Improving FHWA's Ability to Assess Highway Infrastructure Health

Pilot Study Report

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16. Abstract

This report documents the results of a pilot study conducted as part of a project on improving FHWA's ability to assess highway infrastructure health. As part of the pilot study, a section of Interstate 90 through South Dakota, Minnesota, and Wisconsin was evaluated in order to 1) test approaches for categorizing bridge and pavement condition as good/fair/poor that potentially could be used across the country, and 2) provide a proof of concept for a methodology to assess and communicate the overall health of a corridor with respect to bridges and pavements. As a result of the pilot study, it was found that a bridge good/fair/poor methodology can be implemented nationwide today. For pavements, the International Roughness Index can be used today to classify pavement ride quality nationwide. However, additional investigation of other pavement condition metrics is necessary prior to implementation of a holistic pavement indicator that includes distress and structural condition. Also, a conceptual condition and health reporting tool was developed and is presented in the report.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

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List of Acronyms

Acronym	Definition
AADT	average annual daily traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
ASTM	American Society for Testing and Materials
CoRe	Commonly Recognized (related to bridge elements)
CRCP	continuously reinforced concrete pavement
DOT	Department of Transportation
ERD	Engineering Research Division (related to profiler data formats)
ESAL	equivalent single axle load
FCI	functional condition index
FHWA	Federal Highway Administration
FWD	falling weight deflectometer
HERS	Highway Economic Requirements System
HPMS	Highway Performance Monitoring System
IRI	International Roughness Index
JPCP	jointed plain concrete pavement
LRMs	linear referencing methods
M&R	maintenance and rehabilitation
MEPDG	Mechanistic-Empirical Pavement Design Guide
NBI	National Bridge Inventory
NBIAS	National Bridge Inventory Analysis System
NBIS	National Bridge Inspection Standards
NCHRP	National Cooperative Highway Research Program
PCC	Portland cement concrete
PCI	Pavement Condition Index
PHT	Pavement Health Track
PMS	pavement management system
PSR	Present Serviceability Rating
QC/QA	quality control/quality assurance
ROW	right-of-way
RSL	remaining service life
RWD	rolling wheel deflectometer
SD	Structurally Deficient
TAM	Transportation Asset Management
TWG	Technical Working Group
VMT	vehicle miles travelled

Executive Summary

This study focused on enhancing the Federal Highway Administration's (FHWA) ability to assess the health of the nation's highway infrastructure. It had two main objectives:

- Define a consistent and reliable method of assessing infrastructure health with a focus on bridges and pavements on the Interstate Highway System; and
- To develop tools to provide FHWA and State Department of Transportation (DOT) personnel ready access to key information that will allow for a better and more complete view of infrastructure health nationally.

To meet these objectives, the scope of the study consisted of two main tracks:

- Develop an approach for categorizing bridges and pavements as good/fair/poor, which can be used consistently across the country. Performance in this context is based on condition information.
- Develop a methodology for determining the health of a corridor with respect to bridges and pavements. Health in this context is based on factors that go beyond condition, such as age and traffic loads.

Defining Good/Fair/Poor

The approach for categorizing bridges and pavements as good/fair/poor included two key steps:

1. **Develop qualitative definitions for good/fair/poor**. The following definitions were advanced as part of this project:
   - **Good condition** – Bridge and pavement infrastructure that is free of significant defects, and has a condition that does not adversely affect its performance. This level of condition typically requires only preventive maintenance activities.
   - **Fair condition** – Bridge and pavement infrastructure that has minor deterioration of bridge elements; or isolated surface defects or functional deficiencies on pavements. This level of condition typically could be addressed through minor rehabilitation, such as crack sealing, patching of spalls, and corrosion mitigation on bridges, and overlays and patching of pavements that do not require full depth structural improvements.

- **Poor condition** – Bridge and pavement infrastructure that is exhibiting advanced deterioration and conditions that impact structural capacity. This level of condition typically requires structural repair, rehabilitation, reconstruction or replacement.

2. **Define condition metrics and thresholds that can be used to systematically categorize assets based on these definitions**. Table E-1 summarizes the measures evaluated as part of this study. They are organized into tiers that were previously defined by the American Association of State Highway and Transportation Officials (AASHTO). The tiers reflect performance measure readiness and not perceived importance or relative priority.

Table E.1 Performance Measurement Options for Good/Fair/Poor Addressed During this Study

Goal Area	Tier 1	Tier 2	Tier 3
Bridge Preservation	Structural Deficiency (SD)	Structural Adequacy Based on NBI Ratings	See note 1
Pavement Preservation	International Roughness Index (IRI)	Functional Adequacy Based on HPMS Distress Data	Structural Condition Based on Tier 2 Plus Deflection Data

Note 1: Although AASHTO has defined a Tier 3 measure based on element-level bridge data, this measure was not addressed in this study.

Pilot Study

The measures identified above were evaluated along a pilot corridor - I-90 running through Wisconsin, Minnesota, and South Dakota. The measures were evaluated using national data sets, data provided by the corridor State DOTs, and data collected by the project team as part of this effort. This report presents detailed results from the pilot.

The effort put forth by the three State DOTs to fulfill a detailed information request and to cooperate with the pilot study is acknowledged and appreciated by the Federal Highway Administration and the project team. Each State DOT fulfilled the request under a tight deadline in addition to their other daily work assignments. Without the diligence and cooperation of the State DOTs this pilot study would not have been possible.

Health Report

The objective of the health assessment track of this study was to develop a methodology for determining the health of a corridor with respect to bridges and pavements. The health assessment is intended to provide a means for FHWA to examine the overall health of specific corridors and to respond to requests for information. It also enables FHWA to examine corridor health across multiple

States in a consistent manner. In addition, State DOT's may be interested in the results if they would like to review corridor conditions in adjacent States.

The analogy that was used for the health assessment was a visit to the doctor. When visiting the doctor one does not receive a single health score, but rather an in-depth discussion of several health indicators that help to present a comprehensive picture.

A sample health report was designed as part of this study and populated using Highway Performance Monitoring System (HPMS) and National Bridge Inventory (NBI) data along the pilot corridor. The report provides several metrics, such as good/fair/poor results, age, remaining service life for pavements, traffic volumes, etc., and presents these data in a manner that enables users to apply expert judgment in order to assess the overall health of a corridor.

FINDINGS AND RECOMMENDATIONS

Good/Fair/Poor Process

Bridge. The good/fair/poor process for bridges yielded viable and implementable results. NBI data was found to be sufficient for national performance management. Structural Deficiency (SD) status is widely understood and reported, and makes an attractive Tier 1 measure. However, SD status does not fit well into the good/fair/poor approach envisioned by FHWA because it is binary. In addition, SD status includes non-condition components (inventory rating and water adequacy rating), making it less ideal for a pure condition assessment. However, the pilot study found that these non-condition components are not typically the driving factor in the SD calculation.

A measure of structural adequacy based on NBI ratings is a viable supplement to SD status as a national measure of bridge condition. Implementation would require developing a general consensus on its definition.

Pavements. The pilot demonstrated that the good/fair/poor approach is feasible for pavements and implementable today using the International Roughness Index (IRI) as a Tier 1 measure. However IRI does not fully represent the condition of a pavement. It indicates very little about the ability of the pavement structure to withstand traffic loadings.

Implementation of the Tier 2 (pavement roughness and HPMS distresses) and Tier 3 (same as Tier 2 plus structural capacity based on deflections) measures was also shown to be feasible, but additional work is required before they can be implemented. Given the concerns with IRI as a measure of pavement condition, it is recommended that FHWA continue to advance the Tier 2 measure.

Data Collection Improvement Opportunities

Bridge. NBI data were found to be sufficient for national performance measurement, and no recommendations for improvement to bridge data were identified.

Pavement. The common thread through the pavement portion of the pilot study was that the good/fair/poor concept is viable using HPMS data. However, moving beyond IRI is not feasible until the following data collection and processing improvements are made:

- HPMS data summary lengths should be investigated to resolve the analysis bias when using variable sample lengths. At present, the summary lengths are highly variable, which can lead to pavement condition measures being either exaggerated in the case of short lengths or being lost due to averaging over long lengths. Resolution of this issue was beyond the scope of this project.
- HPMS data used for the good/fair/poor indicator needs to be extracted in November or December of each year, after data collection and processing have been completed for the year in question to avoid time lags and therefore potentially erroneous or inaccurate conclusions.
- Incorporate additional checks in the HPMS software to flag HPMS data that is not consistent (for example sections that have a high PSR value but show high distress levels or vice versa). These checks should be applied at the State level, prior to submission of data to FHWA.
- Up-to-date information on maintenance and rehabilitation is important in resolving issues associated with the temporal analysis of pavement condition data.
- The rut depth algorithm should be codified (made consistent) for purposes of the good/fair/poor indicator.
- Cracking data collection should be better defined and a manual for its implementation prepared along with the recommended quality control/quality assurance (QC/QA) standards.
- Faulting data should be investigated to resolve inconsistencies in data collection and analysis. Use of the ProVAL tool to analyze faulting may be a suitable method to standardize the analysis of faulting data.

In addition to the above recommendations, which focus on the HPMS data, a need exists for standards related to calibration, data collection, processing, and analysis of continuous deflection testing. These deflections, along with the HPMS distresses, represent potential Tier 3 measure data requirements, hence the need for continuous deflection testing standards and analysis procedures.

Health Report

The study illustrated that a sample health report can serve as an effective management and communication tool. The report could be used to assess the health of the national highway system and to tell the story of infrastructure needs, all with existing FHWA data sets.

Recommended Next Steps

Bridge. It is recommended that FHWA advance a new measure of structural adequacy based on NBI ratings. This new measure could serve as an eventual supplement to SD as a national measure of bridge condition. It is recommended that the final definition for a structural adequacy measure be based on a policy discussion, focused on the following two questions:

- Should the measure be based on the minimum condition rating or a weighted average?
- What is relative importance of deck compared to superstructure and substructure?

Pavement. The recommended next steps for pavement reflect the data collection opportunities described above. The recommended steps in chronological order are as follows:

- Finalize and implement the good/fair/poor indicator based on pavement roughness (IRI).
- Undertake a study geared towards the incorporation of additional selected distresses into the good/fair/poor indicator, such as cracking and rutting in asphalt concrete (AC) pavements and cracking and faulting in Portland cement concrete (PCC) pavements.
- Concurrent with the above step, pursue improvements to the FHWA Pavement Health Track (PHT) analysis tool for computation of pavement remaining service life, as this tool can potentially serve as a more comprehensive measure of pavement condition in the near future.

Health Report. It is recommended that FHWA consider developing a tool that automates the creation of the health report designed during this study. This tool would enable users to select a corridor and view the results for it. It is further recommended that the tool be implemented in a manner that enables the required HPMS and NBI data elements to be incorporated directly into the report, without manual manipulation.

Implementation. The recommended next steps described above are all ready for immediate implementation at the national level. In fact, many of them are currently underway through various studies conducted by AASHTO and FHWA.

1.0 Study Overview

1.1 Introduction

Over the past several years, the importance of preserving existing transportation infrastructure has received increased focus. A fundamental element of the performance of a transportation system is the physical condition of the assets it comprises. Consequently, the preservation of existing assets is a critical element of the nation's transportation programs, and the identification of performance measures designed to capture and communicate the physical condition of bridges and pavement are needed.

Following are examples of factors driving the need to enhance the FHWA's ability to assess the health of the nation's highway infrastructure.

Potential Changes to the Federal Surface Transportation Program

At the national level, it is expected that the next reauthorization of the Federal surface transportation legislation may significantly change and streamline the Federal program structure and may embrace a performance-based approach to managing the transportation system. As a result, various entities including FHWA, AASHTO, and legislative committees are considering performance measures that could be used to assess performance and options for using these measures to influence resource allocation decisions.

Increased Emphasis on Performance Management and Transportation Asset Management

Performance management is the process of setting goals and regularly checking progress toward achieving them. Key elements of a performance management process include:

1. Establishing goals/objectives;
2. Identifying performance measures;
3. Setting performance measure targets;
4. Allocating resources; and
5. Measuring and reporting results.

Transportation asset management (TAM) encompasses a set of principles which are used to varying degrees by all State DOTs to help them make resource allocation decisions regarding existing assets. A fundamental element of TAM involves the identification of goals and objectives, as well as the selection of performance measures and associated targets which can be used to assess the achievement of, or progress toward, agency goals and objectives. Across the U.S., transportation agencies continue to measure and report a variety of different performance measures. TAM epitomizes performance management. By definition, if an agency is implementing a sound TAM program, it is practicing sound performance management. TAM therefore plays a central role in the establishment and implementation of a comprehensive performance based surface transportation program.

Data Collection Needs

Although States and FHWA collect and track a variety of measures of bridge and pavement condition today, the degree of coverage, consistency of measures, and method and frequency of data collection varies widely. Furthermore, there is debate regarding which, if any, of the existing measures best capture the condition of these assets. Finally, there is the question of whether and how one or more measures of an asset's physical condition might be considered, combined, and possibly supplemented with additional information to provide a more comprehensive assessment of an asset's overall health.

Although a single measure of an asset's physical condition can be related to the asset's overall physical health, it is unlikely to be sufficient to make a comprehensive assessment of the asset's overall physical health. Consider the following two examples:

Current National Bridge Inspection Standards (NBIS) mandate the frequency, nature of inspection, and reporting requirements for highway bridges and culverts. At the present time, among the various data elements that must be reported are condition ratings from 0 (low) to 9 (high) for each component of the bridge including the deck, superstructure and substructure. Each of these condition ratings indicates the overall physical health of a particular bridge, but none of them in isolation enables a comprehensive assessment of a particular bridge's overall health.

Similarly, at the present time the pavement measure that is most widely available is IRI. This index is a measure of a pavement's roughness, which in turn impacts smoothness of the ride experienced by road users. However, IRI measures only a single (albeit the one most directly experienced by the user) facet of pavement condition and it may be possible to achieve good IRI values for some number of years by periodically performing thin overlays on pavements. A potential problem with this approach is that over time and underneath the smooth surface, the structural capacity of the pavement could be deteriorating. This, in turn, reduces the duration that each overlay positively impacts roughness, and sooner or later, a significant and more costly rehabilitation project will be required.

1.2 STUDY OBJECTIVES

The objectives of this study were to:

- Define a consistent and reliable method of assessing infrastructure health with a focus on bridges and pavements on the Interstate Highway System; and
- To develop tools to provide FHWA and State DOTs ready access to key information that will allow for a better and more complete view of infrastructure health nationally.

While initially focusing on the Interstate Highway System, it was the intent of this project to develop methodologies that could be expanded in the future to the National Highway System or any other defined system of bridges or pavements, subject to data availability.

To meet these objectives, the scope of the study consisted of two main tracks:

- Develop an approach for categorizing bridges and pavements as good/fair/poor, which can be used consistently across the country. Performance in this context is based on condition information.
- Develop a methodology for determining the health of a corridor with respect to bridges and pavements. Health in this context is based on factors that go beyond condition, such as age and traffic loads.

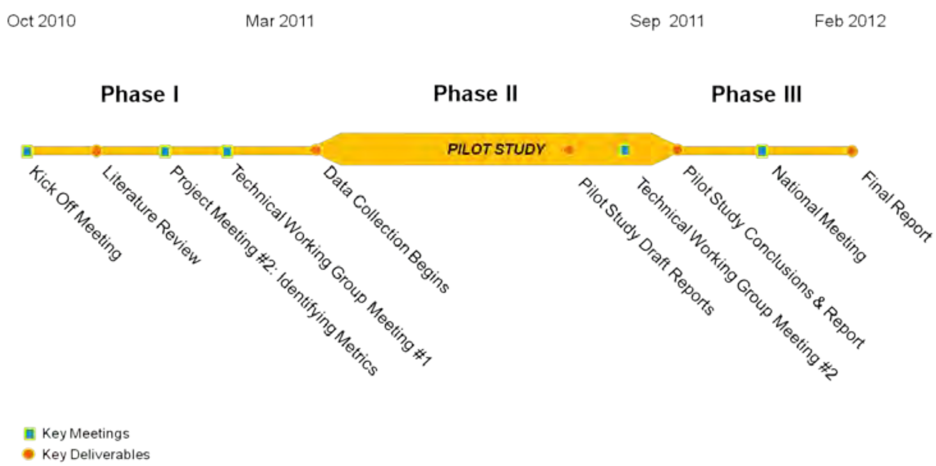
These activities were conducted in coordination with other related FHWA, AASHTO and National Cooperative Highway Research Program (NCHRP) projects focused on performance-based transportation programs.

1.3 STUDY MILESTONES

This effort was divided into three phases. Phase I focused on defining an approach for assessing bridge and pavement condition and health. In Phase II, the approach was refined and tested via a pilot study on a sample corridor. The pilot study corridor was I-90 through South Dakota, Minnesota, and Wisconsin. Phase III consisted of a national meeting to discuss project results with practitioners from across the U.S. These three phases are illustrated in Figure 1.1.

This report documents the results of the pilot study conducted in Phase II. Brief highlights from Phase I and Phase III reports are provided next.

Figure 1.1 Project Milestones



Source: Cambridge Systematics, Inc.

Literature Review (Phase I)

A number of agencies, including various offices of FHWA, AASHTO, the U.S. House of Representatives, and the U.S. Chamber of Commerce, are currently exploring transportation performance measures. It was the goal of FHWA that these efforts be considered and, to the extent possible, accounted for during this project.

To this end, the project team conducted a literature review of recent efforts related to defining, measuring, and presenting bridge condition, pavement condition, and infrastructure health. The intent of the review was to build a foundation of existing knowledge as a basis for further development of the project objectives. Considerable recent work is available which offered the chance to collect and sort relevant findings from peer exchanges, and scans of domestic and international agencies and other multi-agency efforts. The findings of the literature review are available in a separate report entitled *Task 2, Literature Review*, dated December 13, 2010. For complete details on the results of Phase I, refer to the *Phase I Results*[1] report. Both of these documents are available through the FHWA Office of Asset Management.

National Meeting (Phase III)

In Phase III of this study, a national meeting was held to discuss the project results with practitioners from across the U.S. FHWA coordinated with AASHTO and invited transportation professionals from over 40 State DOTs. The

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[1] FHWA. "*Improving FHWA's Ability to Assess Highway Infrastructure Health Phase I Report,*" March 22, 2011.

invitees included a mixture of executives, engineers, planners, and performance management specialists.

The objectives of the national meeting were to:

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

The meeting occurred on October 13, 2011 in Detroit, Michigan. The venue and date were selected to coincide with the 2011 AASHTO Annual Meeting. The discussion and conclusions of the National Meeting are summarized in a separate report entitled *National Meeting Report*[2]. This document is available on the FHWA Office of Asset Management website.

Technical Working Group

Throughout this study, the project team was aided by a Technical Working Group (TWG). FHWA worked with AASHTO to assemble the TWG to:

- Aid in determining metrics and direction for the pilot and overall project;
- Provide necessary data and support for the pilot; and
- Meet with the project team to review interim results.

The TWG included representatives from the following State DOTs and AASHTO:

- North Carolina DOT;
- Minnesota DOT;
- Missouri DOT;
- South Dakota DOT;
- Wisconsin DOT; and
- Washington State DOT.

The TWG met twice over the course of this effort: once in February 2011 to review options for the pilot study and once in September 2011 to review a draft

[2] FHWA. "*Improving FHWA's Ability to Assess Highway Infrastructure Health National Meeting Report*," December 8, 2011.

version of the proposed Health Report (the Health Report is documented in Section 6 of this report).

1.4 STRUCTURE OF THIS REPORT

The remainder of this report focuses on the pilot study.

- Section 2 describes the options for categorizing bridges and pavements as being in good/fair/poor condition that were tested as part of the pilot study;
- Section 3 describes the data used for the pilot study;
- Section 4 presents the results of the pilot study for bridges;
- Section 5 presents the results of the pilot study for pavements;
- Section 6 describes the new health report developed as part of this effort and provides an example report for the pilot study corridor; and
- Section 7 documents conclusions and potential next steps.

2.0 Defining Good/Fair/Poor

As stated earlier, one of the objectives of this study was to develop an approach for categorizing bridges and pavements as being in good/fair/poor condition that could be applied consistently across the U.S. The process for developing this approach included two key steps:

1. Develop qualitative **definitions** for good/fair/poor. By design, these definitions relate solely to the condition of a bridge or pavement, and do not consider other factors such as safety, capacity, etc. In addition, they are metric-neutral, meaning that the definitions will remain constant regardless of the metrics selected in step 2.
2. Define **condition metrics and thresholds** that can be used to systematically categorize assets based on these definitions. It is anticipated that as new data and modeling capabilities become available, these metrics will evolve.

This section presents the good/fair/poor definitions developed as part of the study, and describes the metric and threshold options that were evaluated during the pilot study.

2.1 Good/Fair/Poor Definitions

Based on initial recommendations developed by FHWA and input provided by the TWG, the following definitions were advanced as part of this project:

- **Good condition** – Bridge and pavement infrastructure that is free of significant defects, and has a condition that does not adversely affect its performance. This level of condition typically only requires preventive maintenance activities.
- **Fair condition** – Bridge and pavement infrastructure that has minor deterioration of bridge elements; or isolated surface defects or functional deficiencies on pavements. This level of condition typically could be addressed through minor rehabilitation, such as crack sealing, patching of spalls, and corrosion mitigation on bridges; and overlays and patching of pavements that do not require full depth structural improvements.
- **Poor condition** – Bridge and pavement infrastructure that is exhibiting advanced deterioration and conditions that impact structural capacity. This level of condition typically requires structural repair, rehabilitation, reconstruction or replacement.

These definitions can also be presented in a tabular form, as shown in Table 2.1.

Table 2.1 Defining Good/Fair/Poor

	Condition	Typical Work Activities
Good condition	• Free of significant defects • Condition does not adversely affect performance	• Activities that preserve good conditions (i.e. pavement surface treatments, deck sealing)
Fair condition	• Minor deterioration on primary structural bridge elements • Isolated surface defects or functional deficiencies on pavements •	• Minor rehabilitation - Bridge crack sealing, patching of spalls, and corrosion mitigation - Pavement overlays and patching
Poor condition	• Advanced deterioration • Conditions impact structural capacity	• Structural repairs, major rehabilitation, reconstruction, or replacement

The intended audience for these definitions is the FHWA and State DOTs. They provide a single scale for subsequent measure and threshold discussions. Ultimately, the definitions may need to be simplified for public consumption.

The definitions and metric thresholds (discussed below) are not meant to vary by functional class. These differences could be addressed during a subsequent target setting process, e.g., where a target could be defined as the percent of a network (or portion of a network) that is in good condition.

2.2 Options for Good/Fair/Poor Metrics

This effort built on recent performance measurement work conducted by AASHTO and FHWA, and in particular NCHRP Project 20-24 (37)G, which recommended detailed performance measure definitions for bridges and pavements as well as for other transportation goals areas. The project team started with the recommendations from NCHRP 20-24(37)G, and developed options for specific measures that could be explored further during the pilot study.

Table 2.2 lists the measures that were addressed as part of this study. The measures are organized into tiers, which were defined by AASHTO and documented in NCHRP Project 20-24 (37)G.[3] The tiers reflect performance measure readiness and not perceived importance or relative priority. The tiers are defined as follows:

- Tier 1 measures are considered complete or nearly complete and ready for use at the national level. They meet the criteria of having:

[3] http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-24(37)G_FR.pdf

  - General consensus on the measure's definition,
  - A common or centralized approach to data collection in place, and
  - Established availability of consistent data.

- Tier 2 measures meet one or two of the above criteria, but require further work before being ready for deployment.
- Tier 3 measures are generally still in the proposal stage and require further work before being ready for deployment.

Table 2.2 Performance Measurement Options for Good/Fair/Poor Addressed During this Study

Goal Area	Tier 1	Tier 2	Tier 3
Bridge Condition	Structural Deficiency (SD)	Structural Adequacy Based on NBI Ratings	See note 1
Pavement Condition	International Roughness Index (IRI)	Functional Adequacy Based on HPMS Distress Data	Structural Condition Based on Tier 2 Plus Deflection Data

Note 1: Although AASHTO has defined a Tier 3 measure based on element-level bridge data, this measure was not addressed in this study.

Each option in Table 2.2 is discussed in greater detail below.

2.3 Bridge Good/Fair/Poor Options

This portion of the study focused on good/fair/poor options for bridges that are feasible with NBI data submitted by State DOT's as part of the National Bridge Inspection Program. State DOTs and Federal Agencies that own bridges are required to submit NBI data to the FHWA for highway bridges, including culverts, on public roads that are greater than 20 feet in length. A key component of NBI data is a series of condition ratings that range from 0 (failed condition) to 9 (excellent condition) or N (not applicable). Included in the submitted NBI data are the condition ratings for decks, superstructures, substructures, and culverts. For more detailed information regarding these condition ratings refer to the FHWA NBI guide.[4]

Summary of Options

Through the pilot study, the project team explored three main options for classifying bridges as good/fair/poor.

[4] FHWA, "*Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*." Report No. FHWA PD-96-001, December 1995.

1. Option 1 – SD status. This option was considered even though SD status is a yes or no measure that cannot be converted to a good/fair/poor scale.
2. Option 2 – A measure of structural adequacy based on the minimum NBI condition ratings.
3. Option 3 – A measure of structural adequacy based on a weighted average of the NBI condition ratings. The project team explored various weighting schemes under this option, as defined in Table 2.3.

Table 2.3 Bridge Option 3 – Weights Assigned to the NBI Condition Ratings

		Weight		
Option	Basis for Weights	Deck	Super	Sub
3.a	Bridge Health Index calculation	5%	64%	31%
3.b	Sufficiency Rating calculation	4%	48%	48%
3.c	Equal weights	33%	33%	33%
3.d	Variable	3a or 3c (see note 1)		

Note 1: If the deck condition rating is the lowest rating by two or more, than apply equal weights (option 3.c). If not, then apply the Health Index weights (option 3.a).

Critical Data Items

The following sections all reference specific NBI data elements based on their item number. The item numbers and descriptions for the relevant data items are as follows:

Item 5A Record type

Item 42A Type of service on bridge

Item 49 Structure length

Item 58 Deck condition rating

Item 59 Superstructure condition rating

Item 60 Substructure condition rating

Item 62 Culvert condition rating

Item 67 Structure evaluation rating calculated by FHWA

Item 71 Waterway adequacy

Item 112 Bridge length

Initial Processing Steps

Before any calculations are completed, it is necessary to remove structures that do not meet the Federal regulatory definition of a "bridge." This can be done by removing all structure records that DO NOT meet the following criteria:

Item 5A = 1 (Route carried "on" the structure)

AND

Item 42A = 1, 4, 5, 6, 7 or 8 (Type of service on the bridge: 1 for highway, 4 for highway-railroad, 5 for highway-pedestrian, 6 for overpass structure at an interchange or second level of a multilevel interchange, 7 for third level of multilevel interchange, and 8 for fourth level of multilevel interchange)

AND

Item 49 ≥ 6.1 (Length of bridge greater than or equal to 6.1 meters)

AND

Item 112 = Y (Does the structure meet or exceed the minimum length specified to be designated as a bridge for NBIS purposes)

Option 1 – SD Status

In this option for defining good/fair/poor for bridges, the SD status is determined using NBI data.

1. **Identify SD bridges.** Create a field called *SD,* with all null values**.** Set *SD* = 1 if:[5]

   Item 58 < 5 (Deck condition rating less than 5)

   OR

   Item 59 < 5 (Superstructure condition rating less than 5)

   OR

   Item 60 < 5 (Substructure condition rating less than 5)

   OR

   Item 62 < 5 (Culvert condition rating less than 5)

   OR

   Item 67 < 3 (Structure evaluation rating calculated by FHWA less than 3)

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[5] FHWA. "*Additional Guidance on 23 CFR 650 D. Formerly Federal-aid Policy Guide. Non-Regulatory Supplement NS 23 CFR, Part 650 D, September 30, 1992, Transmittal 5*." September 30, 1992.

OR

Item 71 < 3 (Waterway adequacy less than 3)

2. **Classify as yes/no** (Is bridge SD?)

   If SD = 0, then no

   If SD = 1, then yes

   Note that this option does not convert SD status to a good/fair/poor scale.

Option 2 – Minimum NBI Condition Ratings

For Option 2, bridges are categorized as good/fair/poor based on the minimum of the deck, superstructure, substructure, and culvert condition ratings.

1. **Find minimum NBI rating.**

   Create a field called MinRating.

   Set MinRating as minimum of *Item 58, Item 59, Item 60, and Item 62*.

2. **Classify as Good/Fair/Poor.**

   The following thresholds are consistent with those used by previous FHWA efforts and a recent comparative analysis study of bridge conditions conducted though NCHRP 20-24(37)E[6]:

   If MinRating ≥ 7, then good; If MinRating = 5 or 6, then fair;

   If MinRating < 5, then Poor

Option 3 – Weighted Average of NBI Condition Ratings

Option 3 entails combining NBI condition ratings using a weighted average, and then converting the results to a good/fair/poor scale. The weights reflect the perceived importance of the deck, superstructure, and substructure to overall bridge condition. Four different weighting schemes were explored:

- Option 3.a – weights that are consistent with those used to calculate bridge Health Index.
- Option 3.b – weights that are consistent with those used to calculate Sufficiency Rating.
- Option 3.c – equal weights between the bridge components.
- Option 3.d – variable weights based on the status of deck condition.

[6] "*NCHRP 20-24(37)E, Measuring Performance Among State DOTs, Sharing Best Practices, Comparative Analysis of Bridge Condition*," National Cooperative Highway Research Program, 2010.

Option 3.a – Weighted average based on weights used for bridge Health Index

The bridge Health Index is calculated as a weighted average of the condition of the individual bridge elements. Table 2.4 illustrates the default values used by the FHWA National Bridge Inventory Analysis System (NBIAS) to calculate Health Index. The final weight factor (column f) for each element is calculated as the element's weight (column d) multiplied by the cost of the most expensive action (column e) for that element, which is typically element replacement.

Table 2.4 also shows how the bridge elements are mapped to the NBI items (deck, superstructure, and substructure). Table 2.5 provides the total weight factor for each NBI item and shows the percent distribution between the three items. These percentages are the basis for the weights in Option 3.a; the weights are based on a previous version of AASHTO's Commonly Recognized (CoRe) bridge elements and on existing national estimates for working on them. The CoRe elements have been updated recently. However, for this study, Option 3.a is based on the existing Health Index algorithm used by NBIAS.

The following are the steps involved in classifying bridges as good/fair/poor based on Option 3.a:

1. **Calculate weighted average of NBI Ratings.**

   Create a field called AvgRatingA

   If *Item 62* = N, then AvgRatingA = *Item 58* x 0.05 + *Item 59* x 0.64 + *Item 60* x 0.31. (An "N" value indicates that the structure is not a culvert.)

   Else, AvgRatingA = *Item 62*

2. **Classify as Good/Fair/Poor.**

   If AvgRatingA ≥ 7, then good

   If AvgRatingA = 5 or 6, then fair

   If AvgRatingA < 5, then poor

Option 3.b – Weighted average based on weights used for Sufficiency Rating

Sufficiency Rating is calculated as a weighted average of several NBI items, which go beyond condition ratings and includes aspects of serviceability and functional obsolescence. Table 2.6 provides a list of NBI items included in the Sufficiency Rating calculation. For the purposes of this study, good/fair/poor are defined solely on the basis of condition. Therefore most of the items in Table 2.6 have been dropped from consideration. Items that only reflect a bridge's condition are highlighted in Table 2.6.

Table 2.4 NBIAS Health Index Weight Factors

Bridge Element (a)	Description (b)	NBI Item (c)	Weight (d)	Cost of Most Expensive Action (e)	Weight Factor (f)
12	Concrete Deck - Bare	Deck	6	$427	2,564
13	Concrete Deck - Unprotected w/ AC Overlay	Deck	6	$432	2,593
14	Concrete Deck - Protected w/ AC Overlay	Deck	6	$375	2,250
18	Concrete Deck - Protected w/ Thin Overlay	Deck	6	$407	2,440
22	Concrete Deck - Protected w/ Rigid Overlay	Deck	6	$460	2,761
26	Concrete Deck - Protected w/ Coated Bars	Deck	6	$343	2,060
27	Concrete Deck - Protected w/ Cathodic System	Deck	6	$541	3,243
28	Steel Deck - Open Grid	Deck	6	$526	3,155
29	Steel Deck - Concrete Filled Grid	Deck	6	$670	4,017
30	Steel Deck - Corrugated/Orthotropic/Etc.	Deck	6	$2,075	12,450
31	Timber Deck - Bare	Deck	6	$91	548
32	Timber Deck - w/ AC Overlay	Deck	6	$231	1,388
38	Concrete Slab - Bare	Deck	9	$566	5,094
39	Concrete Slab - Unprotected w/ AC Overlay	Deck	9	$687	6,179
40	Concrete Slab - Protected w/ AC Overlay	Deck	9	$599	5,395
44	Concrete Slab - Protected w/ Thin Overlay	Deck	9	$623	5,603
48	Concrete Slab - Protected w/ Rigid Overlay	Deck	9	$623	5,603
52	Concrete Slab - Protected w/ Coated Bars	Deck	9	$449	4,043
53	Concrete Slab - Protected w/ Cathodic System	Deck	9	$605	5,445
54	Timber Slab	Deck	9	$168	1,512
55	Timber Slab - w/ AC Overlay	Deck	9	$231	2,082
101	Unpainted Steel Closed Web/Box Girder	Superstructure	10	$10,591	105,908
102	Painted Steel Closed Web/Box Girder	Superstructure	10	$10,591	105,908
104	P/S Concrete Closed Web/Box Girder	Superstructure	10	$6,087	60,866
105	Reinforced Concrete Closed Webs/Box Girder	Superstructure	10	$6,087	60,866
106	Unpainted Steel Open Girder/Beam	Superstructure	10	$2,191	21,912
107	Painted Steel Open Girder/Beam	Superstructure	10	$2,313	23,129
109	P/S Concrete Open Girder/Beam	Superstructure	10	$1,217	12,173
110	Reinforced Concrete Open Girder/Beam	Superstructure	10	$1,217	12,173
111	Timber Open Girder/Beam	Superstructure	10	$2,435	24,347
112	Unpainted Steel Stringer	Superstructure	10	$1,096	10,956
113	Painted Steel Stringer	Superstructure	10	$1,948	19,477

Bridge Element (a)	Description (b)	NBI Item (c)	Weight (d)	Cost of Most Expensive Action (e)	Weight Factor (f)
115	P/S Concrete Stringer	Superstructure	10	$730	7,304
116	Reinforced Concrete Stringer	Superstructure	10	$730	7,304
117	Timber Stringer	Superstructure	10	$365	3,652
121	Painted Steel Bottom Chord Thru Truss	Superstructure	14	$3,373	47,224
126	Painted Steel Thru Truss (excl. bottom chord);	Superstructure	14	$4,869	68,170
130	Unpainted Steel Deck Truss	Superstructure	14	$4,869	68,170
131	Painted Steel Deck Truss	Superstructure	14	$6,087	85,213
135	Timber Truss/Arch	Superstructure	14	$3,043	42,606
141	Painted Steel Arch	Superstructure	14	$3,795	53,128
143	P/S Concrete Arch	Superstructure	14	$1,217	17,043
144	Reinforced Concrete Arch	Superstructure	14	$7,432	104,041
145	Other Arch	Superstructure	14	$7,039	98,548
146	Cable - Uncoated (not embedded in concrete);	Superstructure	10	$9,739	97,386
147	Cable - Coated (not embedded in concrete);	Superstructure	10	$9,739	97,386
152	Painted Steel Floor Beam	Superstructure	10	$2,634	26,341
154	P/S Concrete Floor Beam	Superstructure	10	$2,191	21,912
155	Reinforced Concrete Floor Beam	Superstructure	10	$2,191	21,912
156	Timber Floor Beam	Superstructure	10	$5,478	54,780
205	Reinforced Concrete Column or Pile Extension	Substructure	15	$14,608	219,119
206	Timber Column or Pile Extension	Substructure	15	$3,409	51,128
210	Reinforced Concrete Pier Wall	Substructure	8	$12,521	100,170
211	Other Material Pier Wall	Substructure	8	$7,304	58,432
215	Reinforced Concrete Abutment	Substructure	8	$4,991	39,928
216	Timber Abutment	Substructure	8	$4,139	33,111
234	Reinforced Concrete Cap	Substructure	12	$4,504	54,049
235	Timber Cap	Substructure	12	$3,165	37,981
300	Strip Seal Expansion Joint	Deck	3	$1,032	3,097
301	Pourable Joint Seal	Deck	3	$329	986
302	Compression Joint Seal	Deck	3	$508	1,523
303	Assembly Joint/Seal (modular);	Deck	4	$2,191	8,765
304	Open Expansion Joint	Deck	3	$1,281	3,843
310	Elastomeric Bearing	Substructure	5	$2,069	10,347
311	Moveable Bearing (roller, sliding, etc.);	Substructure	5	$3,895	19,477

Bridge Element (a)	Description (b)	NBI Item (c)	Weight (d)	Cost of Most Expensive Action (e)	Weight Factor (f)
312	Enclosed/Concealed Bearing	Substructure	5	$5,235	26,173
313	Fixed Bearing	Substructure	5	$4,139	20,695
330	Metal Bridge Railing - Uncoated	Superstructure	3	$304	913
331	Reinforced Concrete Bridge Railing	Superstructure	3	$414	1,242
332	Timber Bridge Railing	Superstructure	3	$302	906
333	Other Bridge Railing	Superstructure	3	$555	1,665
334	Metal Bridge Railing - Coated	Superstructure	3	$365	1,096

Source: NBIAS default values

Table 2.5 Option 3.a Weights

NBI Item #	NBI Item	Sum of Weight Factor from Table 2.4	Percent/Weight
58	Deck	98,637	5%
59	Superstructure	1,385,657	64%
60	Substructure	670,609	31%

Table 2.6 Components of Sufficiency Rating Calculation

NBI Item	Description	Does Item Reflect Bridge Condition Only?
19	Detour length	No
28	Lanes on structure	No
29	Average daily traffic	No
32	Approach roadway width	No
36	Traffic safety features	No
43	Structure type, main	No
51	Bridge roadway width	No
53	Vertical clearance over deck	No
58	Deck rating	Yes
59	Superstructure rating	Yes
60	Substructure rating	Yes
62	Culvert rating	Yes
66	Inventory rating	No
67	Structural evaluation	No
68	Deck geometry	No
69	Underclearances	No
71	Waterway adequacy	No
72	Approach roadway alignment	No
100	STRAHNET designation	No

Source: FHWA, Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges

Table 2.7 shows the maximum impact on Sufficiency Rating of each condition-based item in Table 2.6. (Culvert rating has been pulled out of this table because culverts are handled separately.) The table also shows the percent distribution between the three items. These percentages are the basis for the weights in Option 3.b. After a weighted average is calculated, the same thresholds for good/fair/poor described in Option 2 and Option 3.a are applied.

Table 2.7 Option 3.b Weights

NBI Item #	NBI Item	Maximum Impact on Sufficiency Rating	Percent/Weight
58	Deck	5	4%
59	Superstructure	55	48%
60	Substructure	55	48%

Following are the steps involved in classifying bridges as good/fair/poor based on Option 3.b:

1. **Calculate the weighted average of NBI Ratings.**

   Create a field called AvgRatingB

   If *Item 62* = N, then AvgRatingB = *Item 58* x 0.04 + *Item 59* x 0.48 + *Item 60* x 0.48. (An "N" value indicates that the structure is not a culvert.)

   Else, AvgRatingB = *Item 62*

2. **Classify as Good/Fair/Poor.**

   If AvgRatingB ≥ 7, then good

   If AvgRatingB = 5 or 6, then fair

   If AvgRatingB < 5, then poor

Option 3.c – Equal weights

In option 3.c, deck, superstructure, and substructure are weighted equally. Following are the steps involved in classifying bridges as good/fair/poor based on Option 3.c:

1. **Calculate weighted average of NBI Ratings.**

   Create a field called AvgRatingC

   If *Item 62* = N, then AvgRatingC = *Item 58* x 0.333 + *Item 59* x 0.333 + *Item 60* x 0.333. (An "N" value indicates that the structure is not a culvert.)

   Else, AvgRatingC = *Item 62*

2. **Classify as Good/Fair/Poor.**

   If AvgRatingC ≥ 7, then good

   If AvgRatingC = 5 or 6, then fair

   If AvgRatingC < 5, then poor

Option 3.d – Weighted average based on variable weights

Option 3.d addresses the case in which a bridge's deck has a condition rating that is significantly worse than the superstructure and substructure ratings. In this scenario, the perceived weight of the deck may increase significantly relative to the low weights assigned to the deck condition rating in Options 3.a and Option 3.b.

Following are the steps involved in classifying bridges as good/fair/poor based on Option 3.d:

1. **Compare Deck Rating to Other Ratings**

   Create a field called DeckComp

Calculate DeckComp = (Minimum of *Item 59* and *Item 60*) - *Item 58*

2. **Calculate weighted average of NBI Ratings with weights based on Deck Rating Comparison.**

   Create a field called AvgRatingD

   If *Item 62* = N and DecComp $\geq$ 2, then AvgRatingD = *Item 58* x 0.333 + *Item 59* x 0.333 + *Item 60* x 0.333. (An "N" value indicates that the structure is not a culvert.)

   If *Item 62* = N and DecComp < 2, then AvgRatingD = *Item 58* x 0.05 + *Item 59* x 0.64 + *Item 60* x 0.31. (An "N" value indicates that the structure is not a culvert.)

   Else, AvgRatingD = *Item 62*

3. **Classify as Good/Fair/Poor.**

   If AvgRatingD ≥ 7, then good

   If AvgRatingD = 5 or 6, then fair

   If AvgRatingD < 5, then poor

2.4 PAVEMENT GOOD/FAIR/POOR OPTIONS

Available systems of pavement condition evaluation and monitoring range from State DOT-specific pavement management systems (PMS) to the national HPMS. The majority of State DOTs collect various distress data along with IRI, which is required for the HPMS. IRI does not provide a complete indicator of pavement condition. The HPMS 2010+ effort will allow for a combined distress and IRI scoring method. In addition, implementation of the FHWA's PHT tool if enhanced as recommended later in this report, would add a level of additional condition information going forward that would enhance asset management/life cycle assessment of investments. This tool performs remaining service life estimation based on data collected in accordance with the HPMS 2010+ requirements along with State DOT PMS and other data expected to be available from the State DOTs. As such, a comprehensive pavement condition score based on ride, distress and structural remaining service life has potential.

Key issues related to pavement condition evaluation and monitoring include:

- The level and quality of pavement structure and materials information is generally inconsistent among State DOTs. For example, in this pilot study two States provided layer structure information but one State could not. Also, it was noted by one State that maintenance data (crack sealing, etc.) is impossible to determine for specific road segments. It is unlikely these data can be relied upon as an input for a national measure of pavement condition without significant improvement in the quality and completeness of structure and materials data.

- Pavement data collection protocols and analysis for IRI are somewhat consistent, although there is variability between the State DOTs.
- A majority of the State DOTs report IRI data as their pavement performance measure. State DOTs that report additional measures generally use simple combined condition indices. Only a few State DOTs use structural condition information in their performance measures.
- FHWA and AASHTO recommend using IRI on an interim basis for national pavement condition reporting until a more comprehensive metric of overall functional/structural condition is feasible.
- Pavement data collection protocols and analysis of rutting data are inconsistent between State DOTs.
- Although there is an AASHTO provisional standard for cracking, pavement data collection protocols and analysis for cracking are inconsistent among State DOTs. It has been documented[7] in the technical literature that cracking data can be quite variable, even within a State DOT.
- Pavement remaining service life (RSL) is an understandable and relatively simple combined health index. The recently developed FHWA PHT tool codifies the calculation of this index. HPMS data can be used to drive the PHT tool calculations.

Summary of Options

Through the pilot study, the project team explored six options for the evaluation of pavement condition. They are:

- Option 1 - Pavement roughness in terms of IRI;
- Option 2 – Pavement surface distresses in accordance with the Pavement Condition Index (PCI) procedure;
- Option 3 - Combination of pavement roughness and selected distresses (cracking, rutting and faulting);
- Option 4 – Pavement structural capacity based on Rolling Wheel Deflectometer (RWD) measurements;
- Option 5 - Combination of roughness, selected distresses and RWD-based structural capacity; and
- Option 6 – Pavement Remaining Service Life.

More detail on each of these options is presented next.

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[7] Flintsch and McGhee, "*NCHRP Synthesis 401, Quality Management of Pavement Condition Data Collection*," National Cooperative Highway Research Program, 2009.

Option 1 – Pavement Roughness

Pavement roughness is perhaps the most widely accepted option for condition evaluation. Table 2.8 presents the thresholds used by FHWA for defining condition based on IRI.

Table 2.8 IRI G/F/P Thresholds

Category	IRI Threshold, in/mile
Good	< 95
Fair	95 ≤ IRI ≤ 170
Poor	> 170

IRI has several advantages. Given proper data collection techniques, IRI means the same thing regardless of the equipment used to collect it. IRI is an established functional measure of pavement condition that is recognized and understood throughout the pavement community. IRI is currently collected and reported as part of the HPMS program so no further data collection or calculation would be required.

The biggest disadvantage of using IRI as a measure of condition is that it does not fully represent the condition of the pavement. IRI indicates very little about the ability of the pavement structure to withstand traffic loadings.

Option 2 - Pavement Condition Index

Another method for evaluating condition is the widely used PCI, as defined in the American Society for Testing and Materials (ASTM) Standard D6433, "Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys." The standard defines condition in accordance with the threshold values presented in Table 2.9. These thresholds were reduced to those identified in Table 2.10 for consideration in this study.

Table 2.9 PCI Thresholds

Category	PCI Threshold
Good	> 85
Satisfactory	71-85
Fair	56-70
Poor	41-55
Very Poor	26-40
Serious	11-25
Failed	< 11

Table 2.10 PCI G/F/P Thresholds Used for this Study

Category	PCI Threshold
Good	> 85
Fair	85 ≥ PCI > 70
Poor	≤ 70

The advantage of the PCI is that it is an established pavement condition indicator widely accepted by the pavement community. This condition indicator is used in some pavement management systems. In these systems, PCI is used to evaluate condition and to develop repair plans for road networks.

The disadvantage of the PCI is that it is data intensive and requires collection of 19 unique distresses on AC pavements and another 19 unique distresses on PCC pavements. It is difficult for agencies to collect these data on high-speed corridors with a high-level of accuracy without serious interruptions to traffic flow. Current "automated' multi-function network data collection vehicles require significant manual interpretation of the pavement images in order to generate a PCI.

Another disadvantage of the PCI is that it does not necessarily correlate with roughness. In other words, it may be necessary to combine the PCI and IRI conditions in order to capture the information each provides about the condition of the pavement.

Option 3 - Combination of Pavement Roughness and Selected Distresses

Given the current readily available data (namely State DOT PMS and HPMS data), the most logical approach to condition assessment is a combination of the data already collected by HPMS - cracking, roughness, rutting, and faulting. The combined condition evaluation would reflect a more complete picture of pavement condition than any one of these items could indicate alone.

For this study's pilot corridor, the project team used ground-truth data to develop a prototype functional condition index (FCI), which combines performance data provided from the HPMS to represent the functional condition of the pavement. For asphalt surfaced pavements this index is calculated as a function of IRI, rut depth, percent cracking and crack length. For jointed plain concrete pavement (JPCP), the FCI is a function of IRI, faulting and percent cracking. For continuously reinforced concrete pavement (CRCP), the FCI is a function of IRI and faulting. More detailed information concerning the FCI is provided in Section 5, including the prototype index equations developed for each pavement type.

The thresholds used for classifying pavements as good/fair/poor based on FCI are provided in Table 2.11.

Table 2.11 FCI G/F/P Thresholds

Pavement Type	Category	FCI Threshold
Asphalt or CRCP	Good	> 85
	Fair	85 ≥ FCI > 60
	Poor	≤ 60
JPCP	Good	> 80
	Fair	80 ≥ FCI > 50
	Poor	≤ 50

The advantage of the FCI approach is that it considers more than one aspect of pavement condition. Establishing condition based upon roughness, rutting and cracking for asphalt pavements will provide a fairly comprehensive review of the functional condition of the pavement. Similarly, incorporating roughness, faulting and cracking for concrete pavements also covers most aspects of the pavement functional condition.

The disadvantage to this approach is that currently there is no recognized condition index involving the distresses as defined and collected for the HPMS database. The FCI discussed and presented in greater detail in Section 5 is an initial example and has not been fully reviewed and evaluated.

Option 4 – Pavement Structural Capacity based on RWD

Another option considered in the study was the structural evaluation of the pavements with continuous deflection information using the FHWA's RWD. See Section 3.4 for a more detailed description of the collection process and equipment.

The condition thresholds established in this study for the RWD data are based on normalized deflections (D_0 – maximum pavement deflection under the applied load). They are presented in Table 2.12. These threshold limits were developed based on a study conducted by the Indiana Department of Transportation.[8]

Table 2.12 Deflection G/F/P Thresholds

Category	D_0 Threshold
Good	≤ 6
Fair	$6 < D_0 \leq 10$
Poor	> 10

[8] Arora, et. Al., "*Continuous Deflection Testing of Highways at Traffic Speeds*," October 2006.

The advantage to using a continuous deflection device such as the RWD is that it evaluates the structural condition of the pavement section (at highway speeds), which none of the previous options do.

A disadvantage to the use of the RWD specifically, is that no industry standards have yet been developed for equipment calibration, data collection, and data analysis. Moreover, no industry standard has been developed for use of the RWD data to evaluate pavement condition. In addition, current RWD analysis methods require pavement layer thickness data, which is difficult to obtain with a high level of confidence. Lastly, D_0 as measured by the RWD cannot by itself give a complete indication of the pavement structural condition.

Option 5 - Combination of Pavement Roughness, Selected Distresses and RWD-Based Structural Capacity.

The most comprehensive condition assessment would combine pavement structural and functional conditions. This type of analysis would provide the most complete picture of the pavement condition with an indication of not just whether intervention is required for a functional issue or for a structural issue, but would also indicate whether either is required.

The approach used in this pilot study was to combine the FCI and D_0 conditions described earlier under Options 3 and 4. In this case, the minimum condition assessed using both the FCI and D_0 would be identified as the condition for each segment. For example, if the condition based on the FCI is good and the condition based on D_0 is fair, then the combined condition is fair.

Option 6 – Pavement Remaining Service Life

The last option considered in this study was to use the FHWA PHT analysis tool to determine the pavement RSL. The PHT tool utilizes simplified versions of the models used in the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG). These simplified models were developed by FHWA for the Highway Economic Requirements System (HERS) and the National Pavement Cost Models. Data requirements for the PHT tool are based largely on the HPMS 2010+ data collection format. State DOT PMS or other sources of data can also be imported into the PHT tool. Default tables for material properties, climate and loading are also included in the PHT tool to supplement the data provided from HPMS or other sources which are required for the models.

A limitation of the PHT tool is that the RSL analysis is only available for bituminous pavements, JPCP, asphalt concrete (AC) overlay over existing AC pavement, and AC overlay over existing jointed concrete pavements. Accordingly, CRCP and CRCP with overlay pavement sections could not be considered.

Using the PHT tool, the predicted values of the distresses (IRI, rutting, fatigue cracking, transverse cracking and faulting) at the end of the overall service life are calculated. The RSL of the pavement for each distress type is calculated as the number or years (or Equivalent Single Axle Loads - ESALs) until the terminal values listed in Table 2.13 are reached for applicable pavement sections (e.g. rutting for flexible pavements and faulting for rigid pavements). The overall RSL is also provided. The user can determine whether this is computed as the minimum of the individual RSL values or a weighted average of the individual RSL values. The minimum value was used for this pilot study.

Table 2.13 RSL Terminal Distress Values

Surface Type	Distress Type	Terminal Value
Rigid Pavement	IRI	170 inch/mile
	Cracking-Transverse	10%
	Faulting	0.15 inch
Flexible Pavement	IRI	170 inch/mile
	Cracking-Fatigue	20%
	Cracking-Transverse	640 feet/mile
	Rutting	0.4 inch
Composite Pavement	IRI	170 inch/mile
	Cracking-Reflection	100 feet/mile

The following good/fair/poor thresholds were used for this pilot study.

Table 2.14 RSL G/F/P Thresholds

Category	RSL Threshold, years
Good	> 10
Fair	1 < RSL < 10
Poor	≤ 1

3.0 Pilot Study Data Collection

The objective of the pilot study was to test options for categorizing bridges and pavements as good/fair/poor (described in Section 2) and the recommended approach for assessing overall health (described in Section 6). This section summarizes the process for selecting the pilot corridor, and describes the process used to compile data on it.

3.1 PILOT CORRIDOR SELECTION

The first step in the pilot study process was to identify a three-State sample corridor. The corridor was selected based on the consideration of a number of criteria, including adjacency and data compilation expediency. To ensure adherence to the overall project schedule, a major consideration was the extent to which data were readily available. For bridges, the potential good/fair/poor approaches rely on NBI data, which is readily available from all State DOTs. Therefore, the data expediency considerations focused on pavement data. The potential good/fair/poor approaches for pavements rely on HPMS 2010+ data format. Therefore, the pilot worked focused on States that had submitted HPMS 2010+ files to FHWA by early 2011. In addition, to minimize data compilation requirements, the selection focused on corridors solely owned and operated by State DOTs, as opposed to a combination of State DOTs and toll authorities.

The I-90 corridor through Wisconsin, Minnesota, and South Dakota was selected for this pilot effort. Figure 3.1 illustrates the pilot corridor in more detail.

Figure 3.1 I-90 Pilot Corridor

Source: Cambridge Systematics, Inc.

3.2 CORRIDOR OVERVIEW

I-90 runs from Seattle to Boston. The pilot study corridor portion of I-90 runs through South Dakota, Minnesota, and Wisconsin for a total of 874 miles. For most of the corridor's length it is signed only I-90, but in southeastern Wisconsin it runs concurrently with I-94 and I-39. I-90 has average annual daily traffic (AADT) in a broad range from about 5,000 to 90,000 vehicles per day. The pilot corridor carries about 15.4 million vehicle-miles in an average day. Much of the corridor is rural (about 85 percent) but it links the urban areas of Rapid City, Sioux Falls, Rochester, Winona, La Crosse, Madison, and Janesville among others. The pilot study corridor is untolled and primarily surrounded by farmland and other rural land uses outside of the urban areas.

Details regarding the bridge and pavement conditions along the pilot corridor are discussed in Sections 4 and 5.

3.3 BRIDGE DATA COLLECTION

Bridge data required for the pilot study was compiled from the FHWA's NBI dataset. All data are from 2010 NBI files submitted by the three State DOTs to FHWA.

3.4 PAVEMENT DATA COLLECTION

The pilot study was designed to help answer the following key questions concerning pavement condition information:

- How difficult is it to obtain each required data set?
- Are the data all from the same time period (temporal consistency)?
- How consistent/complete is data collection between State DOTs?
- Are all data of similar quality (quality = fit for intended purpose)?
- How do various data sets compare?
- How much effort is it to gather and collect the required information?
- Which data sets have potential for use in a National condition metric?
- What are the necessary improvements to data or tools needed for a National condition measure?
- What would a comprehensive condition metric look like?
- Does the condition metric reflect field conditions?

Some of these questions are addressed in this section, while others are addressed in the analysis of results in Section 5.

National Data Gathering

Data were gathered from the HPMS in 2010+ format. These data included roughness, rutting, faulting, percent cracking, and length of cracking as condition indicators of the in-place pavement sections.

Roughness data are presented in terms of IRI. These data are collected at varying intervals for the full extent of the Interstate. The other performance data (rutting, faulting, percent cracking, and crack length) are collected on a sample panel. Rutting is collected in the form of the average depth of rutting in each wheel path. Faulting is the average vertical displacement between adjacent concrete slabs. Percent cracking is the percentage of the wheel-paths that is cracked in asphalt-surfaced pavements or percentage of slabs with cracking on concrete pavements. Cracking length is only collected on asphalt-surfaced pavements and represents the length per mile of transverse cracking.

The data are presented at varying intervals along the corridor. These intervals range in length from 0.001 miles to over 10 miles.

In the initial phase of the study the data obtained from HPMS represented data collected in 2009 for Minnesota and Wisconsin. The data from South Dakota were collected in 2010. Subsequently, complete HPMS data sets from 2009 and 2010 were available from all three State DOTs and were added to the analysis data set.

State DOT Data

A variety of data were requested from the three State highway agencies that participated in the pilot study. This included documentation on the corridor inventory, State DOT pavement management system data, and written documentation describing their systems and processes.

Requested inventory data on the corridor included the following:

- Inventory data (segmented as per State DOT policy) for I-90 including:
  - Functional classification;
  - Urban/rural;
  - County name;
  - Number of through lanes;
  - Ownership (we assume this entire route is State-owned);
  - Lane width;
  - Presence, type and width of shoulders; and
  - Year of construction and/or last resurfacing.
- Linear referencing system w/ route ID and all applicable linear referencing methods (LRMs), for example beginning and ending mileposts of segments.

- Right-of-way (ROW) images (if feasible/available).
- Latest GIS dataset of corridor and information related to inventory, pavement, and bridges with links to a highway linear referencing system.
- Financial information on construction cost, maintenance and rehabilitation costs, (if available); and
- Traffic data (AADT, percent trucks, growth factor) from 2006 through 2010.

State DOT pavement management data were requested for both directions of travel along the corridor. These data were requested to include the pavement structure, performance data used by the State DOT pavement management system, and available construction information and cost data. Network-level falling weight deflectometer (FWD) data were requested from each State DOT, but none were able to furnish this data along the entire corridor. Cost data was received from one State (a partial data set representing 1995-2011). Neither FWD nor cost data were used further in this study due to these limitations.

The specific pavement management data requested included:

- Pavement structure;
- Pavement maintenance/rehabilitation history including costs;
- Network level FWD data;
- Cracking/distress;
- Roughness Data including the IRI and the raw longitudinal profile data files;
- Rutting;
- Faulting;
- Summary condition indicators such as Pavement Quality Index, PCI, or similar; and
- Summary condition data (FWD, cracking/distress, IRI, rutting and faulting) from the last five years - 2006 through 2010.

Documentation requested included the following:

- Linear referencing system documentation;
- Pavement data collection standard operating procedures (including standards for data collection and methods to calculate indices such as IRI);
- Pavement distress identification guide including methods used to develop distress indices;
- Pavement performance reports (i.e. “State of the Pavement”) for 2005-2010;
- Information on construction expected to be performed on the corridor in 2011.

This documentation was important in understanding what and how data were collected for the pavement management system.

The effort put forth by the three State DOTs to fulfill the information request and to cooperate with the pilot study is acknowledged and appreciated by the project team. Each State DOT fulfilled the request under a tight deadline in addition to their other daily work assignments. Without the States diligence and cooperation this pilot study would not have been possible.

It should be noted that all pilot corridor States DOTs were not able to produce all of the requested information, which was expected.

Field Data Collection

Data were collected along the pilot study corridor using a multi-function automated pavement data collection vehicle similar to that shown in Figure 3.2. These data included right-of-way images, roughness, rutting, faulting, and cracking in accordance with HPMS 2010+ standards. Data were collected in the eastbound direction at 0.1-mile intervals along the entire corridor length (similar direction as HPMS data). Images of the pavement surface and right-of-way were used to estimate the PCI for 150 miles (a subset) of the corridor.

Figure 3.2 Automated Multi-Function Vehicle Used for Pavement Condition Evaluation

Source: Mandli Communications, Inc.

In order to facilitate corridor data collection, a request for proposals was provided to three potential vendors on April 29, 2011. Responses were received by May 21, 2011. Data were collected by the selected vendor over the week of June 18, 2011 and the data were processed and delivered on July 18, 2011.

In addition, the FHWA RWD was used to evaluate the structural capacity of the pavements. The equipment, which is illustrated in Figure 3.3, collects deflection measurements at highway speeds.

Figure 3.3 Rolling Wheel Deflectometer Used for Structural Evaluation

Source: Applied Research Associates, Inc.

The RWD uses laser sensors mounted below the trailer to measure pavement deflection as it drives along the roadway. Four lasers work in conjunction to determine the maximum deflection produced by the wheel loads of the tractor-trailer. Two additional lasers are used to measure deflection 15-in forward of the wheels. The deflections are measured at 15-mm intervals with the vehicle moving at highway speeds and a moving average is used to summarize the data at 0.1-mile intervals. The measurements are inherently noisy and the moving average removes some of the excess variability.

In addition to the moving average, data are processed using the pavement structure. However, the Wisconsin DOT was unable to provide information on the pavement structure for I-90 within their limits. Therefore, the analysis of RWD data for the Wisconsin portion of the corridor was not performed.

Data collection occurred from June 27 to June 29, 2011 and the processed data were delivered on August 8, 2011.

As part of pilot study field data collection, a ground-truth visit was performed along the corridor during the week of September 12, 2011. As part of this visit, an evaluation by a panel of raters was performed to subjectively arrive at a good/fair/poor pavement condition for the corridor. The assessment was performed on selected areas of the corridor within South Dakota, Minnesota, and Wisconsin representing asphalt, JPCP, and CRCP surfaces of varying conditions.

Temporal Consistency of Gathered and Collected Data

The National and State DOT PMS data gathering and field data collection proceeded well for the pilot study. The effort did point out temporal issues with gathering and collecting the data. For example, at the time of the pilot study, HPMS data were available for two States DOTs representing 2009 conditions and one State DOT representing 2010 conditions. PMS data representing 2010 conditions were provided by all three State DOTs. Lastly, field data collection represented 2011 conditions. A summary of the initial temporal realities of the gathered/collected data are shown in table 3.1.

Table 3.1 Temporal Consistency of Initial Gathered/Collected Pavement Data

Corridor	National	State	Field	
	HPMS	PMS	Condition	RWD
MN	2009	2010	2011	2011
SD	2010	2010	2011	2011
WI	2009	2010	2011	N/A

Note: Wisconsin RWD could not be processed due to lack of pavement structure information.

During a later part of the study, a complete set of HPMS data from 2009 and 2010 was acquired for all three State DOTs. This second compilation effort resulted in a set of HPMS and PMS data all representing 2010 conditions. Section 5 discusses issues related to using data from inconsistent time periods.

4.0 Pilot Study Bridge Results

This section presents the pilot study findings for bridges. All structures along the corridor were included in the analysis. Table 4.1 provides the number of bridges and culverts as reported in the NBI data set on the I-90 pilot corridor.

Table 4.1 Pilot Corridor Bridges and Culverts

	South Dakota	Minnesota	Wisconsin	Total
Bridges	260	109	182	551
Culverts	21	27	23	71
Total	281	136	205	622

The details of the good/fair/poor approaches evaluated during the pilot are provided in Section 2. In summary, the options include:

- Option 1 – SD status.
- Option 2 – A measure of structural adequacy based on the minimum NBI condition rating.
- Option 3 – A measure of structural adequacy based on a weighted average of the NBI condition ratings. Table 4.2 summarizes the various weights evaluated as part of Option 3

Table 4.2 Option 3 Weights

		Weight		
Option	Basis for Weights	Deck	Super	Sub
3.a	Bridge Health Index calculation	5%	64%	31%
3.b	Sufficiency Rating calculation	4%	48%	48%
3.c	Equal weights	33%	33%	33%
3.d	Variable	3a or 3c (see note 1)		

Note 1: If the deck condition rating is the lowest rating by two or more, than apply equal weights (option 3.c). If not, then apply the Health Index weights (option 3.a).

Several figures and tables below show comparisons between the various good/fair/poor options. Culverts have been removed from the comparative analysis since their classification is based on a single condition rating (culvert condition rating) that is not impacted by the various algorithms explored in Options 2 and 3.

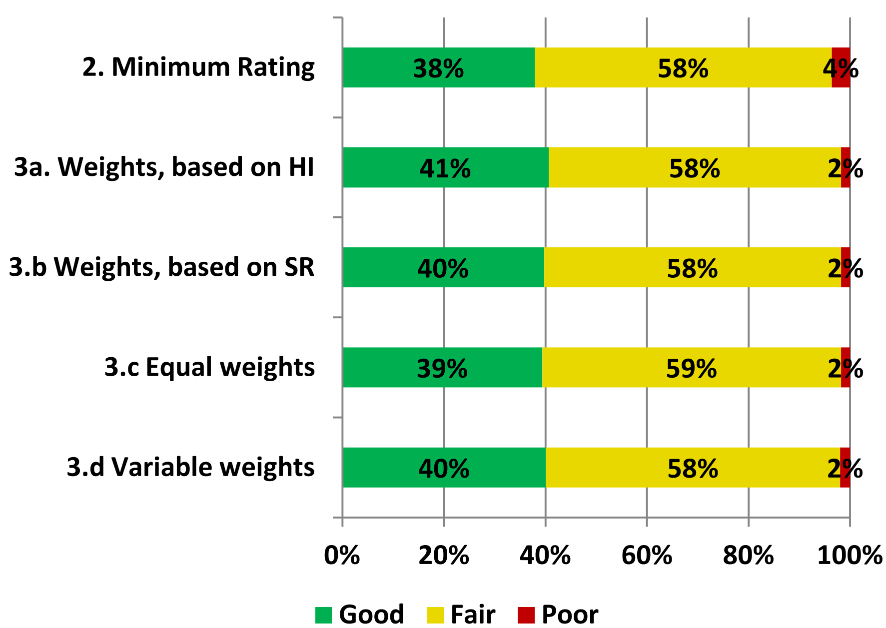
4.1 Data Findings

One of the objectives of the pilot study was to identify data issues impacting the calculation of good/fair/poor. During the pavement analysis, which is described in Section 5, these issues were identified by evaluating three data sets: national data, data collected as part of this study, and data from State DOT databases. In contrast, the bridge analysis used a single data set, NBI data. Data standards, collection procedures, quality control processes, and calculation methods related to NBI data are well established and have been used by State DOTs and the FHWA for several years. The project team found NBI data to be adequate for all of the good/fair/poor options explored.

4.2 Condition Assessment Findings

Bridge finding #1. Corridor results are consistent across all options. Figure 4.1 shows the good/fair/poor distribution of the corridor (none of the remaining tables and charts in this section include culverts). Overall, the results show limited variation across the options. Option 1 (SD status) is not illustrated because it is binary and does not fit into the good/fair/poor model. However, for comparison purposes, Option 1 indicated that about 3 percent of bridge deck area along the corridor is on bridges classified as structurally deficient. This value coincides with the percent poor for Option 2, and is slightly higher than the percent poor calculated for the other options.

Figure 4.1 Results of Bridge Options 2 & 3 for Pilot Corridor



Source: Cambridge Systematics, Inc.

Bridge finding #2. Option 2 (minimum NBI condition rating) results in the highest poor percent. Figure 4.1 indicates that Option 2 (minimum NBI condition rating) resulted in the highest percent of poor, although only slightly higher than the other options. In Option 2, the lowest condition rating drives the good/fair/poor classification. In Options 3a through 3d, a weighted average is used. In some cases (roughly 1 to 2 percent of the corridor), the good/fair/poor result improved when all three ratings were considered, as compared to when only the lowest rating was used.

Bridge finding #3. Bridge level results are highly correlated across all options. In addition to looking at overall corridor results, the project team compared results across individual bridges. Table 4.3 shows a high degree of correlation between good/fair/poor results across the various options for individual bridges. Correlation is a measure of change between two variables. In this context, correlation ranges from 0 (indicating that the good/fair/poor results are completely random) and 1 (indicating that the good/fair/poor results always coincide).

Table 4.3 Correlation of Options for Bridges in the Pilot Corridor

	2	3.a	3.b	3.c	3.d
2	1				
3.a	.93	1			
3.b	.94	.98	1		
3.c	.95	.96	.98	1	
3.d	.94	.98	.96	.98	1

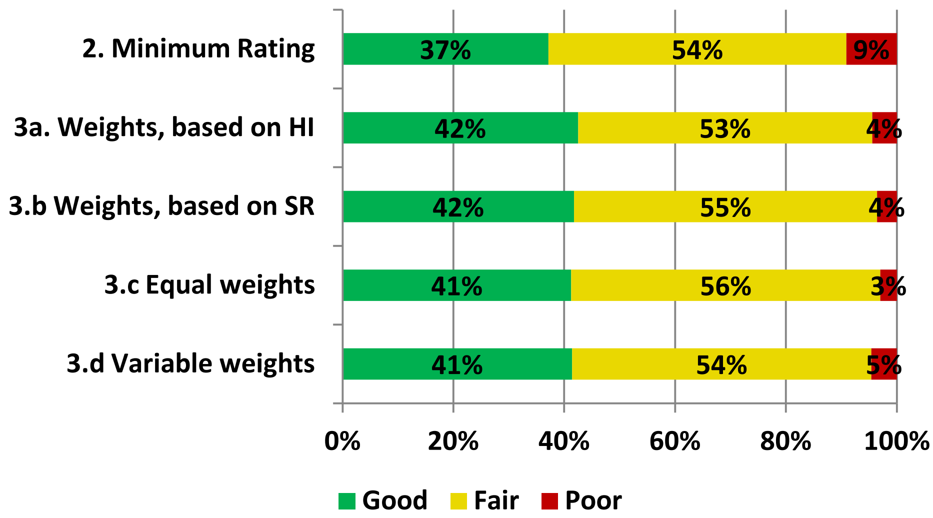
Bridge finding #4. Good/fair/poor results based on a weighted average of NBI condition elements are not sensitive to the weights. The high correlation between Options 3.a (weighted average based on health index weights), Option 3.b (weighted average based on Sufficiency Rating weights), and Option 3.c (weighted average based on equal weights) indicate that the good/fair/poor results are not sensitive to the weights assigned to the various bridge elements. A potential reason for this finding is addressed in finding #9 below.

The remaining findings described below are based on the results of a national (as opposed to corridor) comparison.

Bridge finding #5. Findings #1 through #4 are also true nationally for Interstate bridges. Given the high degree of consistency across all the options along the corridor, the project team conducted a comparative analysis for all Interstate bridges in the 48 contiguous States.

Figure 4.2 and Table 4.4 illustrate the results. For comparison purposes the resulting percent classified as SD was 9 percent, which again coincides with the percent poor from Option 2 (minimum NBI condition rating).

Figure 4.2 Results for Interstate Bridges in the 48 Contiguous States



Source: Cambridge Systematics, Inc.

Table 4.4 Correlation of Options for Interstate Bridges in the 48 Contiguous States

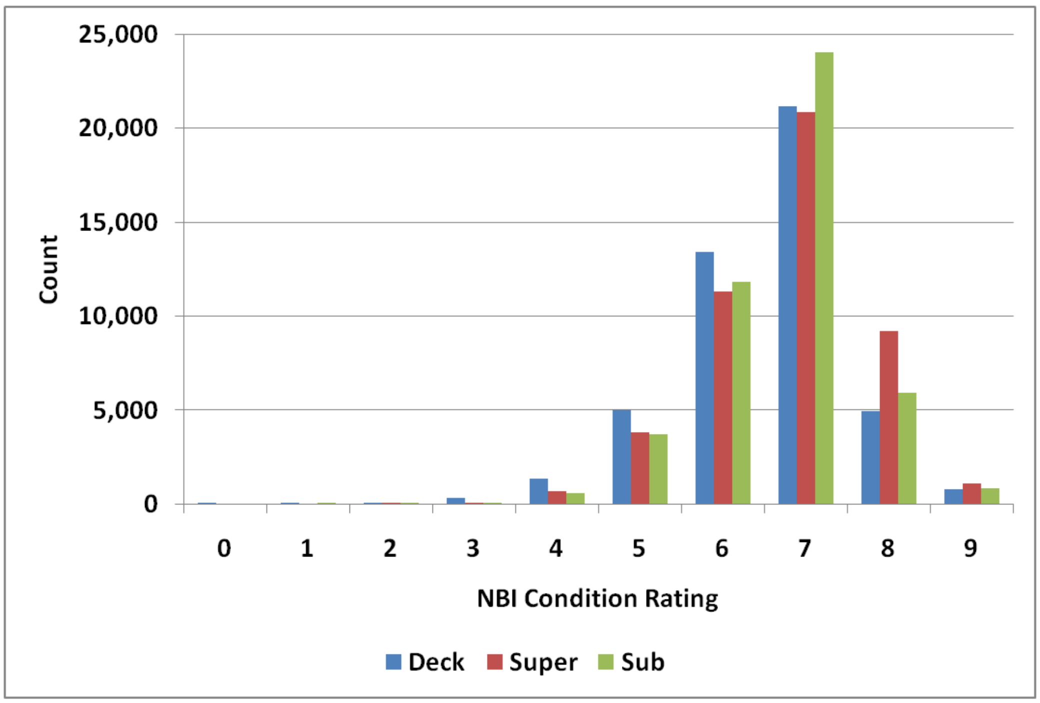
	2	3.a	3.b	3.c	3.d
2	1				
3.a	.88	1			
3.b	.88	.97	1		
3.c	.88	.94	.97	1	
3.d	.90	.99	.96	.96	1

Bridge finding #6. Option 1 (SD) is very consistent with Option 2 (minimum NBI condition Rating). The calculation for Option 2 (minimum NBI condition rating) is essentially the same as that for Option 1 (SD), except that Option 1 also includes structural evaluation and water adequacy ratings, which go beyond condition. In the national analysis, 2,662 bridges were classified as SD. Nationally, all Interstate bridges except for 22 were classified as poor based on Option 2.

Bridge finding #7. Nationally, Interstate bridge deck conditions are typically not the driving factor in the good/fair/poor calculations. Table 4.4 indicates a very high degree of correlation (0.99) between Option 3.a (weighted average based on the Health Index calculation) and Option 3.d (variable weighted average dependent on deck condition). The results for these two options only differ when the deck condition rating is more than 2 ratings less than both the superstructure and substructure ratings. This scenario is rare for Interstate bridges.

Bridge Finding #8. Options 2 and 3 are very sensitive to the "good" threshold. In Options 2 and 3, a bridge is classified as "good" if the resulting condition rating is greater than or equal to 7. Figure 4.3 shows the distribution of condition ratings from the national analysis. It indicates a significant spike at a rating of 7.

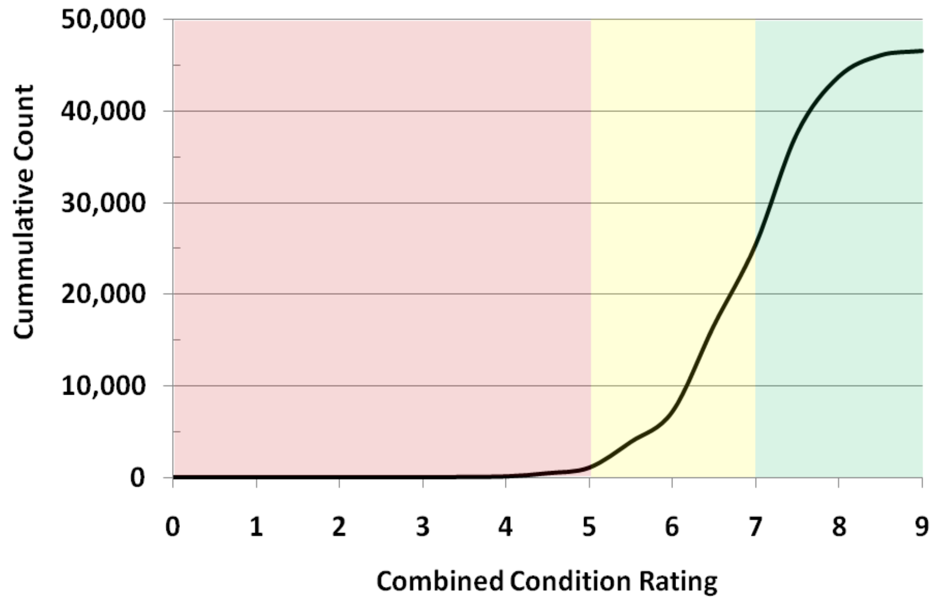
Figure 4.3 Distribution of Condition Ratings for Interstate Bridges in the 48 Contiguous States



Source: Cambridge Systematics, Inc.

Figure 4.4 shows an example of the implications of this spike for the good/fair/poor calculations. It shows the weighted average rating for Option 3a (weights based on the Health Index calculation) for the national analysis. It indicates that moving the threshold for good from 7 to 6 or 8 would significantly impact the results.

Figure 4.4 Weighted Average of Condition Ratings for Option 3.a for Interstate Bridges in the 48 Contiguous States

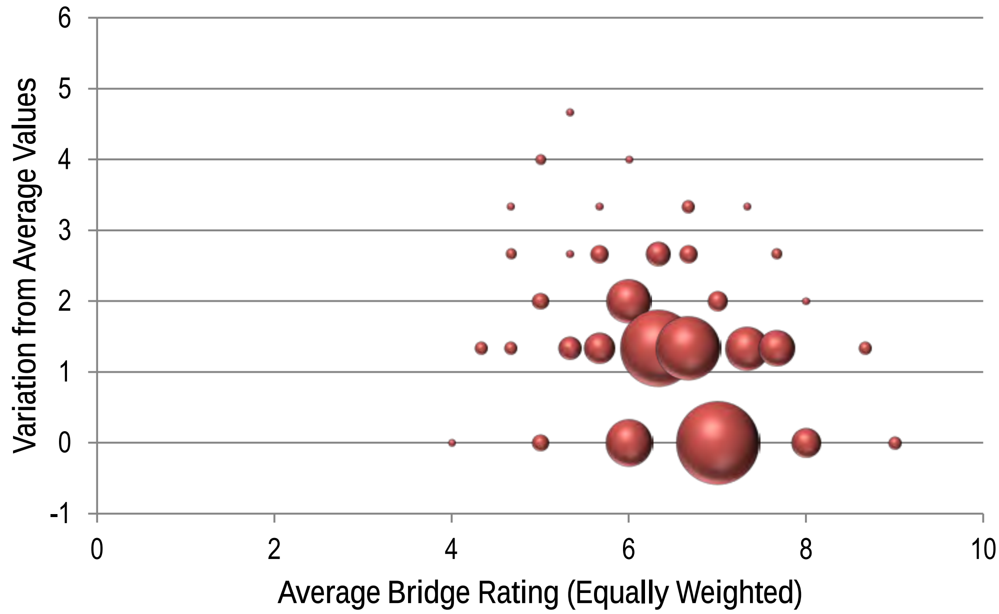


Source: Cambridge Systematics, Inc.

Bridge Finding #9. The main reason for the observed consistency in good/fair/poor results is the consistency of NBI ratings on Interstate bridges throughout the U.S. All of the bridge options explored in this pilot study are based on data from the NBI dataset. Therefore, consistency in the underlying data across the network will result in consistency in ratings developed with these data. For example, nationally about 20 percent of Interstate bridges have deck/superstructure/substructure ratings of 7/7/7. Nearly 40 percent of these bridges have some combination of 7s and 8s for these ratings. These similarities are illustrated further in Figure 4.5 where the size of each sphere represents the proportion of bridges with a certain average bridge rating and variation. It shows two main findings related to the good/fair/poor calculations:

- The average condition ratings are largely between 6 and 8. In particular, this finding helps to explain finding #8, which is that the results are very sensitive to the threshold for good.
- The variation between the average condition rating and the lowest rating is overwhelmingly less than 2 rating points. In particular, this finding helps to explain finding #4 (the results are not sensitive to the weights assigned to the ratings) and finding #7 (the results are not typically being driven by deck condition).

Figure 4.5 Comparison of Average Rating and Variance for Interstate Bridges in the 48 Contiguous States



Source: Cambridge Systematics, Inc.

If the above options were used to analyze a network of bridges with more variable condition ratings between superstructure, substructure and deck then what was observed for the Interstate system, it is anticipated that there would be less consistency between the options. However, if the network was simply in an overall worse condition, but did not have a wide variance in condition ratings on any given bridge, it is anticipated that the above findings would still hold true.

4.3 CONCLUSIONS

Following are the main conclusions from the pilot study for bridges:

- All of the analysis described above was conducted with NBI data. This data set is a viable source for national performance measurement.
- SD status (Option 1) is widely understood and reported. Therefore it makes an attractive national measure. However, SD status does not fit well into the good/fair/poor approach envisioned by FHWA because it is binary. In addition, SD status also includes non-condition components (inventory rating and water adequacy rating), making it less ideal for a pure condition assessment. However, nationally, on the Interstate highway system non-condition components are not typically the driving factor in the SD calculation.

- A measure of structural adequacy based on NBI ratings (Options 2 and 3) is a viable supplement to SD status as a national measure of bridge condition. Implementing this approach would require developing a general consensus on its definition. All of the options explored in the pilot study appear to be viable for a measure of structural adequacy. Given the high degree of correlation between all of the options, it is recommended that the final definition for a structural adequacy measure be based on a policy discussion, focused on the following two questions.
  - Should the measure be based on the minimum condition rating or a weighted average?
  - What is relative importance of deck compared to superstructure and substructure?
- It is recommended that FHWA continue to advance a new measure of structural adequacy based on NBI ratings as an eventual supplement to SD as a national measure of bridge condition.

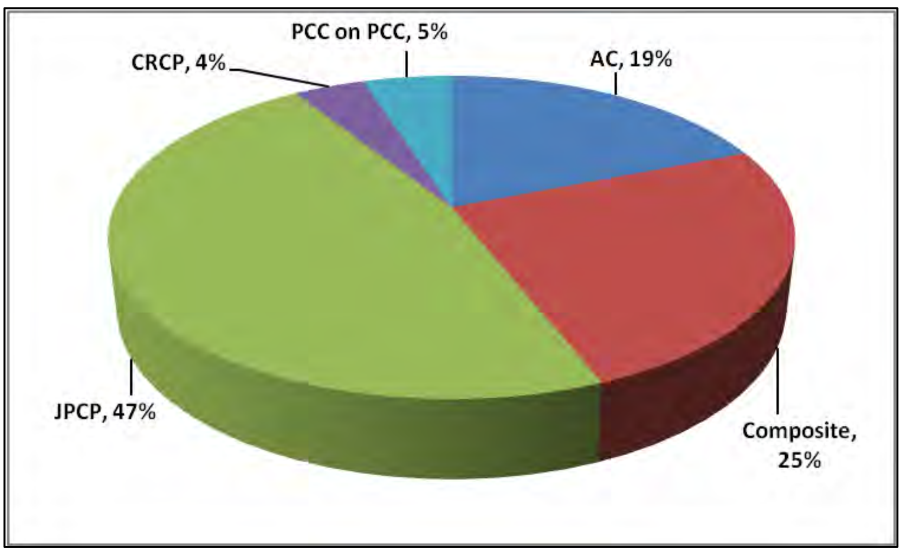
5.0 Pilot Study Pavement Results

This section presents the pilot study findings for pavements. A total of 874 centerline-miles of pavements were included as part of the I-90 pilot corridor, representing approximately 3,900 lane-miles of pavement. The distribution by State is as follows:

- South Dakota: 411 centerline-miles (47%)
- Minnesota: 275 centerline-miles (31%)
- Wisconsin: 188 centerline-miles (22%)

The distribution of pavement and surface types along the pilot corridor is provided in Figure 5.1. As shown, I-90 along the corridor is 44 percent AC surfaced pavements (AC and AC on PCC) and 56 percent PCC surfaced pavements (JPCP, CRCP, and PCC on PCC)[9].

Figure 5.1 Distribution of Pilot Study Pavements by Type



Source: AMEC Environment & Infrastructure, Inc.

The remainder of this section begins with a review of the findings from an analysis of individual pavement condition indicators – namely roughness, cracking, rutting and faulting. Then the results of each good/fair/poor option described in Section 2 are provided. Finally, recommendations and conclusions

[9] Based on HPMS data.

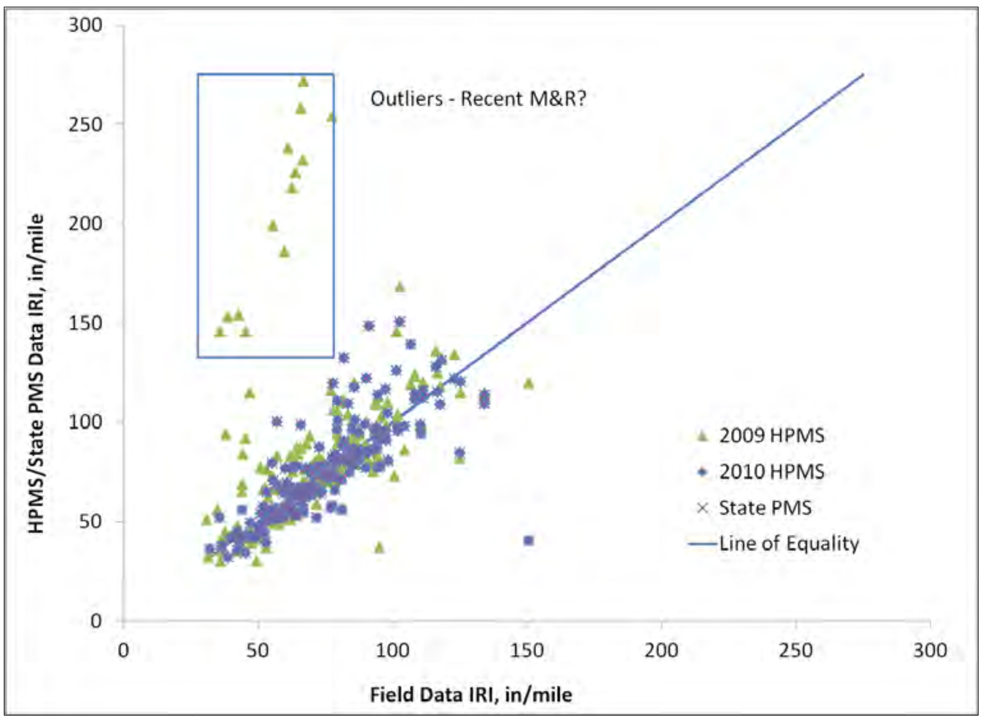
are discussed related to the findings from the pavement condition analysis conducted during the corridor pilot study.

5.1 DATA FINDINGS

Roughness

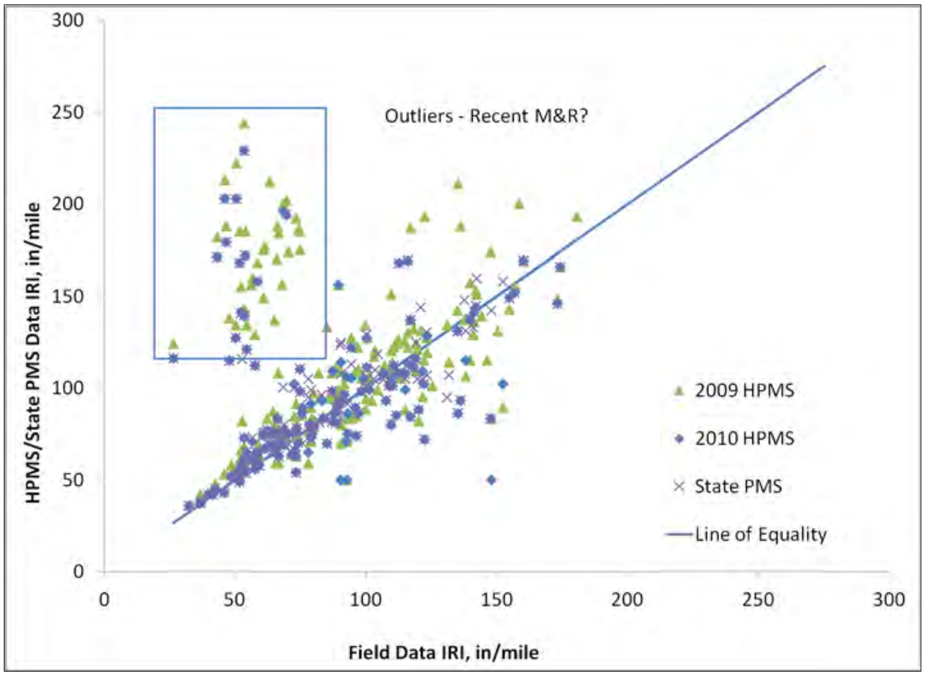
Roughness data were obtained from all three data sources – HPMS, State DOT PMS, and field. In order to complete a comparison of the data, it was necessary to aggregate data to the same data reporting segment limits. Both the State DOT pavement management and field collected data sets were aggregated to the segment limits of HPMS. Figures 5.2 and 5.3 illustrate the comparisons of the data for AC and PCC surfaced pavements, respectively.

Figure 5.2 Comparison of HPMS, State, and Field IRI on Asphalt-Surfaced Pavements



Source: AMEC Environment & Infrastructure, Inc.

Figure 5.3 Comparison of HPMS, State and Field IRI on PCC-Surfaced Pavements



Source: AMEC Environment & Infrastructure, Inc.

Both Figures 5.2 and 5.3 show a number of pilot corridor segments in which the field collected IRI is much lower (smoother) than the data from HPMS and (in some cases) the State DOT PMS; these segments are identified by the outlier boxes. The field data were collected in 2011, the State DOT PMS data were collected in 2010, and the HPMS data were collected in 2009 and 2010. Given the differences in time, a logical explanation for the lower field collected IRI values is that some repair event has occurred on these areas between the times in which the data were collected. These outliers are expected when comparing condition data that are temporally inconsistent. Based upon the available data provided by the States DOTs, it was not possible to determine if these sections had indeed experienced a maintenance or rehabilitation (M&R) event. A key to understanding pavement behavior over time is an understanding of the maintenance and rehabilitation performed on a section. A key finding from this phase of the study is that these data are difficult to obtain from current management systems.

The correlations for the IRI data according to source are presented in Table 5.1. Correlation is a measure of change between two variables. In this context, correlation ranges from 0 (indicating that the results are completely random) and 1 (indicating that the results always coincide.) The correlations are presented both including and excluding the outliers indicated by the boxes in Figures 5.2 and 5.3.

Table 5.1 Correlation of IRI Between Data Sets

	2009 HPMS		2010 HPMS		State	
	Outliers	No Outliers	Outliers	No Outliers	Outliers	No Outliers
2011 Field AC	.33	.62	.78	.78	.78	.78
2009 HPMS AC			.39	.76	.27	.69
2010 HPMS AC	.39	.76			.97	.97
2011 Field PCC	.28	.35	.31	.30	.42	.41
2009 HPMS PCC			.76	.85	.61	.72
2010 HPMS PCC	.76	.85			.93	.93

Several observations can be made when reviewing the Table 5.1 results:

- When outliers are eliminated the different data sets compare much better (as expected) – thus reinforcing the need for good M&R information that could potentially explain the difference.
- The highest correlation is found for both AC and PCC pavements when comparing 2010 HPMS data and State DOT PMS data. This should not be a surprise as the HPMS data is derived from the State DOT PMS in most cases and data is from the same time period (2010).
- When comparing field data collected in 2011 with HPMS and State DOT data AC pavement IRI is correlated much higher than PCC pavement IRI.
- In general, higher correlations are shown for data where the time period of data collection is closer together (for example the correlation between 2010 HPMS and 2011 field data is higher than 2009 HPMS and 2011 field data.

Cracking

Cracking data were reviewed for consistency. The State DOT pavement management data were not collected using the same protocol as HPMS data. South Dakota DOT uses a modified version of the Long Term Pavement Performance Distress Identification Manual that results in a composite surface index, Minnesota DOT uses an internal cracking protocol that results in a surface rating, and Wisconsin DOT is transitioning to the ASTM standard that results in a PCI value. Because of the differences in State DOT pavement management distress data collection techniques, this review was limited to the HPMS[10] and field data. The field data were aggregated to the HPMS reporting interval for comparison.

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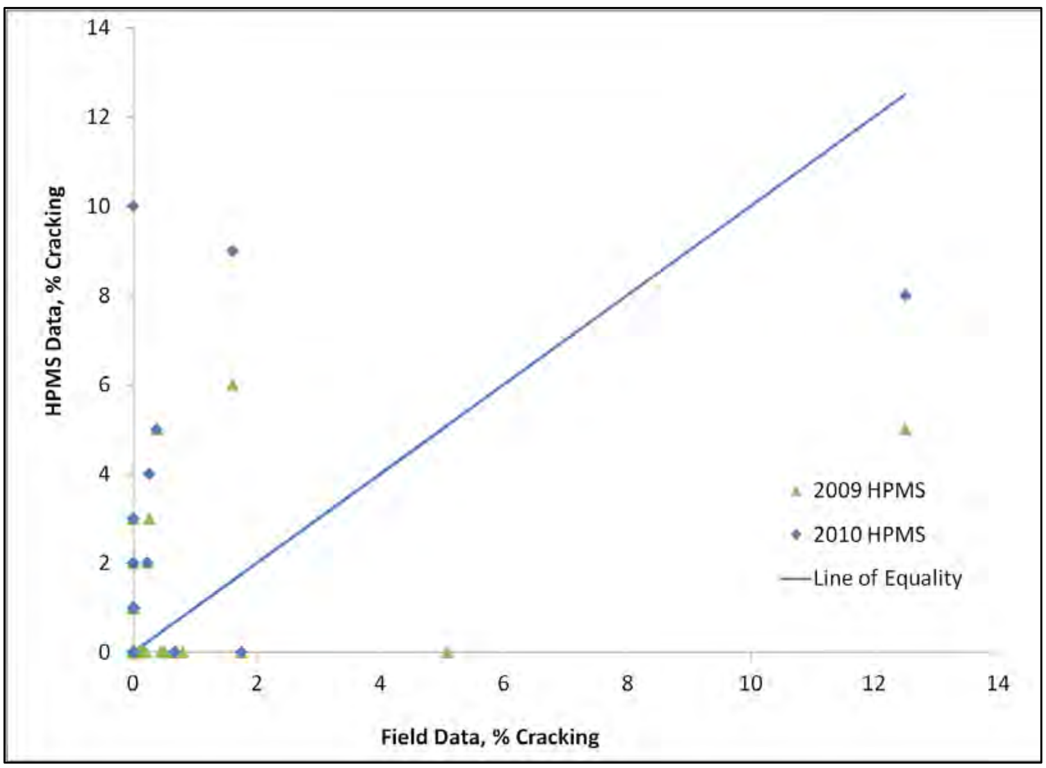
[10] It should be noted that the methods used by each State to develop HPMS cracking data sets vary.

The HPMS data standards provide for collection of percent cracking and crack length. The percent cracking on asphalt-surfaced roadways is the percentage of area in the wheel-paths with fatigue cracking. The percent of slabs with cracking is recorded for jointed concrete pavements and for CRCP pavements the percentage of punchouts is reported.

Crack length is an estimate of the relative length in feet per mile of transverse cracking on asphalt pavements or reflective cracking for composite pavements.

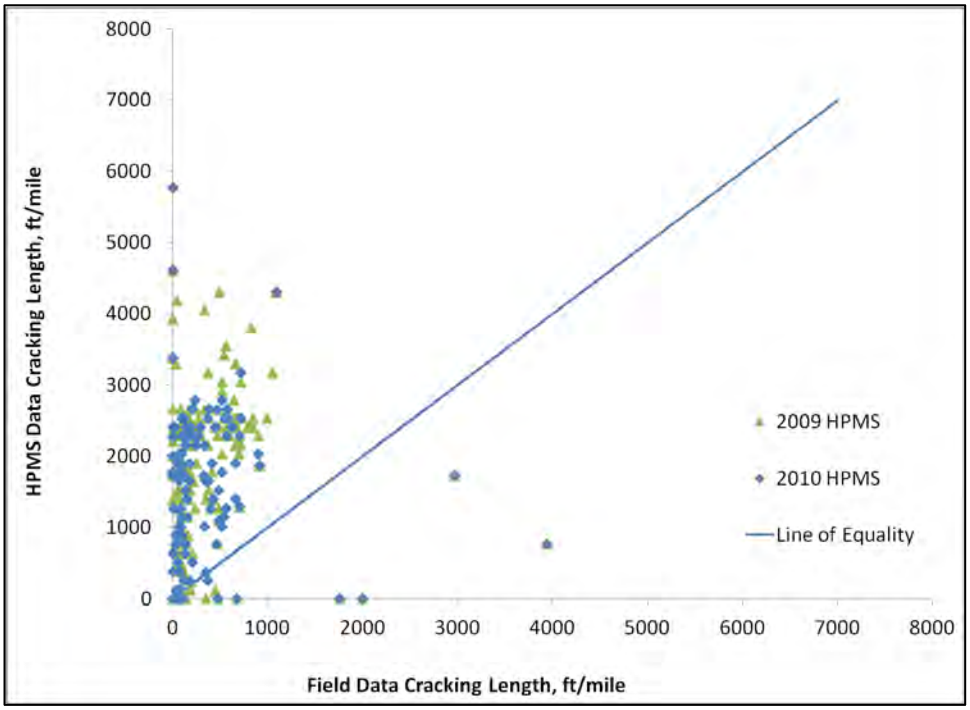
Figures 5.4 and 5.5 present the comparison of the percent cracking and crack length on asphalt-surfaced pavements, respectively. Figure 5.6 presents the comparison of the percent cracking on PCC surfaced pavements. These comparisons illustrate that the data seem to represent completely different data sets. The correlations between HPMS and field data are presented in Table 5.2.

Figure 5.4 Comparison of Percent Cracking on Asphalt-Surfaced Pavements



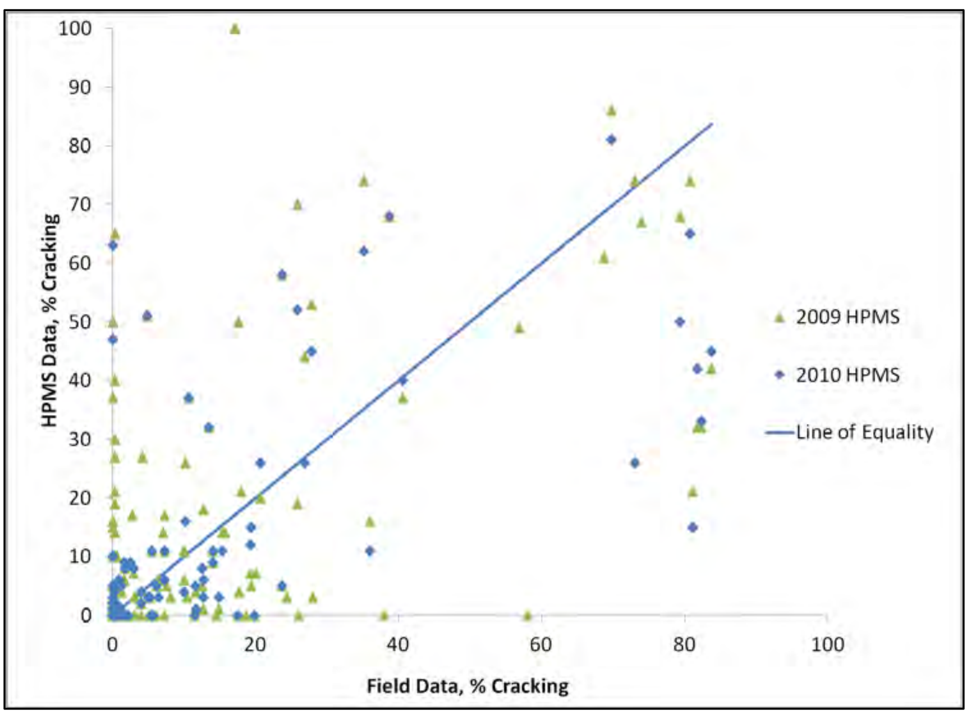
Source: AMEC Environment & Infrastructure, Inc.

Figure 5.5 Comparison of Cracking Length on Asphalt-Surfaced Pavements



Source: AMEC Environment & Infrastructure, Inc.

Figure 5.6 Comparison of Percent Cracking on PCC-Surfaced Pavements



Source: AMEC Environment & Infrastructure, Inc.

Table 5.2 Correlation Between HPMS and Field Cracking Data

Data Set	Correlation between 2009 HPMS and Field	Correlation between 2010 HPMS and Field
Asphalt surface, percent cracking	.45	.46
Asphalt surface, crack length	.08	.00
PCC Surface, percent cracking	.57	.59

As shown in Figures 5.4 through 5.6 and Table 5.2, cracking from HPMS and field data collection does not correlate well. However, it is important to recognize some of the key differences in the data sets. They include:

- The HPMS data were collected in 2009 and 2010 while the field data were collected in 2011.
- The data in question were collected by different methods (manual or automated), different vendors and different automated equipment; changes in data collection personnel and processing methods will always increase the amount of variability in the data collected.
- The HPMS data are collected on a sample while the field data were collected continuously along the corridor.
- Other research (Long-Term Pavement Performance Distress Variability Study[11]) has shown crack detection to be highly variable.

Based on these observations, it is apparent that cracking will require further investigation to develop a more standardized approach to data collection to improve consistency before it is useful as a national indicator of performance.

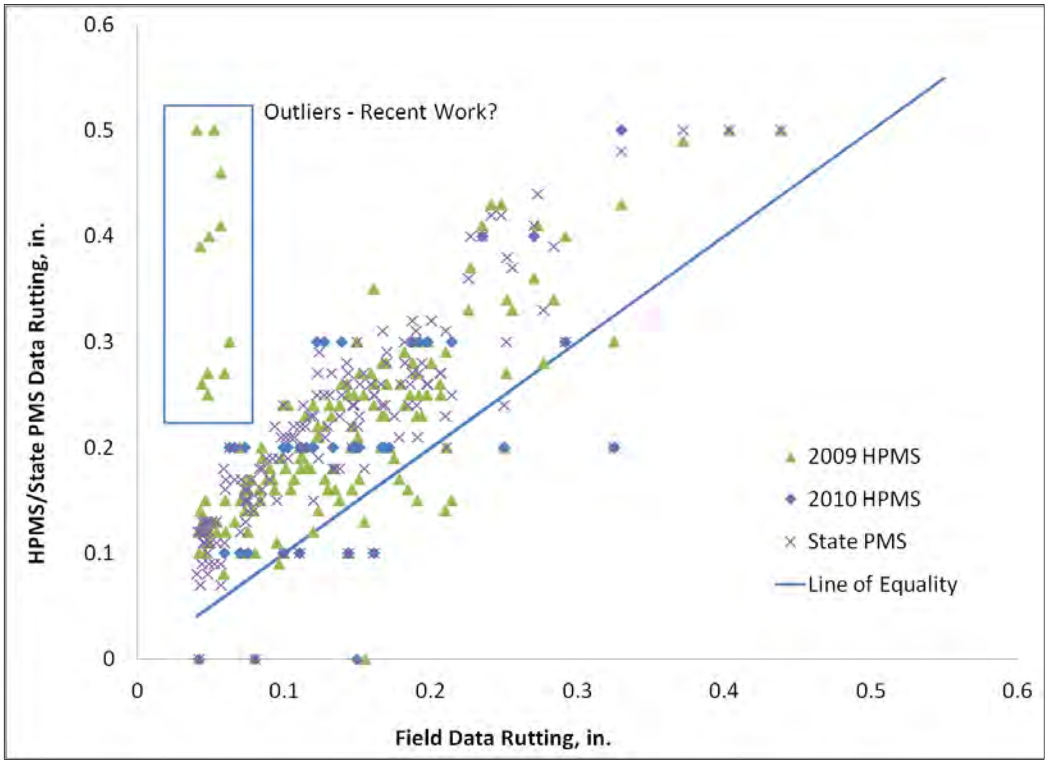
Rutting

Rutting was obtained from all three data sources – HPMS, State DOT and field. As was done with roughness and cracking data, rutting data were aggregated to the same data reporting segment limits as used in the HPMS data set. Figure 5.7 presents a comparison of the rutting data from the HPMS, field and State DOT data sets. As was observed with the IRI data, this figure shows that there are some segments for which the rut depth values obtained from the field data are significantly lower than those obtained from the HPMS or State DOT PMS data. These outliers correspond to the same areas where significantly lower IRI values

[11] "*Variability of Pavement Distress Data from Manual Surveys*," FHWA-RD-00-160, September, 2000.

(as compared to HPMS and State DOT PMS data) were observed in the AC surfaced pavement segments. The correlations between the three rutting data sets are presented in Table 5.3.

Figure 5.7 Comparison of Rutting Data from HPMS, State, and Field Data



Source: AMEC Environment & Infrastructure, Inc.

Table 5.3 Correlations Between Rutting Data Sets

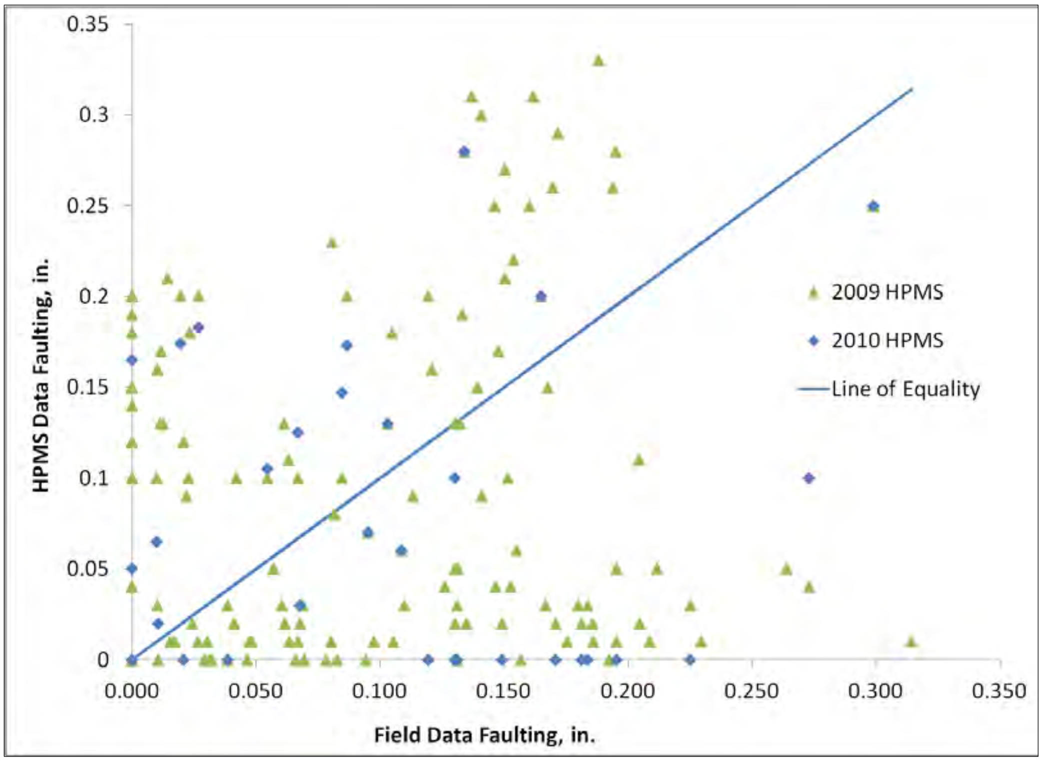
	2009 HPMS Rut		2010 HPMS Rut		State Rut	
	Outliers	No Outliers	Outliers	No Outliers	Outliers	No Outliers
2011 Field Rut	.57	.66	.66	.65	.87	.86
2009 HPMS Rut			.73	.74	.58	.69
2010 HPMS Rut	.73	.74			.85	.84

The rutting data compare well between the three data sets, especially when the outliers are removed. However, it may be observed from Figure 5.7 that there is a bias between the field data and the HPMS and State DOT PMS data –- the field data are consistently lower (0.05 to 0.1 in) than the other two data sets. This bias may be related to a change in the data collection methodology between the field data and the HPMS and State DOT data sets. It is recommended that this bias be investigated further and resolved.

Faulting

Faulting data were included with the HPMS and field data sets. The State DOT PMS faulting data were not collected to the same standard as the HPMS[12] data, and consequently this review was limited to two data sets. Figure 5.8 illustrates the comparison between the HPMS and field collected faulting data.

Figure 5.8 Comparison of HPMS and Field Collected Faulting



Source: AMEC Environment & Infrastructure, Inc.

The correlation coefficient between the data sets in question was computed to be .10, which indicates a poor correlation. This lack of correlation is also readily observed from Figure 5.8. The temporal issues may describe some of the variability observed with these data. Further, faulting is also diurnal with changes occurring throughout the day. Regardless of the cause for the differences observed, faulting does not appear to be a good candidate for national condition assessment.

[12] It should be noted that the methods used by each State to collect HPMS faulting data vary.

5.2 Condition Assessment Findings

As discussed in Section 2.4, six different options were considered for the evaluation of pavement condition. They are:

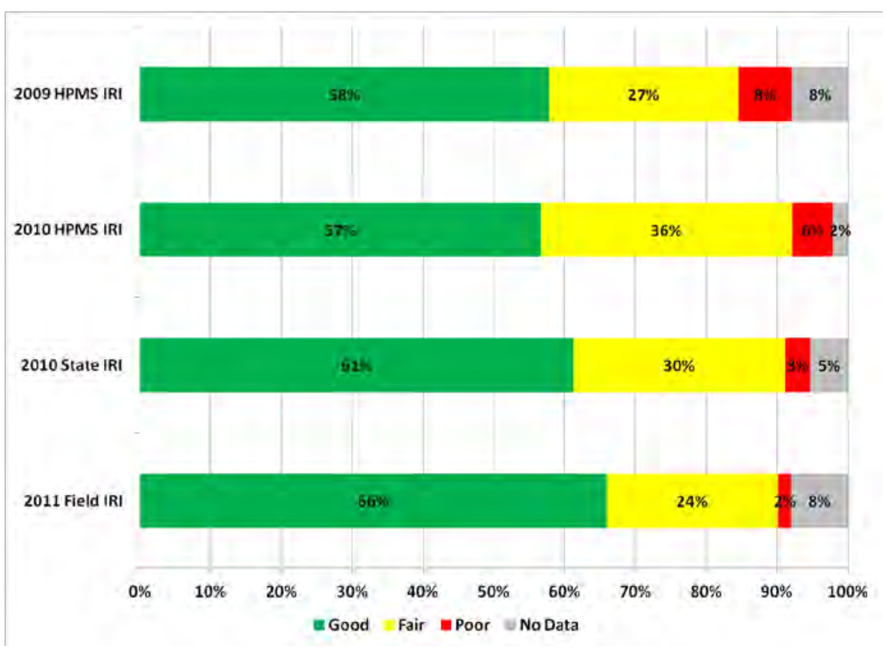
- Option 1 - Pavement roughness in terms of the IRI;
- Option 2 - Pavement surface distresses in accordance with the PCI procedure;
- Option 3 - Combination of pavement roughness and selected distresses (cracking, rutting and faulting);
- Option 4 - Pavement structural capacity based on RWD measurements;
- Option 5 - Combination of pavement roughness, selected distresses and RWD-based structural capacity; and
- Option 6 - Pavement remaining service life.

The project team applied each option to the pilot corridor. The results are provided below.

Option 1 – Pavement Roughness

Pavement roughness in the form of IRI was used to categorize the pavements as good/fair/poor based on the thresholds provided in Table 2.8. Figure 5.9 illustrates the percentage of the pavement falling into each category using the three data sets – HPMS, State DOT, and field.

Figure 5.9 Condition Evaluation Using IRI



Source: AMEC Environment & Infrastructure, Inc.

The evaluation of the different data sets indicates that the condition assessment differs based on which data set is used. The HPMS identifies the smallest area in the good condition and larger areas in the fair and poor conditions, while the largest percentage in the good category is represented by the field IRI. The difference observed between the data sets can be explained based on two reasons. First, some segments in the HPMS data set appear to have received some maintenance or rehabilitation treatment, as discussed earlier in Section 5.1 and illustrated by the outlier boxes in Figures 5.2 and 5.3. The equivalent distance associated with this change is approximately 4 percent of the total length of the pilot corridor route.

The second reason is that the three data sets were aggregated to a different level. The HPMS data intervals range from 0.001 mile to over 10 miles. The State DOT pavement management data set intervals vary between the States and range generally from 0.25 to 1 mile. The field data was collected at 0.1 mile intervals. The longer the reporting interval, the more likely the section condition will not represent either sections of extremely good or extremely poor sections, as it will average conditions over a longer range.

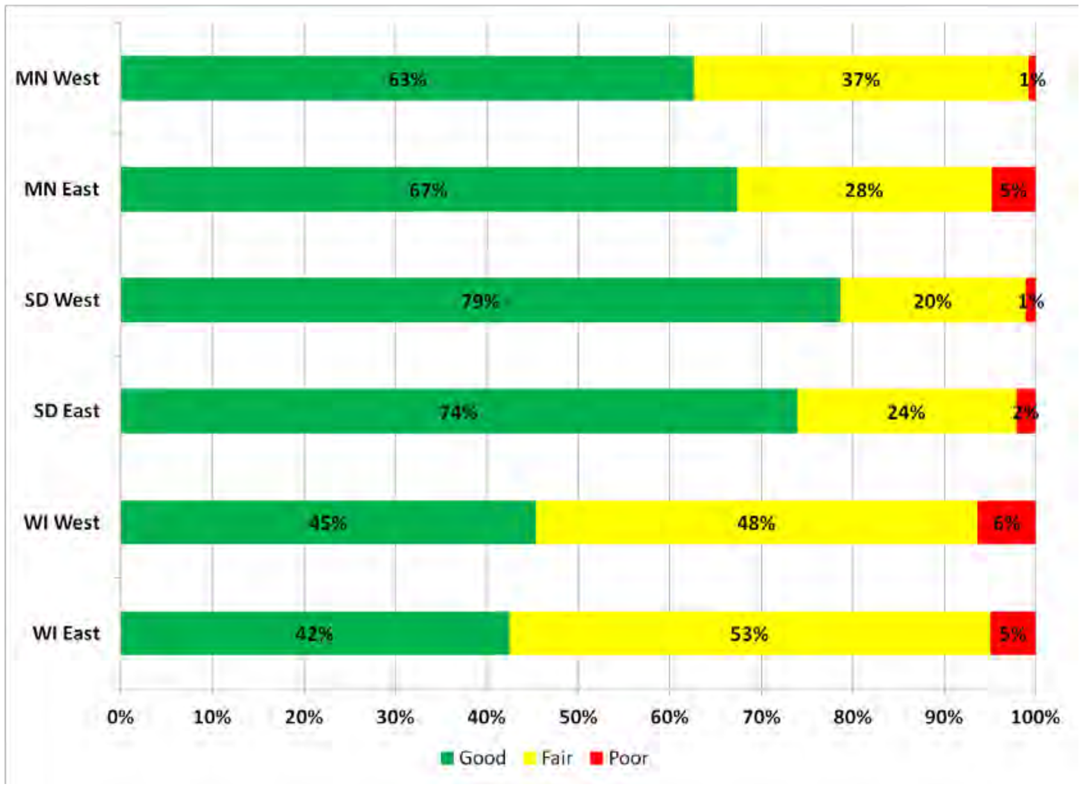
In reviewing the IRI as a condition assessment candidate, the corridor States' PMS IRI data were used to evaluate pavement condition in opposing directions of travel. This comparison is presented in Figure 5.10. As shown in the figure, the West and East directions of travel have fairly similar conditions for the three States. Even though this is a fairly small sample, it appears promising that using the condition of only one direction of travel is fairly representative of both directions of the corridor for IRI. This observation would need to be more rigorously tested prior to drawing final conclusions.

Option 2 - Pavement Condition Index

A total of 150 miles of the corridor were evaluated using the ASTM PCI based on the field data collected as part of this study (PCI could not be calculated for HPMS or State DOT PMS data). Funding limitations prevented PCI data collection for the entire corridor so the 150 miles selected were chosen as a representative sample of the various pavement types present in the corridor. PCI was investigated because it is a relatively common and well understood distress index. The thresholds used for evaluating condition based on PCI are provided in Table 5.4. Table 5.4 also shows the distribution of good/fair/poor according to PCI for the 150 miles evaluated.

For the pavement sections with PCI data, a correlation of good/fair/poor was performed comparing PCI with IRI. A very low correlation was found between the two condition indicators. This finding is consistent with the notion that a pavement's smoothness (IRI) and its distress propagation (PCI) are not well linked and should be treated separately in pavement condition or health models.

Figure 5.10 Comparison of Conditions in Opposing Directions of Travel based on 2010 State PMS IRI



Source: AMEC Environment & Infrastructure, Inc.

Table 5.4 Good/Fair/Poor Based on PCI Field Data

Category	PCI Threshold	% of Corridor
Good	> 86	44%
Fair	85 ≥ PCI > 70	53%
Poor	≤ 70	3%

Option 3 - Combination of Pavement Roughness and Selected Distresses

The project team used ground-truth data from the field testing of the pilot corridor to develop an example FCI that combines pavement roughness with distress data provided by the HPMS to represent the functional condition of the pavement.

For asphalt surfaced pavements the resulting equation for calculating FCI is given by:

$$FCI = \frac{RoC + 3 \times RuC + 2 \times CPC + 10 \times CLC}{16}$$

where:

RoC = Roughness Condition

$$RoC = 100 \times (1 - \frac{IRI}{300})$$

IRI = International Roughness Index, in/mile

RuC = Rutting Condition

$$RuC = 100 \times (1 - 2 \times Rut)$$

Rut = Rut Depth, in.

CPC = Cracking Percent Condition

$$CPC = 100 - 10 \times PC$$

PC = Percent Cracking, %

CLC = Crack Length Condition

$$CLC = 100 \times (1 - 8 \times \frac{CL}{5280})$$

CL = Crack Length, ft/mile

For JPCP surfaced pavements, the equation for computing FCI is given by:

$$FCI = \frac{2 \times RoC + 2 \times FC + CPC}{5}$$

where:

RoC = Roughness Condition

$$RoC = 100 \times \left(1 - \left(\frac{IRI}{200}\right)^2\right)$$

IRI = International Roughness Index, in/mile

FC = Faulting Condition

$$FC = 100 \times (1 - \frac{Fault}{0.5})$$

Fault = Faulting, in.

CPC = Cracking Percent Condition

$$CPC = 100 \times (1 - \sqrt[2]{\frac{PC}{100}})$$

PC = Percent Cracking

And, for CRCP surfaced pavements, the equation for determining FCI is given by:

$$FCI = \frac{RoC + FC}{2}$$

where:

RoC = Roughness Condition

$$RoC = 100 \times \left(1 - \left(\frac{IRI}{200}\right)^2\right)$$

IRI = International Roughness Index, in/mile

FC = Faulting Condition

$$FC = 100 \times \left(1 - \left(\frac{Fault}{0.5}\right)\right)$$

Fault = Faulting, in.

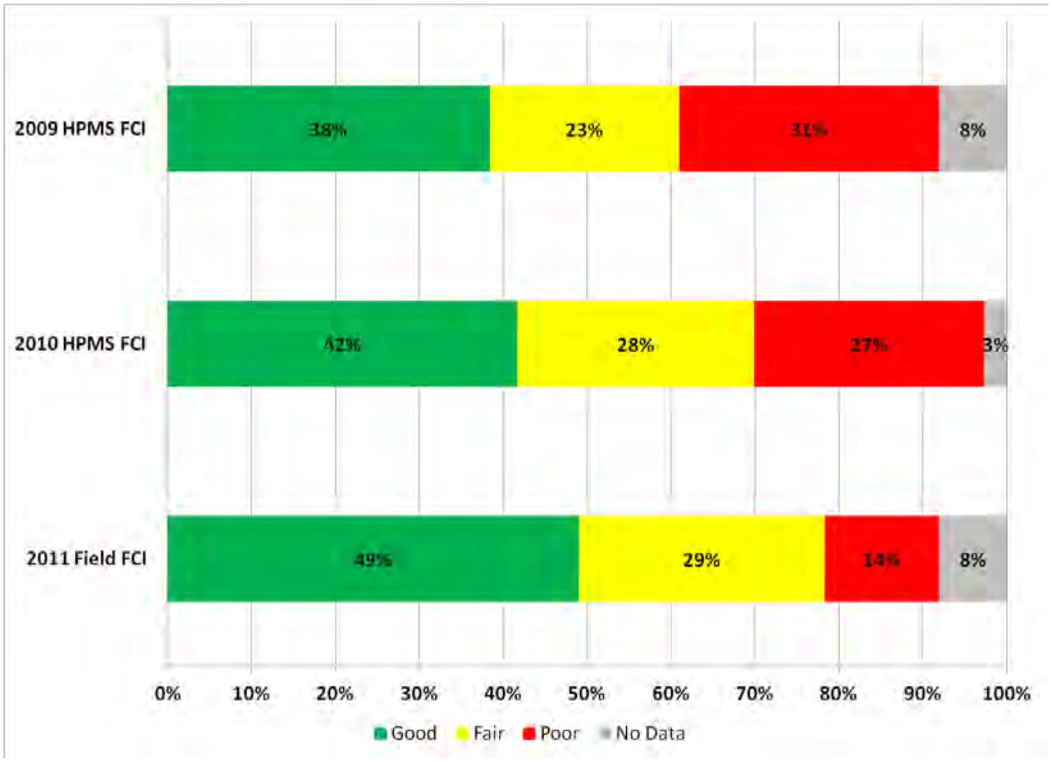
The threshold limits good/fair/poor based on FCI are provided in Table 5.5. The breakpoints for the threshold limits were developed based upon the ground truth exercise. Observed good/fair/poor conditions derived from the ground truth study were correlated to the results of the FCI. Clear breaks in the data were assigned threshold limits. It should be noted that the FCI is an <u>example</u> of how a FCI could be developed. Development of a final, widely accepted FCI was outside the scope of this study.

Table 5.5 FCI Thresholds

Pavement Type	Category	FCI Threshold
Asphalt or CRCP	Good	> 85
	Fair	85 ≥ FCI > 60
	Poor	≤ 60
JPCP	Good	> 80
	Fair	80 ≥ FCI > 50
	Poor	≤ 50

Figure 5.11 illustrates the FCI-based good/fair/poor results based on the HPMS and field data sets. It illustrates the differences observed in HPMS and field cracking values. Specifically, since the HPMS and field IRI and rutting data sets compared well, the primary reason for the differences shown in Figure 5.11 is related to the cracking measurements. It will be necessary for the cracking data collection to be standardized in order to make use of a combined index feasible as a national measure. The temporal issues identified previously are also again illustrated in the figure.

Figure 5.11 Condition Based on FCI Computed Using HPMS and Field Data Sets



Source: AMEC Environment & Infrastructure, Inc.

Option 4 – Pavement Structural Capacity based on RWD

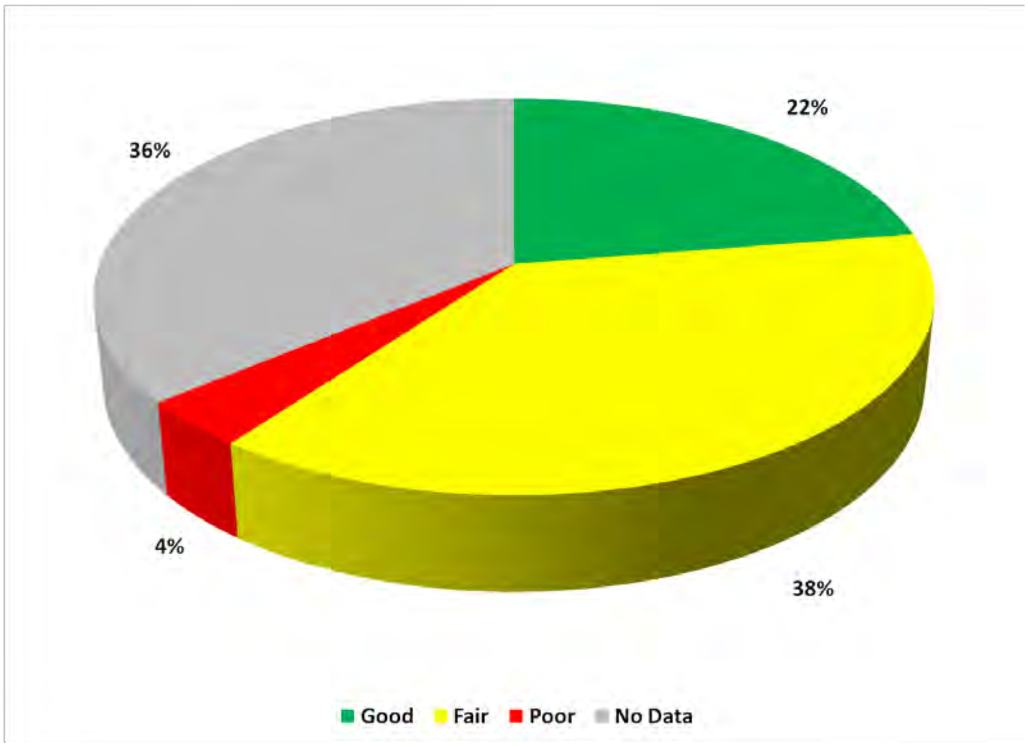
The structural condition was evaluated along the corridor using the data collected by the RWD. None of the results shown here include data from Wisconsin DOT due to the lack of pavement structure information for that portion of the corridor. Additionally, portions of the data collected on the corridor were removed due to quality concerns with the data. The RWD has been reported to be affected by longitudinal tining on concrete pavements and other rough or open surface textures. As a result, 560 centerline-miles of the corridor, or 64% of the 874 mile corridor had RWD data results.

Table 5.6 summarizes the analysis results. The deflection (D_0) thresholds are also provided in this table. Figure 5.12 illustrates the results of RWD analysis based on the referenced threshold limits. These results reflect the entire corridor, including sections that could not be collected/analyzed with the RWD based on the issues mentioned in the paragraph above, which are shown as "no data."

Table 5.6 Good/Fair/Poor Based on RWD Field Data

Category	D_0 Threshold	% of Corridor
Good	≤ 6	22%
Fair	$6 < D_0 \leq 10$	38%
Poor	> 10	4%

Figure 5.12 Condition Based on RWD Field Data



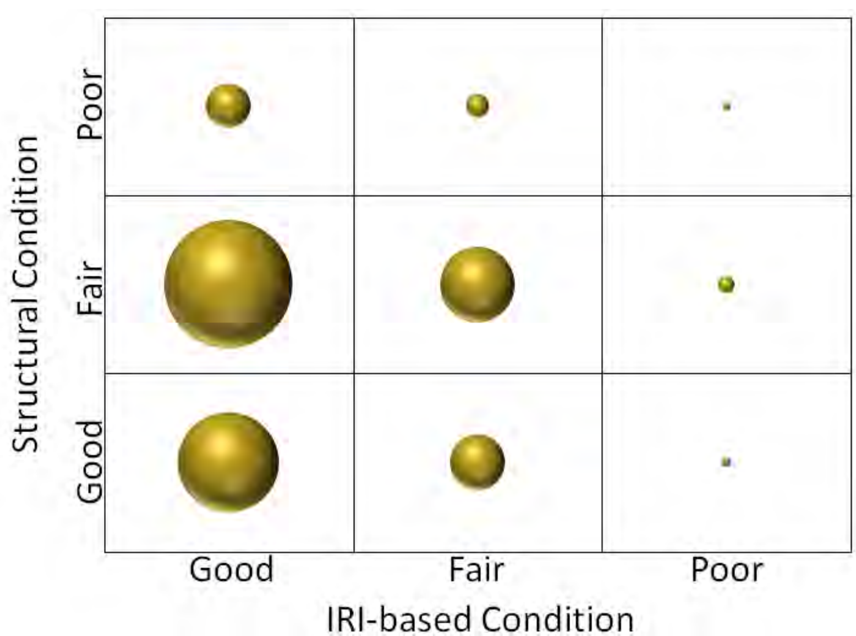
Source: AMEC Environment & Infrastructure, Inc.

Option 5 – Combination of Pavement Roughness, Selected Distress and RWD-Based Structural Capacity

Under this option, the FCI and D_0 conditions derived under Options 3 and 4 using field data were combined for the assessment. The lesser of the conditions assessed using both the FCI and D_0 options was identified as the condition of each segment. For example, if the condition based on the FCI is good and the condition based on D_0 is fair, then the combined condition is fair. Based on this approach, it was determined that 30 percent of the corridor is in good condition, 49 percent is in fair condition, and 17 percent is in poor condition (4% had no data).

This analysis also presented the opportunity to compare the roughness of the section and the structural capacity of a section. Figure 5.13 presents this comparison in a conceptual fashion. The left axis of the figure represents good/fair/poor using structural condition, and similarly the bottom axis represents good/fair/poor for IRI based condition. The bubbles represent the number of records for each good/fair/poor combination. If the data were highly correlated, the bubbles would be of equal size in the good/good, fair/fair, and poor/poor areas. As shown in this figure, the data are not well correlated and, in general, the structural condition tends to result in a lower condition indicator (as evidenced by the largest bubble in fair/good area of the figure) than IRI based condition. Therefore, a general conclusion can be made that both structural and functional condition are needed to adequately represent the condition of a pavement system.

Figure 5.13 Conceptual Relationship between Structural Condition and IRI-based Condition



Source: Cambridge Systematics, Inc.

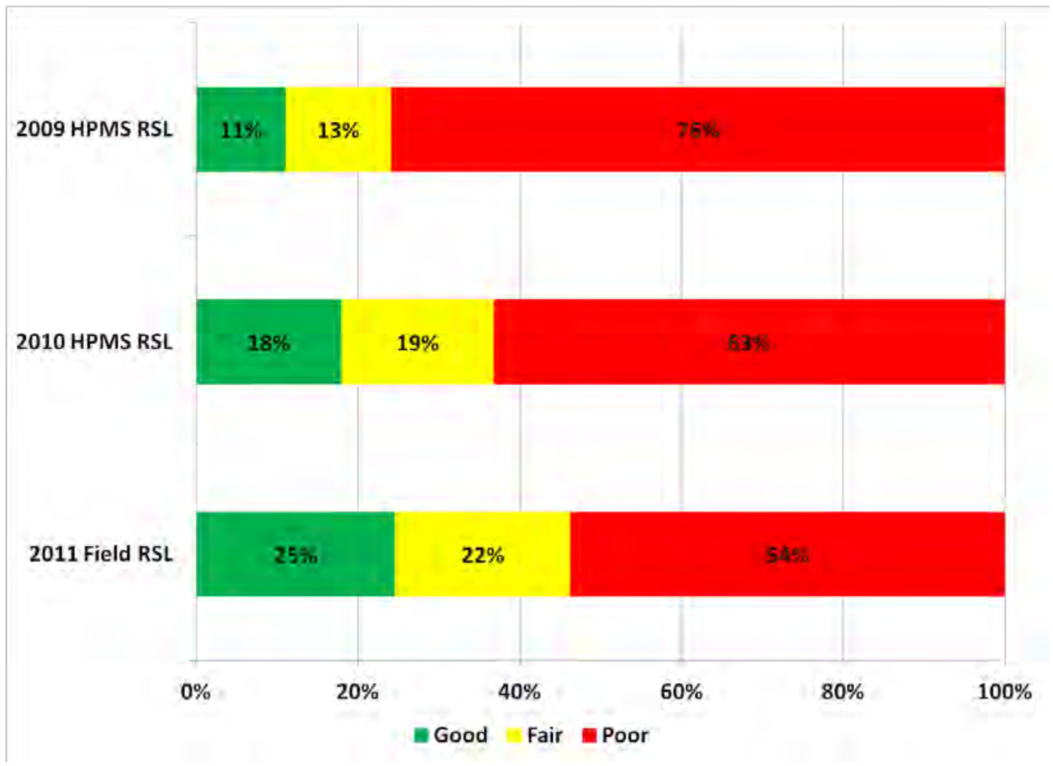
Option 6 - Pavement Remaining Service Life

In this option, the PHT tool was used to estimate RSL using the HPMS and field data sets. State DOT PMS data were also considered for this comparative analysis, but these data did not provide the required cracking values or the values provided were not in the specified format for the PHT tool. In addition, analysis of the Wisconsin DOT data could not be completed because several key data fields were missing from the HPMS and other sources, including Present

Serviceability Rating (PSR), thickness, base type, year last improved and year last constructed.

The RSL for the pilot corridor pavement segments was determined using the PHT tool and the terminal values presented in Table 2.13 for each distress type. The good/fair/poor thresholds for RSL were presented in Table 2.14. The RSL results are presented in Figure 5.14.

Figure 5.14 RSL Results – PHT Tool (SD and MN only)



Source: AMEC Environment & Infrastructure, Inc.

Figures 5.14 illustrates that there are significant differences between the results generated using different data sets. It is also clear that RSL paints a very conservative picture of the condition of the corridor pavement sections with a majority of the pavements in a "poor" condition. The reason for a majority of the sections rated poor was their RSL was zero. In turn, the reason for the large number of zero remaining service life were two-fold and fairly equally balanced. Either the segment had reached the maximum age threshold or it had hit the distress limit set for the analysis.

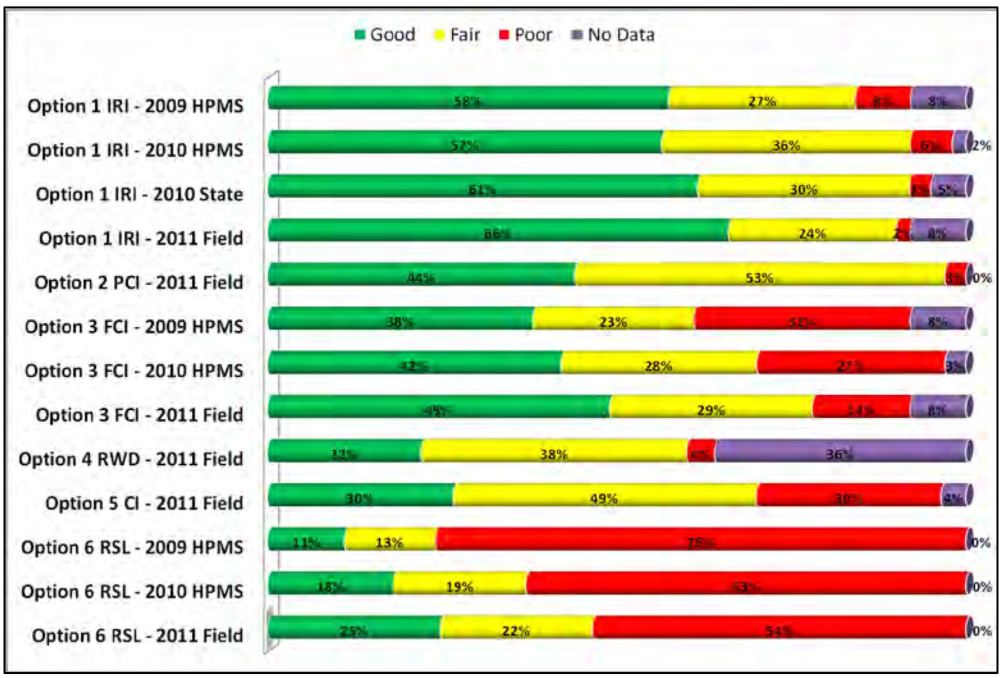
It should also be noted that through the previous analysis presented on the individual HPMS data elements (cracking, rutting, faulting), work is needed to generate consistent, reliable input data to the PHT tool to produce RSL values. In addition, it was noted during data review that some of the input HPMS data did not seem reasonable. For example, sections with a high PSR value had high amounts of cracking or newly overlaid segments had a very low PSR. Determining the root cause of these inconsistencies was beyond the scope of this study.

Although pavement remaining service life using the PHT tool is a potential option, it requires investigation prior to consideration in the assessment of pavement condition. Some of the areas to be investigated are the thresholds for the terminal values for each distress and methods to provide more realistic and consistent pavement M&R history and pavement age information – a significant driver for the PHT analysis. In addition, use of locally calibrated models in the PHT using the recommended 5 year HPMS 2010+ formatted history data (5 years of HPMS 2010+ does not exist at this time) may potentially yield more realistic results.

Summary

A summary comparison of all six good/fair/poor options evaluated in this study is depicted in Figure 5.15.

Figure 5.15 Comparison of Pavement Good/Fair/Poor Results



Source: AMEC Environment & Infrastructure, Inc.

Notes: Option 2 (PCI) was determined on a subset (150 miles) of the corridor. Percentages may sum to > 100% due to rounding.

While there are advantages for moving to the progressively more complex options, as they capture greater information about the condition of the pavement, the preceding discussion in this section illustrates that moving to those options requires further work and/or investigation – they do not provide a consistent picture in terms of pavement condition, and thus, health. At present, relative consistency is only achieved under Option 1 – Pavement Roughness (IRI).

A summary of the key findings by option is provided below:

- **Option 1 – Pavement roughness:** Improvements in IRI data collection and processing are certainly possible and should be pursued. However, this pavement condition measure is ready for implementation as an initial good/fair/poor indicator, and could be implemented immediately. In order for it not to be misconstrued as a holistic condition indicator, it may be advisable to be specific when describing the measure by using the phrase "Good, Fair, and Poor Ride Quality," and not Good, Fair, and Poor Condition."
- **Option 2 – Pavement Condition Index**: Although it would be advantageous to incorporate the full-range of PCI distresses within the good/fair/poor indicator, the associated data collection and processing requirements make this option unrealistic at present and in the near future. Significant advancements in automated pavement condition data collection will be necessary to make this a feasible alternative. Because of the wide disparity in State DOT distress data collection (of the three State DOTs involved in this pilot study each used a different distress capture method) it is currently not feasible to use State DOT pavement management data to drive a distress-based good/fair/poor indicator.
- **Option 3 - Combination of pavement roughness and selected distresses**: Much work needs to be done to incorporate selected distresses along with pavement roughness into a good/fair/poor indicator. The cracking data currently used in HPMS do not correlate well with the field data collected during the pilot. Currently there is no accepted method to convert HPMS distress information into an index that can be used for good/fair/poor evaluation. These obstacles must be resolved in order to move forward with a distress-based approach.
- **Option 4 – Pavement structural capacity**: Much work remains to be done in order to incorporate this important pavement condition measure into a potential good/fair/poor indicator and it is unlikely that this will happen in the near future. Work is needed to establish calibration standards, data collection procedures, and documented analysis procedures in the RWD process or for other continuous deflection devices. In addition, pavement layer thickness is required -- data which are difficult to extract with any certainty from many State DOT PMS. Additionally, the data collection limitations of the RWD need to be improved to increase the coverage of the vehicle to all pavement surface textures.
- **Option 5 - Combination of pavement roughness, selected distresses and structural capacity**: While this option is considered the preferred one in terms of characterizing the condition and health of pavement networks, it is

considered unrealistic at present or in the near future given the outcomes of Options 2, 3 and 4 described above.

- **Option 6 - Pavement remaining service life**: Work is presently on-going to improve the PHT analysis tool and it is anticipated that it will be ready in the near future. If this happens, the revised PHT analysis tool may become the most logical approach towards characterizing the health of pavement networks as good/fair/poor. However, the data limitations mentioned previously (related to cracking, rutting, faulting, M&R history, inconsistent HPMS input values, etc.) must be overcome before the PHT results are considered viable and realistic. In addition, the overall algorithm for RSL in the PHT generates a large number of zero values (and thus poor condition) for RSL. This finding should be investigated on a larger data set to determine if the thresholds should be modified to reflect more realistic estimates of RSL. Use of locally calibrated PHT models instead of the default national models is also essential for use of the PHT. Five years of HPMS data is required for local calibration of the PHT models.

5.3 Conclusions and Recommendations

The following conclusions were developed based upon the data and condition assessment findings presented in Sections 5.1 and 5.2:

- The level of confidence associated with the various pavement condition measures evaluated within the context of good/fair/poor is summarized in Table 5.7 as well as below:
  - There is a high-level of confidence with IRI given the acceptable correlation found in the study between the HPMS, State DOT PMS and field data sources.
  - A medium-level of confidence exists for the rut depth data and additional investigation is required to resolve the bias issue between the HPMS or State DOT PMS data and the field data.
  - For the remaining condition measures (cracking percentage, cracking length and faulting), additional work is required to standardize data collection and processing at the national level.

Table 5.7 Confidence Levels for Pavement Condition Measures Evaluated

Condition Indicator	Confidence in Data
IRI	High
Cracking %	Low/Med
Cracking Length	Low
Rutting	Medium
Faulting	Low

- Because of the high-level of confidence, pavement roughness in terms of IRI is a feasible and the recommended measure for use as the Tier 1 good/fair/poor indicator. FHWA may consider asking States DOTs to provide raw (e.g. ERD [Engineering Research Division] format files or other similar unprocessed profile data) with the HPMS submission so that the IRI can be calculated consistently (using ProVAL) across States. When used, the indicator should specifically mention this is ride quality condition, and not pavement condition.
- Because IRI does not provide a complete picture of pavement condition, other measures were considered in addition to or in combination with IRI, including selected distresses, structural capacity and remaining service life. However, given the level of confidence associated with these other pavement condition measures, significant work is required before they can be implemented.
  - Rutting data could be used as a flag (for safety concerns) to the good/fair/poor indicator. However the rutting algorithm should be codified so that it can be applied consistently across the State DOTs.
  - Cracking data on AC and PCC pavements and faulting data on PCC pavements cannot be used at present as inputs to a Tier 2 good/fair/poor indicator. Much investigation and standardization is required before they can be incorporated into the good/fair/poor indicator with a high-level of confidence.
  - Like cracking and faulting, pavement structural capacity using the RWD or other continuous deflection devices requires much work (both from a technology perspective and through some agreement within the pavement engineering community on appropriate condition thresholds) before this measure can be incorporated into a Tier 3 good/fair/poor indicator.
  - Remaining service life, through use of the PHT tool offers some potential for use as a Tier 2 measure. However, since the tool is driven by HPMS data, much work needs to be done on the distress data collection and reporting before measures can be incorporated into the good/fair/poor indicator.
  - Development of a combined Tier 3 index that addresses the various pavement condition elements (ride quality, surface distresses and structural capacity) will require more work than just resolving the above referenced issues with cracking and faulting. Development of a standardized RWD analysis approach as well as the review and acceptance of the outcomes from the recommended investigations by the pavement community are also required.
  - Given the need for consistent, high-quality data at the National level, use of the HPMS data set to drive the good/fair/poor indicator and possible

associated flags is considered the best option at present and in the near future. However, this does not imply that improvements to the HPMS data are not possible and/or required, as discussed next. Using State DOT PMS data does not seem feasible at this time due to the differences between States. Collecting field data on the entire Interstate system likewise does not appear economically justified at this time.

Based on the above findings, the following are recommendations related to classifying pavements as good/fair/poor (numbered for ease of reference, not to connote recommended priority):

1. HPMS data summary lengths should be investigated to resolve the analysis bias when using variable sample lengths. At present, the summary lengths are highly variable, which can lead to pavement condition measures being either exaggerated in the case of short lengths or being lost due to averaging over long lengths. Resolution of this issue was beyond the scope of this project.
2. Calculation of good/fair/poor should be based on HPMS data extracted in November or December of each year, after data collection and processing have been completed by FHWA for the year in question to minimize temporal distortion issues and therefore potentially erroneous or inaccurate conclusions. Even so, it should be noted that HPMS data will represent conditions 18 months or more in arrears.
3. Incorporate additional checks in the HPMS software to flag HPMS data that is not consistent (for example sections that have a high PSR value but show high distress levels or vice versa). These checks should be applied at the State level, prior to submission of data to FHWA. Having up-to-date information on maintenance and rehabilitation is important to resolve potential issues associated with the temporal analysis of pavement condition data.
4. The HPMS rut depth data collection procedure and analysis algorithm should be codified for purposes of the good/fair/poor indicator. Currently rut depth data collection and calculations are not standardized and there exist several potential procedures.
5. HPMS cracking data collection should be better defined and a manual for its implementation prepared along with the recommended QC/QA standards. FHWA has an ongoing effort to establish uniform data collection methods for use in HPMS reporting.
6. Faulting data should be investigated to resolve the inconsistencies in data collection and analysis. Use of the ProVAL tool to analyze faulting may be a suitable method to standardize the analysis of faulting data.
7. A need exists for standards related to RWD calibration, data collection, processing, and analysis.

8. The PHT tool should be reviewed in detail to determine the reason for the overly conservative RSL values generated by the program.

6.0 Health Assessment and Reporting

The objective of the health assessment track of this study was to develop a methodology for determining the health of a corridor with respect to bridges and pavements. Health in this context is based on factors that go beyond condition, such as age and traffic loads.

The health assessment is intended to provide a means for FHWA to examine the overall health of specific corridors and respond to requests for information. It would enable FHWA to examine corridor health across multiple States in a consistent manner. State DOT's may also be interested in the results if they would like to review corridor conditions in adjacent States.

6.1 Vision for Health Reporting

The vision for the health assessment has two components. The first is a report that summarizes the overall health and identifies potential warning signs. The second component is a tool that automates the creation of the reports and enables users to review metrics and examine detailed data.

Over the course of this effort, FHWA and the project team narrowed down several options, coming to the following conclusions about the health report:

- Scope – The pilot report was created on an Interstate corridor, but the methodology is designed to be applicable for the entire National Highway System.
- Scale – Ideally, data used for the reports should be available by highway segment and flexible for analysis purposes (e.g., can be aggregated across multiple segments). The reliance on HPMS and NBI data for the reports ensures this objective is met.
- Timing – The methodology focuses on a current snapshot of conditions/health, and where possible helps FHWA to anticipate potential near term issues.
- Components of health to be considered - The initial effort focused on system conditions, building on the bridge and pavement metrics developed for good/fair/poor definition and including other metrics when appropriate. The methodology is designed to enable future consideration of additional factors such as operational performance and transportation impacts. Asset characteristics and usage are also included to provide context and help to identify red flags. For example, the sample health report accounts for traffic

volumes, percent trucks, bridge age, remaining service life for pavements (as calculated by the FHWA's PHT), and the financial demands of maintaining the asset.

Based on the input of FHWA and the TWG, the health reporting tool is designed to present an overview of several critical factors rather than a single number or grade for an entire corridor. The analogy that was used for the health reporting tool was a visit to the doctor. When visiting the doctor one does not receive a single health score, but rather an in-depth discussion of several health indicators that help to present a comprehensive picture. As such, the health reporting tool relies on several metrics including good/fair/poor, age, remaining service life for pavements, traffic volumes, etc., and presents these data in a manner that enables users to apply expert judgment in order to assess the overall health of a corridor.

6.2 HEALTH REPORT SAMPLE

Figure 6.1 presents sample health report developed for this project. The information provided on the report is based on actual HPMS and NBI data compiled by the project team throughout the pilot process. Details regarding how this report is developed are provided in the following section.

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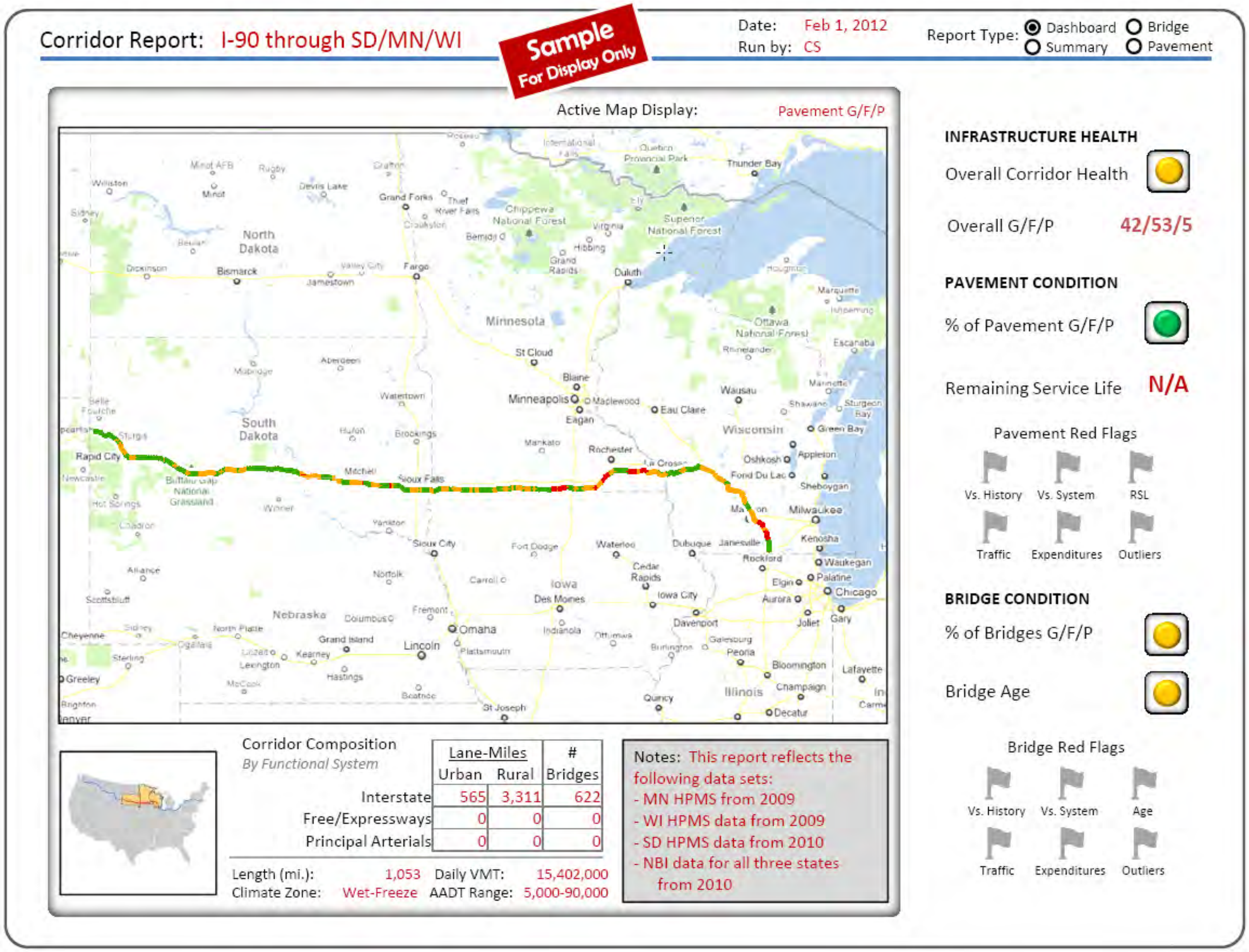
Figure 6.1 Sample Health Report

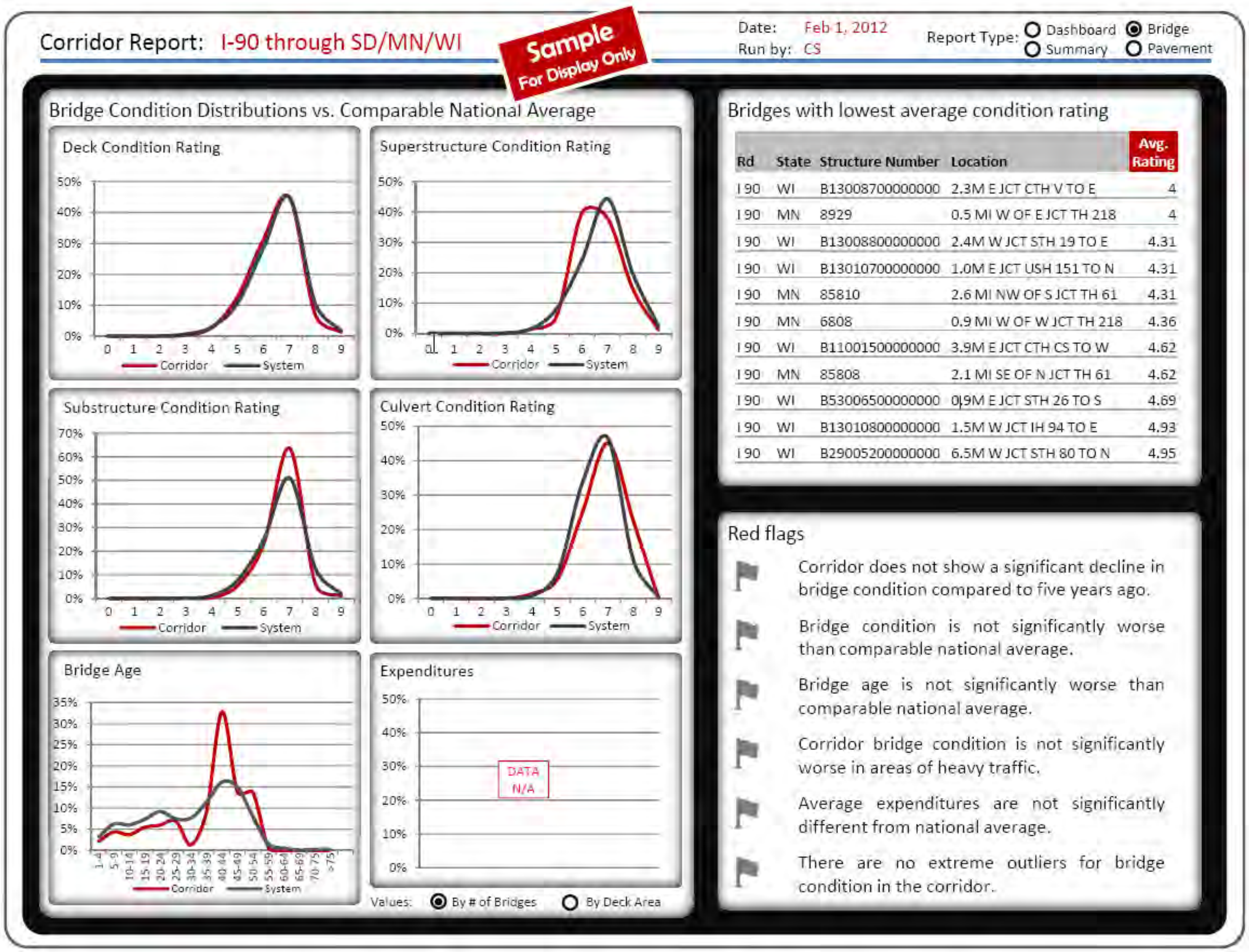


Source: Cambridge Systematics, Inc.

Figure 6.1 Sample Health Report, continued

Source: Cambridge Systematics, Inc.

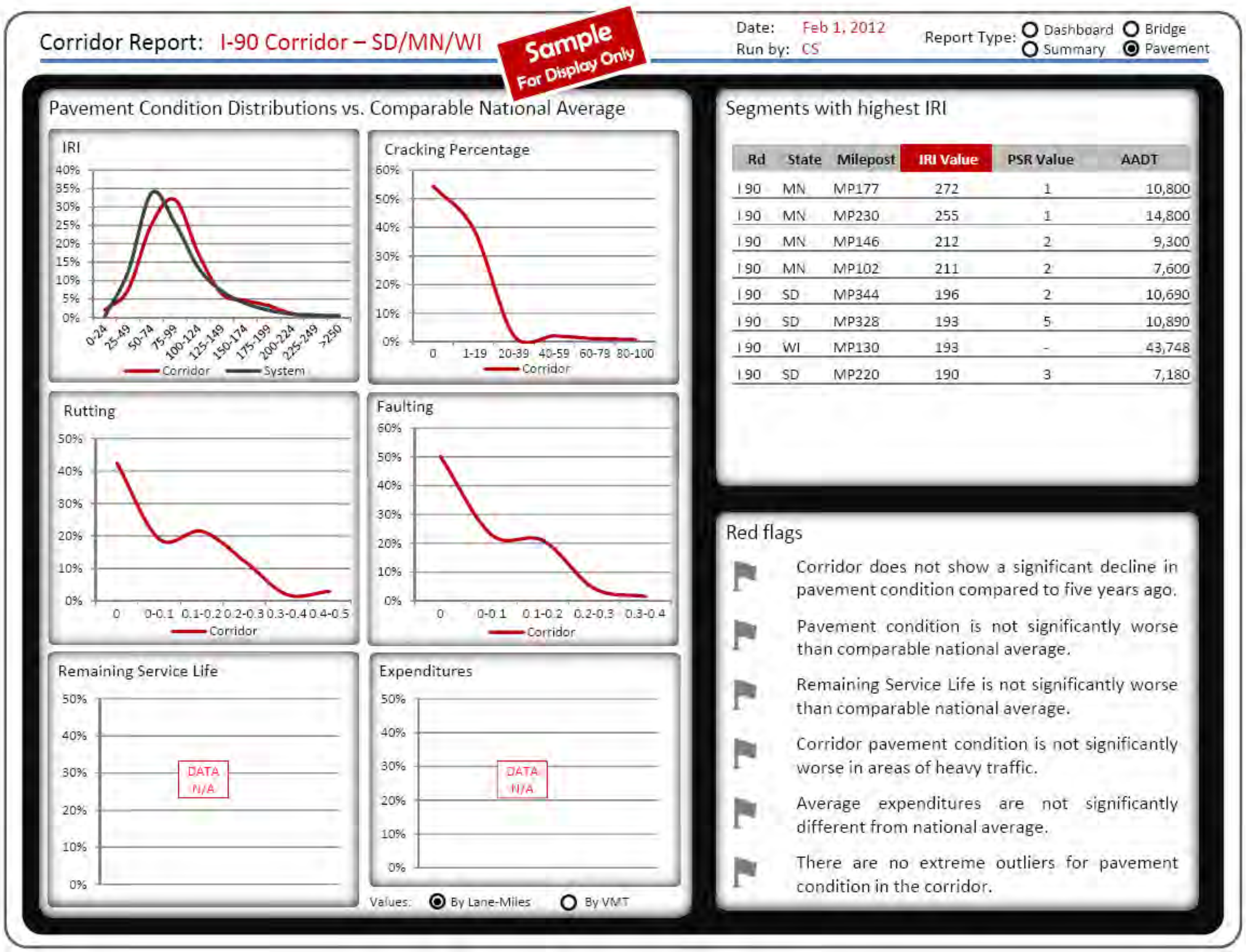
Figure 6.1 Sample Health Report, continued



Rd	State	Structure Number	Location	Avg. Rating
I 90	WI	B13008700000000	2.3M E JCT CTH V TO E	4
I 90	MN	8929	0.5 MI W OF E JCT TH 218	4
I 90	WI	B13008800000000	2.4M W JCT STH 19 TO E	4.31
I 90	WI	B13010700000000	1.0M E JCT USH 151 TO N	4.31
I 90	MN	85810	2.6 MI NW OF S JCT TH 61	4.31
I 90	MN	6808	0.9 MI W OF W JCT TH 218	4.36
I 90	WI	B11001500000000	3.9M E JCT CTH CS TO W	4.62
I 90	MN	85808	2.1 MI SE OF N JCT TH 61	4.62
I 90	WI	B53006500000000	0.9M E JCT STH 26 TO S	4.69
I 90	WI	B13010800000000	1.5M W JCT IH 94 TO E	4.93
I 90	WI	B29005200000000	6.5M W JCT STH 80 TO N	4.95

Source: Cambridge Systematics, Inc.

Figure 6.1 Sample Health Report, continued



Rd	State	Milepost	IRI Value	PSR Value	AADT
I 90	MN	MP177	272	1	10,800
I 90	MN	MP230	255	1	14,800
I 90	MN	MP146	212	2	9,300
I 90	MN	MP102	211	2	7,600
I 90	SD	MP344	196	2	10,690
I 90	SD	MP328	193	5	10,890
I 90	WI	MP130	193	-	43,748
I 90	SD	MP220	190	3	7,180

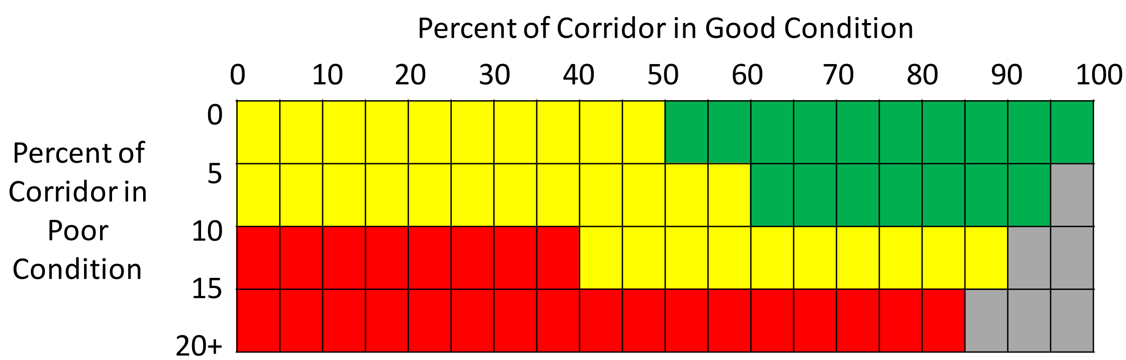
Source: Cambridge Systematics, Inc.

6.3 DEFINING GREEN/YELLOW/RED

Throughout the report, green/yellow/red indicators are used to communicate relative health. The indicators are defined separately for each portion of the report, as described below. In general, it is important to note that the green/yellow/red indicators do not coincide with the good/fair/poor categories. In some instances, they reflect changes in condition over time, or a comparison of corridor conditions to national averages. In other instances, the indicators reflect the distribution of the corridor between the good/fair/poor categories.

For example, Figure 6.2 illustrates how a corridor receives a red/yellow/green indicator based on the percent of that corridor that is in good, fair, and poor condition. The figure is a matrix with two dimensions – percent of the corridor in good condition (along the top) and percent of corridor in poor condition (down the side). Although not shown, the percent of the corridor in fair condition can be found by subtracting the good and poor condition percentages from 100 percent.

Figure 6.2 Example Red/Yellow/Green Thresholds



Source: Cambridge Systematics, Inc.

The easiest way to read the figure is to start at the top left corner and move to the right across the top row. This row shows that a corridor that has 0-5 percent of its lane-miles in "poor" condition would receive a yellow indicator until the point at which 50 percent of its lane-miles are in "good" condition. (This threshold is illustrated on the figure by the yellow boxes on the top row turning green at the 50 percent mark.) After that threshold for percent in good condition, a corridor would receive a green indicator.

Moving down a few rows to the 10-15 percent poor row, and again moving to the right, the figure indicates that a corridor with 10-15 percent of its lane-miles in poor condition would receive a red indicator until the point at which 40 percent of the lane-miles are in good condition. Once it crosses that threshold, it would receive a yellow indicator. The key point to Figure 6.2 is that the red/yellow/green indicators are assigned based on the distribution of conditions.

6.4 HEALTH REPORT ORGANIZATION

The health report provides three levels of detail:

- The dashboard page provides location, inventory, and high level health information.
- The summary page provides more detailed information reflecting underlying condition metrics.
- The technical page contains very detailed statistics, a list of red flags (if any), and a list of pavement sections and bridges with the lowest average condition ratings.

As a whole, the health report supports various uses, from a quick review of overall health to a more detailed technical assessment. The remainder of this section provides the details of the data and algorithms used for each page.

Dashboard Page

Overall Corridor Health

The overall corridor health for infrastructure is based on an average of the following four metrics, which are described in more detail below:

- Distribution of pavements in good/fair/poor condition;
- Distribution of pavement remaining service life;
- Distribution of bridges in good/fair/poor condition; and
- Distribution of bridge age.

To assign a red/yellow/green indicator for infrastructure health:

- Calculate the average percent classified as good for each metric;
- Calculate the average percent classified as fair for each metric;
- Calculate the average percent classified as poor for each metric;
- Assign a red/yellow/green using the thresholds in Figure 6.2.

Pavement Condition

% of Pavement Good/Fair/Poor

To assign a red/yellow/green indicator for *% Pavement in G/F/P:*

- Determine the distribution of lanes miles in good/fair/poor. (The sample health report demo reflects good/fair/poor based on IRI.)
- Assign a red/yellow/green indicator using the thresholds in Figure 6.2.

Remaining Service Life

To assign a red/yellow/green indicator for RSL distribution:

- Determine the distribution of lane-miles in the following three RSL categories[13]:
  - Category 1 RSL >7
  - Category 2 RSL = 4-7
  - Category 3 RSL <4
- Assign a red/yellow/green indicator using the thresholds in Figure 6.2. In this case, Category 1 becomes the x-axis of the table, and Category 3 becomes the y-axis.

Bridge Condition

% Bridges G/F/P

To assign a red/yellow/green indicator for *% Bridges in G/F/P*:

- Determine the distribution of deck area in good/fair/poor. (The sample health report reflects good/fair/poor based on Option 3.a, which is a weighted average of condition data, based on health index weights.)
- Assign a red/yellow/green indicator using the thresholds in Figure 6.2.

Bridge Age

To assign a red/yellow/green indicator for *Bridge Age*:

- Determine the distribution of bridge deck area in the following three age categories:
  - Category 1 age <25
  - Category 2 age = 25-50
  - Category 3 age >50

[13] These categories are presented as an example and these values are not intended to promote a particular set of threshold values. There currently is no accepted RSL good/fair/poor threshold criteria used nationally.

- Assign a red/yellow/green indicator using the thresholds in Figure 6.2. In this case, Category 1 becomes the x-axis of the table, and Category 3 becomes the y-axis.

Summary Page

G/F/P Pavement Condition

This part of the report has two options for reviewing the distribution of good/fair/poor – by lane-miles and by vehicle miles travelled (VMT):

- To summarize by lane-miles:
  - Determine the distribution of lane-miles in good/fair/poor. (The sample health report sample reflects good/fair/poor based on IRI.)
  - Plot this distribution using a pie chart.
  - Assign a red/yellow/green indicator using the thresholds in Figure 6.2.
- To summarize pavement condition by VMT:
  - Determine the distribution VMT by good/fair/poor using the approach recommended during the pilot study. (The sample health report sample reflects good/fair/poor based on IRI.)
  - Plot this distribution using a pie chart.
  - Assign a red/yellow/green indicator using the thresholds in Figure 6.2.

It is envisioned that in an electronic version of the health report, users would be able to toggle back and forth between results by lane-miles and results by VMT.

G/F/P Pavement Condition History

In this part of the report, a red/yellow/green indicator is assigned by comparing conditions in the current year to conditions from a previous year.

Table 6.1 shows the rules used to assign red/yellow/green indicator to a corridor based on pavement condition history. For example, the cell in the top right of the table indicates that if the corridor received a red indicator for current pavement condition (using the distribution approach described above), and had received a green indicator in the previous year (using the same distribution approach), it would receive a red indicator for pavement condition history. In this scenario, the pavement would have experienced significant deterioration over time.

Corridor Pavement vs. National

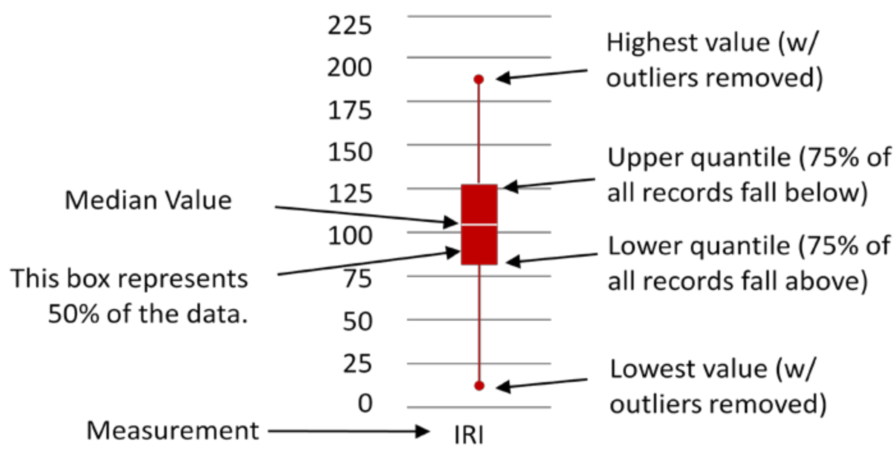
This section contains box plots comparing corridor data to the national average, and a green/yellow/red indicator. In both instances, the national averages should represent the functional class of the selected corridor. For example, the pilot study corridor is an Interstate. Therefore, the national average used for the sample report reflects all Interstate pavements in the U.S.

Table 6.1 Pavement Condition History Matrix

		Current Year		
Previous Year		Green	Yellow	Red
	Green	If the % good decreased by more than 10%, then yellow If not, then green	If the % good decreased by less than 5%, then yellow If not, then red	Red
	Yellow	Green	If the % good increased by more than 5% more than the % poor increased, then green If the % poor increased by more than 5% more than the % good increased, then red If neither of the above conditions is met, then yellow	Red
	Red	Green	If the % poor deceased by less than 5%, then yellow If not, then green	If the % poor decreased by more than 5%, then yellow If not, then red

Figure 6.3 illustrates how to construct a box plot.

Figure 6.3 Box Plot Construction



Source: Cambridge Systematics, Inc.

The red/yellow/green indicator is assigned as follows:

- Determine the distribution of the national system in good/fair/poor
- Compare the selected corridor to the national average.
- Assign a red/yellow/green indicator using the matrix illustrated in Table 6.2.

AADT by Milepost

The graph in this portion of the report shows AADT volumes and a color indicator for every milepost along a corridor. This graph can be based on good/fair/poor categories or RSL:

- To create the graph based on good/fair/poor categories:
  - Determine the distribution of VMT between good/fair/poor.
  - Plot the results by mile post.
  - Assign a red/yellow/green indicator using the thresholds in Figure 6.2.
- To create the graph based on RSL
  - Determine the distribution of VMT in the following three RSL categories:
    - » Category 1 RSL >7
    - » Category 2 RSL = 4-7
    - » Category 3 RSL <4
  - Plot the results by mile post.

Table 6.2 Pavement Comparison to National Average Matrix

		Corridor		
		Green	Yellow	Red
National Average	Green	If the national % good is more than 10% greater than corridor percent good, then yellow If not, then green	If the corridor % good is within 5% of the national % good, then yellow If not, then red	Red
	Yellow	Green	If the corridor % good is greater than the national % good by more than 10%, than green If the corridor %poor is greater than the national % poor by more than 5%, than red If neither of the above conditions is met, then yellow	Red
	Red	Green	If the corridor % poor is within 5% of the national % poor, then red If not, then green	If the corridor % poor is less than the national % poor by more than 5%, then yellow If not, then red

- Assign a red/yellow/green indicator using the thresholds in Figure 6.2. In this case, Category 1 becomes the x-axis of the table, and Category 3 becomes the y-axis.

G/F/P Bridge Condition

This part of the report provides two options for reviewing the distribution of good/fair/poor – by deck area or by bridges.

- To summarize by deck area:
  - Determine the distribution of deck area in good/fair/poor. (The sample health report sample reflects good/fair/poor based on Option 3.a, which is the weighted average of condition data, based on health index weights.)
  - Plot the results in a pie chart.
  - Assign a red/yellow/green indicator using the thresholds in Figure 6.2.
- To summarize by number of bridges:
  - Determine the distribution of bridges in good/fair/poor. (The sample health report sample reflects good/fair/poor based on Option 3.a, which is the weighted average of condition data, based on health index weights.)
  - Plot the results in a pie chart.
  - Assign a red/yellow/green indicator using the thresholds in Figure 6.2

It is envisioned that in an electronic version of the health report, users would be able to toggle back and forth between results by deck area and by number of bridges.

G/F/P Bridge Condition History

In this part of the report, a red/yellow/green indicator is assigned by comparing conditions in the current year to conditions from a previous year.

Table 6.3 shows the rules used to assign the red/yellow/green indicator to a corridor based on pavement condition history. (It is similar to the table provided above for pavement condition history.) For example, the cell in the top right of the table indicates that if the corridor received a red indicator for current bridge condition (using the distribution approach described above), and had received a green indicator in the previous year (using the same distribution approach), it would receive a red indicator for pavement condition history. In this scenario, the bridges along the corridor would have experienced significant deterioration over time.

Table 6.3 Bridge Condition History Matrix

		Current Year		
		Green	Yellow	Red
Previous Year	Green	If the % good decreased by more than 10%, then yellow If not, then green	If the % good decreased by less than 5%, then yellow If not, then red	Red
	Yellow	Green	If the % good increased by more than 5% more than the % poor increased, then green If the % poor increased by more than 5% more than the % good increased, then red If neither of the above conditions is met, then yellow	Red
	Red	Green	If the % poor deceased by less than 5%, then yellow If not, then green	If the % poor decreased by more than 5%, then yellow If not, then red

Corridor Bridges vs. National

This section contains box plots comparing corridor data to the national average, and a green/yellow/red indicator. In both instances, the national averages represent the functional class of the selected corridor. For example, the pilot corridor is an Interstate. Therefore, the national average used for the sample report reflects all Interstate bridges in the U.S.

Figure 6.3 earlier illustrated how to construct a box plot.

The green/yellow/red indicator is assigned as follows:

- Determine the distribution deck area of the national system in good/fair/poor. Compare the selected corridor to the national average.
- Assign a red/yellow/green indicator using the matrix provided in Table 6.4.

Bridge AADT by Mile

The graph in this portion of the report shows AADT volumes and a color indicator for every bridge along a corridor. This graph can be based on good/fair/poor categories or age.

- To create the graph based on good/fair/poor categories:
  - Determine the distribution of VMT between good/fair/poor.
  - Plot the results by mile post.
  - Assign a red/yellow/green indicator using the thresholds in Figure 6.2.
- To create the graph based on age:
  - Determine the distribution of bridge AADT in the following three age categories:
    - » Category 1 age <25
    - » Category 2 age = 25-50
    - » Category 3 age >50
  - Plot the results by mile post.
  - Assign a red/yellow/green indicator using the thresholds in Figure 6.2. In this case, Category 1 becomes the x-axis of the table, and Category 3 becomes the y-axis.

It is envisioned that in an electronic version of the health report, users would be able to toggle back and forth between results by good/fair/poor and bridge age category.

Table 6.4 Bridge Comparison to National Average Matrix

		Corridor		
National Average		Green	Yellow	Red
	Green	If the national % good is more than 10% greater than corridor percent good, then yellow If not, then green	If the corridor % good is within 5% of the national % good, then yellow If not, then red	Red
	Yellow	Green	If the corridor % good is greater than the national % good by more than 10%, than green If the corridor %poor is greater than the national % poor by more than 5%, than red If neither of the above conditions is met, then yellow	Red
	Red	Green	If the corridor % poor is within 5% of the national % poor, then red If not, then green	If the corridor % poor is less than the national % poor by more than 5%, then yellow If not, then red

Detail Pages

The health report includes a details page for both bridges and pavements. Highlights from these pages include:

- The pages do not include red/yellow/green indicators. Rather they provide detailed information regarding the distribution of condition metrics, and comparisons of these distributions to national distributions.
- They provide a table of the pavement segments and bridges with the lowest condition ratings. VMT/AADT are used as a tie breaker when developing this list.
- They include red flag indicators, five for pavement and five for bridge.
- The following flags are used for pavement:
  - *Pavement condition history* – if this indicator (described above) is red, then the corridor receives a flag.
  - *Pavement condition vs. system* - if this indicator (described earlier) is red, then the corridor receives a flag.
  - *AADT with pavement condition by mile* - if this indicator (described earlier) is red, then the corridor receives a flag.
  - *Average Cost per Mile*. This flag was included as a place holder as a potential future enhancement to the health report.
  - *Extreme values for condition indicators*. If more than 5 percent of the corridor length exceeds the following thresholds, then the corridor receives a flag:
    - » IRI - 300
    - » Cracking – 90%
    - » Rutting - 0.75
    - » Faulting - 1
- The following flags are used for bridges:
  - *Bridge condition history* – if this indicator (described earlier) is red, then the corridor receives a flag.
  - *Bridge condition vs. system* - if this indicator (described earlier) is red, then the corridor receives a flag.
  - *Distribution of AADT by bridge age* - if this indicator (described earlier) is red, then the corridor receives a flag.
  - *Average cost per deck area*. This flag was included as a place holder as a potential future enhancement to the health report.

- *Extreme values for condition indicators*. If more than 5 percent of the bridge deck area exceeds the following thresholds, then the corridor receives a flag:
  - » Deck rating - 2
  - » Superstructure rating - 2
  - » Substructure rating - 2
  - » Culvert rating - 2

6.5 IMPLEMENTATION CONSIDERATIONS

The study illustrated that the health report can serve as an effective management and communication tool. It can be used to assess the health of the national highway system and to tell the story of infrastructure needs and return on investment, all with existing FWHA data sets.

Opportunities for enhancing the report include:

- Adding operational elements. The sample health report focuses on condition elements. There is an opportunity to expand the report beyond condition, and include information related to safety and congestion.
- Adding future projections. While a current health "snapshot" is very important and informative, there is a desire to enhance the health report to provide future projected values. This capability could eventually support long-range planning, project prioritization, and the communication of future funding needs.

The health report needs to be implemented in a way that recognizes and mitigates the following potential risks:

- Although, initially designed for internal use by the FHWA, resulting reports may make their way into the public arena. There is a risk that the public may view all data as "real-time" when in reality there is a significant delay between collection and health reporting. Therefore, the data collection dates should be clearly identified on the report.
- The public may assume that lower rated infrastructure (such as infrastructure receiving a "red flag" or "red" health indicator) is unacceptable. In reality, the measures are designed to highlight facilities that may require attention. It is unrealistic to assume the entire system could be in "green" or "yellow", given the nation's current financial situation. However, this reality may be lost if the health reporting tool is viewed out of context and without an understanding of the larger picture.
- Some consumers of the report may assume that it is sufficient to drive detailed project decisions. It is important to understand that the report is designed to enable users to assess the overall health of a corridor and to

quickly identify areas of concern. It is not designed as a project-level decision making tool.

- Some consumers of the report may not appreciate the uncertainties involved in State-to-State comparisons, deriving from the differences in data collection and analysis protocols. Significant work is needed to develop and standardize evaluation methods to enable comparability across the nation.

7.0 Summary of Key Findings and Recommendations

7.1 Good/Fair/Poor Process

Bridges

The good/fair/poor process for bridges yielded viable and implementable results. NBI data was found to be sufficient for national performance management. SD status (Option 1) is widely understood and reported and makes an attractive Tier 1 measure. However, SD status does not fit well into the good/fair/poor approach envisioned by FHWA because it is binary. In addition, SD status also includes non-condition components (inventory rating and water adequacy rating), making it less ideal for a pure condition assessment. However, the pilot study found that these non-condition components are not typically the driving factor in the SD calculation.

A measure of structural adequacy based on NBI ratings (Options 2 and 3) is a viable supplement to SD status as a national measure of bridge condition. Implementation would require developing a general consensus on its definition. All of the options explored in the pilot study appear to be viable for a measure of structural adequacy.

Pavements

The pilot demonstrated that the good/fair/poor approach is not only feasible for pavements, but also implementable at this time - at least the Tier 1 level based on pavement roughness (IRI). Implementation of the Tier 2 (pavement roughness and HPMS distresses) and Tier 3 (same as Tier 2 plus structural capacity based on deflections) was also shown to be feasible, but additional work is required before they can be implemented.

Accordingly, continuation of the good/fair/poor development effort with a focus on the Tier 2 and Tier 3 pavement condition measurement options is highly recommended. Incorporation of the pavement condition measures contemplated by these two tiers is considered of paramount importance, as the Tier 1 pavement roughness provides but one (albeit important) aspect of the overall condition of pavements. As an example, the fact that a pavement provides a smooth ride quality does not imply that it is structurally adequate and vice-versa. This being the case, it is critical that pavement condition be considered from multiple angles, akin to a doctor's visit, in order to properly and accurately assess the condition of the pavement network and hence facilitate the decision making process.

Moreover, with time, the good/fair/poor indicator can continue to evolve and be further enhanced to incorporate other important pavement considerations such as friction or noise, whether directly in the good/fair/poor indicator or as flags to it. Another important future consideration is the incorporation of probabilistic methods into the good/fair/poor concept in order to reflect the level of confidence associated with the data that drives the indicator. Thus, continuation of the good/fair/poor development process is considered meritorious and, as noted earlier, highly recommended.

7.2 DATA COLLECTION IMPROVEMENT OPPORTUNITIES

Bridge

As the NBI data was found to be sufficient for national performance measurement, the pilot resulted in no recommendations for improvement to data collection for bridges.

Pavement

Without question, the common thread through the pavements portion of the pilot study was that the good/fair/poor concept is viable, even today, but the real power from implementation of the concept will only come after a number of pavement data collection and processing improvements are made. The following list highlights some of the higher priority HPMS data improvement opportunities:

- HPMS data summary lengths should be investigated to resolve the analysis bias when using variable sample lengths. At present, the summary lengths are highly variable, which can lead to pavement condition measures being either exaggerated in the case of short lengths or being lost due to averaging over long lengths. Resolution of this issue was beyond the scope of this project.
- Data for use in development of the good/fair/poor indicator needs to be extracted in November or December of each year, after data collection and processing have been completed for the year in question to avoid time lags and therefore potentially erroneous or inaccurate conclusions.
- Up-to-date information on maintenance and rehabilitation is important in resolving issues associated with the temporal analysis of pavement condition data.
- Incorporate additional checks in the HPMS software to flag HPMS data that is not consistent (for example sections that have a high PSR value but show

high distress levels or vice versa). These checks should be applied at the State level, prior to submission of data to FHWA.

- The HPMS rut depth data collection procedure and analysis algorithm should be codified for purposes of the good/fair/poor indicator. Cracking data collection should be better defined and a manual for its implementation prepared along with the recommended QC/QA standards.
- Faulting data should be investigated to resolve the inconsistencies in data collection and analysis. Use of the ProVAL tool to analyze faulting may be a suitable method to standardize the analysis of faulting data.

In addition to the above recommendations, which focus on the HPMS data, a need exists for standards related to continuous deflection testing calibration, data collection, processing, and analysis. These deflections, along with the HPMS distresses, represent potential Tier 3 data requirements, hence the need for standards.

7.3 Health Reporting

The study illustrated that the health report can serve as an effective management and communication tool. The prototype health report tool presented herein could be used to assess the health of the national highway system with existing FHWA data sets.

Despite the usefulness in its current form, there are opportunities to enhance it, such as adding historic expenditure data, operational elements, and future projections. However, any of these enhancements would likely require significant effort.

It is recommended that the health report be implemented in a way that recognizes and mitigates the risks of data misinterpretation. Some consumers of the reports may assume that it is sufficient to drive detailed project decisions. It is important to understand that the report is designed to enable users to assess the overall health of a corridor and to quickly identify areas of concern. It is not designed as a project-level tool.

7.4 Recommended Next Steps

The following presents suggested next steps for bridge and pavement as a result of this pilot study. Cost/benefits must be weighed for all contemplated actions related to national bridge/pavement data collection and reporting as each change or enhancement to a procedure potentially has significant cost implications for FHWA and the States.

Bridge

It is recommended that FHWA advance a new measure of structural adequacy based on NBI ratings. This new measure could serve as an eventual supplement to SD as a national measure of bridge condition. Given the high degree of correlation between all of the options investigated as part of this study, it is recommended that the final definition for a structural adequacy measure be based on a policy discussion, focused on the following two questions:

- Should the measure be based on the minimum condition rating or a weighted average?
- What is relative importance of deck compared to superstructure and substructure?

It is recommended that FHWA continue to consider an eventual good/fair/poor measure based on element level data. However, given that element level data are not available for all States, additional work in this area is not recommended as a short term next step.

Pavement

The recommended next steps for pavement reflect the data collection opportunities discussed earlier in this section. The recommended steps in chronological order are as follows:

- Finalize and implement the good/fair/poor indicator based on pavement roughness (IRI). Label the indicator specifically using the term "Ride Quality" so as not to imply IRI is a holistic pavement condition indicator.
- Undertake a study geared towards the incorporation of additional selected distresses into the good/fair/poor indicator, such as cracking and rutting in AC pavements and cracking and faulting in PCC pavements.
- Incorporate additional checks in the HPMS software to flag HPMS data that is not consistent (for example sections that have a high PSR value but show high distress levels or vice versa). These checks should be applied at the State level, prior to submission of data to FHWA.
- Concurrent with the above step, pursue improvements to the FHWA PHT analysis tool for computation of pavement RSL, as this tool can potentially serve as the most comprehensive measure of pavement condition in the near future. This measure accounts for roughness, selected distresses and structural capacity. Longer-term, pursue incorporation of a measured pavement structural capacity measure into the good/fair/poor indicator. This can be achieved through improvement in the continuous deflection testing technology, as it provides deflection measurements at highway speeds without the need for traffic control. Alternatively, consideration may be given to FWD measurements, as more and more highway agencies are performing deflection testing at the network-level using this device.

Health Report

It is recommended that FHWA consider developing a tool that automates the creation of the health reports illustrated in section 6. This tool would enable users to select a corridor and view the results for it. It is further recommended that the tool be implemented in a manner that enables the required HPMS and NBI data elements to be incorporated directly into the report, without manual manipulation.

Implementation

The recommended next steps described above are all ready for immediate implementation at the national level. In fact, many of them are currently underway through various studies conducted by AASHTO and FHWA.