cracking and rutting for asphalt pavements; cracking and faulting for concrete pavements. One approach for combining different elements is to allow the worst element to drive the category assignment. IRI could also be incorporated into the measure using this approach.

Given the current state of the practice, national implementation of a consistent set of pavement structural health measures cannot be accomplished overnight, and would require commitment of resources. However, an implementation path can be defined to ensure steady progress. Steps in this path – to be undertaken through a collaborative effort by FHWA and AASHTO – would include:

1. **Establish the Measure.** Select one of the above options for reporting. Establish agreement on the details of the calculation methodology – (1) specific measure ranges for condition or need categories, and (2) specific methods for aggregating different distresses into a single measure – e.g. based on lowest value or decision tree approach. If RSL is to be used, agree on standard definition and terminal values that determine end of service life and deterioration curves for different pavement classes.
2. **Produce an Initial Draft Set of Measures**. Calculate the established measures based on current HPMS cracking, rutting and faulting data; and present them with clear caveats about variations in measurement that limit comparability.
3. **Refine Standards and Guidance.** Refine existing HPMS standards and guidance for measurement and reporting of pavement cracking, rutting and faulting. The recent FHWA study on "next generation pavement performance measures" (1) provides several suggested practices for improving consistency; these are summarized in chapter 5 along with additional suggestions based on the data analysis task of the current study.
4. **Identify Gaps.** Develop guidance for states to audit their current practices and identify gaps between current practice and the refined standards. Provide assistance for implementing the pavement data audit – potentially using an approach similar to the recent Roadway Safety Data Assessment program[1]. Ideally this process would result in a nationwide assessment of both the extent and the impact of agency deviations from standards for measuring and calculating cracking, rutting and faulting. The audit process would produce a set of recommendations for changes to data collection, HPMS measure calculation and reporting practices – that could be phased in over time.
5. **Provide Support for Closing the Gaps**. Support and promote voluntary efforts to close the gaps and make data available for comparative analysis. Given likely barriers that will be faced, consider establishing a set of provisional methods to allow for incremental improvements to consistency as states move towards full adoption of the standards.
6. **Make the Data Available**. Make data available to participating states in an easily accessible form for analysis and comparison (along with metadata describing differences in data derivations). This would provide visibility needed to encourage progress towards greater consistency. To be meaningful, the comparative data should be available for

[1] See: http://safety.fhwa.dot.gov/rsdp/

state peer groups (e.g. by region), with the ability to view results by functional class, rural/urban designation, pavement type and traffic level.

1.0 Introduction

1.1 Background

Over the past several years, the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Performance Management (SCOPM) has sponsored a series of comparative performance measurement studies. These studies have involved voluntary efforts among states to identify common performance measures that could potentially be used for cross-state comparisons and benchmarking. Each study has involved measure definition, collection of data from either states or available national sources, computation of measures, and interviews with states to identify practices related to better performance results.

A comparative performance study of pavement smoothness was completed in 2008 (3). Pavement smoothness based on the International Roughness Index (IRI) was selected as an initial pavement condition measure because it was both available from all states and relatively consistent. All states must report IRI to the Federal Highway Administration (FHWA) as part of their Highway Performance Monitoring System (HPMS) submittals, and considerable effort has been made in recent years to establish clear standards and protocols to improve IRI measurement and reporting consistency. However, IRI is primarily useful for assessing ride quality (functional condition); it is not generally used as a measure of pavement structural condition. Most state Departments of Transportation (DOTs) use IRI as only one of several indicators to monitor pavement condition, identify suitable treatments, allocate resources, and prioritize projects. Other common condition indicators in use are based on measurement of the extent and severity of cracking, rutting, and other distresses. In addition, several states (with support from the FHWA Office of Asset Management), have undertaken initiatives to measure network-level deflection.

1.2 Research Objectives

The objective of this research was to identify and assemble common indicators of pavement structural health from a group of state DOTs, and document notable practices in using structural health indicators as a tool for achieving improved performance. Obtaining comparative measures of pavement structural condition across states presents significant challenges. While there are substantial commonalities with respect to the types of pavement distresses recorded, there are many variations in specific distress definitions, measurement methods, and approaches for summarizing distress information for use in performance monitoring and decision making.

Because structural health measurement is not as standardized as pavement smoothness measurement, the current study places greater emphasis than the prior pavement smoothness comparative study on the assessment of candidate measures and work needed to standardize structural health measurement practices. Given the diversity of approaches to pavement condition measurement and assessment in place today, it is not realistic to expect that the states will move to a new, common approach in the near future. However, there are opportunities to establish some building blocks that can provide common ground across states for comparison and national roll-ups. Over time, such building blocks may make their way into standard practice as states continue to refine their approaches and implement new technologies for data capture and reduction.

1.3 Document Overview

This is the Final Report for National Cooperative Highway Research Program (NCHRP) Project 20-24(37)J: Measuring Performance Among State DOTs : Sharing Good Practices – Pavement Structural Health. It describes the study methodology and summarizes the findings and conclusions.

Section 2 of this report describes the process used to identify structural health measures to focus on for this study. Section 3 discusses the process used to gather and analyze sample performance data from a group of volunteer states, and presents a summary of the computed measures. Section 4 presents findings from interviews with states conducted to identify practices for assessing pavement structural health at a network level. Section 5 presents future options for pavement structural health reporting and identifies next steps for moving towards consistent and meaningful measurement and reporting of structural health in support of peer comparisons and benchmarking.

2.0 Identification of Structural Health Measures

2.1 Definition of Pavement Structural Health

In order to identify measures of "pavement structural health," the following working definition of pavement structural health was adopted:

> *"Pavement Structural Health refers to a pavement's ability to carry anticipated traffic loadings without requiring substantial remedial action."*

Structural *health* may be distinguished from structural *condition* by combining multiple condition factors, just as a person's overall health might be based on different aspects of their physical condition and their impacts on quality of life. *Structural* condition can be distinguished from *functional* condition, which characterizes the level of service provided to travelers and is based on characteristics such as smoothness, friction and noise. A candidate structural health measure could be based on strength measures obtained from destructive or nondestructive testing, or based on surrogate condition measures such as cracking, rutting and faulting. The measure could combine multiple individual measures of condition to provide an overall characterization of the pavement from a structural standpoint. For example, a bridge health index has been formulated to combine information about the condition of multiple bridge elements, with weightings across the different elements based on failure costs. From a pavement structure perspective, examples of overall health indicators include composite condition indexes incorporating information about multiple distresses, or Remaining Service Life (RSL) measures based on the estimated number of years before a pavement reaches the point at which rehabilitation is warranted.

2.2 Literature Review

The research team undertook a literature search to identify the current state of the practice in pavement structural health assessment, and evaluate candidate measures for characterizing structural health at the network level. The review emphasized network-level (as opposed to project-level) pavement condition assessment and performance measurement approaches. In general, the literature review found that while individual states have successfully developed and used pavement condition measures reflecting both functional and structural conditions, currently there is no *single*, *widely-accepted* measure of pavement structural health suitable for application at the network level.

More specific findings of the literature review were as follows:

- **Pavement smoothness or ride quality is not a good proxy for pavement structural health.** Several references stressed the importance of distinguishing structural condition (i.e. ability of the pavement to carry loads) from ride quality. While one would expect that pavements with poor ride quality would also tend to have a lot of distress indicating poor structural condition, it is possible to have a rough pavement in good structural condition, and a relatively smooth pavement in poor structural condition. Three references (4, 5 and 6) presented analysis results that found little or no correlation between ride quality and structural condition based on deflection measurements.

- **Structural health can be assessed based on measured deflection or observed distress.** Indicators of structural health fall into two categories – those based primarily on measured deflection and those based on observed distresses (including cracking, rutting and faulting). Measures based on observed distresses include those that combine multiple distresses into a single index, and those that represent individual distresses or damage types. Distress-based indices are typically calculated based on assignment of deduct values based on distress type, severity and/or extent. RSL can be computed based on either distress-based indices or deflection.
- **States use a variety of pavement condition indexes.** Many states utilize a pavement condition index to characterize the structural condition or overall serviceability of their pavements. These indices are used within DOT business processes for performance monitoring, needs identification, and prioritization. However, there are many different condition indices in use, based on varying sets of distresses, weighting factors and calculation methods (7, 8, 9, 10, 11).
- **Rutting is a promising structural health indicator for asphalt pavements.** Average rut depth was a recommended future national measure of pavement condition in the AASHTO SCOPM Task Force report (12), and was included in the FHWA pilot study on pavement health (5), and NCHRP 677 - Development of Levels of Service for the Interstate Highway System (13). Almost all states measure rutting as part of the same data collection process used to measure IRI. Rut depth is one of the required HPMS items for asphalt pavements, and the FHWA pilot study found reasonable correlation between HPMS-reported and field-collected rut depth measurements (though the HPMS-reported rut depths were systematically higher). NCHRP Synthesis 344 (7) indicated that there was a lack of standardization in rut depth measurement practices, though this is based on information from 2003, and may not reflect current practice.
- **Faulting is a desired measure of structural health for concrete pavements, but requires further development.** The AASHTO SCOPM Task Force report (12) identified faulting on Jointed Plain Concrete Pavements (JPCP) as an appropriate counterpart to use of rutting on asphalt pavements as an indicator of structural health. Faulting is a required HPMS data element for JPCP pavements. However, the FHWA pilot study found that methods used by each state for calculating the HPMS-required item varied and there was little correlation between the faulting data reported to HPMS and the data collected in the field. The AASHTO SCOPM Task Force report (12) recommended that a study be undertaken to determine the sensor type and the spacing of data collection intervals necessary to allow repeatable consistent measurement of faulting.
- **Pavement condition measurement practices are not consistent across states.** Methods vary widely across states for measuring, recording and summarizing cracking, rutting and faulting. While HPMS requires reporting of several distress-based indicators, recent studies have found that these reported measures are not yet sufficiently reliable or consistent to provide a basis for comparison. Factors contributing to this lack of reliability and consistency include varying cracking definitions, measurement practices, data aggregation methods, and data conversion methods (2, 5, 7, 8, 9, 10).
- **Use of network-level static deflection data is feasible but not yet widely applied**. Deflection data provide a more direct indicator of structural strength than those based

on observed distress, but are more costly to collect, involve lane closures and are therefore not widely used at the network level. The most commonly used device for deflection measurement is the Falling Weight Deflectometer (FWD). This device is used to produce a response in the pavement similar to what would result from actual traffic loadings. A handful of states have collected network-level FWD data and incorporated deflection measures into their pavement management processes. Because FWD data collection is costly, these were generally one-time efforts spanning 3-to-5 years or were more limited tests for a portion of the network. Programs used to back-calculate layer moduli from FWD results rely on estimates of the layer thicknesses. Because most states do not maintain complete and reliable data on layer thicknesses, researchers have explored use of Ground Penetrating Radar (GPR) to provide equivalent information. Several research efforts (4, 14, 15, 16, 17) have evaluated use of network-level FWD testing or developed simplified approaches to developing structural condition indicators from FWD data suitable for network-level use, but none of these methods have been validated for application across multiple states.

- **New data collection technologies show promise for improving structural health monitoring.** Several organizations have developed devices that can continuously measure deflections. An Austroads Study (18) evaluated use of the Danish Traffic Speed Deflectometer (TSD). FHWA tested the Rolling Wheel Deflectometer (RWD) in 14 states, with overall successful results and good correlation with FWD tests at the same locations. The Strategic Highway Research Program 2 (SHRP2) R06(F) project evaluated use of Traffic Speed Continuous Deflection Devices (including the RWD) with the conclusion that the technology had the potential to provide the level of accuracy and repeatability necessary for network-level analysis (19). Some concerns were identified related to measurement of lower deflection values at highway speeds. There is also the general issue that the RWD technology is not yet commercially available or widely accepted. Beyond RWD, technologies such as three dimensional laser scanning, and, further in the future, self-sensing concrete offer potential to obtain better pavement structural health data at a lower cost.

2.3 Candidate Measures of Structural Health

Based on the literature review, several candidate measures were identified that could be used individually or in combination for characterizing the structural health of a pavement. Measures were classified into three groups: those that are based on individual distresses, those that are based on combinations of distresses, and those that are based on measured deflection information.

The evaluation of candidate measures is summarized in Table 1. Where the measure was identified based on the literature review, references are provided.

Table 1. Candidate Measures of Pavement Structural Health

Measure (References)	Pavement Type(s)	Advantages	Disadvantages
1. Measures based on individual distresses			
a. Percent of pavement area with fatigue cracking (10, 12, 13, 20)	Asphalt	HPMS-required measure Data are generally available	Additional work required to achieve consistency Difficult to communicate - translation into good-fair-poor or percent deficient would facilitate understanding
b. Percentage of slabs that are cracked (10, 12, 13, 20)	Concrete	HPMS-required measure Data are generally available	Additional work required to achieve consistency Difficult to communicate - translation into good-fair-poor or percent deficient would facilitate understanding
c. Average rut depth (10, 13, 20)	Asphalt	HPMS-required measure Data are generally available and collected in conjunction with IRI data	Measure primarily applicable to asphalt pavements Difficult to communicate - translation into good-fair-poor or percent deficient would facilitate understanding
d. Average joint faulting value (10, 12, 13, 20)	Concrete	HPMS required measure	Technically not considered to be a measure of structural capacity, but indicates lack of load transfer Data not consistently collected Measure only suitable for rigid pavements Difficult to communicate - translation into good-fair-poor or percent deficient would facilitate understanding
2. Measures based on combinations of distresses			
a. Pavement Condition Index (5, 10)	Both	Established ASTM International standard	Data intensive; would require significant additional data collection effort for many states
b. Structural Condition Index (SCI) based on rutting and fatigue cracking for asphalt pavements; faulting and cracking for concrete pavements (note: this measure is based on individual state practices; multiple variations exist)	Both	Based on available required HPMS data Single number – simple to understand	Index calculations vary across states Additional work required to achieve data consistency in underlying data
c. Remaining Service Life (5, 10, 21)	Both	Incorporates both current condition and rate of future deterioration Straightforward to use for programming decisions Applicable to multiple asset classes	Requires reliable performance models More difficult to get consistency across agencies than a more directly measured indicator Differences of opinion exist as to ease of communication

Measure (References)	Pavement Type(s)	Advantages	Disadvantages
3. Measures based on deflection data			
a. Effective Structural Number (SN) (17, 19)	Asphalt	Calculation methodology and software tools exist for project-level analysis	Typically requires pavement layer thickness as input Network-level deflection data not widely available Not meaningful for characterizing condition at network level
b. Effective concrete slab thickness	Concrete	Calculation methodology and software tools exist for project-level analysis	Network level deflection data not widely available Not meaningful for characterizing condition at network level
c. Good-fair-poor based on measured deflections, pavement type and traffic category	Both	Simple method suitable for network-level analysis	Network level deflection data not widely available Methodology development would be required
d. Structural Strength Index (SSI) (4)	Both	Methodology developed for Indiana intended for network-level analysis Produces bounded index from 0-100 Applicable to both concrete and asphalt Does not require layer thickness information	Network level deflection data not widely available Transferability has not been established
e. Structural Condition Index (SCI) (17) (Note: this is a different index from 2b – based on deflection)	Asphalt	Methodology for Texas has been validated, calculation software produced	Network level deflection data not widely available Transferability has not been established; only applicable for asphalt pavements
f. Premature failure probability based on FWD (16)	Both	Methodology based on Long Term Pavement Performance (LTPP) data analysis has been published by FHWA	Network-level deflection data not widely available Transferability has not been established; local calibration is recommended

2.4 Measure Selection

Based on the results of the literature review and the assessment of candidate measures, the four measures in Group 1 of Table 1 were selected as the focus for the remaining tasks:

- Percent of cracked slabs (concrete pavements)
- Average joint faulting (concrete pavements)
- Percent of pavement area with fatigue cracking (asphalt pavements)
- Average rut depth (asphalt pavements)

These measures were selected for several reasons. First, they are required by HPMS and are consistent with the approach recommended by the AASHTO SCOPM for future development (12). These measures are also consistent with those recommended in the recent FHWA study on next generation pavement performance measures (1). In addition, because further work is required to ensure standard definition and consistent measurements for these individual distresses, it is premature to move forward with a composite SCI measure based on these distresses. Other measures in group 2 were ruled out for short term consideration because of data requirements (PCI) or modeling requirements (RSL). While the RSL has some attractive features, it currently lacks a widely accepted standard methodology for its calculation – and requires integration of information on current condition with projected deterioration. While a few states have embraced the RSL concept, each has different ways of calculating RSL, and there are differing opinions as to whether RSL is meaningful to a general audience. More widespread adoption of a standardized RSL approach utilizing a tool such as FHWA's Pavement Health Track software (21) could increase the feasibility of an RSL approach in the future.

The candidate measures in group 3 based on deflection data – while promising – were not considered feasible for implementation across all states in the near term. The cost of FWD data collection and the lack of widely accepted options for dynamic data collection are currently significant barriers to pursuing national performance measures based on deflection data.

3.0 Comparative Performance Data Analysis

3.1 Involvement of Volunteer Agencies

The research team enlisted participation of volunteer states to provide data for the target set of measures. The purpose of this data collection was to gain a better understanding of data derivation methods and variability across states.

States were identified with input from the project panel. Criteria included:

- Diversity with respect to geographic location and network size;
- Ability to provide data for both asphalt and concrete pavements;
- Use of automated or semi-automated pavement data collection methods and
- Ability to provide data within a relatively short timeframe

The team distributed an informational flyer to states providing basic information about the context and objectives of the research and requirements for participation. Twelve agencies (shown in Figure 1) agreed to participate.

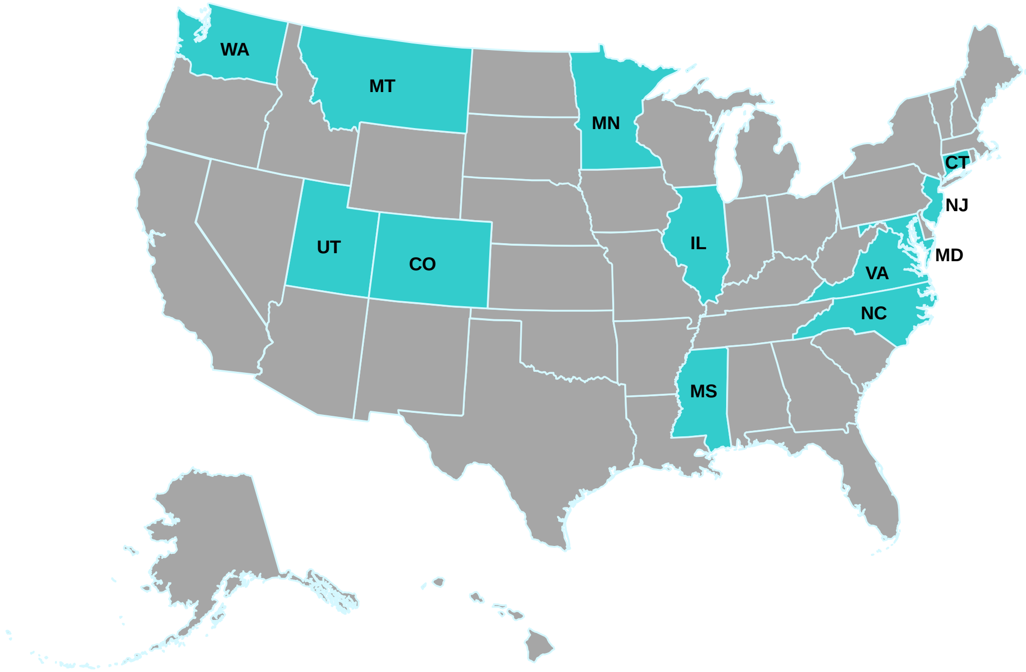

Figure 1. Participating Agencies

3.2 Data Specifications

Data specifications were developed to maximize the consistency in information provided by each participating state. Agencies were requested to provide cracking, faulting, rutting and IRI data for two Interstate and two non-Interstate NHS corridors, at least 10 miles in length, with representation of asphalt, composite and concrete pavement types. Data were to be reported in 0.1-mile segments. Agencies were also asked to provide the HPMS-defined cracking measures, the source data, and assumptions used to calculate these measures from their pavement management databases. The detailed data specifications are provided in Appendix A.

3.3 Data Compilation

The research team received spreadsheets with data from each of the 12 agencies. Several follow-up contacts were also required to obtain information sufficient to reproduce the calculation of the cracking measures based on the raw data. This information was eventually provided by all but one agency. The research team checked the raw data to ensure that it was complete, properly formatted and that all values fell within expected ranges.

Following the review of each data submittal, and coordination with the agency contact person as needed, the data sets were loaded into a single spreadsheet. Even though a specific data template was provided for the data request, there were many variations in the format of data submittals.

Characteristics of the sample data set compiled from the 12 states are shown in Figure 2.

Data were provided for 23 Interstate corridors representing 349 centerline miles[2] and 25 non-Interstate NHS corridors representing roughly 362 centerline miles. The 711 centerline miles represented 2,649 lane-miles of pavement. Figure 2 provides a summary of the data provided by each agency.

Agencies were requested to provide a mix of asphalt, composite and concrete pavement types, but (as shown in Figure 2), the sample data was dominated by asphalt and composite pavements, which comprised 85 percent of Interstate and 88 percent of non-Interstate NHS centerline miles. Two agencies did not provide data for concrete pavements; a third provided data for less than one mile of concrete pavement. Eight agencies provided data for both directions for each corridor. Four agencies provided data for only a single direction; however, these agencies informed the research team that data are collected separately for each direction. In addition, one agency noted that data are collected for each direction in alternate years.

[2] A centerline mile is defined here as one mile section of a bi-directional highway, even if the highway is divided.

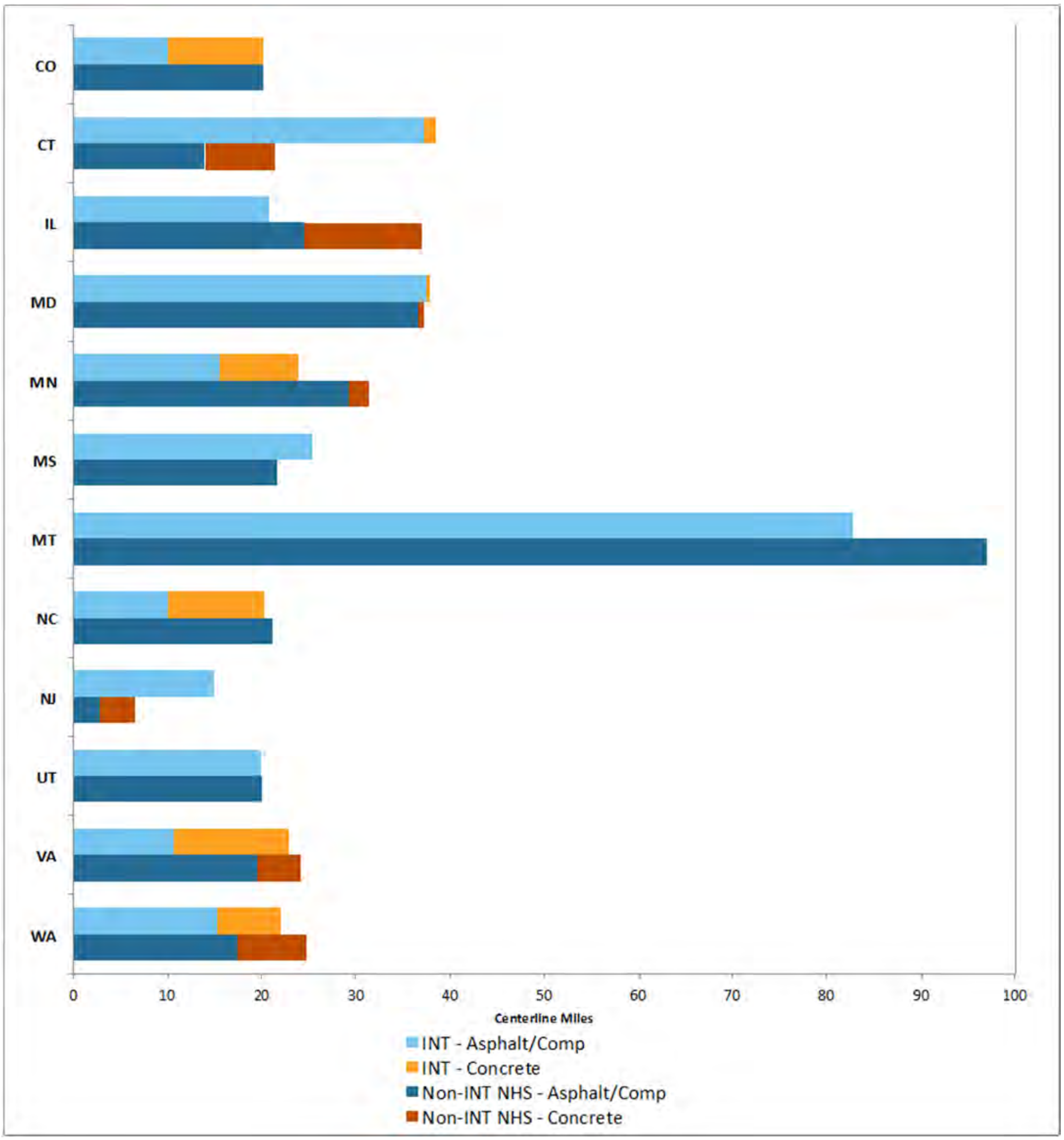

Figure 2. Characteristics of the Sample Data Set

Raw performance data provided by each agency included average rut depth, percent fatigue cracking for asphalt and composite pavements, and average joint faulting and percent cracked slabs for concrete pavements for 0.1 mile sections. Agencies also provided IRI data for all pavement types to allow for comparison to the distress-based performance measures.

3.4 Analysis of Data Derivation Methods

The measures selected for this study were consistent with those defined in the 2012 HPMS Field Manual (20). Participating agencies were able to provide the rutting, faulting, and IRI data directly based on their automated data collection efforts. However, as was anticipated, agencies derived percent fatigue cracking (for asphalt/composite) and percent of cracked slabs (for concrete) from more detailed distress data.

Agencies were asked to provide their calculation methodologies for the HPMS cracking measures and supply the raw distress data from which these measures were derived. The research team reviewed the different methodologies and assumptions reported by each participating agency in order to identify steps that might be warranted to move towards a greater level of consistency in the cracking measures across states.

Nine of the agencies provided the raw data and their calculation methodologies for fatigue cracking. For these agencies, the research team calculated the cracking measures based on the information provided. Three of the agencies provided both raw data and cracking measures – for these agencies, the research team verified that the calculations matched the specified methodology. In one case, an agency provided both raw data and cracking measures, but the calculation methodology did not match HPMS guidelines (non-wheelpath distress was included). The research team re-calculated the cracking measure for this agency to exclude the non-wheelpath distress.

Methodologies for deriving cracking measures varied across agencies. There was more variation for the percent fatigue cracking measure for asphalt /composite pavements than there was for the percent cracked slabs measure for concrete pavements. Key dimensions of variation identified were:

- The types of distresses included – generally called “alligator,” “longitudinal,” or “multiple,” though there were variations in definitions and measurement protocols from agency to agency;
- Assumptions about wheelpath widths – used in percent cracking calculations;
- Assumptions about the width of lanes – generally 12 feet but some agencies used actual measurements;
- Assumptions about the average width of cracks, based on crack type and severity;
- Use of sampling methods for cracking calculations (e.g. sample only the first 500 ft of a section);
- Correction methods (e.g. one agency limits the area of reported fatigue cracking to the total wheelpath area) and
- Methods for determining the number of slabs in a section.

3.5 Performance Measure Calculation

Length-weighted averages for each corridor and each agency were calculated, with weights based on the lane-miles represented by each record. Bridge sections were included in the calculations, though agencies were asked not to provide data for corridors with long bridge sections. A sensitivity analysis was conducted for two agencies to determine how using centerline miles (rather than lane-miles) as a weighting factor impacted the results; and to determine what impact excluding bridge sections would have on the results.

To provide an alternative to performance measures based on average values, measures based on the percent of lane-miles in good, fair and poor condition ranges were also calculated. Condition ranges for cracking, rutting and faulting were established based on information reported in NCHRP Report 677[3] (13) as illustrated in Table 2. Ranges for good condition were

[3] Adapted from Table 4-1 of this report

based on Level of Service A, ranges for fair condition were based on Level of Service B and C, and ranges for poor condition were based on Level of Service D and F. For IRI, ranges were based on the November, 2012 report of the AASHTO SCOPM Task Force on Performance Measure Development, Coordination and Reporting (12). These ranges were: Good - IRI < 95 in/mi; Fair - IRI 95-170 in/mi, Poor - IRI >170 in/mi. The ranges utilized for this project were based on existing published sources. They are intended to be illustrative and were not validated by the research team.

Table 2. Ranges for Good-Fair-Poor Classification for Cracking, Rutting and Faulting

Element	Indicators	Measure	Level of Service				
			A	B	C	D	F
Fatigue Cracking: Asphalt Concrete and Composite	Cracking of the pavement surface best described as an area feature rather than a linear feature. Includes alligator cracking, patching, and potholes.	Percentage of surface area with fatigue cracking[4]	0.0-4.9	5.0-9.9	10.0-14.9	15.0-34.9	>=35.0
Fatigue Cracking (Jointed Concrete Pavements)	Cracking or patching of the pavement slabs. Includes corner breaks[5], transverse cracking and longitudinal cracking.	Percentage of Slabs with Fatigue Cracking	0.0-1.9	2.0-4.9	5.0-9.9	10.0-34.9	>=35.0
Faulting (Jointed Concrete Pavements)	Difference in elevation across joints or cracks.	Average Fault Height (inches)	<0.125	0.125-0.24	0.25-0.49	0.50-0.74	>=0.75
Rutting (Asphalt Concrete and Composite)	Longitudinal surface depressions in wheelpaths.	Average rut depth (inches)	<0.125	0.125-0.24	0.25-0.49	0.50-0.74	>=0.75
			Good	**Fair**		**Poor**	

3.6 Performance Results

As described above, agencies were asked to provide data for sample corridors – rather than their entire Interstate and NHS systems. For purposes of this study, data were summarized at the agency level to illustrate how calculations would be done if complete data were available. However*, it is important to keep in mind that agency-level summaries were produced for illustrative purposes only; they should not be used to draw conclusions about overall system conditions in the individual states*.

Figures 3 and 4 show performance measures for asphalt and composite pavements – Figure 3 shows average rutting, percent fatigue cracking and average IRI; Figure 4 shows percent of lane-miles in "good" condition using the ranges presented in Table 2.

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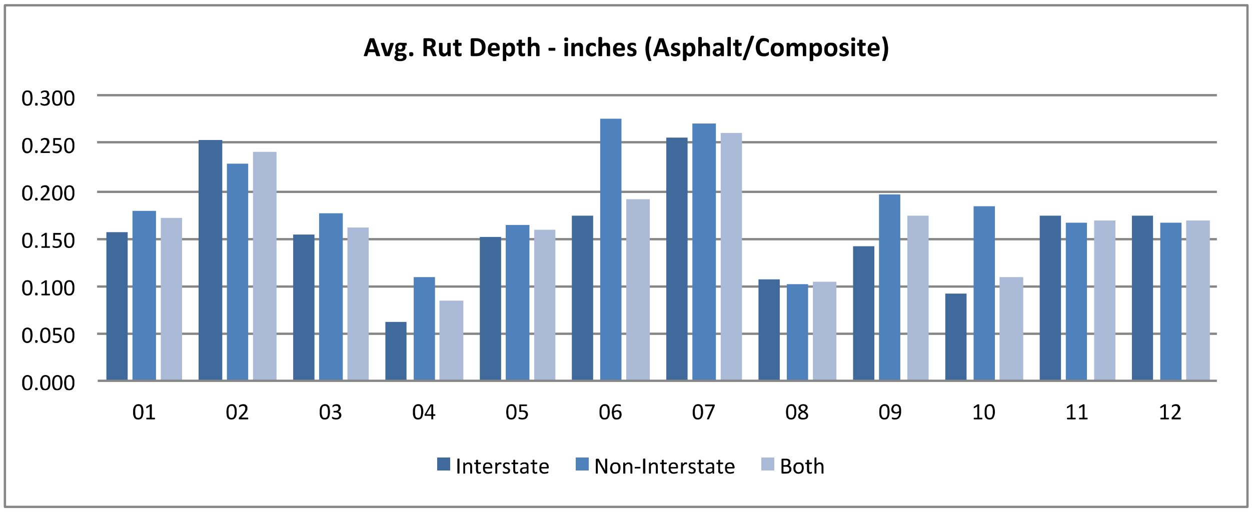
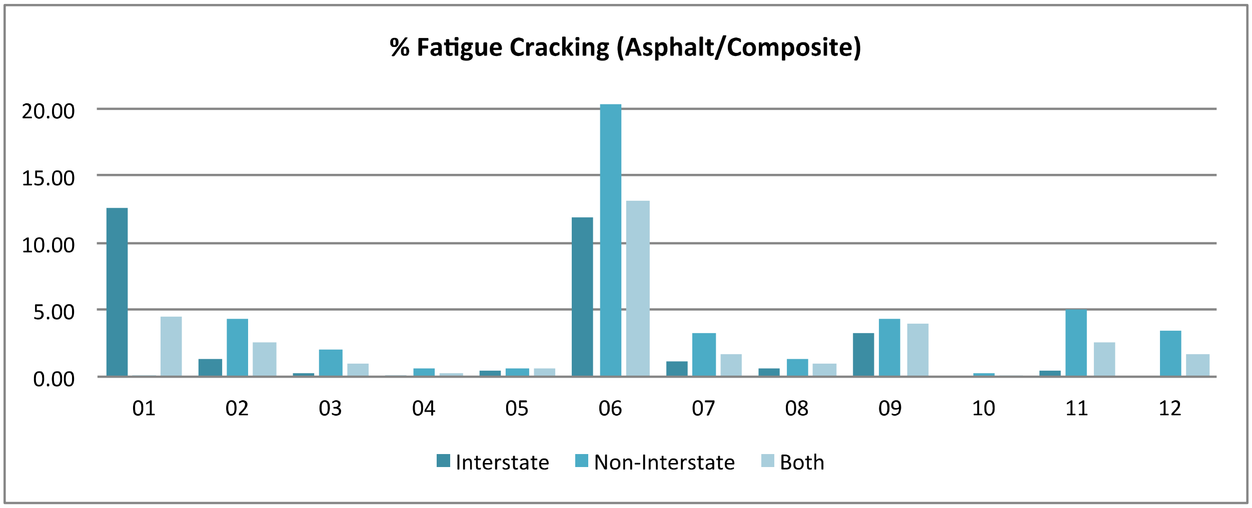
[4] Percentage of entire pavement surface area, consistent with the guidance provided in the HPMS Field Manual

[5] Inclusion of corner breaks is not consistent with guidance provided in the HPMS manual. The specifications for this study excluded corner breaks.

Figures 5 and 6 show performance measures for concrete pavements – Figure 5 shows percent crack slabs, average joint faulting depth, and average IRI for concrete pavements; Figure 6 shows percent of lane-miles in “good” condition using the ranges presented in Table 2. States shown with asterisks did not provide data for concrete pavements (or the data provided were only for a short segment and were not included in the analysis).

Appendix B provides detailed results for each agency at the corridor level.


Avg. Rut Depth - inches (Asphalt/Composite)
0.300
0.250
0.200
0.150
0.100
0.050
0.000
01 02 03 04 05 06 07 08 09 10 11 12
Interstate
Non-Interstate
Both


% Fatigue Cracking (Asphalt/Composite)
20.00
15.00
10.00
5.00
0.00
01 02 03 04 05 06 07 08 09 10 11 12
Interstate
Non-Interstate
Both

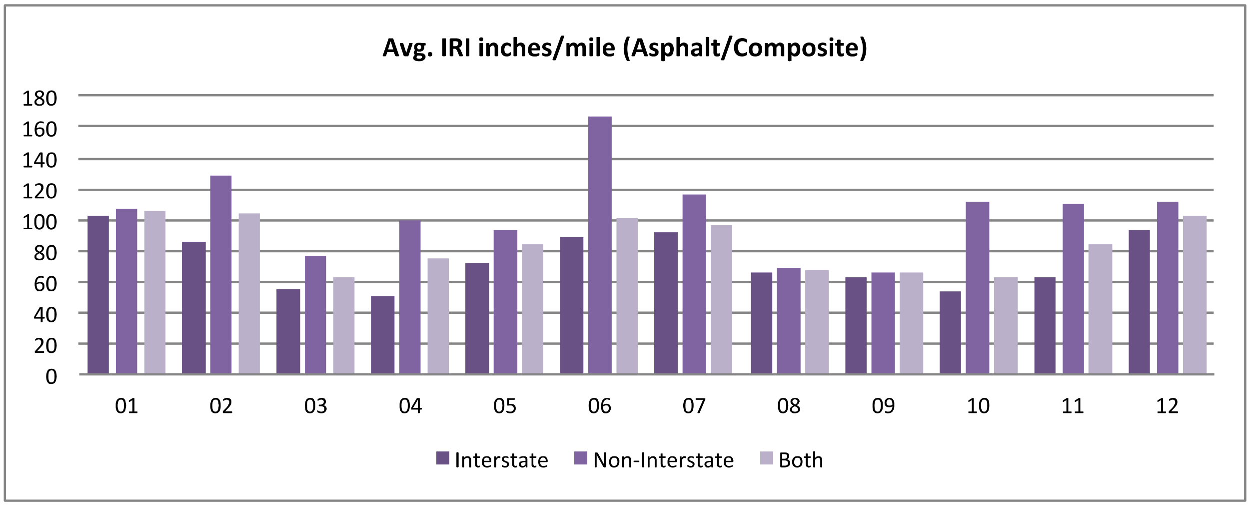
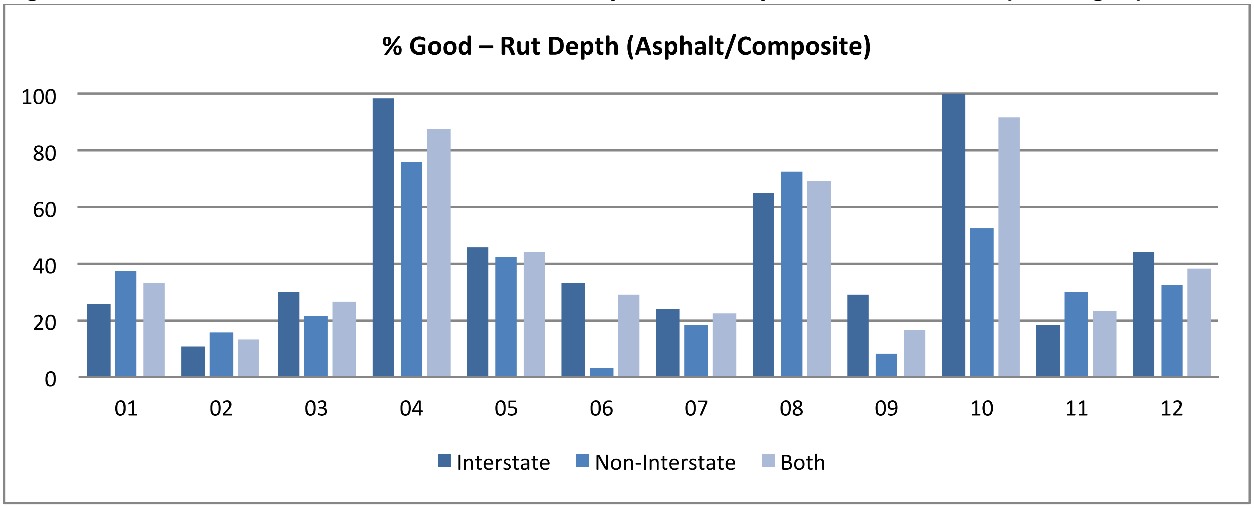
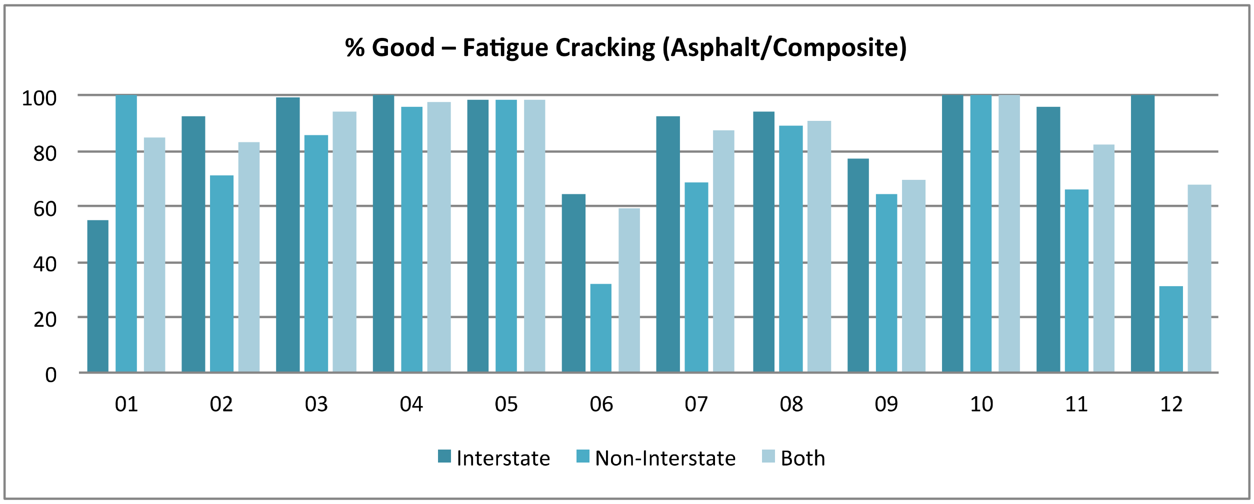

Avg. IRI inches/mile (Asphalt/Composite)
180
160
140
120
100
80
60
40
20
0
01 02 03 04 05 06 07 08 09 10 11 12
Interstate
Non-Interstate
Both

Figure 3. Performance Measure Results for Asphalt /Composite Pavements (Averages)





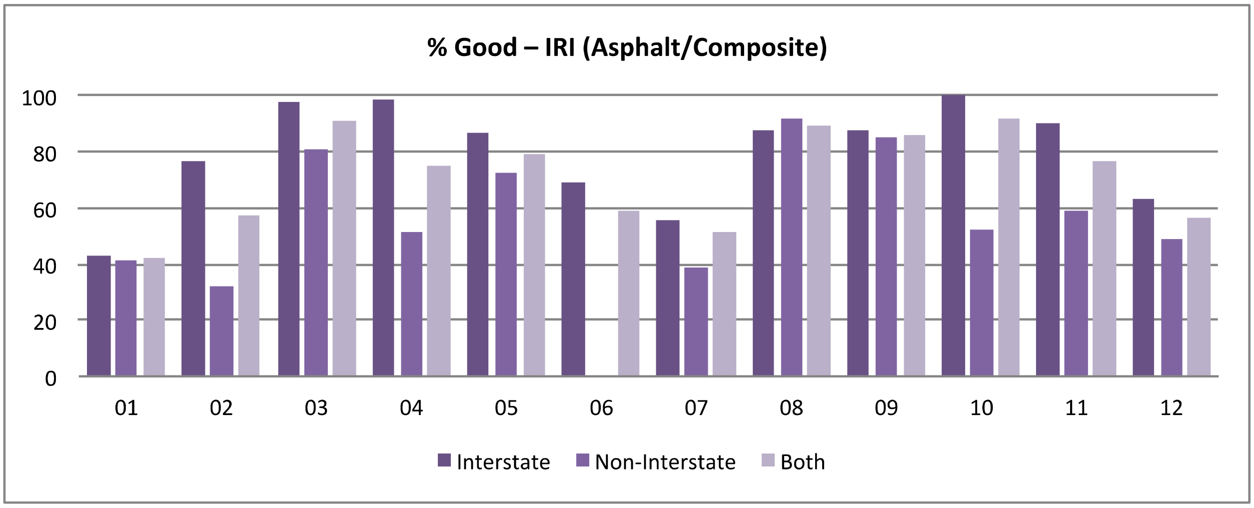
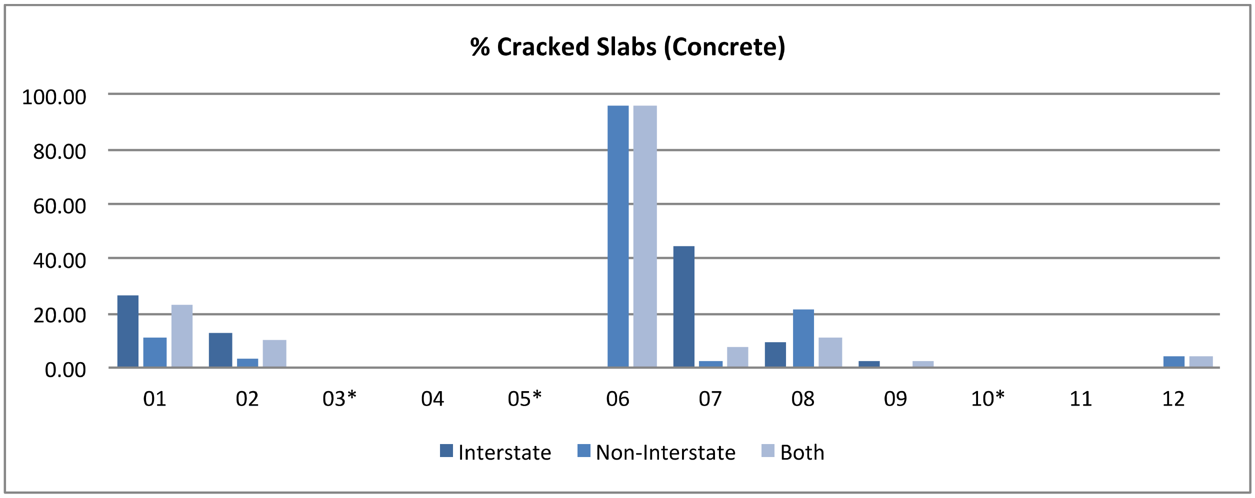
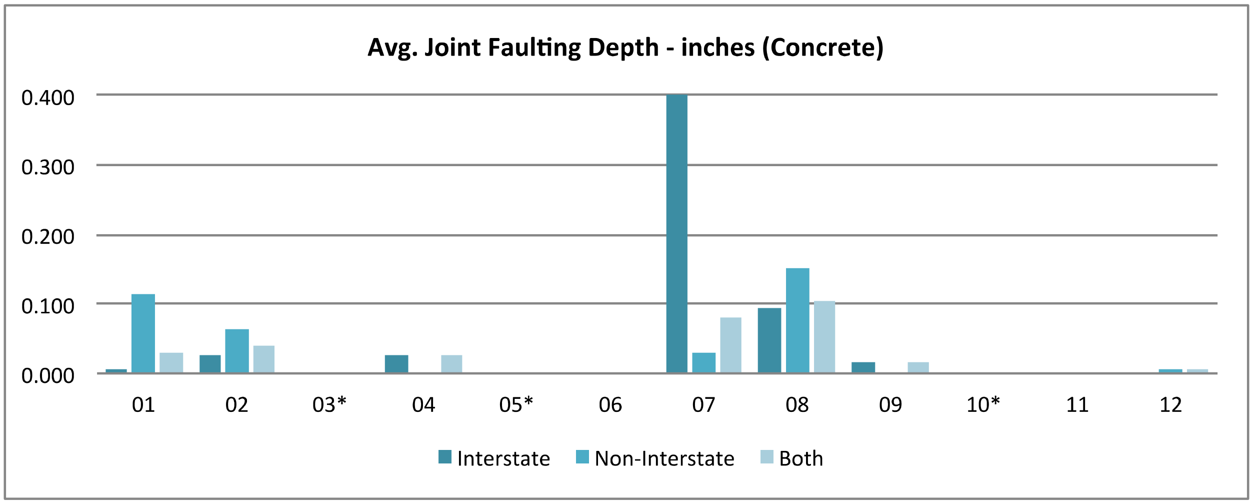


Figure 4. Performance Measure Results for Asphalt /Composite Pavements (% Good)





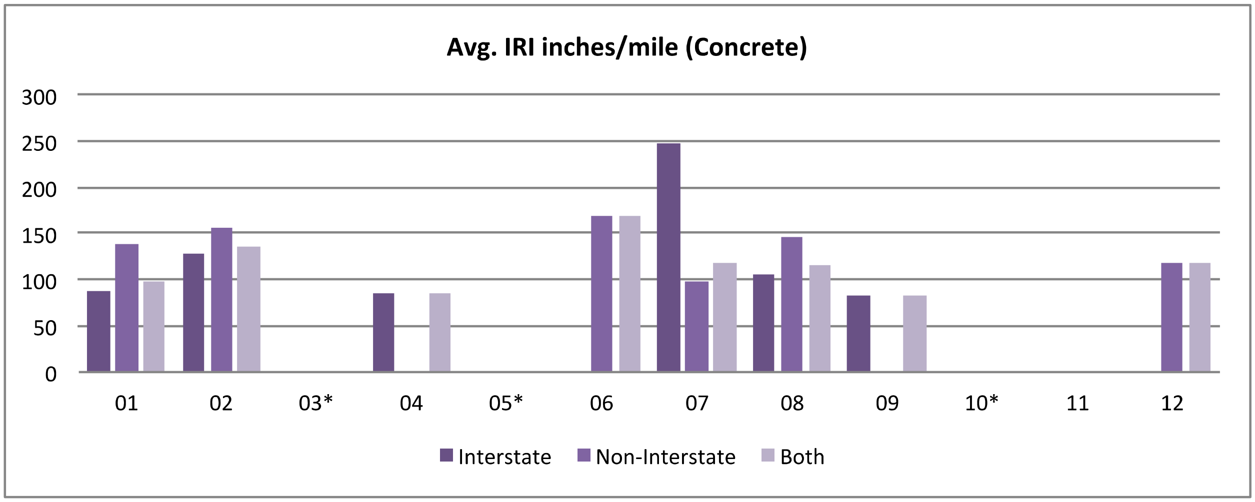
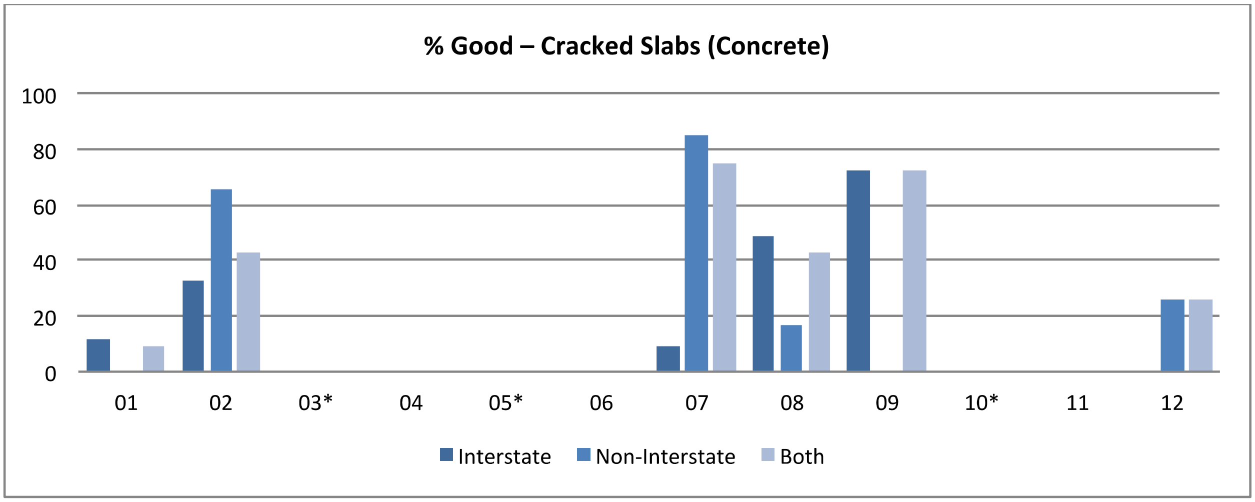
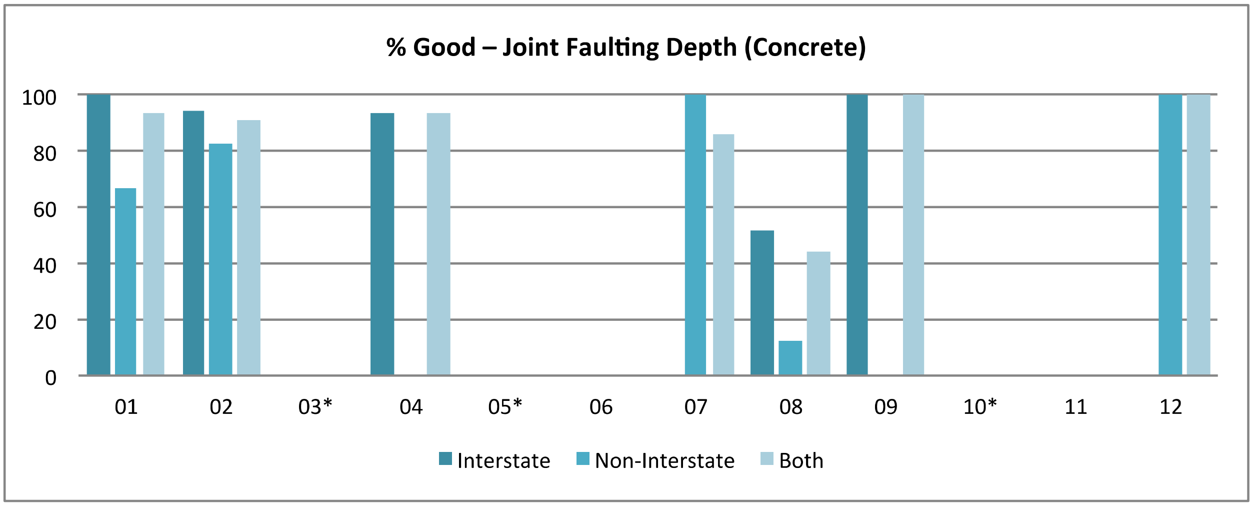


Figure 5. Performance Measure Results for Concrete Pavements (Averages)





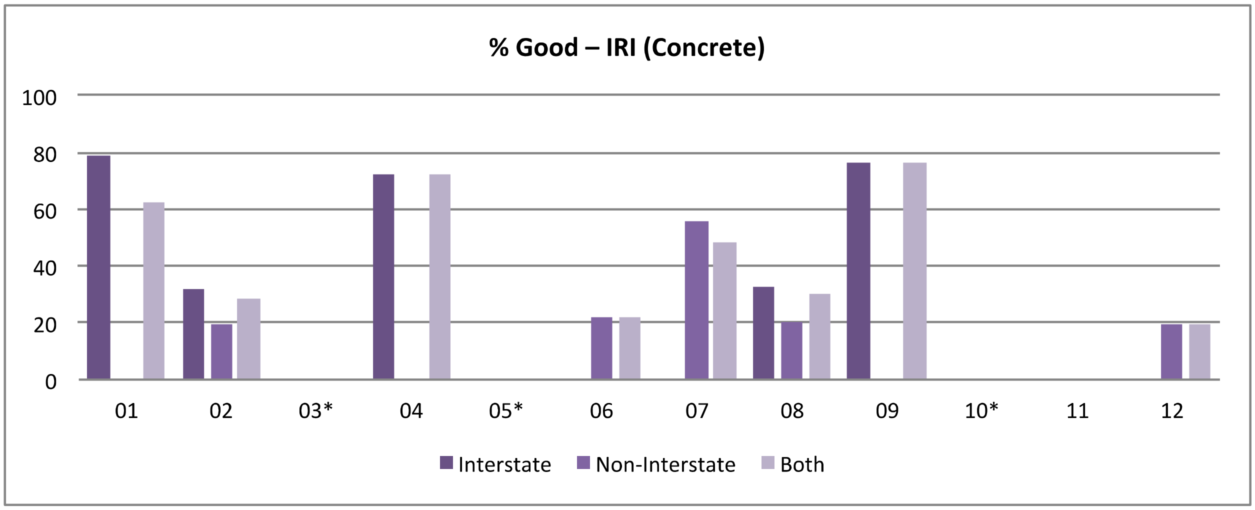


Figure 6. Performance Measure Results for Concrete Pavements (% Good)

Visual examination of the data indicates that the different condition measures are sometimes correlated, and sometimes not. For example, considering the data for asphalt /composite pavements, results for corridors provided by agency 6 – non-Interstate stand out for all six measures as one of the poorest across all participating agencies – highest averages and lowest percent good for cracking, rutting and IRI. On the other hand, results for agency 7 show one of the higher average rut depths (and lower percent good based on rutting) across the participating agencies but cracking and IRI values that are on-par with the other agencies. As another example, agency 12 shows no fatigue cracking for the Interstate asphalt/composite, but one of the higher average IRI values (93.6 in/mile). This is likely due to presence of (non-wheelpath) transverse and longitudinal cracking on sections that are not classified as fatigue cracking.

Results also illustrate how averages tell a different story than the percent of lane-miles in good condition. For example, agencies 3 and 5 have nearly identical average rut depths for their reported asphalt /composite pavements. However, agency 5 has 46 percent of lane-miles in good condition (based on rutting) while agency 3 has 30 percent of lane-miles in good condition.

4.0 Investigation of State Practices

4.1 Overview

An important objective of this study was to identify notable practices used by state highway agencies for quantifying network-level pavement structural health. Specific practices of interest include how pavement structural condition data are collected, summarized, and used within the context of pavement management, asset management, and broader performance management activities.

The research team undertook a three-tiered approach to identify practices of potential interest:

- First, a brief email (with two questions) was sent to pavement management lead contacts at 50 state highway transportation agencies to identify those that are either collecting network-level deflection data or using a structural health measure;
- Second, an online survey was distributed to the 12 states that provided data for NCHRP 20-24(37)J plus an additional 12 agencies with potential practices of interest that responded to the broader email and
- Third, based on responses to the online survey, three agencies were selected for a detailed phone interview.

The remainder of this chapter:

- Provides background on the current state of the practice for pavement condition assessment, based on the Task 1 literature review;
- Presents the results of the initial email and online survey;
- Presents the results of follow up telephone interviews with the three selected state DOTs and
- Summarizes key findings.

4.2 Background on State DOT Pavement Condition Measurement Practices

As part of the HPMS submittal, all state highway agencies are required to report pavement smoothness data based on IRI. However, IRI is primarily useful for assessing ride quality and is generally not used as a measure of pavement structural condition. Most state highway agencies use IRI as only one of several indicators to monitor pavement condition, identify suitable treatments, allocate resources, and prioritize projects. Other common condition indicators in use are based on measurement of the extent and severity of cracking, rutting, and other distresses. State highway agencies utilize a variety of approaches to summarizing condition information. Some calculate indices for individual distress types; others calculate indices for certain categories of distresses (e.g. structural versus environmental). Most of the states calculate an overall condition index combining multiple distresses and in some instances roughness, but there are nearly as many different indexes as there are highway agencies. Overall condition indices include Present Serviceability Index (PSI), PCI, Pavement Quality Index (PQI), Critical Condition Index (CCI), and Overall Performance Index (OPI). A handful of states are using RSL to characterize their pavement conditions and determine suitability for different treatment types.

4.3 State DOT Surveys

Email Survey of Agencies

An email request was sent to the pavement management engineer in each of the 50 state highway agencies. The intent of the email survey was to determine which agencies conduct network-level deflection data collection and whether a direct or surrogate measure of pavement structural health is used to quantify the pavement network condition. Specifically, the research team requested a response to the following two questions:

1. *Has your agency collected and used deflection data for network-level reporting or treatment selection?*
2. *Does your agency utilize a direct measure or surrogate measure of network-level structural health?*

A total of sixteen responses were received from the email survey. Table 3 summarizes the received responses. Of the sixteen responding agencies, only Iowa and Kansas indicated that network-level deflection data is collected on a routine basis. In addition, eleven agencies indicated the use of a network-level structural health measure. The Iowa DOT indicated that network-level deflection testing is converted to a structural rating for determining treatment selection. Seven agencies (Arkansas, Massachusetts, New Mexico, New York, North Dakota, Ohio, and Oregon) indicated the use of measures based on existing pavement condition. Michigan and Nevada DOTs estimate structural health based on the length of time until rehabilitation/reconstruction is needed. The Pennsylvania DOT estimates structural health based on calculation of SN. Finally, five agencies indicated that they are not currently using a measure for quantification of pavement structural health.

Table 3. Summary of Agency Responses to the Email Survey

Agency	Network-Level Deflection Data	Network-Level Structural Health Measure
Alabama	No	No measure for network-level pavement structural health is currently used.
Alaska	No	No measure for network-level pavement structural health is currently used.
Arkansas	No	A surrogate measure is used based on existing distress conditions.
Iowa	Every 2 to 6 years	FWD data is converted to a structural rating for network level treatment selection only.
Kansas	Pavement selection analysis only	No measure for network-level pavement structural health is currently used.
Kentucky	No	No measure of network-level pavement structural health is currently used.
Massachusetts	No	A pavement structural index is used that considers rutting, fatigue cracking, aging, and raveling to determine remaining service life.
Michigan	No	Estimate time remaining until needed rehabilitation or reconstruction.
Nevada	No	Calculate the percentage of roads requiring preservation work to eliminate the accumulated backlog.
New Mexico	No	Use a pavement condition rating to represent all aspects of pavement condition.

Agency	Network-Level Deflection Data	Network-Level Structural Health Measure
New York	No	Use a surface cracking index and calculate PCI.
North Dakota	No	Use a structural index and distress score to determine network-wide and roadway classification-wide "average" for system-tracking purposes.
Ohio	No	Pavement condition rating designates certain distresses as structural related. The structural deduct value is used as a threshold trigger in pavement management decision trees.
Oregon	No	Surrogate measure using cracking, patching, and rut depth distress indicators.
Pennsylvania	No	Structural number calculation.
Tennessee	No	No measure for network-level pavement structural health is currently used.

Online Survey

An online survey was sent to the volunteer agencies that provided data, and the agencies that indicated a positive response to either or both of the email survey questions (those listed in Table 3). The online survey consisted of eight questions. Agency responses are summarized below:

1. *How does your agency assess and communicate the structural health of your pavements to the public? What indicators are used and how is the meaning of these indicators explained?*
    - The **Colorado DOT** assesses and reports structural health in relation to the Driveability Life. Driveability Life is defined as the number of years a pavement has until its driveability is unacceptable. Acceptability is based on measures of rutting, IRI and cracking.
    - The **Connecticut, Illinois, Nevada, New Jersey, North Carolina North Dakota, and Washington State DOTs** determine and communicate pavement structural health through an examination of cracking, rutting and/or roughness.
    - **Maryland State Highway Administration (SHA)** and the **Minnesota DOT** assess and communicate only ride quality to the public.
    - The **Montana DOT** reports IRI to the Transportation Commission and the Legislature; however, Pavement Management uses an OPI to communicate pavement health of the individual systems or sections. OPI is a multiplicative calculation with weighted distresses (e.g., roughness, rut depth and cracking).
2. *What direction has your agency's leadership provided regarding establishment, use, and communication of pavement structural health indicators? What factors are important to them?*
    - In **Colorado**, the DOT Executive Management's primary factor for quantifying pavement condition is related to the user experience (rutting, IRI, and cracking) and safety.
    - For the **Maryland SHA**, and the **Minnesota** and **Montana DOTs**, ride quality is most important to senior leadership. The Nevada DOT focuses on addressing

pavement needs to meet the Department's proactive pavement preservation program.

- In **New Jersey**, state law requires the agency to annually assess the pavement network, to indicate funds allocated to pavement restoration, to describe what projects were completed with those funds, and to indicate pavement locations which need future restoration.
- The **North Dakota DOT** presents long- and short-term pavement condition information, predictions, and recommendations based on the pavement management system each year during the development of the State Transportation Improvement Program (STIP).

3. *Has your agency used deflection data to characterize system structural health or assess rehabilitation needs at the network level? If your agency collected network-level deflection data, for what portions of your network are data collected (e.g., interstates only)? How often are data collected (e.g., one time, every three years)?*
    - The **Iowa DOT** collects network-level deflection data on interstate and primary routes, every two to six years depending on the functional classification of the roadway.
    - The **Utah DOT** has tested the entire state highway network; however, this practice was stopped several years ago.
    - Approximately four years ago, the **Virginia DOT** conducted network-level deflection testing on only the interstate routes.
    - The remaining agencies indicated that network-level deflection testing has not been conducted.
4. *Has your agency developed and used deterioration models for structural health indicators?*
    - **Maryland SHA**, **Colorado**, **Connecticut**, **Minnesota**, **New Jersey**, **North Carolina**, **North Dakota**, **Utah**, and **Washington State DOTs** have all developed performance prediction models based on surface distress.
    - The **Illinois DOT** deterioration models are also based on surface distresses; however, structural-related distresses are weighted heavier than other distress.
    - The **Montana DOT** uses deterioration models for individual distresses which are then multiplicatively combined to calculate OPI.
5. *What methods do you use to ensure accuracy and consistency of the structural health information you collect?*
    - The **Colorado DOT** indicated that acceptance procedures are in place for surface distress data collection and the resulting distress maps and reports are provided to Region offices for review.
    - After data collection is complete, the **Connecticut DOT** reviews the photo log to validate the data and identify potential sources of error (bias, inaccuracy).
    - The **Illinois DOT** requires annual condition rater training and spot checks ratings using core office staff.

- The **Iowa DOT** conducts FWD calibration and reviews field data to identify out-of-range data.
- The **Maryland SHA** manually reviews pavement images to assess the accuracy of reported cracking data.
- The **Minnesota DOT** data collection vehicle is certified each year by collecting data on baseline sections, and comparing the new year's data to the previous year's data for each pavement section.
- During production, the **Montana DOT** calibrates the data collection equipment weekly, and visually checks the collected data. After production, the agency compares the current year's pavement condition indices to previous years' data.
- The **New Jersey DOT** reviews video images to verify condition data assessment on pavement segments that have been identified as potential projects.
- The **North Carolina DOT** uses a third-party contractor to conduct quality control and acceptance testing.
- The **North Dakota DOT** conducts annual equipment measurement certification.
- Finally, the **Washington DOT** conducts quality control procedures to evaluate the repeatability of the pavement condition rating.

6. *How do you use structural health information?*
   Agency responses are summarized in Table 4.

Table 4. Agency uses of structural health information.

Agency	Overall Network Condition	Set Network Performance Targets	Estimate Remaining Service Life	Pavement Management Decision Trees	Prioritize Locations for Funding	Project-Level Decisions	Forecast Future Rehabilitation Needs	Pavement Design
Colorado	✓	✓		✓	✓	✓		
Connecticut	✓			✓	✓			
Illinois						✓		
Iowa				✓		✓		✓
Maryland	✓		✓			✓		✓
Minnesota	✓	✓	✓	✓	✓	✓		✓
Mississippi				✓		✓		
Montana	✓			✓				
Nevada	✓	✓	✓	✓	✓	✓		
New Jersey	✓	✓	✓	✓	✓	✓		✓
North Carolina	✓	✓	✓	✓	✓	✓		✓
North Dakota	✓		✓	✓	✓			
Ohio				✓				
Pennsylvania						✓		✓
Utah	✓	✓		✓	✓	✓	✓	
Virginia				✓				
Washington	✓	✓	✓	✓	✓	✓	✓	

7. *What particularly successful practices is your agency using to collect, process, verify and use pavement structural health information at the network level?*
    - The **Colorado DOT** has de-emphasized the importance of directly measuring structural condition through techniques like GPR or deflection testing and has placed more emphasis on assessing rut depth and cracking.
    - **Connecticut DOT** has been concentrating on transitioning to new condition data collection technology without losing the applicability of historical condition data. The agency has developed transfer functions to express the new data in the older format, and to define the data in such a way as to be usable with a measurement-technology change. Connecticut DOT also uses regression techniques with "image-ground-truth" to compare results from different data collection technologies.

- The **Maryland SHA** stated a lack of confidence in the accuracy or consistency of the results from the fully-automated process, therefore, a manual review of the condition images is conducted to assess the accuracy of the cracking measurement.
- **New Jersey DOT** has used pavement structural health information to predict pavement restoration funding levels to meet established performance goals and to predict performance in the event of reduced or inadequate funding. This has resulted in focused effort to adequately fund the pavement preservation program. In addition, New Jersey DOT has also automated the processing and analysis of pavement condition data which has improved the accuracy and reduced data processing time and effort.
- The **North Carolina DOT** stated that the use of a proven data collection vendor, in conjunction with a third-party quality control process, is resulting in quality pavement condition data.
- The **North Dakota DOT** places infrastructure data and pavement condition images onto an internal Geographic Information System (GIS) platform that allows users to consolidate numerous data elements into a single viewable map format.
- The **Washington State DOT** stated that successful practices are due to a long history (many decades) of consistent database implementation, which allows tracking of pavement condition in addition to construction history, traffic, and location data. This long-term data resource allows for the evaluation of the network-level pavement health over time, and the analysis of the contributing factors to the observed pavement conditions.

8. *Given variations in condition measurement across agencies, what structural health indicators do you feel have the greatest promise for use in characterizing pavement health at the national level?*
    - **IRI**. Four agencies indicated that IRI should be used as a national measure of structural health. However, five other agencies indicated that although IRI is a standard measure and therefore comparable across agencies, it does not directly reflect the structural condition of the pavement network.
    - **Cracking, Rutting, Faulting**. Agencies also indicated using fatigue cracking (three agencies) and rut depth (four agencies) for asphalt pavements, and joint faulting (one agency) and slab cracking (two agencies) for concrete pavements.
    - **Remaining Service Life.** Two agencies stated that RSL, which could be calculated using a variety of measures (e.g., deflection, rut depth, cracking, faulting), should be used as the national measure.
    - **Deflection.** Two agencies indicated that the structural health should be based on deflection data and layer thickness information.

- **Agency Condition Category.** Finally, three agencies indicated that structural health should be based on an agency measure of pavement condition (categorized as good, fair and poor).

4.4 State DOT Interviews

Using the results of the online survey, the research team evaluated which of the responding agencies should be interviewed on practices for quantifying pavement structural health. During this assessment, the research team reviewed agencies that indicated the use of a pavement structural health measure that went beyond the use of IRI, rut depth, or a surface cracking measure. Based on this assessment, the telephone interviews were conducted with the pavement management engineers from the Colorado, New Jersey, and Virginia DOTs to further determine practices and methods used for determining pavement structural health. Specifically, these agencies were asked to describe data collection practices for network-level pavement condition data, quality control (QC) and acceptance procedures for pavement condition data, the methods used for determining pavement structural health, HPMS reporting process, the applicability of RSL as a measure of structural health, and the probability of having a network-level deflection device within the next five years. A summary of each agency's responses is provided in Table 5 and discussed below.

Colorado

The Colorado DOT (CDOT) currently contracts with a vendor for pavement condition data collection. Currently, Pathway Services, Inc. is under contract with the Colorado DOT to collect and analyze pavement condition data using semi-automated procedures (data are collected using a high-speed data collection vehicle, images are viewed for the presence of surface distress, and sensor data are processed to determine transverse and longitudinal profile). Pavement distress data are collected annually on the state highway network. Condition data are collected in the increasing direction on all state highways, and in both directions for multi-lane facilities. The types of data collected include video images and profile measurements. Video images are used to quantify the extent and severity of longitudinal, transverse, and fatigue (asphalt pavements only) cracking and corner breaks (concrete pavements only). Profile data are used to determine rut depth and IRI on asphalt pavements and faulting and IRI on concrete pavements. Data are analyzed on 100 percent of the collected lane (i.e., no sampling).

QC and acceptance procedures are conducted on the profile data using eight test sections located in the Denver, Colorado metro area. The contractor is required to run each test section at least five times prior to data collection to verify data repeatability. Test sections are rerun periodically during data collection to verify data collection repeatability. Due to traffic and safety concerns, no field verification is conducted. In addition, computer scripts are run on the database to check data for exceeding expected limits, for data completeness, and for record duplication. Pavement segments are identified based on low, medium, and high distresses for each batch and checked for accuracy using the video images (quantity of distress, distress type, and distress severity). Finally, pavement segments are verified for pavement type.

Table 5. State DOT Phone Interviews

Agency	Condition Data Collection			Current Measure of Pavement Health	In favor of RSL as a Measure of pavement health	Likelihood of network level deflection in 5 years
	Automated or Windshield	In-house or Vendor	QC procedures			
Colorado	Automated	Vendor	Yes	Driveabilty Life	Yes	Not likely
New Jersey	Automated[1]	In-house	Yes	Surface Distress Index[2]	No	Not likely due to lane closure requirements
Virginia	Automated	Vendor	Yes	Multiple measures[3]	Yes, but not for determining treatment timing	Not likely due to analysis effort. RWD not helpful in quantifying pavement structural health due to only collecting center deflection.

1 Currently developing correlation between previous windshield surveys to recently purchased automated data collection van.

2 Based on a combination of load and non-load related distress.

3 Load and nonload-related distress, and critical condition index.

Starting this year, CDOT is using Driveability Life as their structural health performance measure. Driveability Life is defined as the amount of remaining acceptable drivable life based on rut depth, smoothness, longitudinal cracking, transverse cracking, fatigue cracking, and corner breaks. Individual distress regression equations have been determined to estimate the timing when an unacceptable threshold is reached. The Driveability Life is based on the distress that is in worst condition. The Driveability Life and condition index values for each distress type are used to estimate the timing of treatment application.

Prior to this year, CDOT used RSL as their structural health performance measure. RSL was based primarily upon pavement age, design expectations, and surface distress. Driveability Life is much more focused on surface distresses and the "user experience" as opposed to "engineering expectations."

Pavement management data are provided to the Data Management/GIS unit within CDOT for HPMS data processing and submittal. The HPMS group conducts the required data manipulation, segmentation, and any required calculations. As part of the pavement condition data collection contract, the Colorado DOT requires the data collection vendor to collect and provide the condition data in HPMS format on all non-state routes.

The Driveability Life is a similar measure to RSL, in that they are both time-based measures that count down to a zero-condition. However, the Driveability Life is an easier measure to communicate to upper management and other non-pavement staff than RSL (depending on its definition). In addition, the respondent indicated support for developing a national RSL measure to enable the comparison of pavement condition measures to other agencies.

The respondent did not believe that moving toward a network-level structural health measure based on deflection data within the next five years was likely. He noted two primary challenges to this: (1) a relatively low demand from agencies and (2) the lack of a high-speed deflection measurement supplier who could readily provide the service.

New Jersey

The New Jersey DOT conducts an annual pavement condition survey on the state-maintained highway system (excludes toll roads). Pavement condition assessment has traditionally been conducted using manual distress collection techniques for surface cracking and high-speed profiler equipment, using the INO system, for measuring transverse and longitudinal profile to determine rut depth, faulting, and IRI. The manual distress collection includes a 100 percent survey of the rightmost lane in each direction of travel using a keyboard-related distress accounting process. The keyboard-related distress accounting process includes a windshield survey using a computer keyboard with designated keys for distress type and severity level. Computer software records the location of distress and summarizes the results over 0.1-mile increments. For asphalt and composite pavements, collected surface distress includes nonload-related multiple and longitudinal cracking (outside wheelpaths), transverse cracking, and load-related multiple cracking (within wheelpaths). For concrete pavements, collected surface distress includes cracking and joint deterioration. For all pavements, additional collected distress includes patching, shoulder deterioration, and shoulder drop-off. The condition assessment process does not measure actual length of distress, just that the distress type was present over the measurement interval. During the manual distress data collection process, the forward driver view is also captured using a camera mounted on the survey van. The New Jersey DOT has also recently purchased a Pathway Services, Inc. 3-D automated data collection van. Data collection will be conducted using both the existing keyboard-based distress survey process and with the Pathway Services, Inc. van. The results will be compared and an algorithm between the two survey processes developed. New Jersey DOT intends to eventually collect pavement condition data using the automated data collection process.

QC and assurance practices include conducting automated system checks on the profiler equipment (e.g., bounce tests) and database checks on the collected distress data. The database checks include conducting a visual rating of the roadway (using the video from the forward view camera) and comparing the results to the manual distress ratings.

The condition data is used to calculate a nonload-related distress index (NDI) and a load-related distress index (LDI), which uses a point penalty-type system for assessing load-related cracking outside the wheelpath and inside the wheelpath, respectively. The NDI and LDI are based on a zero to five scale, where five means very good or better condition. NDI and LDI are calculated as follows (22):

$$NDI = (500 - \Sigma DV_N) / 100 \quad (1)$$

$$LDI = (500 – (\Sigma DV_L + DV_R) / 100 \quad (2)$$

where,

NDI	=	Nonload-related distress index
LDI	=	Load-related distress index
DV_N	=	Deduct value for nonload-related distress types in 0.1-mile increments
	=	Distress Weight x Severity Coefficient x Occurrence (percent) / 100
DV_L	=	Deduct value for load-related distress types in 0.1-mile increments
	=	350 x Severity Coefficient x Occurrence (percent) / 100

DV_R = Deduct value for rutting
= 150 x Severity Coefficient for Rutting

Tables 6 and 7 provide the distress weight and severity adjustment coefficients, by distress type.

Table 6. Distress Weight

Distress Type	Flexible	Composite	Concrete
Nonload-related multiple cracking	150	150	n/a
Transverse cracking	140	140	n/a
Nonload-related longitudinal cracking	140	140	n/a
Patching	60	60	100
Shoulder deterioration	10	10	10
Shoulder drop-off	0	0	0
Cracking	n/a	n/a	100
Faulting	n/a	n/a	0
Longitudinal joint deterioration	n/a	n/a	145
Transverse joint deterioration	n/a	n/a	145

Ref: (22)

Note: Shoulder drop-off and faulting were assigned zero weights since these distresses were not being significantly recorded by technicians because they were difficult to observe from the high speed windshield survey.

Table 7. Severity Adjustment Coefficients

Distress Type	Severity Level		
	Slight	Moderate	Severe
Nonload-related multiple cracking	0.8	0.9	1.0
Nonload-related longitudinal cracking	0.8	0.9	1.0
Load-related multiple cracking	0.8	0.9	1.0
Transverse cracking	0.8	0.9	1.0
Average rut depth < 0.2 inches	0.0		
Average rut depth 0.2 in to 0.8 inches	(Average rut depth – 0.2) x 5/3		
Average rut depth > 0.8 inches	1.0		
Patching	0.4	0.6	0.8
Shoulder deterioration	0.4	0.6	0.8
Shoulder drop-off	0.4	0.6	0.8
Cracking	0.8	0.9	1.0
Faulting	0.8	0.9	1.0
Longitudinal joint deterioration	0.8	0.9	1.0
Transverse joint deterioration	0.8	0.9	1.0

Ref: (22)

The combined Surface Distress Index (SDI) includes both NDI and SDI (for asphalt pavements, SDI = (NDI x LDI) / 5; and for concrete pavements, SDI = NDI) and is used to determine the timing for project treatment. Table 8 provides a summary of the condition criteria used for treatment timing application. The New Jersey DOT has also developed an overall distress rating that combines SDI and IRI; however, only SDI is used in for deciding treatment timing. Within the pavement management system, the SDI, in addition to the IRI and the traffic level, are used to develop a project list.

Table 8. Condition Criteria

Condition Status	Condition Index Criteria	Engineering Significance
Deficient (Poor)	IRI > 170 inches/mile *or* SDI ≤ 2.4	Overdue for treatment.
Fair / Mediocre	95 ≤ IRI ≤ 170 inches/mile *and* SDI > 2.4 *or* IRI < 95 inches/mile *and* 2.4 < SDI < 3.5	Program rehabilitation treatment to restore roadway to good condition.
Good	IRI < 95 inches/mile *and* SDI ≥ 3.5	Program proactive preventive maintenance strategy.

Modified from Ref: (22)

Cracking data for HPMS submittal is provided to the HPMS group based on the calculations conducted by the Pavement Management and Technology Bureau. The HPMS group does minimal data manipulation prior to submitting to the FHWA. The pavement manager runs an analysis process (computer program) to calculate the required cracking data on the HPMS sample sections. Differences between HPMS and pavement management data were reported to be primarily due to differences in data analysis. For example, New Jersey DOT uses IRI data in both directions, while HPMS data is only in one direction.

For the New Jersey state highway network, non-uniformity of pavements makes the use of RSL impractical for the most part. The New Jersey state highway network is made up of pavement structures that are comprised of non-uniform pavement segments (e.g., due to pavement widening, realignment). Therefore, it is difficult to accurately model pavement performance due to the non-uniform pavement segments. Because of the varied performance, it is also difficult to develop project-specific performance prediction models. Therefore, New Jersey DOT stated that it is difficult for them to determine the number of years of remaining useful life, but based on the existing condition they are able to determine the shorter-term timing for preventive maintenance and rehabilitation treatment application.

New Jersey DOT noted that it would be very useful to have a network-level structural health measured based on deflection data, but at this time, conducting the analysis for network-level deflection data would be difficult unless the deflection data could accurately be obtained at safe travel speeds without lane closures. Deflection data is currently used at the project level, and can be used to refine or trigger specific treatment types. However, they do not foresee using only deflection data to identify treatment type and timing since surface distress would also be required. New Jersey DOT also indicated that the current process using surface distress is good for determining treatment timing; however, it is not as useful for determining the type of treatment.

Virginia

Since 2006, the Virginia DOT has contracted pavement condition data collection through Fugro Roadware, Inc. (Fugro). The contractor uses an Automatic Road Analyzer (ARAN) van for data collection. The pavement condition assessment is conducted using WiseCrax, a proprietary image-processing software tool, and a visual review of the collected video images (i.e., semi-automated analysis). Pavement condition surveys are conducted annually, in the right lane only, on interstate and primary roadways. In addition, 20 to 25 percent of the secondary highway network is collected each year. Internal QC practices are conducted by Fugro. during data collection and processing and the Virginia DOT requires quality assessment using control sites. The Virginia DOT requires that five runs of the ARAN van be conducted on the control sites for assessing IRI and rutting. During production, an independent verification and validation of noted distress are conducted by a third-party contractor. A five percent random sample is used for verification by the third-party contractor. As part of the acceptance process, the distresses identified by Fugro are verified by the Virginia DOT by manually reviewing the pavement images and comparing to the Fugro-conducted survey results.

The Virginia DOT has developed three pavement condition indices for asphalt pavements (based on a scale of 100 to 0); a load-related distress index (LDR), a nonload-related distress index (NDR), and a CCI (23). LDR is based on assigned deduct values for alligator cracking, rutting, wheelpath patching, potholes, and delamination. NDR is based on assigned deduct values for non-wheelpath patching, longitudinal cracking outside the wheelpath, transverse cracking, reflection cracking and bleeding. CCI is defined as the lower value of LDR or NDR.

For jointed concrete pavements, a slab distress rating (SDR) is used. The SDR is based on deduct values for corner breaks, transverse and longitudinal joint spalling, transverse cracking, longitudinal cracking, divided slabs, and concrete and asphalt patching (all distress are expressed as percent of effected slabs)(24).

A concrete punchout rating (CPR) and concrete distress rating (CDR) are determined for continuously reinforced concrete pavements. The CPR is based on the percent of the pavement section distressed with punchouts, cluster cracking, and/or asphalt patching, while CDR is based on the percent of the pavement section distressed with transverse cracking, longitudinal cracking, concrete patching, and longitudinal joint spalling (24).

Table 9 provides a summary of the condition category for all condition indices and IRI.

Table 9. Condition Indices by Condition Category

Condition Category	ALL Condition Indices	IRI (inches/mile)	
		Interstate & Primary Roads	Secondary Roads
Excellent	≥ 90	< 60	< 95
Good	70 – 89	60 – 99	95 – 169
Fair	60 – 69	100 – 139	170 – 219
Poor	50 – 59	140 – 199	220 – 279
Very Poor	≤ 49	≥ 200	≥ 280

Ref: (25)

When the condition assessment score drops to 60 or less, the pavement is considered deficient and typically requires treatment application. For interstate and primary pavements, distress extent and severity are used in making treatment decision along with the CCI. In some instances, pavement segments with CCI values greater than 60 may also require treatment application. As part of the condition assessment reporting process, the Virginia DOT reports the number of miles in fair or better condition. The condition assessment score is used to make initial screening recommendations, but the recommended treatment varies depending on specific distresses (in addition to the overall condition assessment score).

Analysis and conversion of the data for HPMS reporting is conducted by the Virginia DOT HPMS group using the data contained within the pavement management system.

RSL is viewed as a good measure for communication since it can be used to define the health of the pavement network that could be understood by a larger group of people. However, the RSL is not viewed to be a good measure for making decisions related to treatment timing and treatment type selection. Therefore, RSL is not considered to be an effective measure for determining budgetary requirements.

The Virginia DOT conducted a network-level deflection testing program that required 2 years to collect, and additional time and effort was needed to analyze the data. Significant work was also required between the data collection and reporting process. While the agency has made use of the FWD data within its pavement management system, a continuing program of network-level structural health measure based on deflection data is not considered to be feasible for the Virginia DOT.

The agency has participated in testing of the RWD data collection approach. However, data obtained from the RWD only includes a single deflection measurement at this time and therefore, is not viewed to be very helpful in quantifying pavement structural health.

4.5 Summary of Findings

Notable findings from the surveys and interviews were as follows:

Collection and Use of Pavement Structural Health Measures

- **Network-Level Deflection Testing:** Three agencies (Iowa, Kansas and Virginia) indicated the use of network-level pavement deflection testing. For the Iowa DOT, the deflection data is collected on a 2 to 6 year cycle depending on the highway functional class and is converted to a structural rating. The Kansas DOT uses the network-level deflection data for identifying pavement segments that require treatment application. Virginia DOT undertook a one-time collection effort and incorporated the information into its pavement management system.

- **Pavement Condition or Remaining Service Life Measures**: A majority of the seventeen agencies responding to the online survey reported using a surrogate measure for structural health based on pavement distress (e.g., cracking, patching, rutting, faulting), RSL or both.
- **Use of Structural Condition or Health Measures for Performance Reporting and Target Setting**: Agencies responding to the survey indicated that they used structural health information to report overall network condition (eight agencies), and set network performance targets (six agencies).
- **Use of Structural Condition or Health Measures for Treatment Selection and Prioritization**: Agencies responding to the survey indicated that they used structural health information to identify appropriate treatments for assignment by PMS decision trees (ten agencies), prioritize locations for funding (seven agencies), and forecast future rehabilitation needs (one agency).

Agency Opinions about Suitable Comparative Pavement Structural Health Measures

There was no consensus on suitable measures. Options suggested – with dissenting opinions are summarized below.

- **IRI:** Three agencies indicated that although data collection for IRI is relatively standardized, it may not be the most beneficial measure for quantifying pavement structural health.
- **Distress:** Three agencies supported the use of fatigue cracking and rutting for structural health of asphalt pavements. One agency each supported the use of joint faulting and mid-panel cracking for measuring the structural health in concrete pavements. Each of the agencies interviewed quantify pavement structural health based on surface distress.
- **RSL:** Two agencies supported the use of RSL as an indicator of structural health (e.g., agency could include cracking, rutting, deflection data, pavement thickness, and so on). Of the three agencies interviewed, Colorado DOT supports using RSL as measure of pavement structural health, while the New Jersey and Virginia DOTs do not.
- **Good-Fair-Poor:** One agency suggested that pavements be classified pavements as good, fair, or poor based on categories of distress.
- **Deflection/Structural Number:** One agency suggested calculation of a structural number based on deflection data. The three agencies interviewed also indicated that while network-level deflection data could be useful, they do not believe that implementation of a high-speed, network-level pavement deflection survey is possible within the next five years.

5.0 Future Options for Structural Health Reporting

5.1 Context for Structural Health Reporting

The final task in this study was to define options for how such structural health measures could be reported by each state, and used by AASHTO and FHWA to support national performance reporting, benchmarking and comparative analysis needs. Future options for structural health reporting were identified based on the literature review, analysis of state data submittals, and results of the state DOT survey and interviews.

The following principles were established to guide definition of reporting options:

- **Recognize Existing State Pavement Performance Monitoring Processes.** It is important to recognize that state DOTs generally have established processes for measuring, reporting and utilizing pavement condition and performance data. These processes are embedded in agency business processes and are, for the most part, meeting agency needs for pavement program development and external reporting. It would be difficult to make a compelling case for change, particularly if it involved adoption of new measurement approaches that would disrupt agencies' ability to maintain and utilize consistent trend information. However, as technologies for automated pavement data collection improve there may be future opportunities to move towards greater consistency in measurement practices.
- **Clarify Use of National Measures for Structural Health.** Performance measures can be used to serve different purposes. A measure that is suitable for one purpose (e.g. reporting to Congress on the state of the Interstate System) may not be suitable for another purpose (agency selection and prioritization of specific road sections for rehabilitation). It will be difficult to achieve consensus about structural health measures unless there is clarity about how these measures will be used. The assumption used here to identify structural reporting options is that national measures would be used to (1) characterize the structural health of the Interstate and NHS at the national level, (2) characterize the structural health of each individual state's Interstate and NHS for purposes of comparative analysis and benchmarking, and (3) potentially provide the basis for meeting target-setting requirements of the Moving Ahead for Progress in the 21st Century Act (MAP-21). It is *not* intended that these measures would be used to (1) allocate funding to individual states, (2) determine eligibility for funding of specific road sections or constrain an agency's use of federal funding, or (3) determine how agencies select pavement treatments or projects.
- **Build on Existing HPMS Reporting.** Future national reporting of pavement structural health should build on existing data standards and processes for HPMS reporting. This approach will minimize additional burdens on state DOTs. It also supports current efforts to improve HPMS data quality and value added for both state and national use.
- **Allow for Future Evolution.** Given advances in technology for automated pavement condition assessment, performance measures should be established that allow for the underlying basis for measure calculation to change over time. For example, measures

based on a condition category (e.g. "good-fair-poor") or need category (e.g. "maintain-renew-reconstruct) can be established to be stable over time even as the basis for determining condition or need category changes.

5.2 Options for Structural Health Reporting

In the short term (1-3 years), viable options for national structural health reporting could involve use of the measures selected for this study – cracking and rutting for asphalt and composite pavements; cracking and faulting for concrete pavements. There are several options that can be considered for combining and reporting these measures.

Table 10 presents options for structural health measures. Each row indicates the measure or measures to be reported – options are average values, percent good-fair-poor, percent by need category, or percent by remaining service life category. For each option, (other than the first) measures could be reported separately for each item (cracking, rutting and faulting), or a combined measure could be calculated based on the worst of the three items. IRI could also potentially be included in the combined measure.

Table 10. Options for Structural Health Measure Calculation

	A. Report Individual Measures	B. Report Single Combined Measure
1. Average values for cracking, rutting and faulting summarized by pavement type for Interstate and NHS systems (these could also be summarized by 0.1 mile section, pavement management section, and route/corridor);	Asphalt Pavement: average percent fatigue cracking, average rut depth Concrete Pavement: average percent of cracked slabs, average joint faulting depth	NA
2. Percent of lane-miles by condition category (good-fair- poor)	Percent good-fair-poor for each item based on ranges to be established. Calculate based on measures for uniform length sections (0.1-mile), weight by lane-miles	Percent good-fair-poor using the worst of the individual distress measures for each section. Calculate based on measures for uniform length sections (0.1-mile), weight by lane-miles
3. Percent of lane-miles by need category (RM-routine maintenance, CM-corrective maintenance, RH-rehabilitation/reconstruction)	Percent RM, CM, RH for each item based on ranges to be established. Calculate based on measures for uniform length sections (0.1-mile), weight by lane-miles	Percent RM, CM, RH using the worst of the individual distress measures for each section. Calculate based on measures for uniform length sections (0.1-mile), weight by lane-miles
4. RSL category (e.g. <2 years, 3-10 years, 11+ years)	RSL category based on standard performance curves and terminal values for each individual measure	RSL category based on the lowest individual RSL value for each of the measures

From a national reporting standpoint, measures in Column B are preferable, since they would be simpler to present than multiple measures based on individual distresses. Option 1 - use of averages to characterize entire systems (e.g. average rut depth for Interstates) is problematic in that it makes it difficult to distinguish a network with fairly uniform conditions from one with a mix of very good and very poor condition segments. Options 2 and 3 (percent of lane-miles by condition or need category) would be more straightforward to calculate than Option 4 - RSL, since RSL requires use of performance curves and a commonly agreed-upon method for translating different distress values to remaining life.

Utilizing option 3B - Percent of lane-miles by need category - would be consistent with the approach that has been recommended by the AASHTO Standing Committee on Highways Standing Committee on Highways (SCOH) Subcommittee on Bridges and Structures (SCOBS)[6]. The SCOBS-recommended approach is to report numbers of bridges and deck area on bridges falling into three need categories:

- Cyclical or Routine Maintenance
- Preventative Maintenance, and
- Rehabilitation/Replacement

SCOBS' intent of using need categories rather than condition categories was to provide more effective language for communicating asset performance. Either condition categories or need categories would be based on the same underlying data (National Bridge Inventory ratings). SCOBS recommended that need categories be assigned based on the bridge element (superstructure, substructure, deck) in the lowest condition, since this would drive the need. A similar approach could be used for pavements, though a more nuanced method (e.g. based on a decision tree) could be utilized as well. A collaborative exercise across states to further investigate this approach would be required to determine the feasibility of defining and obtaining agreement on a common set of thresholds or decision rules for assigning need categories based on condition measures.

Option 2B is consistent with the approach featured in the recent FHWA report on "Next Generation Pavement Performance Measures"(1). This report recommends use of the good-fair-poor option for individual distresses, though the definitions used for condition categories refer to the type of applicable treatment: Good = Preventive Maintenance, Fair = Minor Rehabilitation (Patching and Overlays), and Poor = Structural Repair/Rehab/Replacement.

Either option 2 (condition categories) or 3 (need categories) allows for future improvement in the underlying measurement approach.

5.3 Activities Required for Successful Implementation

Given the current state of the practice national implementation of a consistent set of pavement structural health measures cannot be accomplished overnight, and would require commitment of resources. However, an implementation path can be defined to ensure steady progress. Steps in this path – to be undertaken through a collaborative effort by FHWA and AASHTO - would include:

1. **Establish the Measure.** Select one of the options in Table 10 for reporting. Establish agreement on the details of the calculation methodology –agree on (1) specific measure ranges for condition or need categories, and (2) specific methods for aggregating different distresses into a single measure – e.g. based on lowest value or decision tree approach. If RSL is to be used, agree on a precise definition, standard terminal values and deterioration curves for different pavement classes.

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[6] Memo from Gregg C. Fredrick, P.E., Chair, AASHTO Subcommittee on Bridges and Structures to Paul Degges, P.E., Chair, SCOPM Task Force on Performance Measure Development, Coordination and Reporting, Matthew H. Hardy, PhD., AASHTO Program Director for Planningand Policy, Tim Gatz, P.E., Chief Engineer, Oklahoma DOT Re: Subcommittee on Bridges and Structures National Performance Measures and Reporting for Highway Bridges, July 10, 2013

2. **Produce an Initial Draft Set of Measures**. Calculate the established measures based on current HPMS cracking, rutting and faulting data; and present with clear caveats about variations in measurement that limit comparability.
3. **Refine Standards and Guidance.** Refine existing HPMS standards and guidance for measurement and reporting of pavement cracking, rutting and faulting. (Table 11 below includes recommendations on this from a recent FHWA study.)
4. **Identify Gaps.** Develop guidance for states to audit their current practices and identify gaps between current practice and the refined standards. Provide assistance for implementing the pavement data audit – potentially using an approach similar to the recent Roadway Safety Data Assessment program. Ideally this process would result in a nationwide assessment of both the extent and the impact of agency deviations from standards for measuring and calculating faulting, rutting and cracking. The audit process would produce a set of recommendations for changes to data collection, HPMS measure calculation and reporting practices – that could be phased in over time. See Table 12 for an example approach to documenting adherence to standards.
5. **Provide Support for Closing the Gaps**. Support and promote voluntary efforts to close the gaps and make data available for comparative analysis. Given likely barriers that will be faced, a set of provisional methods could be established to incrementally increase consistency as states move towards full adoption of the standards.
6. **Make the Data Available**. Making data available to participating states in an easily accessible form for analysis and comparison (along with metadata describing differences in data derivations) would provide visibility needed to encourage progress towards greater consistency. To be meaningful, the comparative data should be available for state peer groups (e.g. by region), with the ability to view results by functional class, rural/urban designation, pavement type and traffic level.

The recently completed study of next generation pavement performance measures provided several recommendations for improving quality and consistency of the HPMS cracking, rutting and faulting data (1). These recommendations are summarized in Table 11 and provide a good starting point for refinement of the HPMS standards (step 3).

Table 11. Recommendations for Pavement Data Consistency Improvement

Element	Recommendation
Cracking	*Data Collection & Processing* • Use automated data collection method, with a 100 percent sampling rate. • Summarize data in 0.1-mile sections. *Quality Control* • Validate any new equipment for data collection and processing against a crack map for sample sections prepared by a rating team. Validate under varying anticipated operational conditions (sun/shade, moisture, surface texture, speed). • Utilize a continuous quality control approach such as that proposed by AASHTO PP68-10 – involving multiple checks against a verification site throughout the season. • Perform manual quality checks on a minimum of 5 percent of collected sections. Expand this percentage if error rate is over 15 percent. *Storage* • Archive images to enable review and potential future re-calculation of summary data. • Flag potential quality issues (e.g. inconsistent spatial referencing with prior year) and include such flags as HPMS metadata elements.
Faulting	*Data Collection & Processing* • Measurement spacing should be every 0.75 inches as identified in AASHTO R36-12, consistent with ASTM STP 1555. • Summarize data in 0.1-mile sections. • Schedule measurements for each location to minimize differences in the degree of curling from one date to another. • Calculate faulting from longitudinal profile data using ProVAL version 3.3 (or later version), which utilizes Method A of AASHTO R36-12. • Both joints and cracks should be analyzed and reviewed for faulting on jointed concrete pavements (though it is acknowledged that improvements are needed to current technology for automated faulting detection at cracks). *Quality Control* • Validate any new data collection process (equipment and operator) per AASHTO R56-10. Validation should include review of joint detection for different texture types, joint spacings and joint types. • Perform daily equipment checks and maintain logs per AASHTO R57-10, to include tire pressure, block check of height sensor, and a bounce test. • Conduct an annual QA review and use the following criteria to trigger more detailed review: increase in faulting >.08 in/year, decrease in faulting >.04 in/year, difference between segments >.1 inch. *Storage* • Store average, minimum, maximum and standard deviation values for each 0.1-mile section. • Store the full longitudinal profiles to enable future review or re-calculation. • Include additional metadata for each section: joint detection method, number of detected cracks and joints, joint spacing, date and time of data collection. • Flag potential quality issues (e.g. inconsistent spatial referencing with prior year) and include such flags as HPMS metadata elements.
Rutting	*Data Collection & Processing* • Collect data points to cover a minimum width of 13 feet, consistent with AASHTO PP70-10. • Ensure that the separation between data points is less than or equal to 0.4 inches, per AASHTO PP70-10. • Ensure that the maximum longitudinal spacing between profiles is 10 feet, per AASHTO PP70-10. • Apply a 2-inch moving average filter to the transverse profile, per AASHTO PP69-10. • Utilize the wireline method as the basis for rut depth computation. • Utilize a gage width of 1.2 to 1.5 inches for calculating the rut depth. *Quality Control*

Element	Recommendation
	• For data collection, follow system validation protocols described in AASHTO PP70-10, covering each device component and reflecting typical variations in operating conditions. • Per AASHTO PP70-10, include regular (e.g. monthly) checks of collected data against a validation section and checks of the distance measuring instrument throughout the active data collection cycle. • Conduct quality reviews of collected data and trigger additional reviews based on the error limits identified within AASHTO PP69-10: spatial change in rutting greater than 0.1 in/foot; increase in rutting more than 0.1 in; decrease in rutting more than 0.5 in. *Storage* • Store values for average, minimum, maximum, and standard deviation of rutting; and cross slope for each 0.1-mile section within the HPMS database. • Store the full transverse profiles to enable future review or re-calculation. • Flag potential quality issues (e.g. inconsistent spatial referencing with prior year) and include such flags as HPMS metadata elements.

Note: Table content is summarized from reference (1)

Table 12 presents a sample format that could be used to assess a state's level of consistency with established standards. This format could include elements from Table 11, as well as the following additional items that may contribute to variability in reported measures:

- The types and specific definitions of distresses included as fatigue cracking, and whether the agency distinguishes wheelpath from non-wheelpath cracking;
- Methods for calculating area of cracking – including assumptions about wheelpath widths, lane widths, and crack widths; and correction methods (e.g. one agency limits the area of reported fatigue cracking to the total wheelpath area);
- Use of sampling methods for cracking calculations (e.g. sample only the first 500 feet of a section);
- Methods for determining the number of slabs in a section;
- Lanes surveyed (e.g. right-most lane); and
- Inclusion of data for one or both directions.

Table 12. Sample Format for Pavement Data Assessment

Parameter	Standard/Protocol	Compliance Level	Notes
Scope	**Example:** *Include 100 percent of NHS roadways*	**Example:** *Compliant* ✓***Semi-compliant*** *Non-compliant* *N/A*	**Example:** *100 percent of Interstates – both directions; 75 percent of NHS – single direction for undivided roads with less than 4 lanes*
Cracking Definition			
Data Recording			

Parameter	Standard/Protocol	Compliance Level	Notes
Quality Assurance			

(Table adapted from *Evaluation of AASHTO Cracking Protocol: Quantifying Distress in Asphalt Pavement Surfaces*, 2003)

While establishing clear and precise standards is an important activity, it is important to note that many of these recommendations would require significant additional effort on the part of states to implement. This may impact feasibility of implementation, particularly where existing data accuracy is judged to be sufficient to meet state pavement management needs. The current study and the recent study on increasing consistency of HPMS pavement reporting data (2) identified several barriers to be overcome:

- Some state practices do not currently support collection or summarization of cracking or faulting consistent with current HPMS definitions. These states currently use conversion formulas with default values for HPMS reporting. These states would need to undertake changes to their data collection and/or summarization specifications, with associated changes to databases and calculation programs. Many states do not perceive that their own pavement management programs would benefit from such activities.
- Some states obtain summarized data from their data collection vendors and cannot readily access or integrate the raw data that would be required to calculate the HPMS pavement data.
- Many states do not currently collect detailed pavement data on non state-maintained sections of the NHS. Moving to a 100 percent sampling approach would represent a substantial new data collection burden.
- There are currently significant variations in reporting intervals used for HPMS pavement data. Work is required to shift to consistent use of 0.1-mile summarization sections for their pavement data. Variations in section lengths are extremely problematic since they have a large impact on performance results.
- Quality assurance checks for HPMS pavement data may not be as stringent as those used for agency PMS data. Additional range checks and cross-element consistency checks would be beneficial to ensure that errors are not introduced in the process of data conversion and transfer.
- Many states cannot readily perform geospatial comparisons of HPMS and PMS data which limits the ability to perform cross-checks for quality assurance purposes.

These barriers underscore the need for a phased approach in moving towards implementation of the selected structural health measures, beginning with a clear understanding of gaps and a realistic plan for closing them. As incremental progress is made, reporting processes can be put into place with full disclosure of metadata that allows data users to understand limitations.

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Appendix A. Data Specifications

Data Specifications

Data Submittal Guidelines

Corridor Selection

1. Please provide data for 2 Interstate and 2 non-Interstate NHS corridors
2. Each corridor should be at least 10 miles in length (longer is OK).
3. The corridors should ideally include a mix of rigid and flexible/composite pavement types. Each corridor does not need to include only a single pavement type - there may be a mixture of pavement types within a corridor.
4. Please exclude Continuously Reinforced Concrete (CRC) pavements from your submittal. CRC overlaid with ACP can be included.
5. If your state has a negligible amount of concrete pavement mileage it is OK to just provide data for flexible and composite pavements – just note that in your submittal email.
6. Avoid selecting corridors with long bridges. If selected corridors include short bridge sections, please identify these if possible.

General Guidance for Data Submittals

1. Please provide your data summarized into 0.1 mile sections.
2. Data should be provided representing 2012 conditions if possible or 2011 conditions otherwise.
3. If you collect data for both directions of the corridor separately, please provide data for each direction. The number of lanes item should be the number of lanes represented by the collected data. If you collect data for a single direction to represent both directions of travel, enter a “B” for item C4 (Directions Represented)
4. If you have derived the percent cracking/percent cracked slabs items from other data in your pavement condition data set, please provide the data elements from which these were derived and attach a specification with any assumptions/factors utilized that would allow the research team to reproduce these calculations.
5. If you are unable to supply the HPMS Surface Type field, we will contact you to get a mapping from your agency’s Surface Type field.
6. For item C17 (Bound Layer Thickness) – if you have info on thickness, please supply the # inches. If you do not, please supply an estimate: Thin (<4”), Medium (4-8”) or Thick (>8”).

7. Note: following our conference call the research team conferred and decided to add IRI to the items being requested. This will allow us the option of computing performance indicators based on combinations of roughness and structural condition. If this addition poses a problem for you, please contact Frances Harrison to discuss.
8. If shape files are available for the data being submitted please include them. This will be helpful, but is optional.

Data Submittal Template

The following template was provided to all participating states for data submittal.

Table A-1. Data Submittal Template

Col ID	Col Name	Metadata	Example
Section Description			
C1	State	2-letter state abbrevation	MA
C2	Route	Route Number	I-95
C3	Survey Direction	Survey Direction (N/S/E/W)	N
C4	Both Directions Represented?	Y - data represents condition of both directions N - data for each direction provided separately	B
C5	From	Rt-MP preferred	0
C6	To	Rt-MP preferred	0.12
C7	Length	Section length (mi)	0.11
C8	# Lanes	# Thru Lanes - Both Directions	4
C9	Bridge Section?	Y - Yes N - No U - Unknown	N
C10	Survey Date (for distress and IRI)	Date of condition data (full date preferred, use Jan 1 if only the year is available)	5/8/11
C11	HPMS Surface Type*	HPMS Item 49 - Code 1-11	4
C12	Agency Pavement Type	Your agency's classification of pavement type	JRCP
C13	Federal Functional Class	HPMS Item 1	1
C14	Rural/Urban	R if Rural, U if Urban	U
C15	Year of Last Improvement	HPMS Item 54	2010
C16	Year of Constr/ Reconstr	HPMS Item 55	2003

Col ID	Col Name	Metadata	Example
C17	Bound Layer Thickness	Enter # in or estimated category: Thin (< 4") Med (4-8") Thick (>8")	5 or "Med"
C18	AADT (most recent year available)	HPMS Item 21	4,369
C19	% Trucks	Percent trucks or HPMS Items 22 and 24	20
C20	IRI	HPMS Item 47	90.0
Standard Distress Info			
C21	Average Rut Depth (in)	Flexible pavement only (9.999)	0.252
C22	Average Joint Faulting (in)	Jointed PCC pavement only	0.423
C23	Pct Fatigue Cracking*	Flexible pavement only - percent of total are with fatigue cracking - any severity (99.9)	10.2
C24	Pct Cracked Slabs*	Rigid pavement only - percent of cracked slabs	4.3
Agency Distress Info			

Item-Specific Guidance

The following item-specific guidance was provided as a supplement to the data submittal guidelines and data submittal template.

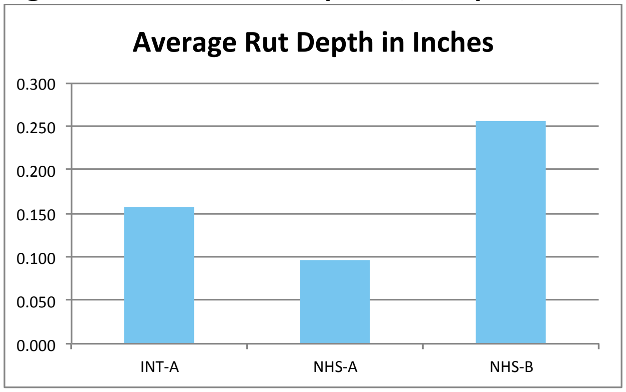
Table A-2. Item-Specific Guidance

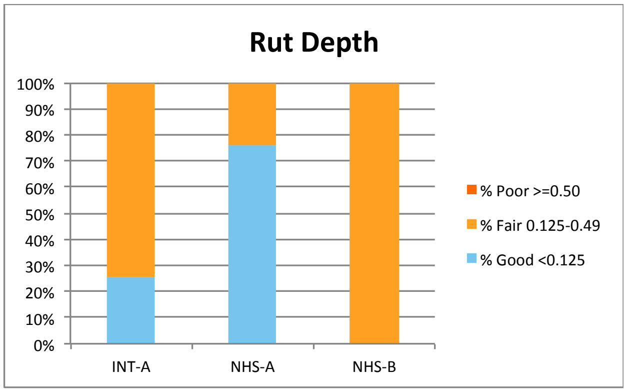
Col	Item Name	Description/Guidance
C1	State	2 letter state abbreviation (this can be left blank as long as your file is clearly marked with your state name.)
C2	Route	Name of the route (e.g. I-95)
C3	Survey Direction	Signed direction of travel for the roadway surveyed (N-North, S-South, E-East or W-West)
C4	Both Directions Represented?	If you are providing a single direction of data for the corridor, enter Y. If you are providing data for each direction separately, enter N.
C5	From	A milepoint or other location reference indicating the starting point for the .1 mile section
C6	To	A milepoint or other location reference indicating the ending point for the .1 mile section

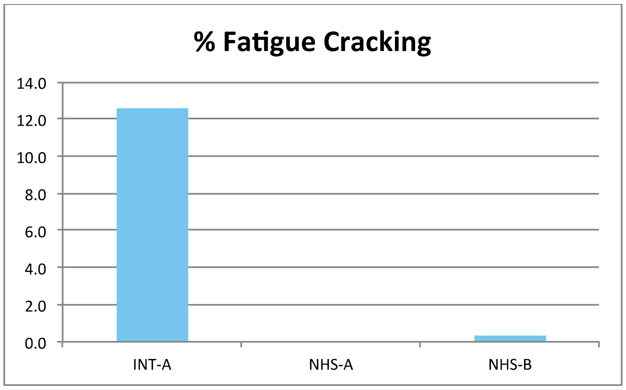
Col	Item Name	Description/Guidance
C7	Length	The length in miles (to the nearest 100th of a mile of the section.
C8	# Lanes	The number of lanes represented by the survey data. For example, if you collect data for the right-most lane only in a corridor with 2 lanes in each direction, the survey data would represent 4 lanes.
C9	Bridge Section?	Enter Y if the section is on a bridge (fully or partially)
C10	Survey Date (for distress and IRI)	Enter the date that the IRI, rutting, faulting, and cracking data were collected. If the exact date is not available, use January 1 as the month and day.
C11	HPMS Surface Type*	Enter the code (1-11) for the HPMS Surface Type (HPMS Item 49). If unknown, the research team will contact you to develop a mapping from item C12.
C12	Agency Pavement Type	Enter your agency's classification of the pavement type for the section.
C13	Federal Functional Class	Enter the federal functional class code (HPMS Item 1)
C14	Rural/Urban	Enter R for a rural section, or U for an urban section
C15	Year of Last Improvement	Enter the year (9999) of the last pavement surface improvement on the section (HPMS Item 54). 0.5 inch or more of compacted pavement material must be put in place for it to be considered a surface improvement.
C16	Year of Construction/ Reconstruct-ion	Enter the year (9999) of the last construction or reconstruction on the section (HPMS Item 55). Reconstruction is the replacement of the existing pavement structure with an equivalent or increased structure. If a new pavement surface were placed without first removing the old pavement surface, the resulting pavement should be considered an surface improvement, not reconstruction.
C17	Bound Layer Thickness	Enter the thickness in inches of the bound layers. If not known, estimate thickness and provide one of the following categories: Thin (< 4"), Medium (4-8"), or Thick (>8")
C18	AADT (most recent year available)	Enter the Annual Average Daily Traffic for the section for the most recent year available (HPMS Item 21)
C19	% Trucks	Enter the Percent Trucks for the section for the most recent year available. (Sum of HPMS Items 22 and 24 divided by the AADT- Item 21)
C20	IRI	Enter the IRI for the section in inches per mile
C21	Average Rut Depth (in)	For flexible or composite pavements only: Enter the average rut depth in inches to the nearest 1,000th of an inch.
C22	Average Joint Faulting (in)	For rigid pavements only: Enter the average joint faulting depth in inches to the nearest 1,000th of an inch.
C23	Pct Fatigue Cracking*	For flexible or composite pavements only: Enter the percent of the section with fatigue cracking. Include fatigue cracking and longitudinal cracking in the wheel path that has associated random cracking (any cracks in the wheel path that have a quantifiable area).
C24	Pct Cracked Slabs*	For rigid pavements only: Enter the percent of cracked PCC slabs.
		In the remaining columns, please provide source cracking data from which items C23 and C24 are derived, and attach a separate specification that would allow the research team to reproduce these calculations.

Appendix B: Detailed Performance Results

Figure B-1. State 01 – Asphalt /Composite







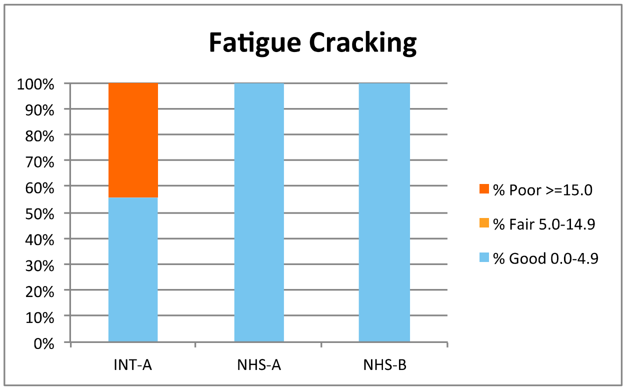
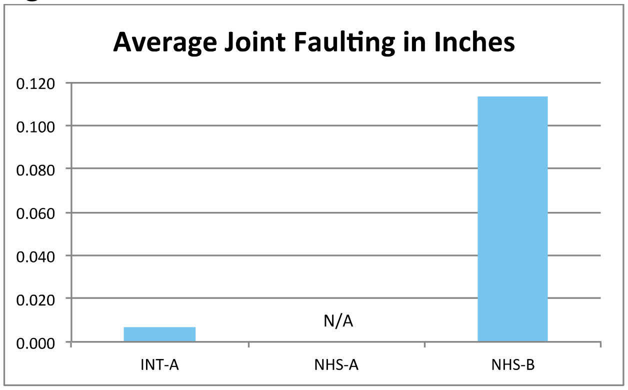
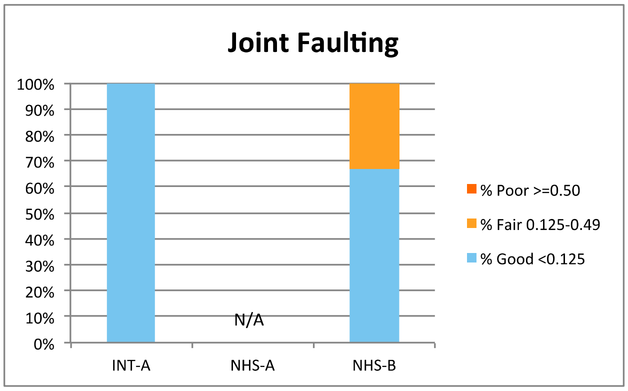
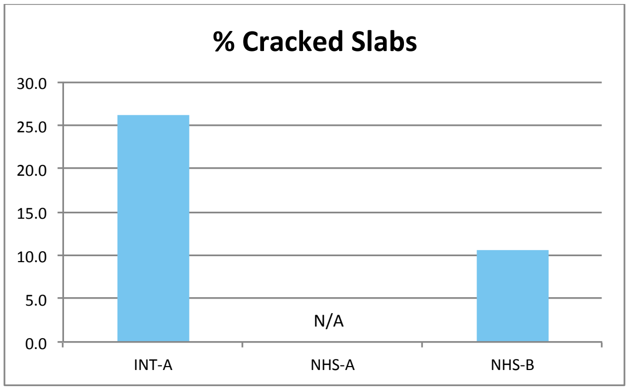


Figure B-2. State 01 – Concrete






% Cracked Slabs
30.0
25.0
20.0
15.0
10.0
5.0
0.0
N/A
INT-A
NHS-A
NHS-B

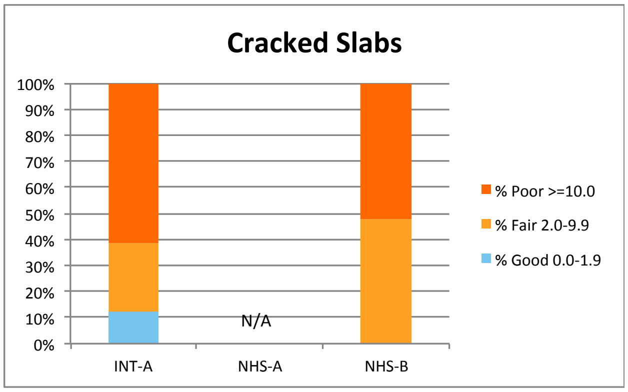

Cracked Slabs
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
N/A
INT-A
NHS-A
NHS-B
% Poor >=10.0
% Fair 2.0-9.9
% Good 0.0-1.9

Figure B-3. State 02 – Asphalt /Composite

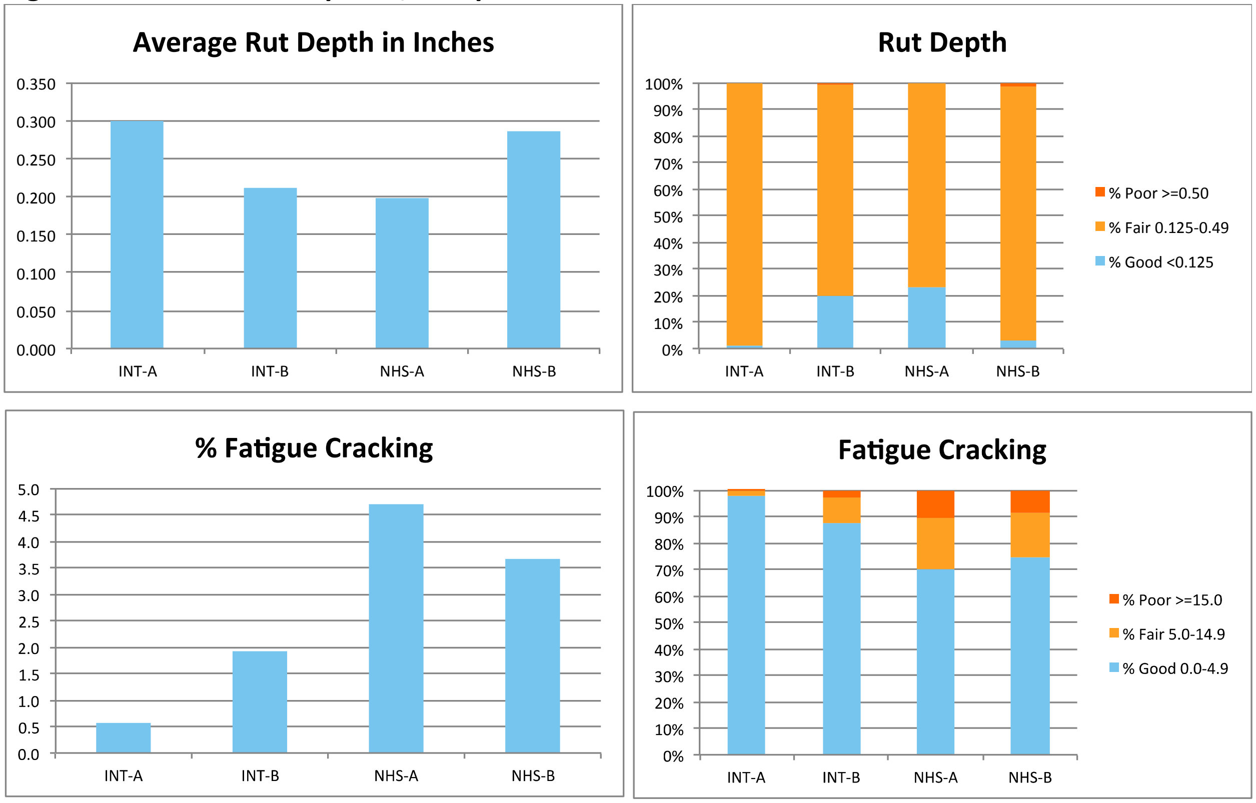


Figure B-4. State 02 – Concrete

Figure B-5. State 03 – Asphalt/Composite

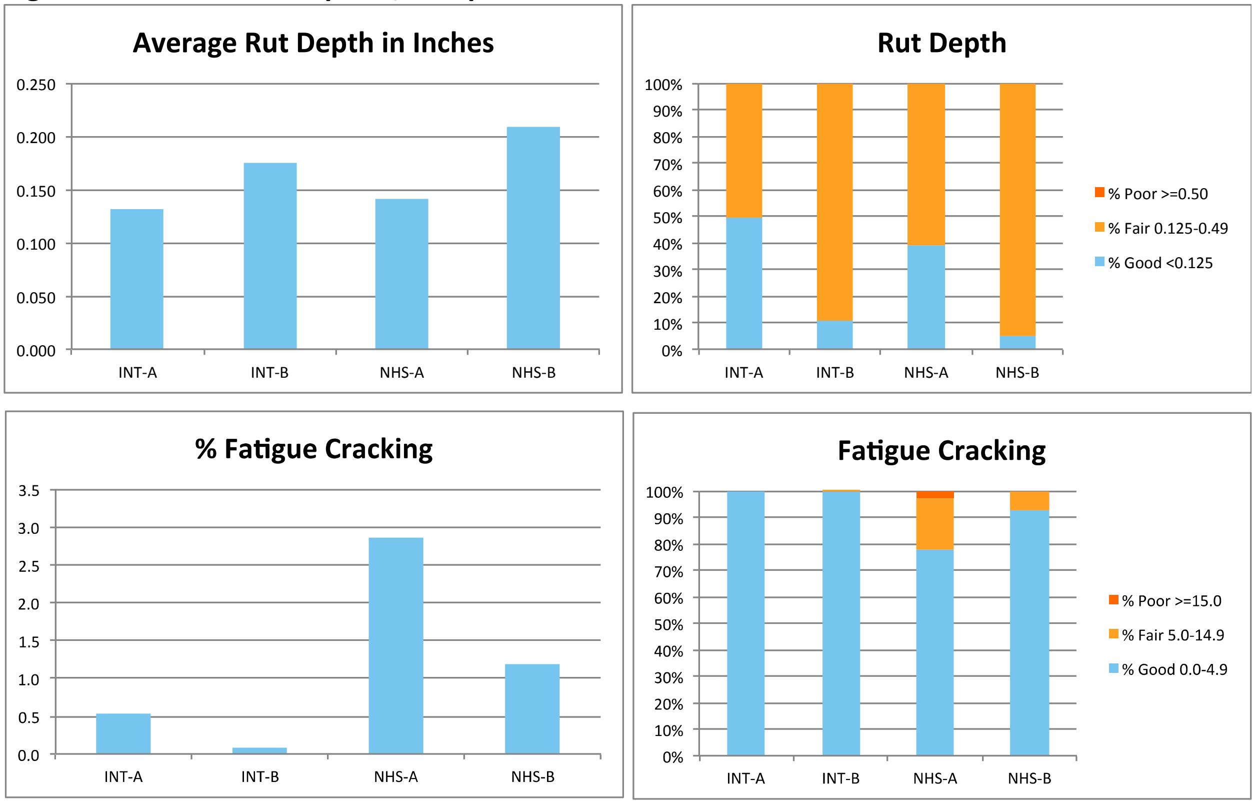


Figure B-6. State 03 – Concrete

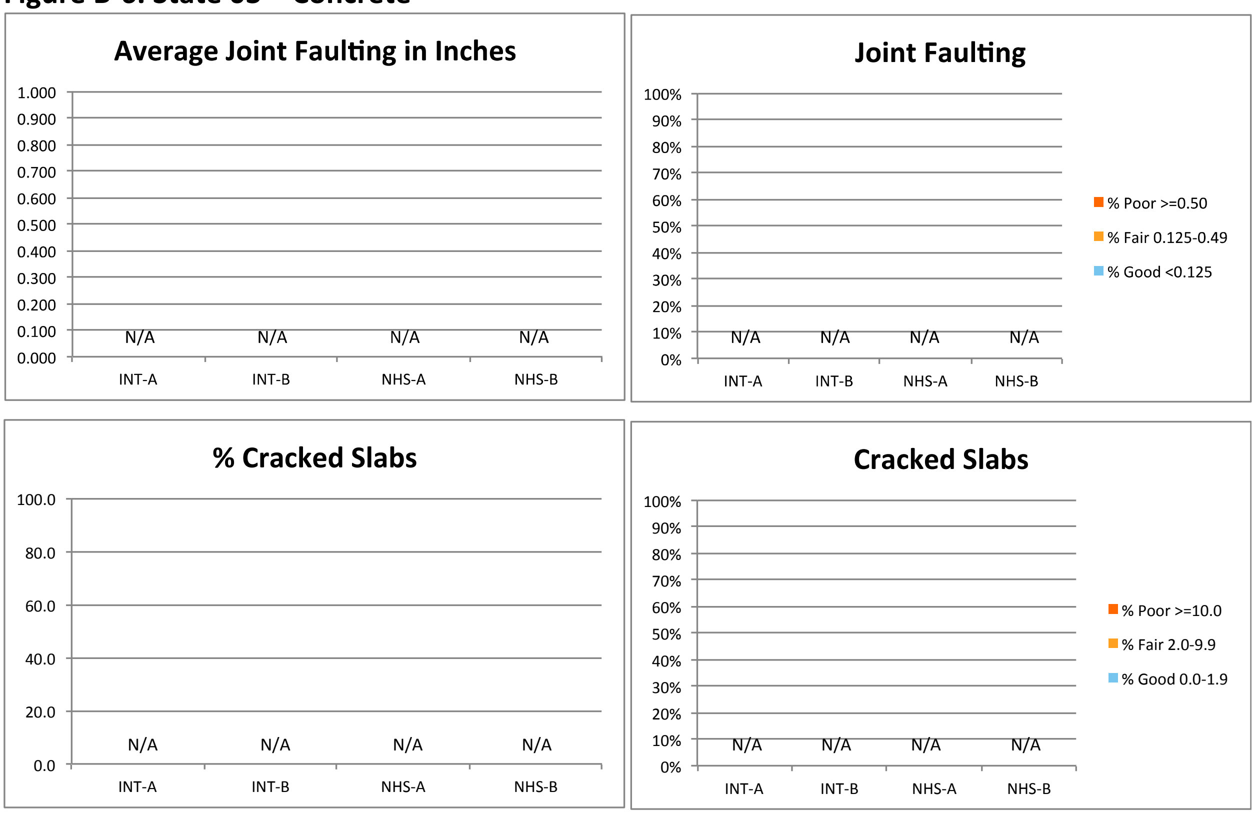


Figure B-7. State 04 – Asphalt/Composite

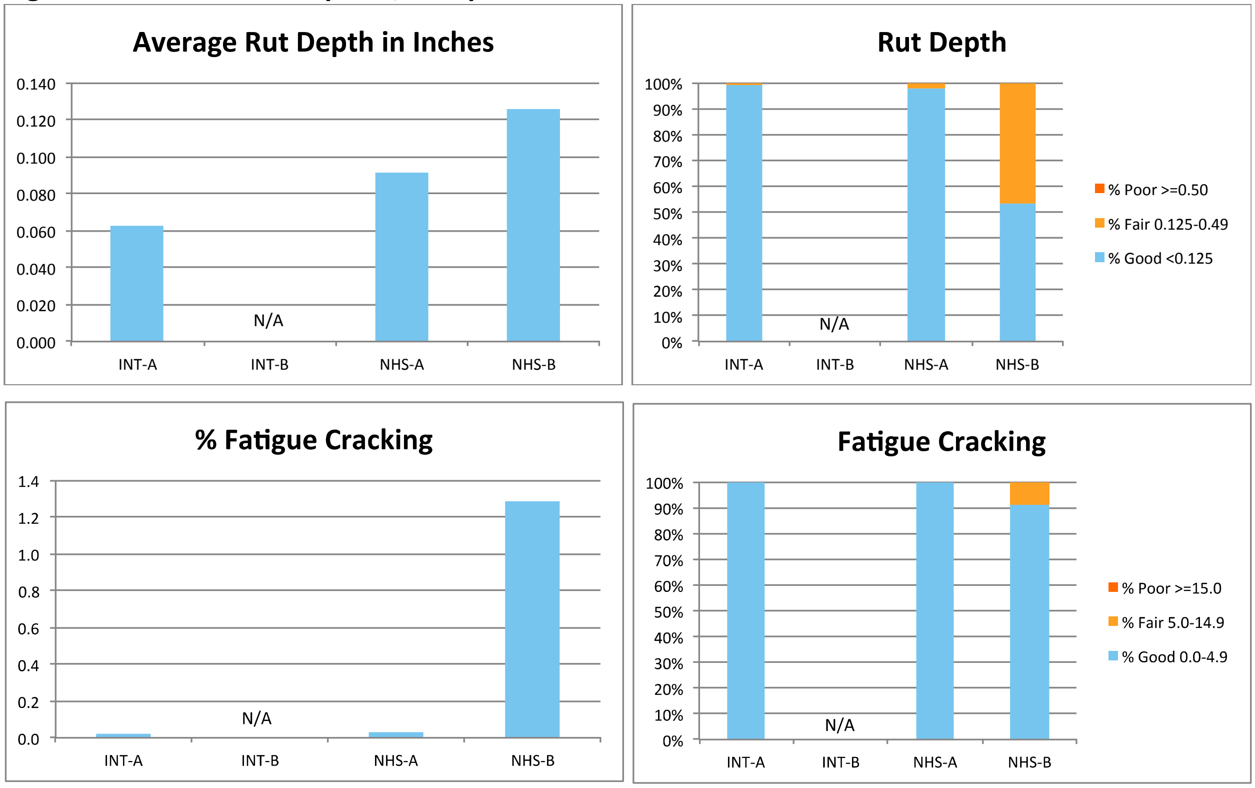


Figure B-8. State 04 – Concrete

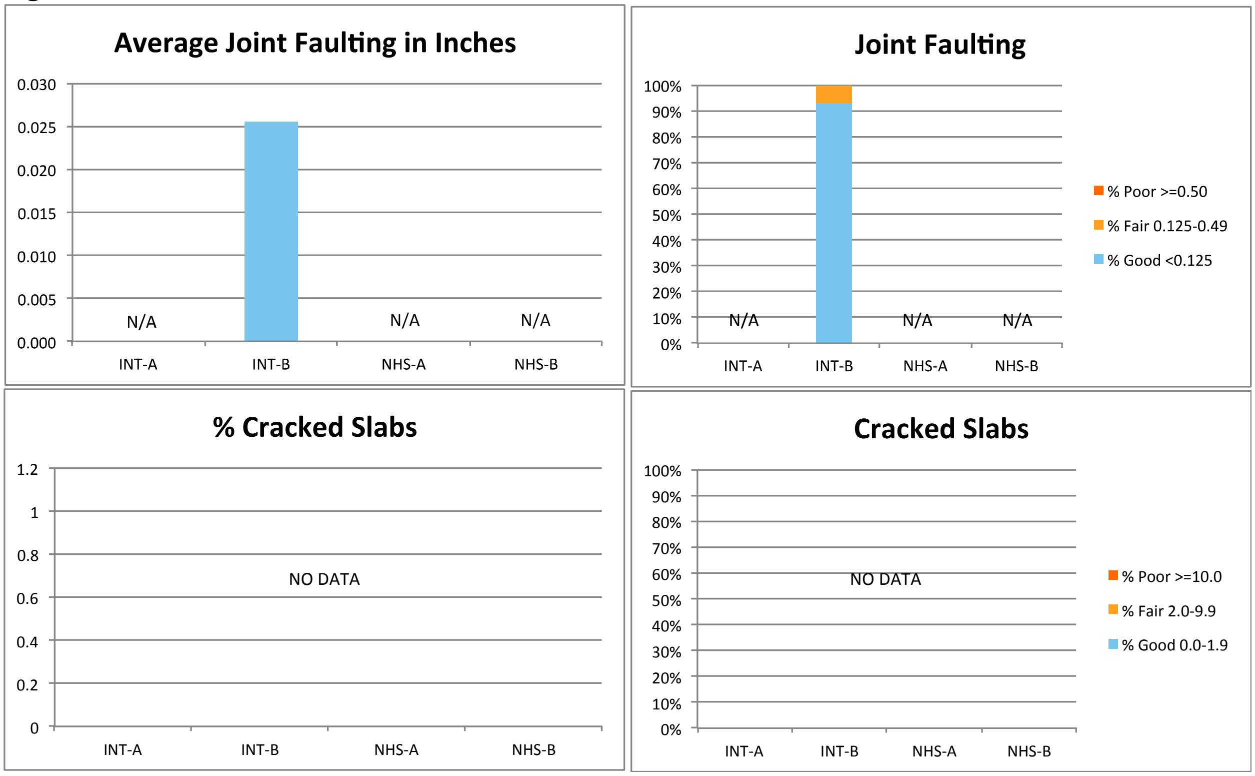


Figure B-9. State 05 – Asphalt/Composite

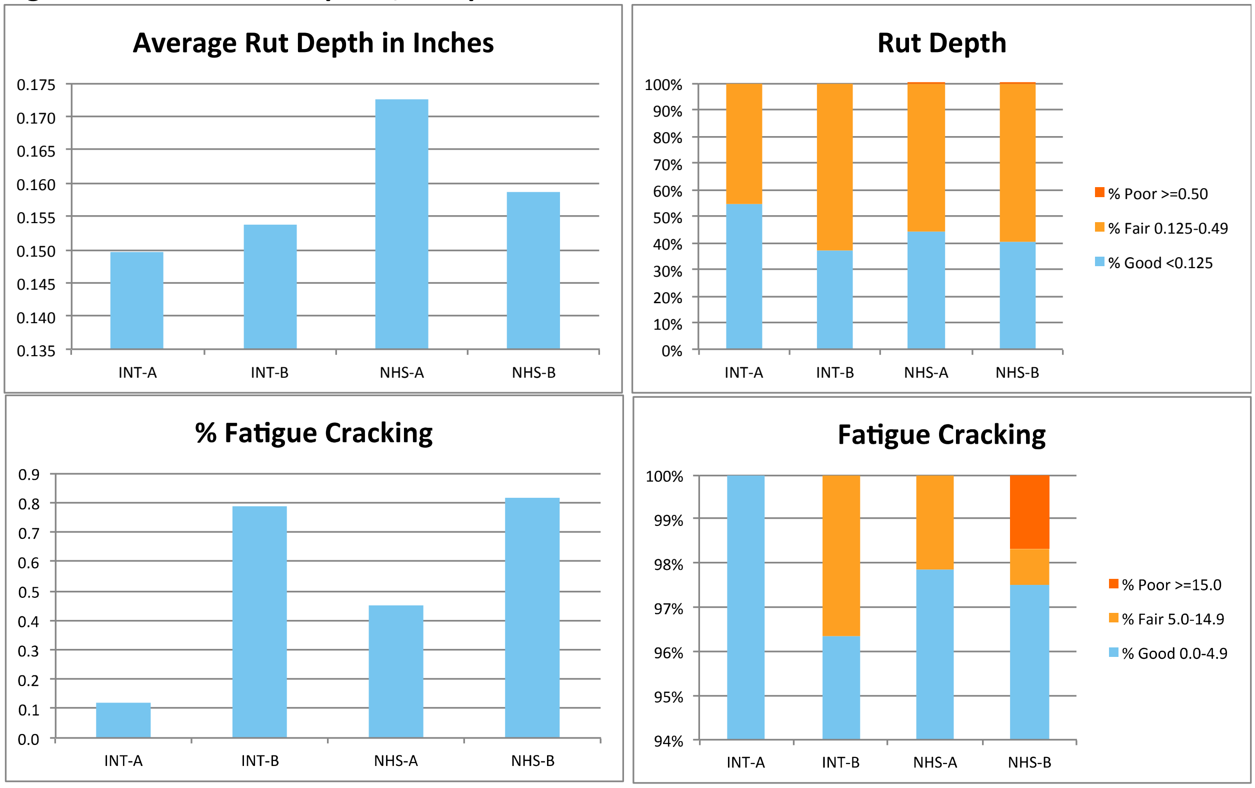


Figure B-10. State 05 – Concrete

Figure B-11. State 06 – Asphalt/Composite

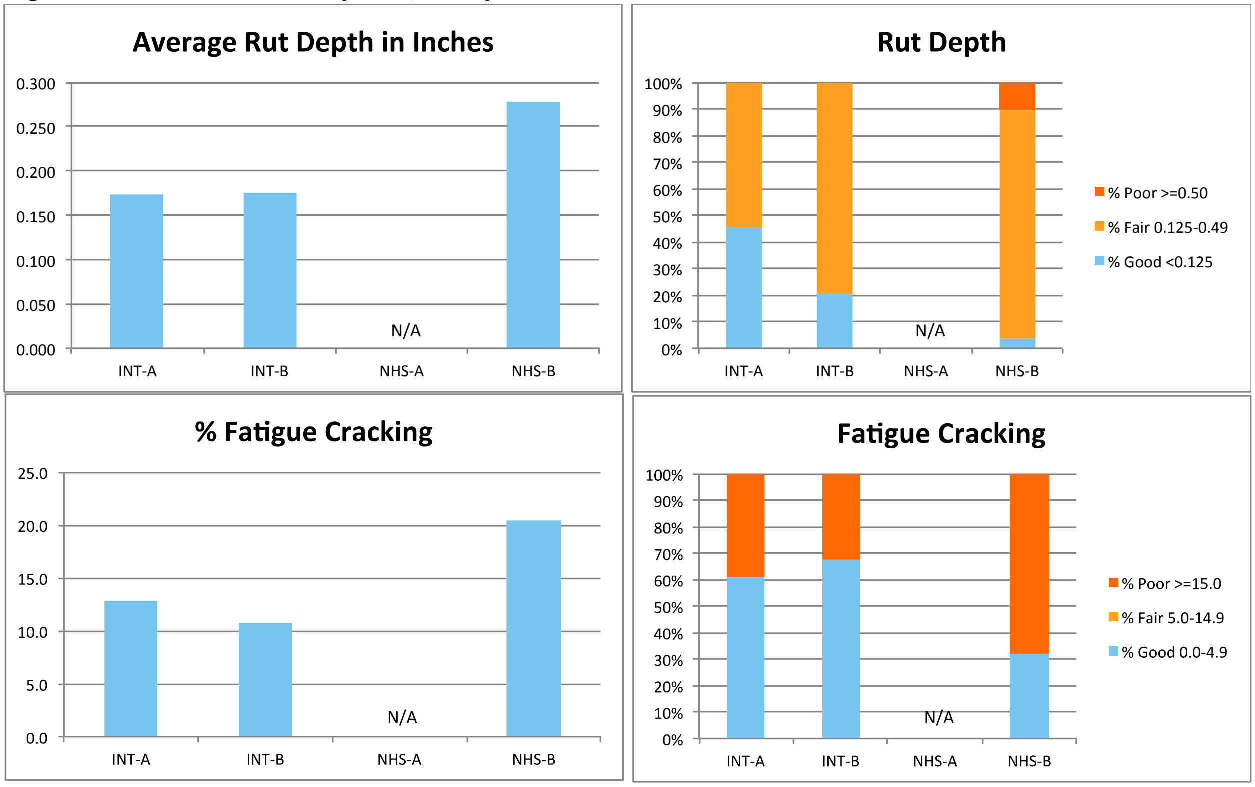


Figure B-12. State 06 – Concrete

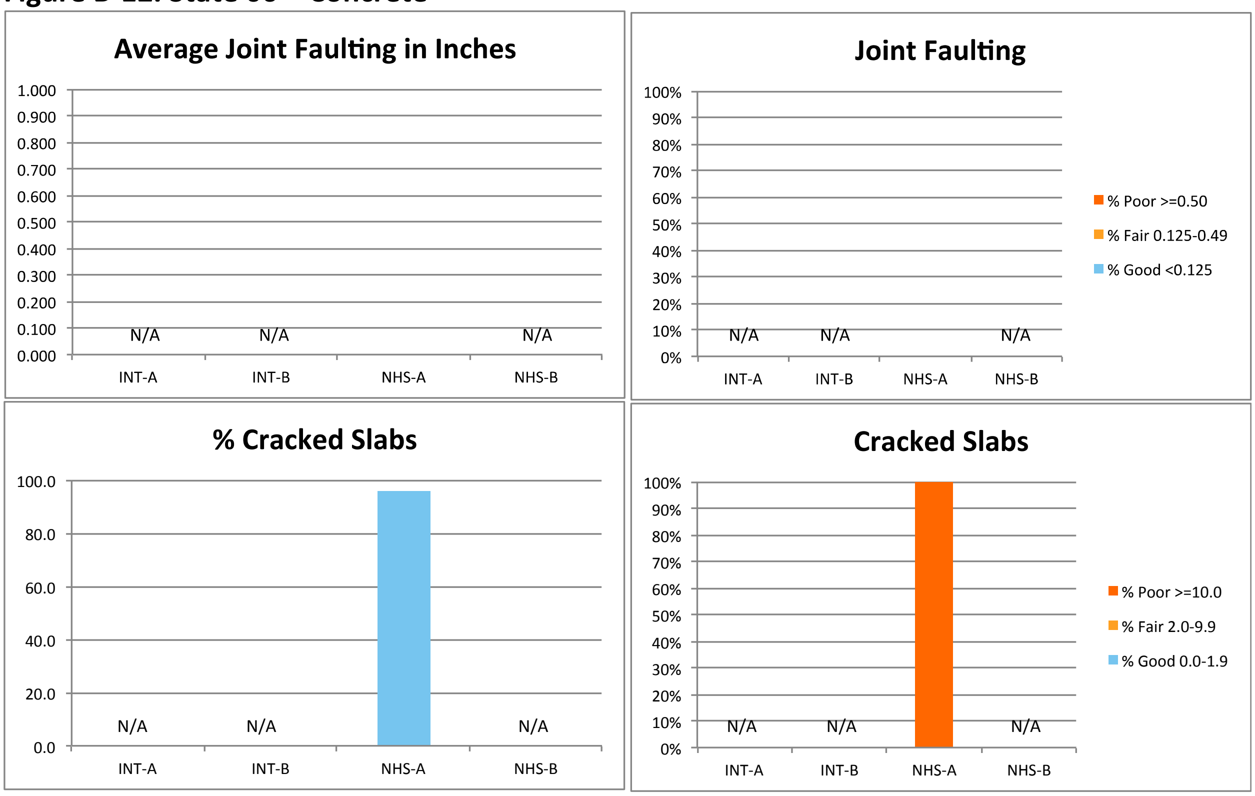


Figure B-13. State 07 – Asphalt/Composite

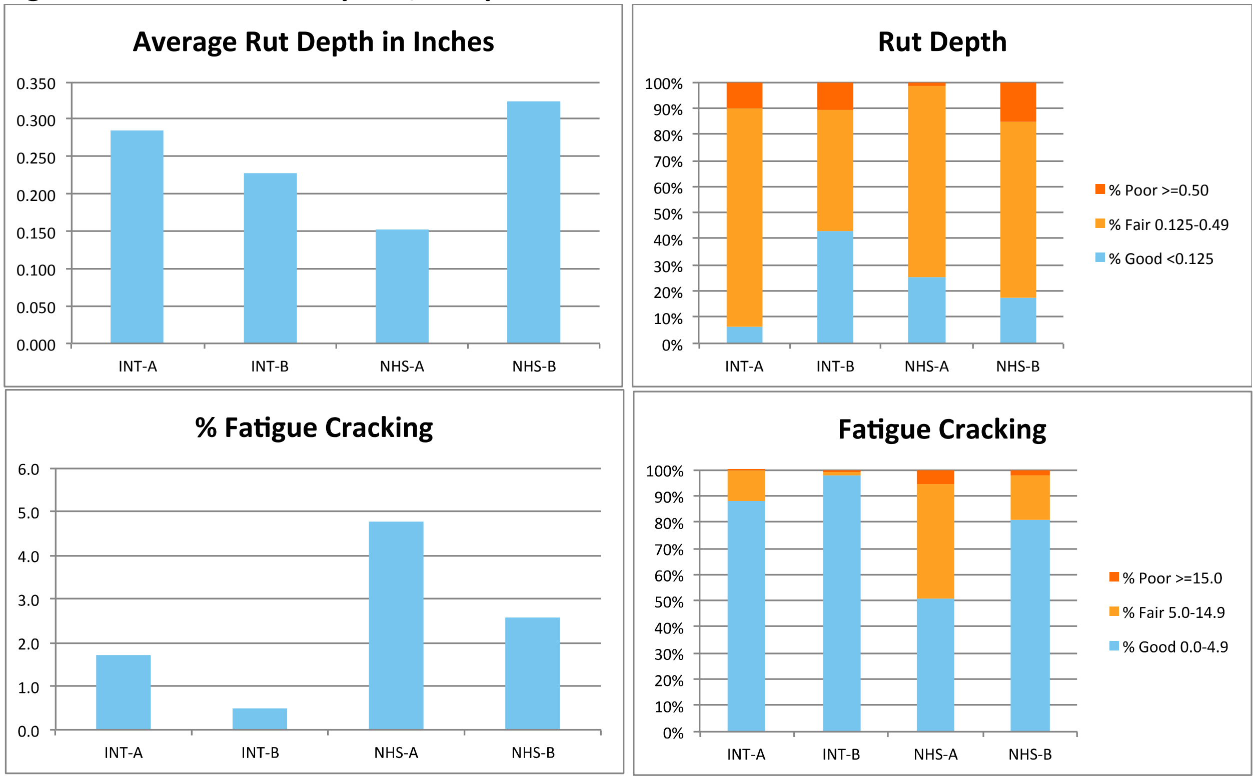


Figure B-14. State 07 – Concrete

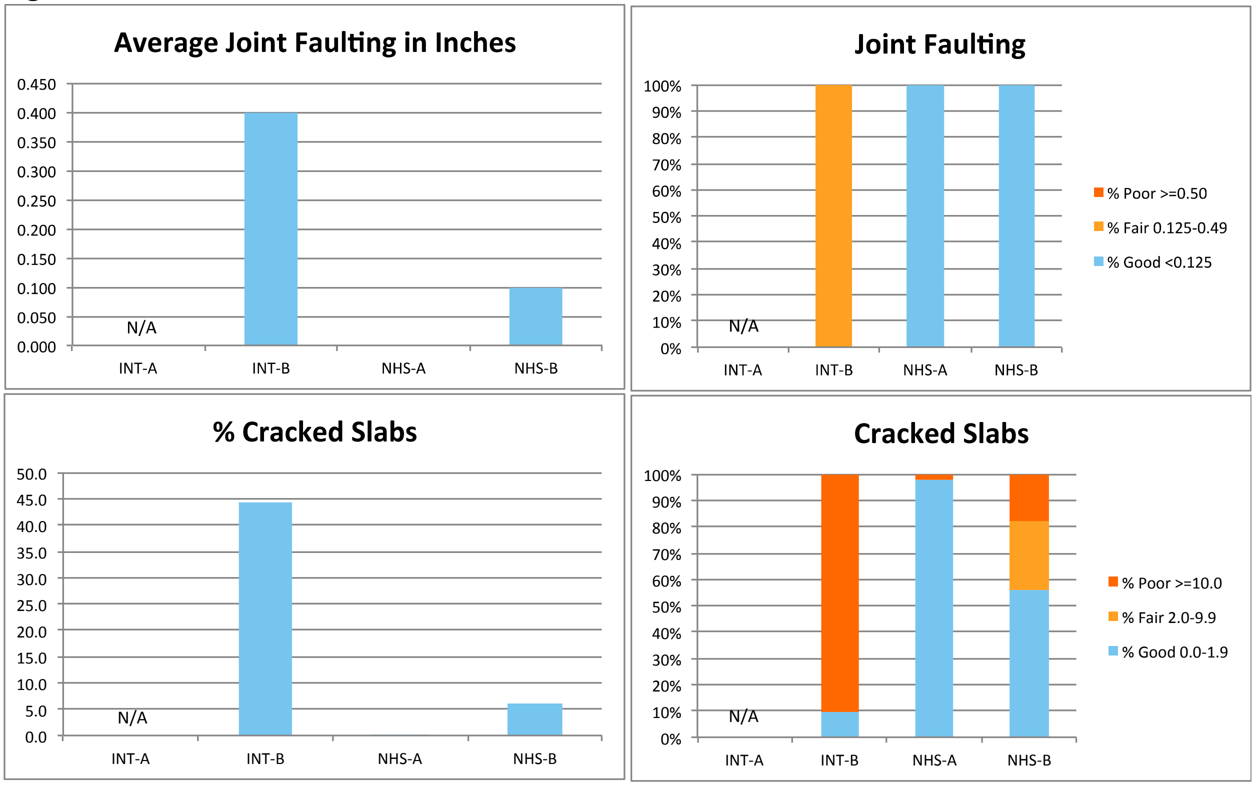


Figure B-15. State 08 – Asphalt/Composite

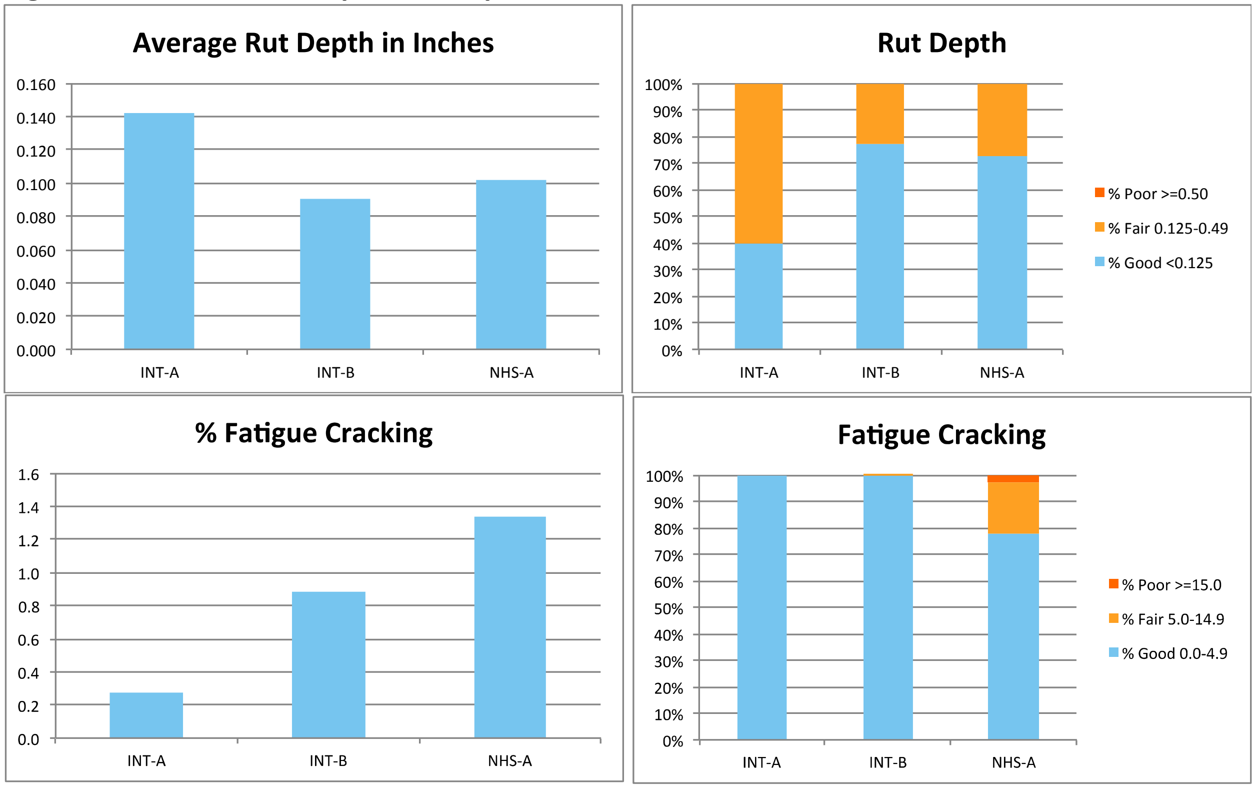


Figure B-16. State 08 – Concrete

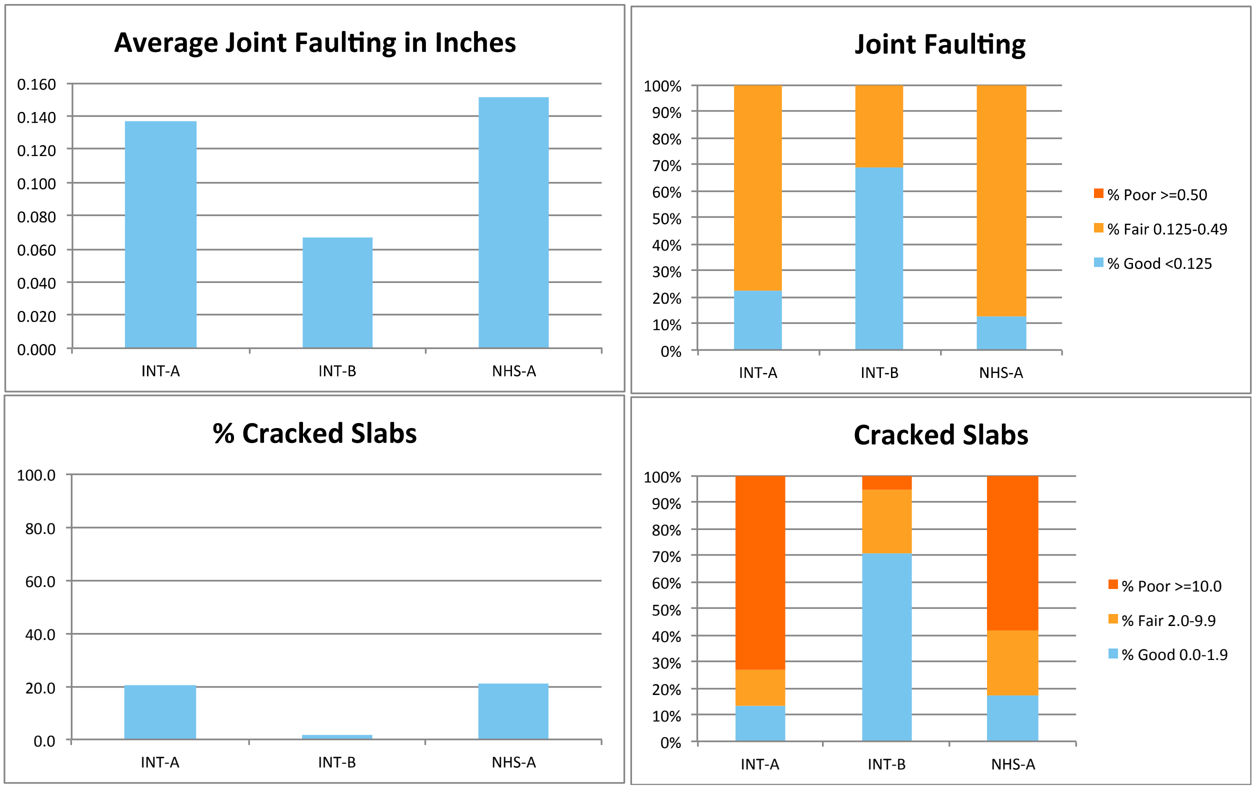


Figure B-17. State 09 – Asphalt/Composite

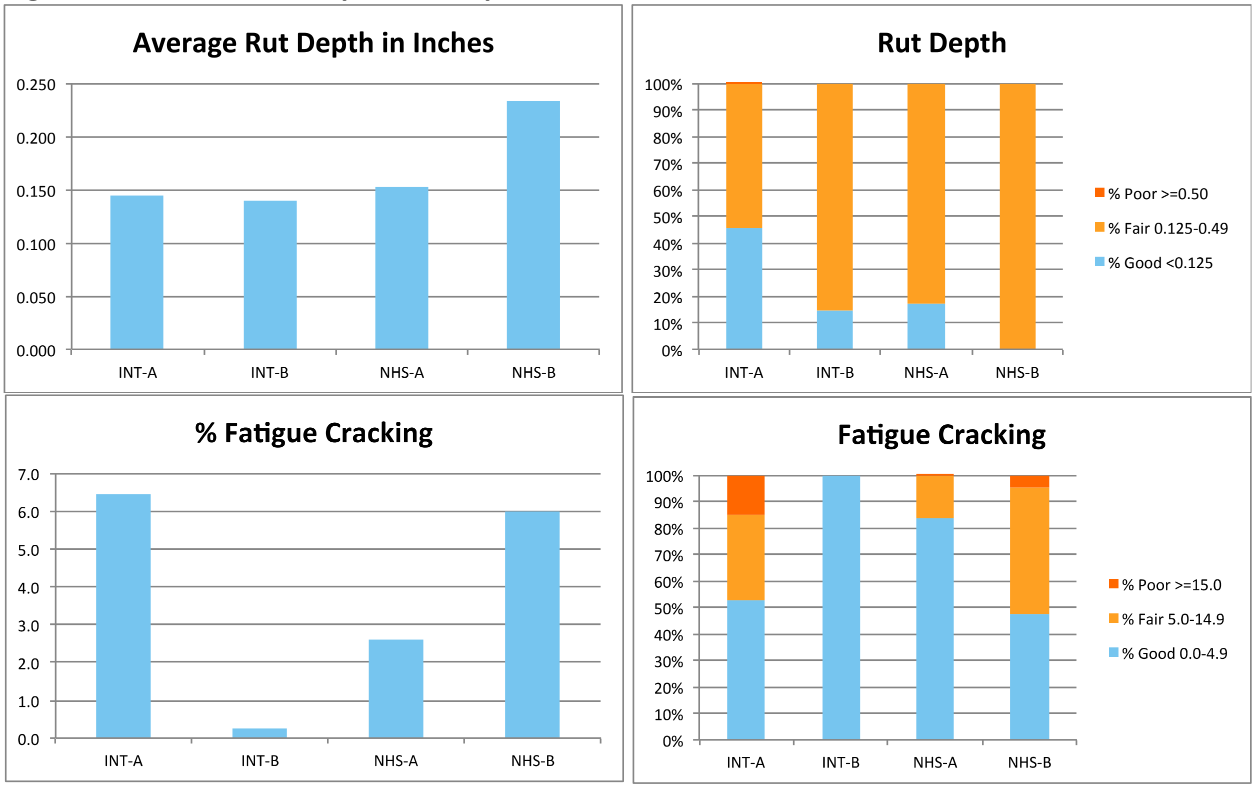
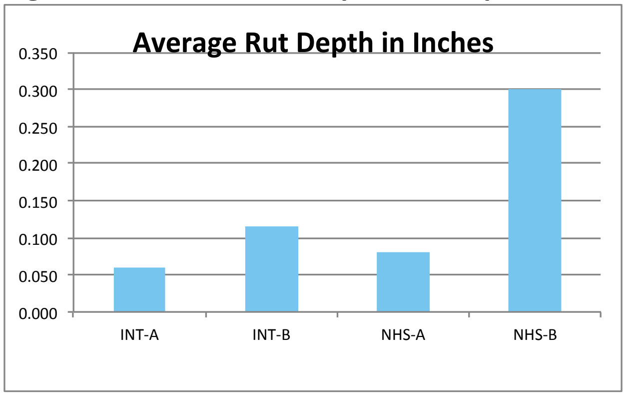
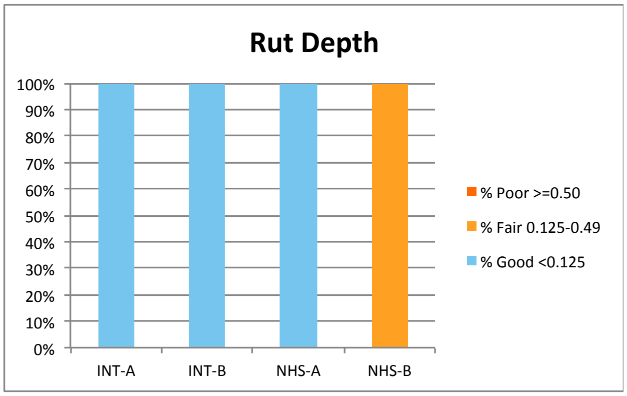
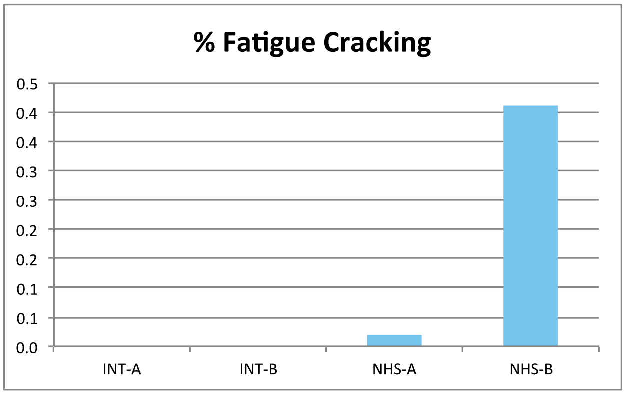


Figure B-18. State 09 – Concrete

Figure B-19. State 10 – Asphalt/Composite







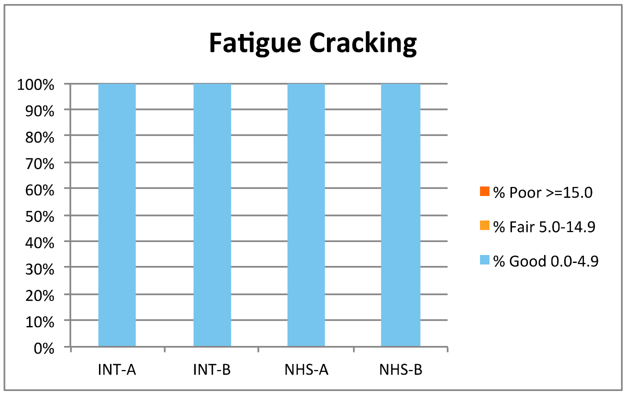
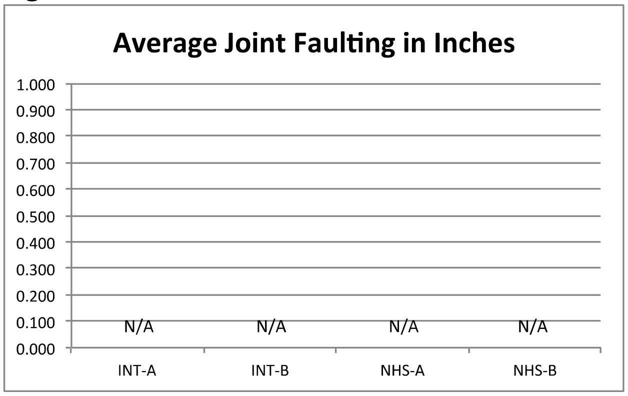
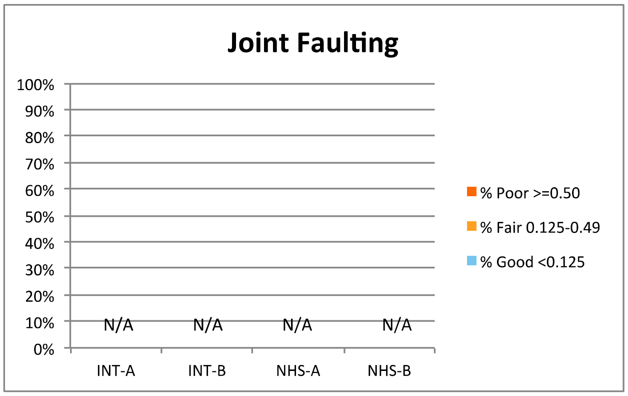
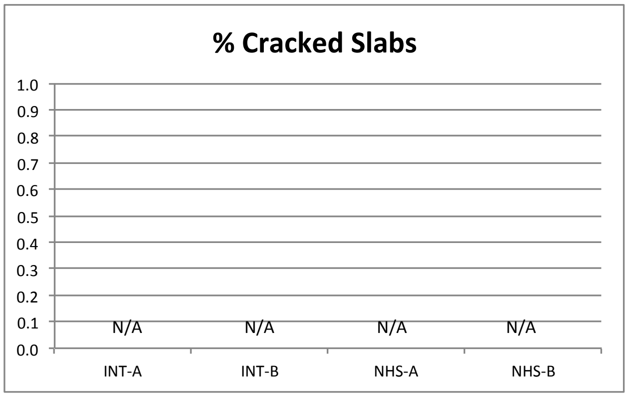


Figure B-20. State 10 – Concrete







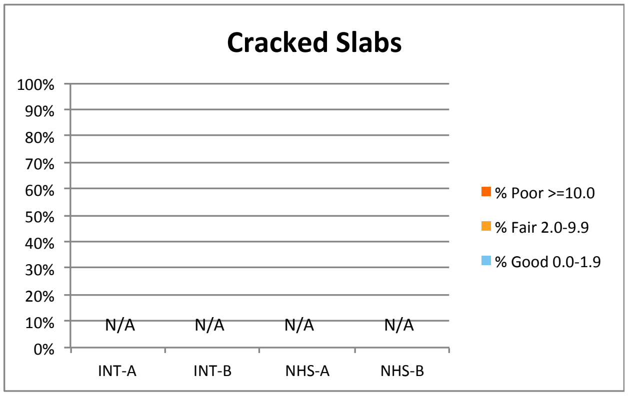


Figure B-21. State 11 – Asphalt/Composite

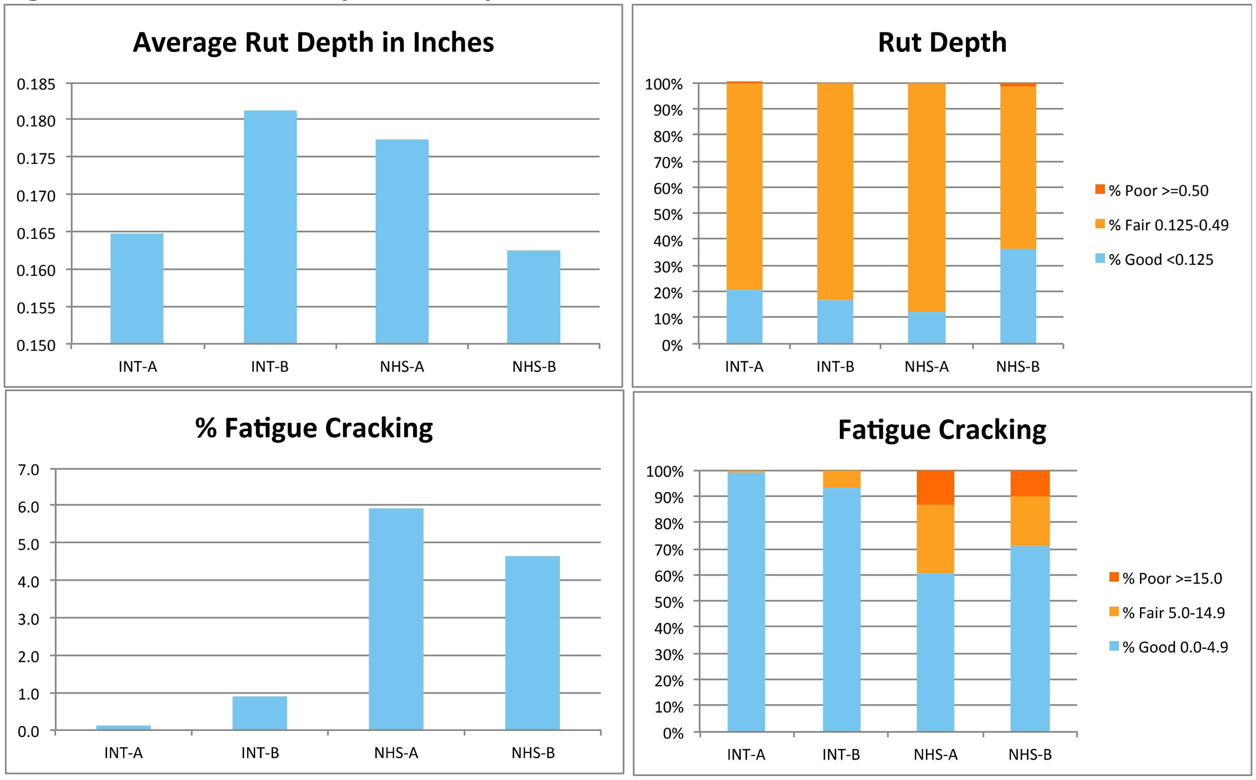


Figure B-22. State 11 – Concrete

Figure B-23. State 12 – Asphalt/Composite

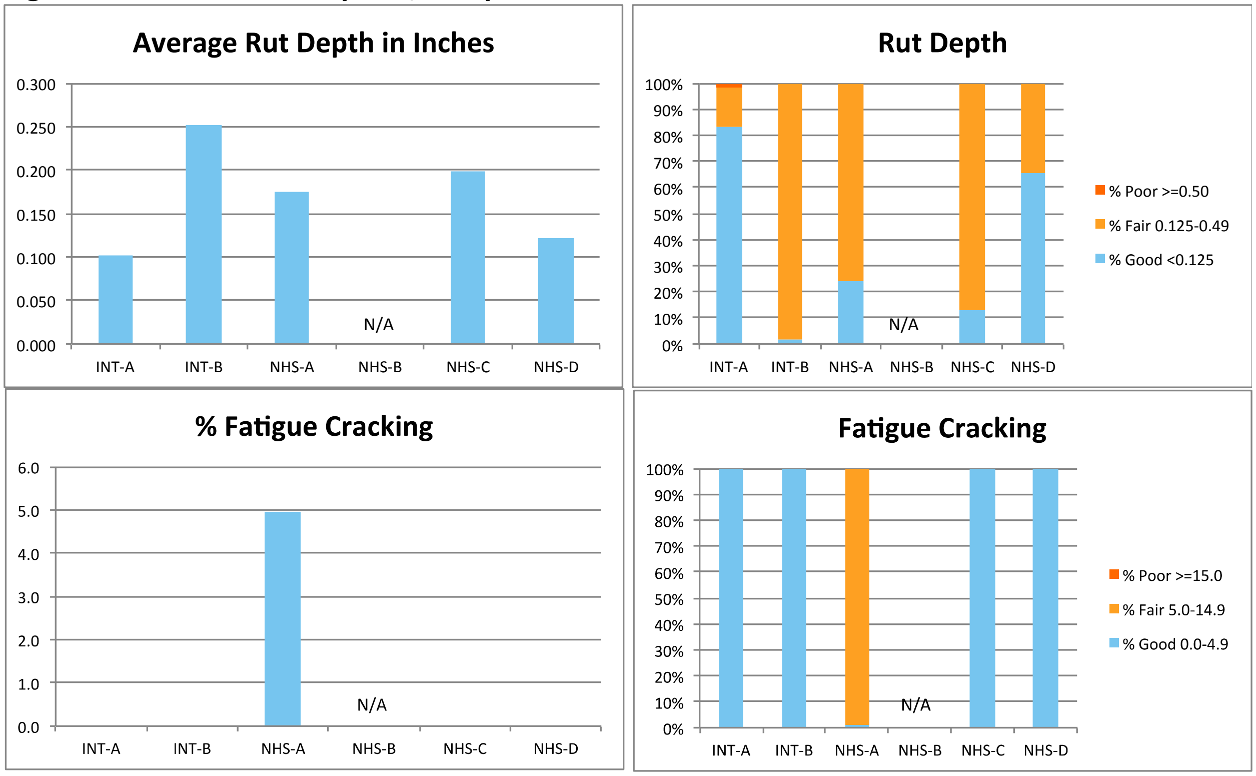


Figure B-24. State 12 – Concrete