Investigation of Increase in Roughness Due to Environmental Factors in Flexible Pavements Using Profile Data from Long-Term Pavement Performance Specific Pavement Studies 1 Experiment

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LTPP™

FOREWORD

Previous studies have been performed to investigate roughness development in pavements. The Long-Term Pavement Performance (LTPP) Program has been collecting longitudinal profile data for the two wheelpaths and the center of the lane using an inertial profiler for over 20 years. The goal of this study was to evaluate the changes in roughness as measured by the International Roughness Index (IRI) along the center of the lane at Specific Pavement Studies 1 (structural factors for flexible pavement) sections over time and identify environmental and subgrade parameters that contribute to the increase in roughness. This information can be used to improve pavement design procedures and further develop models for predicting the change in roughness due to environmental conditions. The study shows it is very important to provide drainage for pavements built over fine-grained subgrade in the wet-freeze zone to reduce the rate of change of roughness. This study also compared the changes in roughness using the computed IRI along the center of the lane with the changes in mean IRI (i.e., average IRI of the left and the right wheelpaths). The intended audiences for this report are pavement engineers and researchers.

Cheryl Allen Richter, Ph.D., P.E.
Director, Office of Infrastructure
Research and Development

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From the start of the Long-Term Pavement Performance (LTPP) Program, the longitudinal profiles along the two wheelpaths at test sections have been collected using an inertial profiler. In December 1996, starting with the K.J. Law T-6600 inertial profiler, all profilers used in the LTPP Program have collected profile data along the center of the lane in addition to collecting data along the two wheelpaths. The change in the profile along the center of the lane in flexible pavements was expected to be affected mainly by environmental effects. The goal of this project was to evaluate the changes in the International Roughness Index (IRI) along the center of the lane at Specific Pavement Studies 1 test sections over time and identify environmental and subgrade parameters that contribute to an increase in IRI along the center of the lane. The following activities were performed for this project: (1) analyze the center of the lane IRI (CLIRI) and mean IRI (MIRI) (i.e., average IRI of the left and the right wheelpaths) at test sections to evaluate changes over time, (2) compare the change in IRI for the center of the lane with the change in MIRI at the test sections, (3) identify subgrade and environmental parameters that contribute to an increase in IRI along the center of the lane, (4) perform a detailed evaluation to identify how the CLIRI changes for a select group of test sections, and (5) develop models to predict the change in CLIRI at the test sections.</td></tr>
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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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AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
AIMS	Ancillary Information Management System
ATB	asphalt-treated base
CLIRI	center of the lane IRI
DF	dry-freeze
DNF	dry no-freeze
DGAB	dense graded aggregate base
ERD	Engineering Research Division
ESAL	equivalent single axle load
FI	freezing index
FHWA	Federal Highway Administration
GPS	General Pavement Studies
ICC	International Cybernetics Corporation
IQD	interquartile distance
IRI	International Roughness Index
KESAL	1,000 equivalent single axle loads
LTPP	Long-Term Pavement Performance
MEPDG	*Mechanistic-Empirical Pavement Design Guide*
MIRI	mean IRI
PATB	permeable asphalt-treated base
PI	Plasticity Index
PPDB	Pavement Performance Database
PSD	power spectral density
RMS	root mean square
SDR	Standard Data Release
SF	site factor
SMP	seasonal monitoring program
SN	structural number
SPS	Specific Pavement Studies
WF	wet-freeze
WNF	wet no-freeze

CHAPTER 1. INTRODUCTION

This chapter provides the background for this study, including a general description of the Long-Term Pavement Performance (LTPP) Program; information on how pavement profile information has been collected for the program over the years; a discussion of the Specific Pavement Studies (SPS) 1 experiment, the data from which was used in this study; and a description of the objectives of the current study.

LTPP PROGRAM

The LTPP Program is a research program that investigates in-service pavement performance. Started in 1987 as part of the first Strategic Highway Research Program, the LTPP Program has been managed by the Federal Highway Administration (FHWA) since 1992. The primary goal of the LTPP Program is to determine how and why pavements perform as they do. To accomplish this goal, the LTPP Program monitors test sections established on in-service roads by collecting a variety of data on these test sections such as pavement distress, longitudinal profile, and deflection data at regular intervals using standard data collection protocols. The collected data are stored in the Pavement Performance Database (PPDB) and can be used by pavement engineers and researchers worldwide to advance the science of pavement engineering.[(1)]

The LTPP Program consists of two complementary kinds of research: General Pavement Studies (GPS) and SPS experiments. The study of the performance of in-service pavement test sections that were either in their original design phase or in their first overlay phase has been addressed in the GPS experiment. The effect of specific design features on pavement performance has been addressed in the SPS experiment.

PROFILE DATA COLLECTION FOR THE LTPP PROGRAM

From the start of the LTPP Program, the longitudinal profiles along the two wheelpaths at test sections have been collected using an inertial profiler. The LTPP Program has always used four inertial profilers, each operated by a regional contractor, to collect profile data at the test sections. Data at test sections located in a specific geographical area have been collected by a single regional contractor. From the start of the LTPP Program until November 1996, profile data at test sections were collected using K.J. Law DNC 690 inertial profilers. In December 1996, these profilers were replaced with K.J. Law T-6600 inertial profilers. In September 2002, the K.J. Law T-6600 profilers were replaced with International Cybernetics Corporation (ICC) MDR 4086L3 inertial profilers. In April 2013, the ICC profilers were replaced with Ames Engineering Model 8300 inertial profilers.

The K.J. Law DNC 690 inertial profiler only collected profile data along the two wheelpaths. Starting with the K.J. Law T-6600 inertial profiler, all profilers used in the LTPP Program have collected profile data along the center of the lane in addition to collecting data along the two wheelpaths.

When collecting data with an inertial profiler, seven to nine repeat runs have typically been performed at an LTPP section during a site visit. After performing quality control checks on the data, ride quality parameters computed from the profile data and the profile data corresponding to five repeat runs for each site visit have been uploaded to the PPDB. The International Roughness Index (IRI) has been one of the ride quality parameters computed from the profile data that has been uploaded to the PPDB.[(1)]

The K.J. Law DNC 690 profiler collected profile data at 1-inch intervals and then applied a 12-inch moving average to these data and recorded the profile data at 6-inch intervals. The recorded profile data as well as ride quality parameters computed from these data for the five selected profile runs for each site visit were uploaded to the PPDB.[(1)]

The K.J. Law T-6600 profiler and the ICC profiler recorded profile data at 0.98-inch intervals. The left and right wheelpath profile data collected by these devices were processed by applying an 11.8-inch moving average to the data, and then data at 5.9-inch intervals were extracted. The 5.9-inch interval profile data for the two wheelpaths and the ride quality indices computed from these data for five selected runs for each site visit were uploaded to the PPDB. In addition, data files conforming to the University of Michigan Transportation Research Institute Engineering Research Division (ERD) file format that contained the 0.98-inch interval profile data were created for all profile runs obtained at a site. These ERD files contained the 0.98-inch interval profile data for the left wheelpath, right wheelpath, and center of the lane and were stored in the LTPP Ancillary Information Management System (AIMS). These ERD files could be requested for analysis through the LTPP Customer Support Service.[(2)]

The Ames Engineering profilers also recorded profile data at 0.98-inch intervals. The left wheelpath, right wheelpath, and center of the lane profile data collected by these devices were processed by applying an 11.8-inch moving average to the data and then extracting data at 5.9-inch intervals. The 5.9-inch interval profile data were used to compute the IRI of the left wheelpath, right wheelpath, and center of the lane. The 5.9-inch interval profile data and the IRI values for the three paths for five profile runs for each site visit were uploaded to the PPDB. In addition, profile data collected at 0.98-inch intervals along the left wheelpath, right wheelpath, and center of the lane for these five runs were also uploaded to the PPDB.

THE LTPP SPS-1 EXPERIMENT

The LTPP SPS-1 experiment was developed to investigate the effect of selected structural factors on the long-term performance of flexible pavements that were constructed on different subgrade types and in different environmental regions. New pavements were constructed for the SPS-1 experiment. In the SPS-1 experiment, 12 test sections were constructed at a project location. Each test section was 500 ft long with a transition area between the test sections. The pavement structure of the test sections in the SPS-1 experiment are shown in table 1. The 12 test sections in an SPS-1 project were either section numbers 1 through 12 or section numbers 13 through 24. These test sections have been referred to as *core test sections* at an SPS-1 project. In addition to these core test sections, some State transportation departments constructed other test sections referred to as supplemental sections at the SPS-1 project location to study factors that were of interest to the State transportation departments.

The structural factors considered in the SPS-1 experiment have been asphalt thickness, base type, base thickness, and drainability (presence or lack of it as provided by an open-graded permeable asphalt-treated layer and edge drains). Five different base types have been used in this experiment: dense graded aggregate base (DGAB), asphalt-treated base (ATB), ATB over DGAB, permeable asphalt-treated base (PATB) over DGAB, and ATB over PATB. The subgrade types considered in this experiment were classified as fine- and coarse-grained, and the environmental regions considered were the four LTPP environmental regions, which were wet-freeze (WF), wet-no freeze (WNF), dry-freeze (DF) and dry-no freeze (DNF).

Table 1. SPS-1 test sections.

Test Section Number	AC Thickness (Inches)	Layer 2		Layer 3	
		Material	Thickness (Inches)	Material	Thickness (Inches)
1	7	DGAB	8	—	—
2	4	DGAB	12	—	—
3	4	ATB	8	—	—
4	7	ATB	12	—	—
5	4	ATB	4	DGAB	4
6	7	ATB	8	DGAB	4
7	4	PATB	4	DGAB	4
8	7	PATB	4	DGAB	8
9	7	PATB	4	DGAB	12
10	7	ATB	4	PATB	4
11	4	ATB	8	PATB	4
12	4	ATB	12	PATB	4
13	4	DGAB	8	—	—
14	7	DGAB	12	—	—
15	7	ATB	8	—	—
16	4	ATB	12	—	—
17	7	ATB	4	DGAB	4
18	4	ATB	8	DGAB	4
19	7	PATB	4	DGAB	4
20	4	PATB	4	DGAB	8
21	4	PATB	4	DGAB	12
22	4	ATB	4	PATB	4
23	7	ATB	8	PATB	4
24	7	ATB	12	PATB	4

AC = asphalt concrete.
—Indicates not applicable.

Eighteen SPS-1 projects were constructed for the LTPP Program. Table 2 shows the States where the SPS-1 projects were constructed, the State code, test section numbers constructed for each project, and the date the project was opened to traffic.

Table 2. SPS-1 projects.

Project Location	State Code	Section Numbers in Project	Traffic Open Date
Alabama	1	1-12	3/1/1993
Arizona	4	13-24	8/1/1993
Arkansas	5	13-24	9/1/1994
Delaware	10	1-12	5/1/1996
Florida	12	1-12	11/1/1995
Iowa	19	1-12	6/1/1993
Kansas	20	1-12	11/1/1993
Louisiana	22	13-24	7/1/1997
Michigan	26	13-24	11/1/1995
Montana	30	13-24	10/1/1998
Nebraska	31	13-24	8/1/1995
Nevada	32	1-12	9/1/1995
New Mexico	35	1-12	11/1/1995
Ohio	39	1-12	11/1/1995
Oklahoma	40	13-24	7/1/1997
Texas	48	13-24	7/1/1997
Virginia	51	13-24	3/1/1993
Wisconsin	55	13-24	11/1/1997

The profile data collection at an SPS-1 project has typically been performed by collecting data along the entire SPS-1 project, which means data have been collected over the test sections as well as within the transition areas between the test sections. Thereafter, the data corresponding to each test section have been extracted from the collected data using software that employed the stationing associated with each test section. This process has been referred to as *subsectioning* in the LTPP Program.

The first profile measurements at an SPS-1 project were performed within a short time after construction. Thereafter, profile data at SPS-1 test sections were collected at regular intervals following the guidelines established by the FHWA. Profile data collection at a test section ended when the test section was taken out of the LTPP study because of rehabilitation. A test section is said to have been deassigned when it is taken out of the LTPP Program.

OBJECTIVES OF THIS STUDY

State transportation departments use the mean IRI (MIRI), which is the average of the left and the right wheelpath IRI, to monitor the roughness of their pavement network. The change in roughness of a pavement segment over a specified time interval can be evaluated by determining the change in MIRI over that period. The change in roughness over time along the wheelpaths of a pavement segment occurs because of the change in the profile of the wheelpaths over time.

As described previously, profile data along the center of the lane as well as along the wheelpaths were collected at the LTPP test sections starting in December 1996. The change in the profile along the center of the lane in flexible pavements was expected to be affected mainly by environmental effects. The only traffic the center of the lane received was when vehicles change lanes, and such maneuvers were expected to apply only minimal traffic to the center of the lane. Environmental effects can cause changes in the moisture content of the subgrade from the as-constructed value, which can cause the subgrade to shrink or swell. This can affect the profile of the pavement and cause a change in roughness. Freezing temperatures can cause frost heave, which can also affect the pavement profile and cause an increase in roughness. Therefore, the interaction between environmental effects and subsurface layers can cause a change in the profile of a pavement, thereby increasing the roughness of a pavement. In flexible pavements, transverse cracking can occur because of thermal movements induced on the AC surface, and this cracking can also increase the roughness. Hence, along the center of the lane, transverse cracking and the interaction between environmental effects and subsurface layers that cause a change in the profile can cause an increase in roughness.

Along the wheelpaths of a flexible pavement, fatigue cracking and rutting caused by traffic can contribute to an increase in roughness. Therefore, the increase in roughness along the wheelpaths can be attributed to the change in the profile along the wheelpaths caused by traffic loadings and environmental effects. When evaluating the changes in roughness that have occurred along the wheelpaths, environmental effects could not be separated from traffic effects because the collected profile showed the consequences of both factors. However, the profile data collected along the center of the lane in a flexible pavement could be used to evaluate the change in roughness due only to environmental effects. On a flexible pavement, the change in roughness along the center of the lane could be compared with the change in roughness along the wheelpaths to evaluate the contribution of environmental factors to the increase in roughness along the wheelpaths. The profile data collected at SPS-1 projects have provided an excellent dataset to perform this type of analysis for flexible pavements because the effect of environmental factors on the change in roughness could be evaluated for a variety of pavement structures.

The goal of this study was to evaluate the changes in IRI along the center of the lane over time and to identify subgrade and environmental parameters that have contributed to an increase in the center lane IRI. The specific objectives of this study were to use the data collected at SPS-1 test sections to do the following:

- Analyze the center of the lane IRI (CLIRI) and MIRI at test sections to evaluate changes over time.

- Compare the change in CLIRI with the change in MIRI at the test sections.

- Identify subgrade and environmental parameters that influence the changes in the center of the lane profile that contribute to an increase in CLIRI.

- Perform a detailed evaluation to identify how CLIRI changes for a select group of test sections and to determine whether wavelengths that contribute to the increase in CLIRI can be identified.

- Develop models to predict the change in CLIRI at the test sections.

This study was intended to provide information on how environmental conditions interact with subgrade conditions and influence the increase in roughness for the different pavement structures present on an SPS-1 project.

CHAPTER 2. LITERATURE REVIEW AND *MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE* (MEPDG) MODEL

This chapter begins with a summary of the results of a literature review of previous studies performed to investigate development of roughness in pavements. It concludes with a description of the models used in the MEPDG software to predict the increase in IRI.(3)

LITERATURE REVIEW

A literature review was performed that reviewed the results from previous studies that have been performed to investigate roughness development in pavements. A summary of the findings from the reviewed studies are presented in this section.

Ciavola and Mukherjee investigated roughness development trends at LTPP test sections.(4) A construction number change at an LTPP test section indicated that maintenance or repairs had been performed at that section. The authors referred to the first change in construction number at a test section as the first intervention on the test section. The authors found that the average age of the pavement at the first intervention for AC pavements in the North Atlantic, North Central, Southern, and Western regions were 10.8, 15.5, 15.2, and 11.8 years, respectively. MIRIs of the AC pavements when the first intervention occurred in the North Atlantic, North Central, Southern, and Western regions were 105, 129, 91, and 107 inches/mi, respectively. They also studied the effect of traffic on IRI development by grouping the test sections into four groups based on their yearly equivalent single axle loads (ESALs). They saw no evidence that MIRI performance over time was sensitive to traffic loading in the four groups.(4)

Corley-Lay and Mastin used GPS sections that were flexible pavements in the PPDB to study the increase in MIRI over time.(5) The purpose of this study was to determine whether the Highway Performance Monitoring System reassessment guidelines that require annual roughness measurements were justified.(6) They fitted polynomial curves on the time-sequence MIRI data to evaluate changes in MIRI. Of the 189 sites analyzed, 88 sites were characterized as having little change in MIRI, with the change in MIRI being less than 15 inches/mi over a 3,000-day period. Several sites had slightly declining slopes, but this trend was considered to be within the range of test variability. Forty-one sites had a change in IRI of more than 50 inches/mi within 5,000 days, with half of these sites located in the WF zone.(5)

Stoffels et al. investigated the influence of moisture in the subgrade on roughness progression at 43 AC pavement sections that were included in the seasonal monitoring program (SMP) in the LTPP Program.(7) The volumetric moisture content in the subgrade computed from the time domain reflectometer gauges located in the test sections were available in the PPDB. Moisture content values measured within 24 to 35 inches from the top of the subgrade were used for their analysis. The volumetric moisture content in the subgrade was used to develop a parameter called the moisture index. A mean value and a standard deviation was computed for this moisture index using the moisture index values computed over the period when moisture measurements were made on the subgrade. The power spectral density (PSD) function was used to decompose the longitudinal profile to different wavebands, and the change in roughness in each waveband was evaluated using the root mean square (RMS) slope of the waveband. The time dependent change of roughness in each waveband was statistically analyzed using the RMS slope with the soil information, freezing index (FI), freezing-thaw cycles, and moisture content of the subgrade. The analysis indicated that moisture in the subgrade significantly affected wavebands from 16 to 102 ft for freezing areas and 16 to 128 ft for nonfreezing areas. The wavebands that were most responsive to moisture were from 49 to 79 ft for freezing sites and 33 to 128 ft for nonfreezing sites. In the nonfreezing sites, the change in roughness increased with moisture variations and the moisture level. The moisture variations usually affected the longer wavebands. At the nonfreezing sites, the depth to the top of the subgrade was a significant factor affecting the increase in roughness, with deeper depth to subgrade decreasing the increase in roughness. For the freezing sites, moisture variations increased roughness progression, and the roughness increase was heavily influenced by the percentage of subgrade passing the 0.002-mm sieve.(7)

Von Quintus et al. developed distress-based models for predicting pavement smoothness of AC pavements and AC overlaid pavements.(8) They concluded the initial pavement smoothness strongly influenced smoothness over time for new construction as well as for overlaid pavements. They found that transverse cracks influenced roughness progression for all AC pavements (i.e., overlaid and nonoverlaid). All severity levels of transverse cracks were found to have an effect on increasing the IRI for new pavements with relatively thin AC layers, but only the moderate and/or high severity levels were found to influence the IRI of AC overlays and deep strength flexible pavements (i.e., new pavements with ATB). Fatigue cracking caused an increase in IRI except for AC overlays on rigid pavements. All severity levels of fatigue cracking affected IRI. For relatively thin AC surfaces, the variation of rutting either measured by the coefficient of variation of rutting or standard deviation of rutting influenced IRI rather than the mean rut depth. The mean rut depth was found to be important for AC overlays of rigid pavements. For deep strength AC pavements and AC overlays of flexible pavements, rutting or variation of rutting did not influence IRI. Age affected IRI for new AC pavements over aggregate base and AC overlays of flexible pavements. For the other pavement types, the surface distresses were more important than the age and explained the increase in IRI. The authors defined a parameter called site factor, which depended on soil properties and climatic factors, and the site factor only influenced IRI progression of flexible pavements on aggregate base. Block cracking had a significant effect on IRI except on new pavements with an ATB and AC overlays of flexible pavements. Patching had a significant effect on IRI for new pavements with ATB and AC overlays of flexible as well as rigid pavements. The authors found that small high-severity patches dramatically increased IRI.(8)

Lu and Tolliver used LTPP data to investigate the effect of freeze-thaw cycles and wet days on development of roughness.(9) They used an exponential function of pavement age to represent the increase in IRI at the test sections. The test sections were divided into environmental zones based on the number of freeze-thaw days and the number of wet days. A *freeze-thaw day* was defined as a day when the air temperature in the day changed from less than 32 °F to greater than 32 °F. A *wet day* was defined as a day when the amount of precipitation exceeded 0.01 inches. The authors used the following freeze-thaw regions: no freeze-thaw where the freeze-thaw days in a year was fewer than 70, medium freeze-thaw where the freeze-thaw days in a year were between 70 and 140, and severe freeze-thaw where the freeze-thaw days in a year ranged from 140 to 230. They used two precipitation regions classified as dry where the wet days were fewer than 100 days a year and wet where the wet days were greater than 100 days per year. These freeze-thaw classifications and wet day classifications resulted in six environmental zones. They found that IRI increased with increasing freeze-thaw cycles and that the IRI deterioration rates are greater in the wet region compared with dry regions. They found the lowest increase in IRI was obtained in the no-freeze-thaw dry region.[(9)]

Tighe et. al. studied the change in roughness at 65 overlaid test sections in Canada.[(10)] IRIs of these test sections were determined before the overlay and after the overlay at annual intervals. Nine years of IRI data were available for these sites at the time of analysis. The climatic regions considered in this study were no- to low-freeze, wet high-freeze, and dry high-freeze. The subgrade at the sites was classified as fine or coarse, while the overlay thickness was divided into three categories (i.e., 0.8 to 2 inches, 2 to 4 inches, and 4 to 6.1 inches). The authors found that the overall national trend of roughness progression for the analyzed period was essentially linear, with an average starting IRI after overlay of 70 inches/mi and the average overall IRI after 9 years being 108 inches/mi. They found overlay thickness and climatic factors were the two major factors that had a significant effect on roughness progression, with subgrade type also having a substantial effect under certain conditions. The test sections in the dry and high-freeze zones showed little change in IRI over the evaluated period. IRIs of the test sections on fine-grained subgrade soils increased at a higher rate than the test sections that were on coarse-grained subgrades. The authors indicated the greatest increase in roughness would occur for the following combination of factors: thin overlay thickness, wet and low-freeze zone, fine-grained subgrade, and high traffic. The conditions that would minimize roughness progression would be a thick overlay, dry high-freeze zone, and coarse-grained subgrade. Observations and statistical analysis indicated that traffic effect on roughness progression was not significant in most cases. The authors indicated the lack of apparent traffic level effect might have been due to the boundary that was chosen to differentiate between high and low traffic levels (i.e., 200,000 ESALs per year), and in reality, the traffic on the sections might have only represented one level of traffic.[(7)]

Kutay investigated the roughness development of flexible pavements for different wavelengths using PSDs of longitudinal pavement profile data.[(11)] Data collected at SPS-1 test sections in the LTPP Program were used in this study. The change in roughness was evaluated using the change in the amplitude of the PSD of the longitudinal profile over different wavelengths. Eight wavelength ranges were used in this study. The results indicated that the AC thickness and base thickness influenced roughness development at most wavelengths, with thicker AC and base thicknesses resulting in a smaller increase in IRI. The plasticity index (PI) of the subgrade and the fines content in the subgrade affected roughness development for wavelengths shorter than 1.6 ft, with greater fines content and greater PI values resulting in greater increases in roughness. The mean summer temperature affected the roughness development for wavelengths up to 33 ft, with higher temperatures resulting in a greater increase in roughness. The annual precipitation affected roughness increase for wavelengths greater than 1.6 ft, with roughness development increasing with increasing level of precipitation. The roughness development decreased with increasing traffic levels for wavelengths less than 3.2 ft, while roughness development increased with increasing traffic levels for wavelengths greater than 3.2 ft.[(11)]

Paterson presented a model for predicting roughness progression in flexible pavements.[(12)] He indicated roughness increase could not be directly related to traffic because each pavement was designed for the expected traffic, and consequently, pavements subjected to higher traffic would have greater initial structural strength compared with lower traffic pavements. In the model

Paterson developed, the incremental changes in IRI were modeled through three components: structural effects, surface distress, and environment-age factors. He used data collected in Brazil for a United Nations project to develop the model. The data showed that road roughness developed through multiple mechanisms, and significant increases in roughness could occur even without structural weakness. Paterson indicated roughness progression followed a generally accelerating pattern, with the initial increase in roughness depending on traffic loading relative to pavement strength and environmental effects. The rate increased once surface defects such as cracking, potholes, and patching occurred. Factors that affected roughness changes were rut depth variations, pavement strength, cracking, and traffic in the structural deformation component; cracking, patching, and potholes on the surface defects component; and roughness and time in the environment-age component. Most of the increase in roughness in high-strength pavements was caused by nontraffic factors such as the environment.(12)

Puccinelli and Jackson studied the effect of deep frost penetration and freeze-thaw cycling on pavement performance.(13) They defined three environmental zones for freezing: no freeze that had an FI of less than 90 °F days per year, a moderate freeze region that had an FI between 90 and 720 °F days per year, and a deep freeze region having an FI greater than 720 °F days per year. The authors developed performance models to evaluate the independent effect of freeze-thaw cycles and FI on pavement performance using data from the PPDB. They developed models to predict fatigue cracking, rutting, and roughness of flexible pavements using data from 510 test sections that included data from GPS experiments 1, 2, and 6 and SPS experiments 1 and 2. The predictions indicated significant differences existed among the different climatic regions.(13)

Chatti et al. used data collected at SPS-1 and SPS-8 projects in the LTPP Program to evaluate the effect of different structural, material, and environmental factors on pavement performance.(14) Their analysis of pavement roughness data for the SPS-1 projects found that pavement roughness was affected by all experiment factors in the SPS-1 experiment (i.e., AC layer thickness, base type, base thickness, drainage, climatic zone, and subgrade type) but not at the same level. Pavements with an ATB base performed best in terms of roughness, and pavements with thicker bases had lesser increases in IRI. In general, pavements built on fine-grained soils showed greater increases in roughness compared with pavements built on coarse-grained soils, especially in the WF region. The authors also noted that the changes in roughness of the sections in the WF zone were significantly greater than those in the WNF zone. For undrained pavement sections, the change in IRI for pavements with an ATB base was less than the change in IRI for pavement with a DGAB base. The effect of drainage was only significant for DGAB sections. Based on their observations, the authors suggested that for pavements built on fine-grained soils, greater AC thicknesses and/or treated bases would help to reduce the rate of roughness progression. They also indicated that drainage appeared to be effective in reducing the rate of increase of roughness for sections with a DGAB base, especially for the sections located in the WF zone. For the SPS-8 experiment, the authors observed that pavements located in wet climates had a greater increase in IRI compared with pavements in dry climates. They also indicated that sections in the WF zone and sections built on active soils had greater changes in IRI.(14)

Martin studied the environmental contribution to the total roughness of sealed granular unbound pavements and AC pavements in Australia.(15) For his study, he used the Australian Road Research Board Transport Research roughness progression model for sealed granular unbound pavements and the World Bank's Highway Design and Maintenance Standard Model HDM-III for AC pavements. Both of these models predicted the portion of the change in IRI of a pavement that could be attributed to environmental effects. Martin used the results from these models to estimate the cost of road maintenance that could be attributed to environmental effects.(15)

Perera and Kohn performed a study to investigate roughness development of pavements using the data from the PPDB.(16) For GPS-1 test sections, which were AC pavements on a granular base, the factors that had the strongest relationship to the increase in roughness were the percentage of material in the base passing through the No. 200 sieve, FI, PI of the subgrade, and pavement age.(16)

MEPDG MODEL FOR PREDICTING ROUGHNESS OF FLEXIBLE PAVEMENTS

The MEPDG describes the models that predict the increase in IRI that are used in the MEPDG software.(3) The models that predict the increase in IRI use the premise that the increase in roughness is caused by occurrence of surface distress on the pavement. The MEPDG is published by the American Association of State Highway and Transportation Officials (AASHTO), and the MEPDG software is referred to as AASHTOWare® Pavement ME Design.

Model in the 2008 Interim Edition of the MEPDG

The MEPDG interim guide released in 2008 listed the model shown in figure 1 to predict the increase in IRI for new AC pavements and AC overlays of existing flexible pavements.(17)

$$IRI = IRI_0 + 0.0150\,(SF) + 0.4\,(FC_{Total}) + 0.0080\,(TC) + 40.0\,(RD)$$

Figure 1. Equation. Formula for predicting the increase in IRI for new AC pavements and AC overlays of existing flexible pavements.(17)

Where:

- IRI = predicted IRI (inches/mi).
- IRI_0 = initial IRI after construction (inches/mi).
- SF = site factor (see figure 2).
- FC_{Total} = area of fatigue cracking (combined alligator, longitudinal, and reflection cracking in the wheelpath) expressed as a percentage of total lane area. All load-related cracks are combined on an area basis, with length of cracks multiplied by 1 ft to convert length to area.
- TC = length of transverse cracking (including the reflection of transverse cracking in the existing AC pavement) (ft/mi).
- RD = average rut depth (inches).

The site factor is calculated according to the equation shown in figure 2.

$$SF = Age\,[0.02003(PI + 1) + 0.007947(Precip+1) + 0.000636\,(FI+1)]$$

Figure 2. Equation. Formula for computing the *SF*.(17)

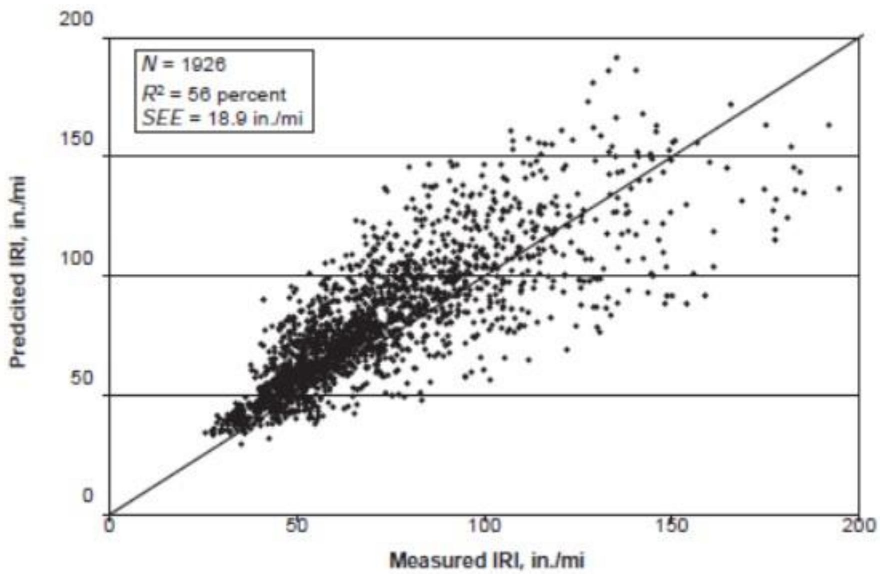
Where:

- Age = pavement age (years).
- PI = plasticity index of the soil (percent).

Precip = average annual precipitation (inches).
FI = average annual FI (°F days).

As seen in figure 1, the distresses that affect IRI are fatigue cracking, transverse cracking, and rutting. In addition to these distresses, the increase in IRI is also related to the interaction of pavement age with the PI of the subgrade, average annual precipitation, and average annual FI.

The model shown in figure 1 was developed using the data available in the PPDB and has been referred to as the globally calibrated model. Figure 3 shows the comparison of measured and predicted IRI values from this model.(17) The coefficient of determination (R^2) of the model was 0.56, and the standard error of estimate for this model was 18.9 inches/mi. As seen in figure 3, there can be a considerable error associated with the IRI values predicted from this model, with the error appearing to increase with the magnitude of IRI.



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SEE = Standard error of estimate.

Figure 3. Graph. Relationship between measured and predicted IRI from the MEPDG model for flexible pavements, [17] **from *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice*, 2015, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.**

An evaluation was performed to study the sensitivity of the parameters included in the site factor, (i.e., PI, average annual precipitation, and average annual FI) on the increase in IRI.

Figure 4 shows the increase in IRI predicted by the MEPDG model for flexible pavements due to the PI of the subgrade as a function of pavement age for four different PI values. As shown in figure 4, the impact of PI on the increase in IRI was negligible. For example, the increase in IRI after 20 years attributed to a PI value of 40 was only 0.25 inches/mi, which was a negligible increase in IRI.

Figure 4. Graph. Increase in IRI due to PI of subgrade predicted by the MEPDG model for four different PI values.

Figure 5 shows the increase in IRI predicted by the MEPDG model for flexible pavements due to average annual precipitation as a function of age for four different precipitation levels. As shown in figure 5, the impact of precipitation on the increase in IRI was negligible. For example, the increase in IRI after 20 years attributed to an annual average precipitation of 70 inches was only 0.17 inches/mi, which was a negligible increase in IRI.

Figure 5. Graph. Increase in IRI due to precipitation predicted by the MEPDG model for four different annual precipitation levels.

Figure 6 shows the increase in IRI predicted by the MEPDG model for flexible pavements due to the FI as a function of pavement age for four different FI values. As shown in figure 6, the impact of FI on the increase in IRI was negligible. For example, the increase in IRI after 20 years attributed to an average annual FI of 1,200 °F days was only 0.23 inches/mi, which was a negligible increase in IRI.

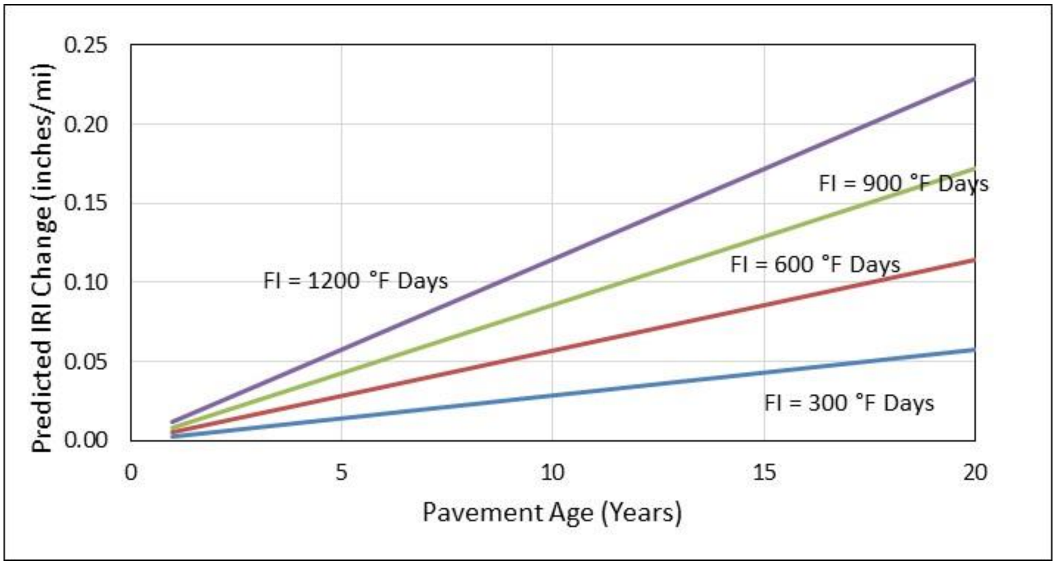

Figure 6. Graph. Increase in IRI due to FI predicted by the MEPDG model for four different average annual FI values.

Model in the 2015 Version of the MEPDG

The MEPDG manual of practice released in 2015 listed the model shown in figure 7 to predict the increase in IRI for new AC pavements and AC overlays of existing flexible pavements.(3)

$$IRI = IRI_0 + 0.0150\ (SF) + 0.4\ (FC_{Total}) + 0.008\ (TC) + 40.0\ (RD)$$

Figure 7. Equation. Formula for predicting the increase in IRI for new AC pavements and AC overlays of existing flexible pavements.(3)

This equation is similar to the model that was presented in the interim edition.(17) However, the 2015 version has a new equation for computing the SF.(3) The equation presented in the 2015 version for computing the site factor is shown in figure 8.

$$SF = Age^{1.5}\ \{\ln[(Precip + 1)\ (FI + 1)\ P_{02}]\} + \{\ln[(Precip + 1)\ (PI + 1)\ P_{200}]\}$$

Figure 8. Equation. Formula for computing *SF*.(3)

Where:

P_{02} = percentage passing through the 0.02-mm sieve.
P_{200} = percentage passing through the 0.075-mm sieve.

The first part of the equation for computing SF has age as a factor, while the second part does not have age. Therefore, the contribution to SF from the second part is constant, irrespective of the age of the pavement.

The sensitivity of the parameters in the first part of the SF equation to IRI with increasing pavement age was evaluated using the following procedure:

- Hold annual precipitation and FI constant at 30 inches and 500 °F days, respectively, and evaluate IRI changes for P_{02} values of 20, 40, and 60 percent.
- Hold FI and P_{02} constant at 500 °F days and 50 percent, respectively, and evaluate IRI changes for annual precipitation values of 20, 40, and 60 inches.
- Hold annual precipitation and P_{02} constant at 30 inches and 50 percent, respectively, and evaluate IRI changes for FI values of 100, 500, and 900 °F days.

Figure 9 shows the impact on IRI of holding annual precipitation and FI constant at 30 inches and 500 °F days, respectively, and varying P_{02} from 20 to 60 percent. Figure 10 shows the impact on IRI of holding FI and P_{02} constant at 500 °F days and 50 percent, respectively, and varying the average annual precipitation from 20 to 60 inches. Figure 11 shows the impact on IRI of holding the average annual precipitation and P_{02} constant at 30 inches and 50 percent, respectively, and varying the FI values from 100 to 900 °F days. Although variations in the parameters did affect IRI for all three cases, the changes in IRI at 20 years that were observed for all three cases due to the variation of each parameter were small. For all three cases, the difference in IRI at 20 years between the lowest and highest value of the parameter being varied was 3 inches/mi.

Figure 9. Graph. Change in IRI by fixing precipitation and FI and varying P_{02}.

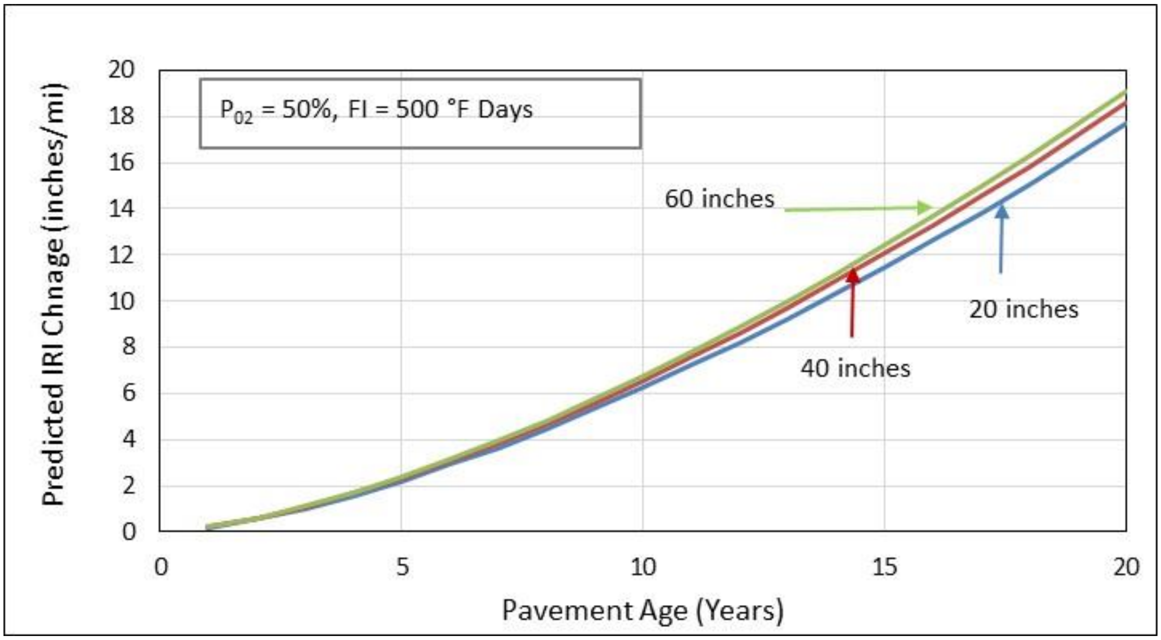

Figure 10. Graph. Change in IRI by fixing FI and P_{02} and varying average annual precipitation.

Figure 11. Graph. Change in IRI by fixing average annual precipitation and P_{02} and varying average annual FI.

As indicated previously, the second term in the SF equation (figure 8) does not have age as a parameter and is therefore constant. Table 3 shows the IRI values corresponding to the second part of the SF equation for various values of precipitation, PI, and P_{200}. In this table, the effect of a parameter was studied by holding two parameters constant and then changing the value of the third parameter. As seen from the IRI values shown in table 3, the effect of parameters in the second term of the SF equation on IRI was negligible.

Table 3. Effect of parameters in the second term of the SF equation on IRI.

Case	Precipitation (Inches)	PI	P_{200} (Percent)	Predicted IRI Change (Inches/mi)
Vary precipitation	10	20	50	0.14
	20	20	50	0.15
	30	20	50	0.15
	40	20	50	0.16
Vary PI	20	10	50	0.14
	20	20	50	0.15
	20	30	50	0.15
	20	40	50	0.16
Vary P_{200}	20	20	20	0.13
	20	20	40	0.15
	20	20	60	0.15
	20	20	80	0.16

CHAPTER 3. IRI DATA USED FOR THE STUDY

This chapter describes the sources and nature of the data used for this study.

OBTAINING DATA FOR ANALYSIS

As indicated previously, since December 1996, center of the lane profile data at the test sections in the LTPP Program have been collected along with the wheelpath profile data, starting with use of the K.J. Law T-6600 profiler. The 0.98-inch interval profile data collected at the SPS-1 projects shown in table 2 since December 1996 were used for analysis. As described previously, profile data files containing the 0.98-inch interval profile data in ERD format have been stored in the AIMS. These ERD files were obtained through the LTPP customer support service over the period of October to November 2014. In most cases, profile data for seven to nine repeat runs for each profile date were available.

The profile data collection dates at LTPP sections and the ride parameters computed from the profile data have been stored in the MON PROFILE MASTER table in the PPDB.[1] Records for SPS-1 sections were extracted from this table from Standard Data Release (SDR) 28. The information obtained was used to determine the following information for each test section: the date when the section was first profiled, the date when the section was first profiled with the K.J. Law T-6600 profiler, and the last profile date. The EXPERIMENT SECTION table in the PPDB was used to obtain the date when each LTPP section was opened to traffic and to determine whether the section was out of the LTPP study (i.e., deassigned), and if so, what date the section was deassigned (i.e., deassign date). Appendix A of this report contains a table that shows the following information for each SPS-1 test section:

- State where the section was located and the State code.
- Date when the section was opened to traffic.
- Whether the section was deassigned.
- If the section was deassigned from the LTPP Program, the date when that occurred.
- Date when profile data were first collected at the section.
- Date when profile data were first collected at the section by the K.J. Law T-6600 profiler.
- Date when profile data were last collected at the section.
- Number of times center of the lane profile data were collected at the section.
- Time period over which center of the lane data were available (i.e., difference in years between last profile date and date when section was first profiled with the T-6600 profiler).
- Age of the pavement at the last profile date (i.e., difference in years between last profile date and date when section was opened to traffic).

The information contained in appendix A was obtained as described previously from the MON PROFILE MASTER table and the EXPERIMENT SECTION table in the PPDB. For sections that were still active in the LTPP study, the last profile date shown in appendix A represents the most recent profile date indicated in the MON PROFILE MASTER table obtained from SDR 28.

The profile dates for SPS-1 sections in the MON PROFILE MASTER table were used to check whether the ERD files corresponding to all profile dates were obtained. The table obtained from SDR 28 indicated 2,250 site visits had been made to SPS-1 sections during which center of the lane profile data were collected, and it was possible to obtain ERD files for approximately 98 percent of these site visits.

The LTPP Program's SMP collected data in the different seasons as a subset of LTPP sections over a time period. Some SPS-1 sections were included in the SMP. The sections in the SMP were profiled four times a year during each season (i.e., spring, summer, fall, and winter) while the SMP program was active. Table 4 shows the SPS-1 sections that were included in the SMP. This table shows the following information for the section: State where the section was located, LTPP section number, whether the section was deassigned, date when profile data were first collected at the section, date when profile data were first collected at the section by the K.J. Law T-6600 profiler, date when the section was last profiled, and number of times profile data were collected at the site that included center of the lane data.

Table 4. SPS-1 sections that were SMP sites.

State	LTPP Section Number	Deassigned?	First Profile Date: At the Section	First Profile Date: With T-6600	Last Profile Date	Number of Times Profiled With Center of the Lane Data
Arizona	040113	Yes	1/27/1994	7/3/1997	3/27/2006	27
Arizona	040114	Yes	1/27/1994	1/23/1997	3/27/2006	27
Montana	300114	No	11/19/1998	11/19/1998	9/5/2012	32
Nevada	320101	Yes	12/3/1996	12/3/1996	6/24/2009	30
Virginia	510114	Yes	4/24/1996	10/9/1997	3/27/2012	29

COMPUTATION OF IRI VALUES

The profile data in the ERD files were used to compute the left wheelpath, right wheelpath, and the center of the lane IRI values for all profile runs made at SPS-1 sections. Thereafter, for each site visit, the IRI values for the repeat runs were averaged to obtain an average IRI for each profiled path (i.e., left wheelpath, right wheelpath, and center of the lane). These averaged IRI values were used for analysis.

As an example, table 5 shows the IRI values for each profiled path for the seven runs collected at section 010101 on 7/3/1997 and the average IRI values for each path. The IRI values shown for each run in table 5 are about 3 to 4 percent greater than the IRI values shown in the MON PROFILE MASTER table in the PPDB for the corresponding run.

The IRI values included in the PPDB were computed by smoothening the 0.98-inch interval profile data with an 11.8-inch moving average, extracting data at 5.9-inch intervals, and using the resulting profile to compute the IRI values. The IRI computation program has a 9.8-inch moving average built into it to address tire enveloping before computing IRI. If the profile data used in the IRI computation had already been subjected to a moving average, the 9.8-inch moving average in the IRI program should not be applied to that data.(18) However, this procedure was not followed when computing IRI from the 5.9-inch interval profile data in the LTPP Program. The application of the 9.8-inch interval moving average in the IRI program to data that had already been subjected to a moving average would cause further smoothening of the data, resulting in a decrease in the IRI value. This was the reason IRI computed from the 0.98-inch interval profile data was slightly greater than IRI computed from the 5.9-inch interval profile data.

Table 5. IRI values at section 010101 for profile data collected on 7/3/1997.

Run Number	IRI (Inches/mi)		
	Left Wheelpath	Right Wheelpath	Center of the Lane
1	47.8	43.6	41.7
2	45.9	44.7	40.4
3	47.2	44.5	41.3
4	45.0	44.0	38.9
5	46.1	43.7	40.6
6	45.4	46.1	41.0
7	45.8	45.1	40.9
Average	46.2	44.5	40.7

The center sensor data were not available or the center sensor data values were zeros for the cases shown in table 6. Study researchers verified with the regional contractors that the center sensor in the profiler was not functioning for the cases shown in table 6.

Table 6. Sections and profile dates for which center sensor data were not available.

State	Sections	Profile Date	Comment
Michigan	13–24	8/10/2010	Center sensor values are zero
Ohio	1–12	8/11/2010	Center sensor values are zero
Montana	13–24	7/21/2011	No center sensor data
Montana	13–24	9/15/2012	No center sensor data

CONSTRUCTION NUMBER OF LTPP SECTIONS

The construction number "1" was assigned to an SPS-1 section initially after construction. Whenever any maintenance or rehabilitation activity was performed at an SPS-1 section, the construction number was incremented, and the date the maintenance or rehabilitation was performed, including the type of maintenance or rehabilitation activity, was recorded in the PPDB table EXPERIMENT SECTION. Maintenance activities at a section could include crack sealing, slurry sealing, application of an aggregate seal coat, or patching. Such activity could cause a decrease in IRI, cause an increase in IRI, or have no impact on IRI. Rehabilitation performed at a section typically involved the placement of an overlay, which would usually cause a sharp reduction in the IRI of the pavement. It was possible that some maintenance or rehabilitation activities performed at a test section might not have been recorded in the EXPERIMENT SECTION table in the PPDB.

Evaluation of the information contained in the table EXPERIMENT SECTION indicated there were only three SPS-1 projects where no maintenance or rehabilitation activities had been performed on any test section in that project during the monitoring period. These SPS-1 projects were those located in Florida, Louisiana, and Wisconsin.

EVALUATION OF IRI VALUES

IRI versus pavement age plots were developed for each test section to evaluate how the IRI of the left wheelpath, right wheelpath, and center of the lane changed over time. Figure 12 shows an example of such a plot for section 010106. The horizontal axis of this plot represents the pavement age, with the pavement age being assigned a value of 0 for the traffic open date. The first IRI value shown in this plot corresponds to the date when center of the lane profile data were first collected at this section. As described previously, center of the lane profile data were first collected at the LTPP sections starting with the K.J. Law T-6600 profilers that went into operation in December 1996. At most test sections, profile data were collected previously along the two wheelpaths with the K.J. Law DNC690 profilers, but as described previously, this profiler did not have a sensor to collect the center of the lane data.

Figure 12. Graph. IRI progression at section 010106.

The time sequence IRI values at each test section were visually examined to evaluate the changes in IRI over time. Particular attention was paid to the following items when evaluating the IRI plots:

- Review the IRI values measured before and after a change in construction number to evaluate the effect of the maintenance or rehabilitation activity on the IRI value. If that activity had an impact on IRI, a sharp change in IRI should be noticed between IRI before and after the maintenance or rehabilitation activity.

- If a sharp increase or decrease in IRI occurred between visits and there was no maintenance or rehabilitation activity indicated in the PPDB table EXPERIMENT SECTION, such data points were closely evaluated to determine the cause for the sharp increase or decrease in IRI. The sudden change in IRI between the two visits might have been caused by a variety of factors such as erroneous data, maintenance or rehabilitation activity at the section that was not documented, rapid increase in distress at the site that resulted in an increase in IRI, or environmental effects on the subgrade that caused changes in IRI. When investigating the cause for the change in IRI, in addition to evaluating the profile data, distress data, cracks maps, photographs, and videos obtained during the distress surveys were used, as appropriate, to determine the cause for the sudden change in IRI.

The evaluation of time-series IRI data indicated that the sudden increases or decreases in IRI between profile visits could be attributed to one of the following reasons:

- Equipment errors.
- Data assigned to the section from an incorrect location.
- An overlay placed on the section.
- Surface grinding performed on the section.
- Patching performed at the section.
- Surface treatments applied to the section.
- Variability in the profiled path.
- Increasing distress at the section.

The following subsections describe examples illustrating the influence of each of these conditions on IRI. Crack sealing is also included although it did not appear to be a factor that caused a noticeable change in IRI.

Equipment Errors

This section describes several examples of instances where bad data were collected because of equipment problems. The time-sequence IRI values for section 010104 are shown in table 7, while the time-sequence IRI plot for these data is shown in figure 13. The right wheelpath IRI values for 4/23/1998, 12/7/1998, and 3/14/2001 were 42, 62, and 39 inches/mi, respectively. As seen from these values, IRI for 12/7/1998 was higher than IRI for previous and subsequent profiling dates. Figure 14 shows the left wheelpath, center of the lane, and right wheelpath profile data collected by the profiler on 12/7/1998 for a portion of this section. This plot shows the profile data for the right sensor had “noise” compared with the data from the other two sensors, which indicates that the sensor was not functioning properly.

Table 7. Time-sequence IRI values at section 010104.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
7/3/1997	4.3	47	38	41
1/27/1998	4.9	45	40	38
4/23/1998	5.1	47	42	38
12/7/1998	5.8	50	62	38
3/14/2001	8.0	46	39	41
3/10/2002	9.0	48	45	46
1/29/2003	9.9	48	40	41
4/27/2004	11.2	47	40	42
5/4/2005	12.2	49	41	42

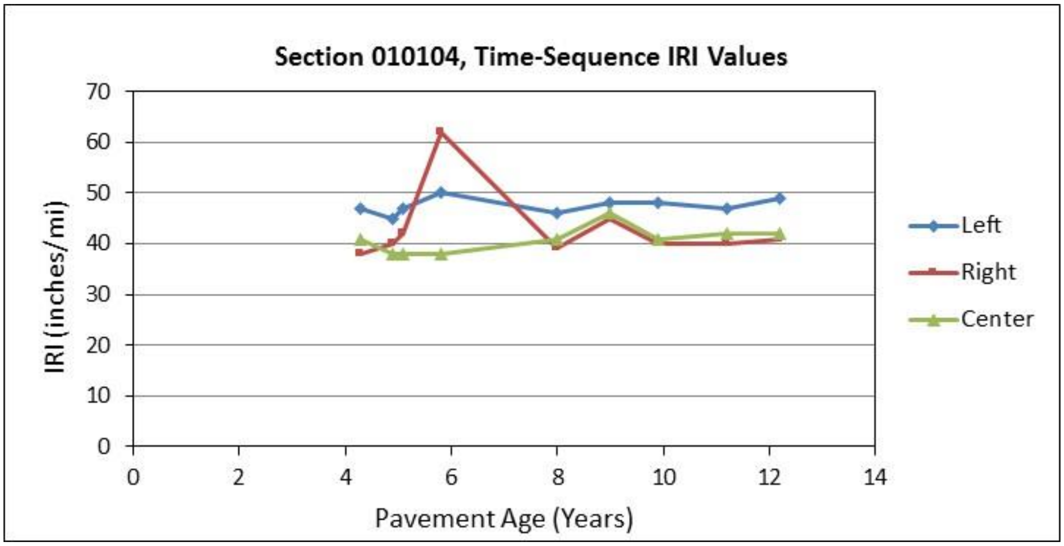

Figure 13. Graph. Time-sequence IRI values at section 010104.

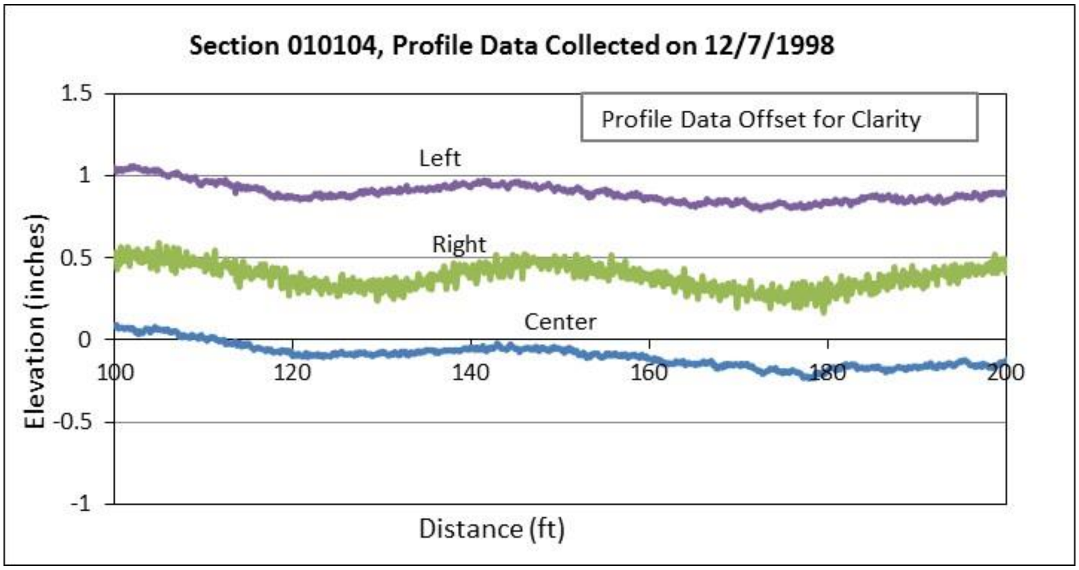

Figure 14. Graph. Profile data collected at section 010104 on 12/7/1998.

The time-sequence IRI values for section 260115 for the first five site visits with the K.J. Law T-6600 profiler are shown in table 8. The CLIRI value for 12/30/1996 was 177 inches/mi, while this value for the subsequent profile date of 4/16/1997 was 50 inches/mi. The IRI values for the left and right wheelpaths did not show such a drop between these two visits, which indicates there might have been a problem with the center sensor during the 12/30/1996 data collection. Figure 15 shows the left wheelpath, right wheelpath, and center of the lane profile data collected by the profiler on 12/30/1996 for a portion of the test section. This plot shows the profile data for the center sensor had a sinusoidal pattern indicating that the sensor was not functioning properly.

Table 8. IRI from first five site visits with K.J. Law T-6600 profiler at site 260115.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
12/30/1996	1.2	48	47	177
4/16/1997	1.5	48	46	50
6/25/1997	1.6	48	47	49
10/27/1998	3.0	57	49	52
4/8/1999	3.4	57	51	54

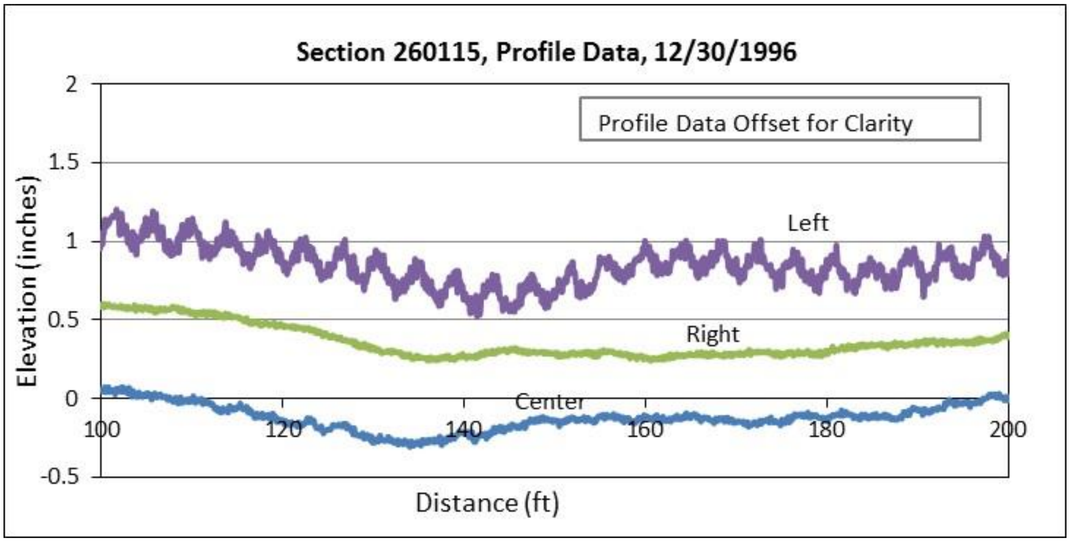

Figure 15. Graph. Profile data collected at section 260115 on 12/30/1996.

Evaluation of time-sequence IRI values at all sections indicated only a few cases where a sudden increase in IRI could be attributed to errors associated with equipment. Table 9 shows the cases where equipment-related issues affected IRI, and these data were not used for analysis.

Table 9. Cases where equipment-related issues affected the collected data.

State	State Code	Section	Profile Date	Issue
Alabama	01	4	12/7/1998	Right wheelpath sensor had noise
Michigan	26	15–18, 20, 21, 23, 24	12/30/1996	Center sensor collected bad data
Ohio	39	3, 4, 6, 8–12	12/8/1997	Center sensor collected bad data
Ohio	39	3, 4, 6, 8–12	12/27/1996	Center sensor collected bad data

Data for approximately 2,250 visits to SPS-1 test sections were evaluated in this study. As shown in table 9, only 25 visits to test sections were identified where equipment issues affected the IRI values.

Data Assigned to the Section from an Incorrect Location

Several examples of assignment of incorrect data to a test section are presented in this section. Table 10 shows the time-sequence IRI values for section 010102, while a plot of these IRI values is shown in figure 16.

Table 10. Time-sequence IRI values at section 010102.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
7/3/1997	4.3	58	59	54
1/27/1998	4.9	59	70	55
4/23/1998	5.1	60	69	55
8/5/1998	5.4	67	91	58
12/7/1998	5.8	63	86	57
3/14/2001	8.0	85	94	58
3/10/2002	9.0	57	58	56
1/29/2003	9.9	140	144	58
4/27/2004	11.2	171	214	90
5/4/2005	12.2	194	211	86

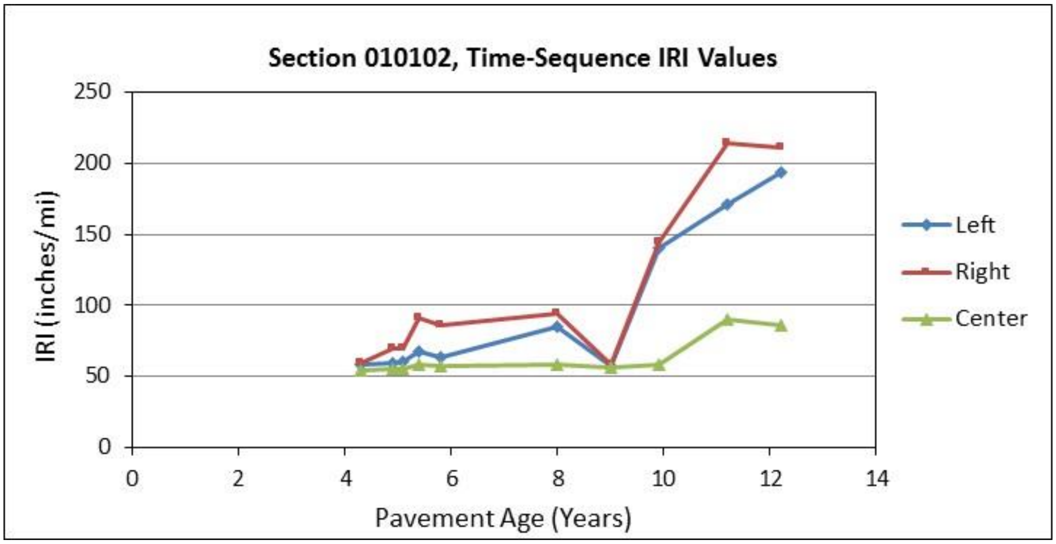

Figure 16. Graph. Time-sequence IRI values at section 010102.

The left and right wheelpath IRI values showed a sharp drop on 3/10/2002 compared with IRI for the previous visit. Thereafter, the left and right wheelpath IRI values showed a sharp increase in IRI for 1/29/2003 compared with the IRI values obtained on 3/10/2002. Figure 17 shows the left wheelpath profile data plots for 3/14/2001, 3/10/2002, and 1/29/2003 for a portion of the section. These plots show that the profile trace for the 3/10/2002 data was completely different from the traces obtained before and after this date. Evaluation of the right and center of the lane data also showed similar results. Therefore, it was concluded that the data for 3/10/2002 were not associated with section 010102.

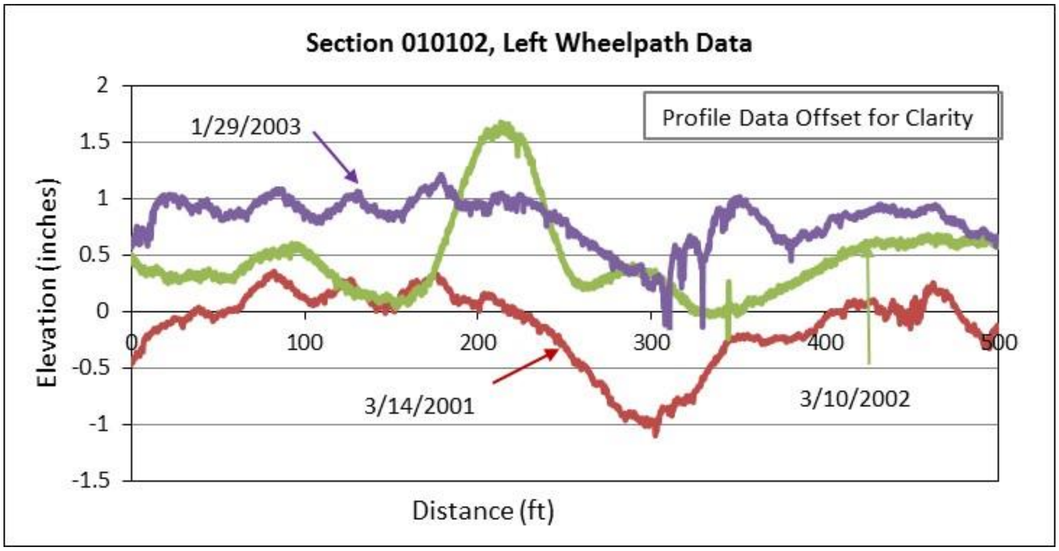

Figure 17. Graph. Left wheelpath profile data at section 010102.

Table 11 shows the time-sequence IRI values for section 050122. A sudden increase in IRI occurred for the right wheelpath and center of the lane data on 9/21/2008 compared with IRI obtained on 5/22/2007. There was no record of rehabilitation or maintenance activities performed on this section between these two dates.

Table 11. Time-sequence IRI values at section 050122.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
7/1/1997	2.8	48	49	41
1/22/2001	6.4	67	55	43
4/1/2002	7.6	64	50	53
4/23/2003	8.6	75	54	48
3/19/2004	9.6	71	55	48
4/6/2005	10.6	78	58	50
5/22/2007	12.7	84	65	54
9/21/2008	14.1	87	96	92

Figure 18 shows the right wheelpath profile plots for 4/6/2005, 5/22/2007, and 9/21/2008. Evaluation of these plots showed that the plot for the 9/21/2008 data was not similar to the plots obtained for the two previous site visits. Therefore, it was concluded that the data for 9/21/2008 were not associated with section 050122.

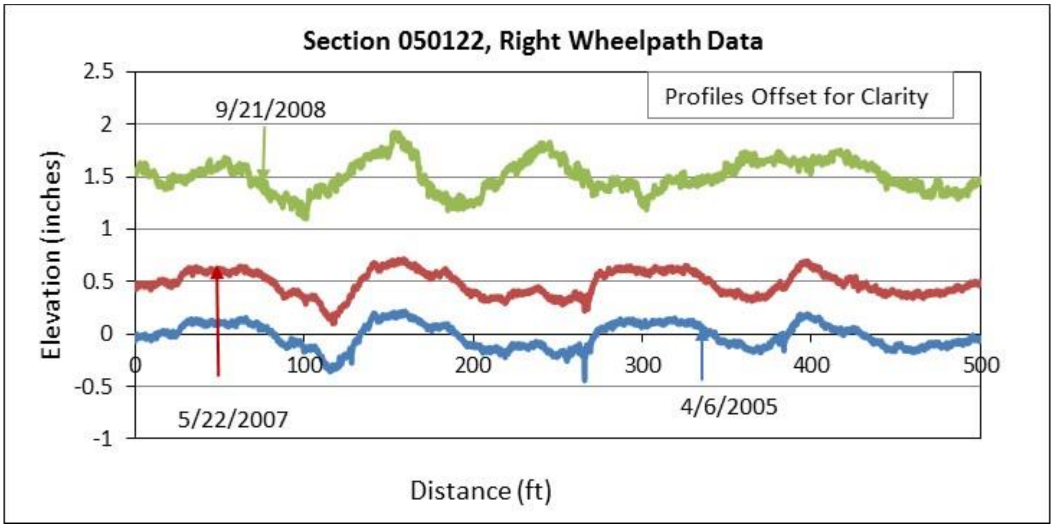

Figure 18. Graph. Right wheelpath profile data at section 050122.

The profile data for all sections in an SPS-1 project were collected in a single run, and thereafter, the collected data were subsectioned to extract the profile corresponding to each test section. Incorrect subsectioning can be a reason for assigning incorrect data to a test section. Evaluation of time-sequence IRI plots indicated only a very few cases where a sudden change in IRI could be attributed to assignment of incorrect data to a section. The cases that were identified are shown in table 12, and these data were not used for analysis.

Table 12. Cases where data from an incorrect location were assigned to sections.

State	State Code	Section	Profile Date
Alabama	01	2	3/10/2002
Arkansas	05	13–18, 22–24	9/21/2008
Oklahoma	40	13–24	10/11/2001

In this study, a comparison of profile data collected during different site visits was not performed to investigate whether the profile data matched because it was beyond the scope of this project. It is possible for the profile data not to match between visits because of incorrect subsectioning and for the IRI plot not to show any anomalous trends. This could occur if the IRI of the incorrectly subsectioned section had a value that was close to the IRI of the test section.

Overlay Placed on the Section

An overlay placed on a test section should result in a decrease in the IRI value unless the section is so smooth that an overlay would not have much of an impact on IRI. (Note that an increase in IRI could occur if the contractor did not follow best practices for constructing a smooth pavement.) A decrease in IRI was usually noted for all three paths (i.e., left wheelpath, right wheelpath, and center of the lane); however, the change in CLIRI might not be very noticeable if the center of the pavement was smooth. The magnitude of the decrease in IRI caused by an overlay would depend on the IRI of the pavement before the overlay. Sections with a high IRI before an overlay would typically show a greater decrease in IRI compared with sections with lower IRI values. In the LTPP Program, if an SPS-1 test section continued to be monitored after an overlay, the experiment number would be changed from SPS-1 to GPS-6. The date when the overlay was placed, as well as the date when the experiment number was changed, was shown in the PPDB table EXPERIMENT SECTION. Although a change in experiment number was made after the overlay, the section number of the section was not changed. Several examples of reduction in IRI caused by an overlay are presented in this section.

Table 13 shows the time-sequence IRI values at section 260117, while a plot of these data is shown in figure 19. At this section, the first overlay was placed on 10/1/2002, while the second overlay was placed on 6/1/2012. The IRI of the left wheelpath before the overlay on 10/1/2002 was more than double the IRI for the right wheelpath and center of the lane. The overlay placed on 10/1/2002 caused a reduction in IRI for all three paths, with the reduction being greatest for the left wheelpath that had an IRI of 137 inches/mi before the overlay. The overlay on 6/1/2012 also caused a reduction in IRI for all three paths. This overlay resulted in a very smooth pavement that had a MIRI of 27 inches/mi.

Table 13. Time-sequence IRI values at section 260117.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
4/16/1997	1.5	52	50	54
6/25/1997	1.6	55	50	50
10/27/1998	3.0	107	59	54
4/8/1999	3.4	95	61	53
4/19/2000	4.5	114	61	56
5/29/2002	6.6	137	63	60
10/1/2002	First overlay			
4/10/2003	7.4	58	50	54
4/21/2005	9.5	69	50	56
6/2/2006	10.6	66	50	57
4/22/2008	12.5	69	55	59
10/14/2009	14.0	72	59	60
8/24/2011	15.8	73	59	61
4/25/2012	16.5	73	60	58
6/1/2012	Second overlay			
9/11/2012	16.9	27	27	31

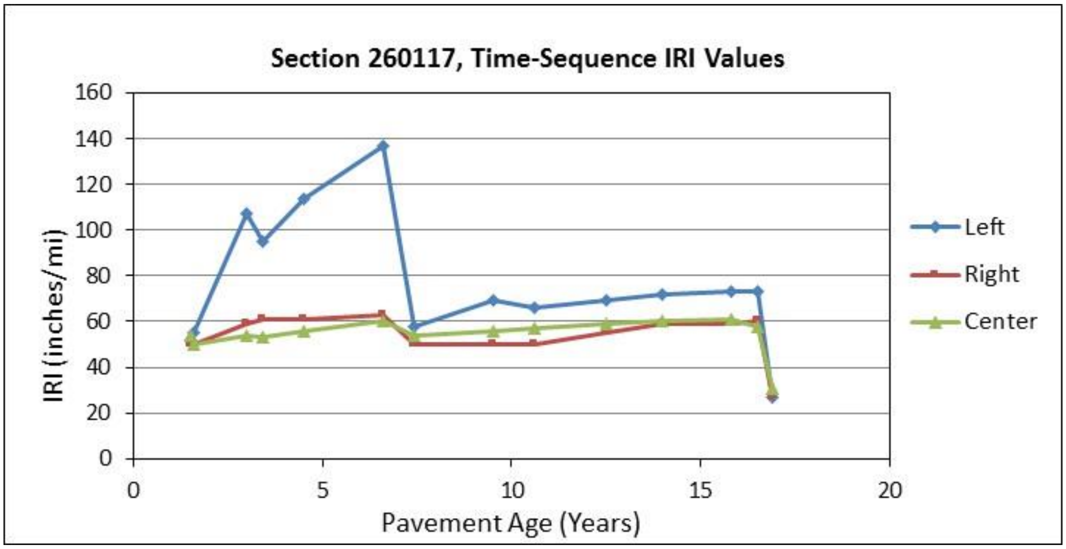

Figure 19. Graph. Time-sequence IRI values at section 260117.

Table 14 shows the time-sequence IRI values at section 350101. IRI for all three paths at this section showed a steady increase in IRI, and thereafter, a sudden drop in IRI occurred for the last profile date of 5/15/2008. The PPDB table EXPERIMENT SECTION indicated that this test section was deassigned on 6/15/2009 but made no mention of any rehabilitation performed on this test section between 4/24/2006 and 5/15/2008. This test section was in the New Mexico SPS-1 project, and evaluation of the IRI data for all test sections in the New Mexico SPS-1 project showed a sudden decrease in IRI between 4/24/2006 and 5/15/2008. The only possible reason for this decrease was either an overlay was placed on the test section or grinding was performed on the test section to eliminate rutting. However, because rutting in this section was 0.25 inches based on the transverse profile data collected 3/28/2006, it was unlikely that grinding was performed to eliminate rutting. Therefore, it was very likely that an overlay was placed on this section between 4/24/2006 and 5/15/2008 that resulted in the decrease in IRI. Changes in rut depth at this section after 3/28/2006 could be used to verify whether an overlay was placed, but no transverse profile data used to compute rut depths were collected at this site after 4/24/06.

Table 14. Time-sequence IRI values at section 350101.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
3/11/1997	1.4	36	41	34
5/21/2000	4.6	50	42	44
5/4/2001	5.5	80	49	51
1/9/2003	7.2	74	64	62
6/9/2004	8.6	81	69	71
3/11/2005	9.4	102	86	93
4/24/2006	10.5	112	92	100
5/15/2008	12.5	50	69	59

If a section was overlaid, only the data up to the point before the overlay were used for analysis in this project. If the section was monitored after the overlay and sufficient post-overlay IRI values were available, the increase in IRI of the overlaid pavement was analyzed separately.

As indicated previously, information about overlays placed on SPS-1 sections was contained in the PPDB table EXPERIMENT SECTION. Evaluation of the time-sequence IRI data indicated overlays placed on SPS-1 sections were correctly identified in this table except for the possible overlay placed at all sections on the New Mexico project.

Table 15 shows the SPS-1 sections that were overlaid and the overlay date. All sections in the Delaware SPS-1 project were overlaid immediately after opening to traffic. The first IRI values available for the sections in this project were after the overlay on 6/10/1997, and the IRI values on the overlaid sections were used for analysis. For the sections in Kansas, Ohio, and Virginia, the IRI values up to the first overlay were used for analysis. The sections in Michigan and Texas SPS-1 project were overlaid twice. For these two projects, two sets of IRI data were created for each test section. The first dataset consisted of IRI values up to the first overlay, while the second dataset contained IRI values after the first overlay up to the second overlay. These datasets were treated separately for analysis purposes to determine roughness progression of the original sections and the overlaid sections.

Table 15. SPS-1 sections that were overlaid.

State	State Code	Sections	Overlay Date	Comment
Delaware	10	1–12	9/22/1996	—
Kansas	20	3, 4, 5, 6, 8, 9, 10, 11, 12	10/1/2001	—
Michigan	26	15 to 18, 20, 21, 23, 24	10/1/2002	First overlay
			6/1/2012	Second overlay
New Mexico	35	1–12	Between 4/24/2006 and 5/15/2008	—
Ohio	39	11	5/30/2007	—
		4, 12	6/1/2012	—
Texas	48	13–24	4/29/2002	First overlay
			3/31/2007	Second overlay
Virginia	51	14–24	7/1/2011	—

—Indicates there is no comment.

Grinding Performed on the Section

A few SPS-1 sections were ground to eliminate rutting. All active sections in the Nebraska SPS-1 project were ground on 7/12/2000. The grinding reduced the IRI along the two wheelpaths at all sections except for one where it increased the IRI. The effect of grinding on CLIRI was mixed, with grinding having no impact on IRI on some sections, reducing IRI on others, and increasing IRI on still others.

Table 16 shows the time-sequence IRI values at section 310118 in the SPS-1 project in Nebraska. Grinding reduced the IRI of all three paths at this section, with a reduction in IRI of 9, 18, and 20 inches/mi for the left wheelpath, right wheelpath, and center of the lane, respectively.

Table 16. Time-sequence IRI values at section 310118.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
2/18/1997	1.6	87	83	88
5/16/1998	2.8	89	83	89
5/7/1999	3.8	86	82	89
10/13/1999	4.2	91	77	95
3/20/2000	4.6	85	83	93
7/12/2000	Grinding			
5/16/2001	5.8	76	65	63
4/24/2002	6.7	65	55	68

Table 17 shows the SPS-1 sections where grinding was performed according to the information in the PPDB table EXPERIMENT SECTION. For the sections in Nebraska, the IRI data up to the point when grinding was performed were used for analysis. Only two IRI data points were available after grinding for the test sections in the Nebraska SPS-1 project. Therefore, sufficient data were not available to investigate IRI progression on the ground pavement. Investigation of IRI values at the two sections in New Mexico shown in table 17 did not show evidence of grinding having an effect on the IRI. Therefore, all available time-sequence data were used for analysis at these two sections. The three sections in Texas showed an increase in IRI after grinding; the average increase in MIRI of a section was 32 inches/mi. Only one IRI data point was available before grinding for these three sections. For these three sections, the pre-grinding IRI was ignored, and only the IRI values obtained after grinding were used for analysis.

Table 17. Sections where grinding had been performed.

State	Sections	Grinding Date
Nebraska	13–24	7/12/2000
New Mexico	2, 11	3/15/2005
Texas	15, 16, 19	7/7/1998

Patching at Sections

Several SPS-1 sections had patching performed on them. The date when patching was performed, the number of patches, and the area of patches were available in the PPDB. Some patches were placed across the entire lane, which affected the IRI for all three paths. In some cases, patching might only be performed along a single wheelpath, and in such cases, only the IRI of that wheelpath would be affected. This section presents several examples of how patching affected the IRI.

The time-sequence IRI values at section 200105 are shown in table 18, while a plot of these data are shown in figure 20. CLIRI showed a sudden increase of 22 inches/mi between 3/21/1999 and

3/17/2000, with the IRI along the left and the right wheelpath reduced by 27 and 9 inches/mi, respectively. The EXPERIMENT SECTION table in the PPDB indicated that full-depth patching had been performed at this section on 6/1/1999. Figure 21 shows the continuous IRI plots based on a 25-ft base length for the center of the lane data collected on 3/21/1999 and 3/17/2000. A data point on a continuous IRI plot shows the average IRI over the base length centered at that location. For example, the IRI shown on the plot at 100 ft was the average IRI from 87.5 to 112.5 ft. This plot shows that CLIRI agreed up to about 225 ft for the two dates, and thereafter they were different. This difference occurred because of patching performed on the test section after 225 ft. The patching performed on 6/1/1999 caused the IRI of the left and right wheelpaths to be reduced by 27 and 9 inches/mi, respectively, but increased CLIRI by 22 inches/mi.

Table 18. Time-sequence IRI values at section 200105.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
2/13/1997	3.3	96	95	59
8/21/1998	4.8	129	142	63
3/21/1999	5.4	173	149	68
6/1/1999	Full-depth patching			
3/17/2000	6.4	146	140	90
5/12/2001	7.5	180	176	95

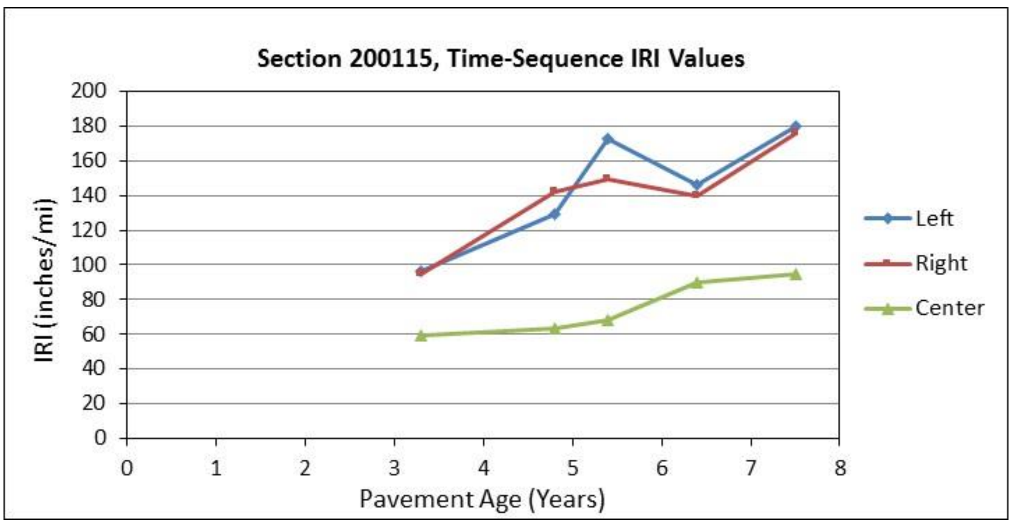

Figure 20. Graph. Time-sequence IRI values at section 200105.

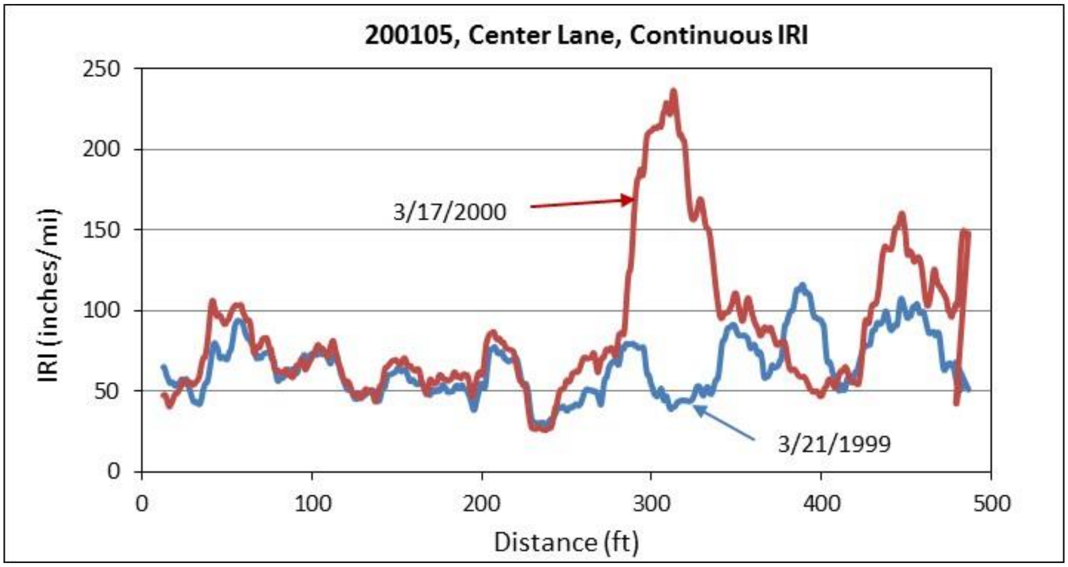

Figure 21. Graph. Continuous IRI plot for center of the lane for section 200105.

The time-sequence IRI values at section 200106 are shown in table 19. The IRI for all three paths showed a sudden increase in IRI after 3/21/1999, with the IRI increasing by 24, 33, and 37 inches/mi for the left wheelpath, right wheelpath, and center of the lane, respectively. The EXPERIMENT SECTION table in the PPDB did not indicate any maintenance activities occurred at this section between these two profile dates. However, the distress survey performed at this section on 12/6/1999 indicated the section was patched from 0 to 50 ft and from 278 to 500 ft. Figure 22 shows continuous IRI plots based on a 25-ft base length for the center of the lane for the data collected on 3/21/1999 and 3/17/2000. The two plots agreed well with each other up to about 270 ft, and thereafter, they were different. This difference was attributed to the patching that was performed at the section, which caused the CLIRI to increase. Hence, the changes in IRI noted at this section between 3/21/1999 and 3/17/2000 were attributed to the patching that was performed at this section. The patching caused the IRI of the left wheelpath, right wheelpath, and center of the lane to increase by 24, 33, and 37 inches/mi, respectively.

Table 19. Time-sequence IRI values at section 200106.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
8/21/1998	4.8	71	81	67
3/21/1999	5.4	71	79	67
3/17/2000	6.4	95	112	104
5/12/2001	7.5	107	95	104

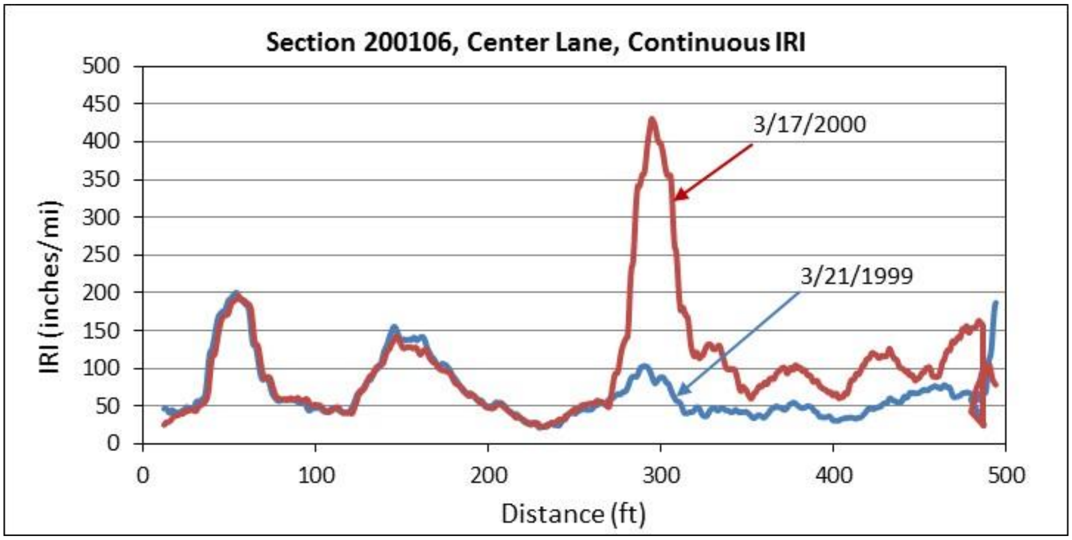

Figure 22. Graph. Continuous IRI plot for center of the lane for section 200106.

The time-sequence IRI values at section 050119 are shown in table 20. The IRI for all three paths showed a sharp increase in IRI between 7/1/1997 and 1/22/2001, with the IRI increasing by 67, 34, and 61 inches/mi for the left wheelpath, right wheelpath, and center of the lane, respectively. The EXPERIMENT SECTION table in the PPDB indicated that full-depth patching was performed on this section on 5/15/1999. The distress data indicated that this section had two patches with a total patch area of 565 sq ft. Figure 23 shows the continuous IRI plots based on a 25-ft base length for the center of the lane for the data collected on 7/1/1997 and 1/22/2001. The two plots agreed well with each other except for two localized areas. These were the areas where patching was performed that resulted in an increase in IRI. The increase in IRI noted at this section along all three paths between 7/1/1997 and 1/22/2001 was primarily attributed to the patching that was performed at this section.

Table 20. Time-sequence IRI values at section 050119.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
7/1/1997	2.8	53	51	43
5/15/1999	Full-depth patching			
1/22/2001	6.4	120	85	104
4/1/2002	7.6	121	85	105
4/23/2003	8.6	148	87	105
3/19/2004	9.6	167	102	106

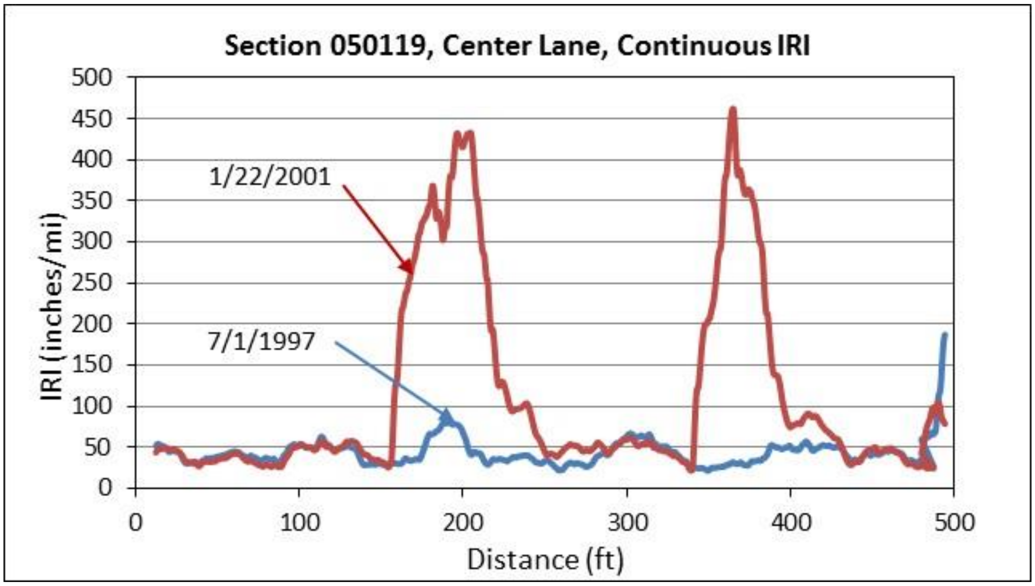

Figure 23. Graph. Continuous IRI plot for center of the lane for section 050119.

The time-sequence IRI values at section 010102 are shown in table 21. The IRI for all three paths showed a sharp increase in IRI between 1/29/2003 and 4/27/2004, with the IRI increasing by 31, 70, and 32 inches/mi for the left wheelpath, right wheelpath, and center of the lane, respectively. The EXPERIMENT SECTION table in the PPDB indicated that full-depth patching was performed on this section between these two profile visits. The distress data indicated that this section had 19 patches with a total patch area of 3,378 ft^2.

Table 21. Time-sequence IRI values at section 010102.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
7/3/1997	4.3	58	59	54
1/27/1998	4.9	59	70	55
4/23/1998	5.1	60	69	55
8/5/1998	5.4	67	91	58
12/7/1998	5.8	63	86	57
3/14/2001	8	85	94	58
1/29/2003	9.9	140	144	58
4/17/2003	Full-depth patching			
4/27/2004	11.2	171	214	90
5/4/2005	12.2	194	211	86

Figure 24 shows the continuous IRI plot based on a 25-ft base length for the center of the lane for the data collected on 1/29/2003 and 4/27/2004. The two plots agreed well with each other up to about 275 ft, and thereafter, they were different. Between about 275 and 390 ft, the IRI for 4/27/2004 was much greater than that for 1/29/2003, and this increase in IRI was attributed to the patching that was performed at the section. The increase in IRI noted at this section between

1/29/2003 and 4/27/2004 for all three paths was attributed to the patching that was performed at this section.

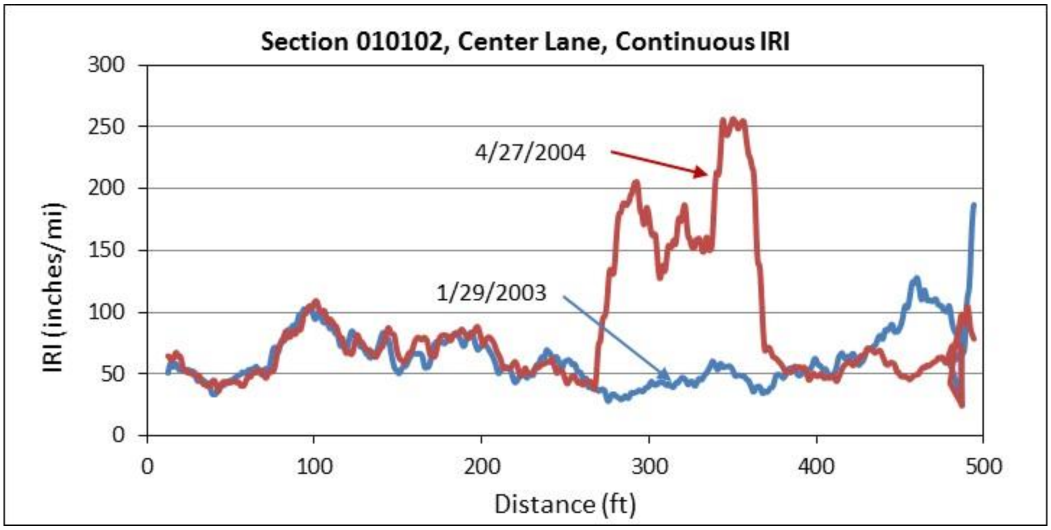

Figure 24. Graph. Continuous IRI plot for center of the lane for section 010102.

The four examples previously described showed CLIRI increasing after patching for all cases, with the left and right wheelpath IRI increasing after patching for three cases. For many cases where patching was performed such that the patch extended to the center of the lane, CLIRI increased.

An example of a case where the IRI of all three paths decreased after patching was noted for section 190110. The time-sequence IRI values at section 190110 are shown in table 22. The IRI for all three paths showed a decrease between 5/29/2001 and 8/6/2001, with the IRI decreasing by 13, 20, and 15 inches/mi for the left wheelpath, right wheelpath, and center of the lane, respectively.

Table 22. Time-sequence IRI values at section 190110.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
9/25/1997	4.3	84	88	87
10/13/1998	5.4	90	69	94
7/19/1999	6.1	96	100	101
5/22/2000	7.0	99	101	100
5/29/2001	8.0	106	110	107
7/1/2001	Strip patching			
8/6/2001	8.2	93	90	92
11/22/2002	9.5	101	101	92
9/22/2004	11.3	116	115	106

The EXPERIMENT SECTION table in the PPDB indicated that strip patching was performed on this section on 7/1/2001. The distress data indicated this section had five patches with a total patch area of 2,895 ft^2. Figure 25 shows the continuous IRI plots based on a 10-ft base length for the center of the lane for the data collected on 5/29/2001 and 8/6/2001.

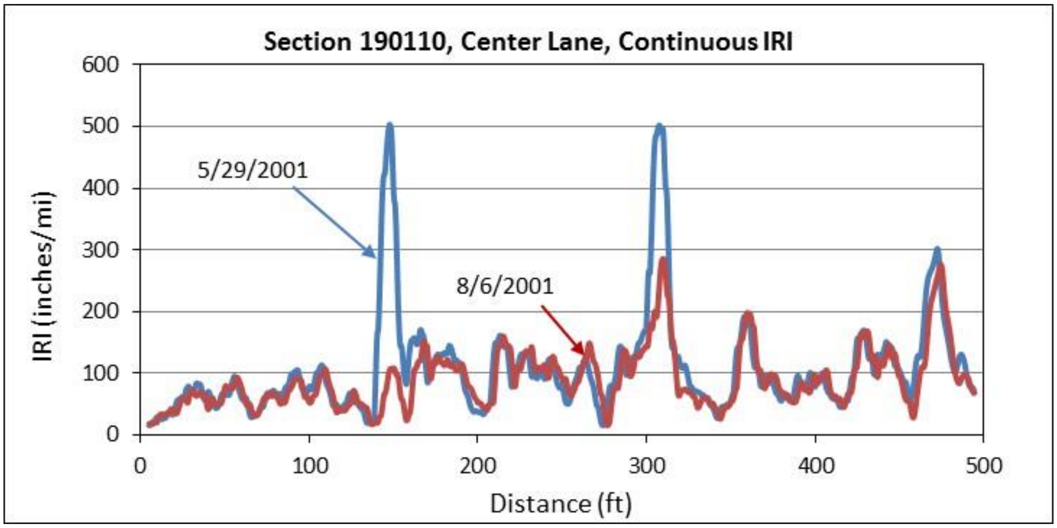

Figure 25. Graph. Continuous IRI plot for center of the lane for section 190110.

The two plots agreed well with each other except between 140 and 160 ft and 300 and 320 ft, with a much lower IRI on 8/6/2001 in these two areas compared with the IRI obtained on 5/29/2001. This reduction in IRI was attributed to patching performed in these two areas, and the decrease in IRI noted at this section between 5/29/2001 and 8/6/2001 was attributed to the patching that was performed at this section.

In many cases when patching was performed, it appeared that sufficient attention had not been paid to achieving a smooth pavement in the patched areas. As seen from the examples shown in this section, patching could cause a significant increase in IRI in the patched areas, which increased the overall IRI of the section. The IRI of a section could be reduced by patching when the patch repaired the damaged pavement that contributed to roughness. However, sufficient attention should be paid to properly construct the patch and compact the patch adequately to ensure a smooth patch. Otherwise, although the damaged pavement was repaired, the patch could create localized roughness. The effect of patching on the IRI would depend on the number of patches performed as well as the total area of the patches. In some cases, the patch might not have an effect on the IRI because the constructed patch had the same roughness level as the original pavement or because the area of the patch was too small to have any impact on the overall IRI of the pavement.

The effect of patching on IRI was evaluated for all cases where patching was recorded in the PDBB table EXPERIMENT SECTION by evaluating the time-sequence IRI values. If the patching had an effect in reducing or increasing the IRI of the section that would impact analysis of roughness progression at the section, only the IRI data up to the patch date were considered for analysis. Table 23 shows the sections that were identified where patching had an impact on the overall section IRI either by increasing or reducing the IRI of the section substantially. For these sections, only the IRI data up to the patch date were used for analysis.

Table 23. Sections whose IRI was identified as affected by patching.

State	State Code	Sections	Patch Date
Alabama	01	2	4/27/2004
		7	3/14/2001
Arkansas	05	19, 20	5/5/1999
Iowa	19	1–12	7/1/2001
Kansas	20	5, 6	6/1/1999
Nevada	32	8	4/1/2009
Virginia	51	24	10/1/2004

Surface Treatments Applied to Sections

Surface treatments applied to SPS-1 sections have included slurry seals and aggregate seals. The cases where a surface treatment was applied to SPS-1 sections are shown in table 24. If distresses were present on the pavement, a slurry seal or an aggregate seal could cover up the distresses, which could cause the IRI to decrease. However, a slurry seal or an aggregate seal might also increase the IRI of the pavement, especially if the pavement was smooth.

Table 24. Cases where a surface treatment was applied to SPS-1 sections.

State	State Code	Sections	Activity	Date
Arizona	4	13, 14, 16, 18, 20, 21, 22	Slurry seal	5/1/2002
Kansas	20	5	Aggregate seal	6/1/2004
Montana	30	13–24	Aggregate seal	7/24/2004
Texas	48	13–24	Aggregate seal	6/15/2011

Evaluation of the IRI values for the Arizona SPS-1 sections before the slurry seal and after the slurry seal indicated the right wheelpath IRI of all sections decreased after the slurry seal. However, the left wheelpath IRI and CLIRI increased at all sections except for both of these paths at section 040113 and the center of the lane of section 040119.

The time-sequence IRI values at section 040118, which is a section in the Arizona SPS-1 project that was subjected to the slurry seal on 5/1/2002, are shown in table 25, while figure 26 shows the time-sequence IRI values at this section. The application of the slurry seal reduced the IRI of the right wheelpath by 37 inches/mi but caused the left wheelpath IRI and CLIRI to increase by 16 and 14 inches/mi, respectively. As shown in table 25 and figure 26, CLIRI had the same value on 11/6/2001 and 2/20/2002 and then increased by 14 inches/mi because of the slurry seal.

Table 25. Time-sequence IRI values at section 040118.

Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
1/23/1997	3.5	35	73	38
4/8/1998	4.7	36	69	46
12/4/1998	5.3	35	72	40
11/17/1999	6.3	38	74	38
12/19/2000	7.4	37	78	38
11/6/2001	8.3	38	101	38
2/20/2002	8.6	38	103	38
5/1/2002	Slurry seal			
3/2/2003	9.6	54	66	52
3/10/2004	10.6	54	74	68
3/15/2005	11.6	56	69	59
3/27/2006	12.7	57	71	62

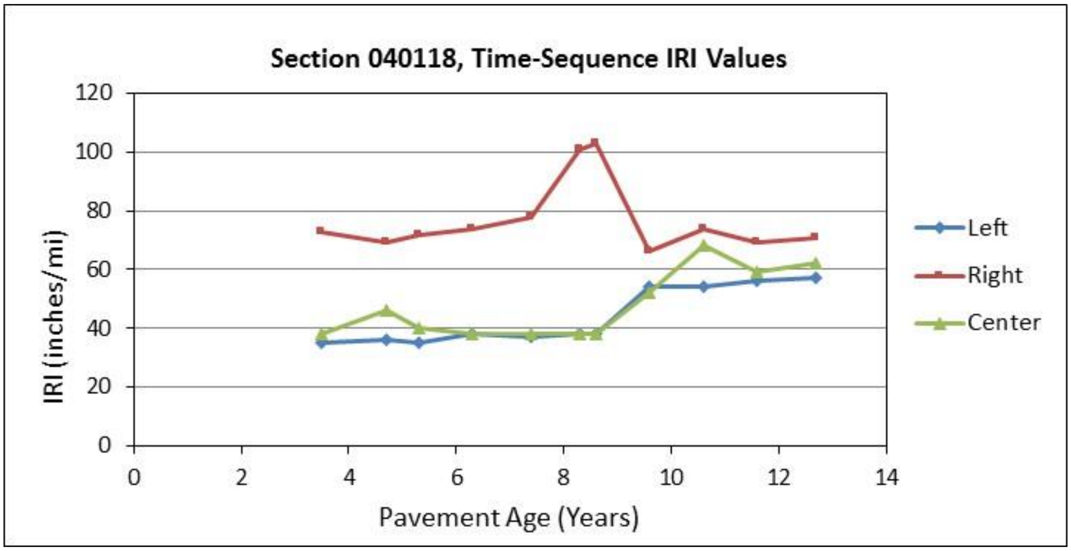

Figure 26. Graph. Time-sequence IRI values at section 010418.

Because the application of a slurry seal had a noticeable impact on the IRI at all sections in the Arizona SPS-1 project shown in table 24, only the data up to the application of the slurry seal were considered for analysis.

All sections in the SPS-1 project in Montana were subjected to an aggregate seal on 7/24/2004. An evaluation of the IRI values before and after the aggregate seal was performed to assess the effect of the aggregate seal on IRI. At seven sections, the IRI along the right wheelpath decreased after the application of the aggregate seal, with an average reduction in IRI of 7 inches/mi. The reduction in IRI was greater for the sections that had higher IRI values. The reduction in IRI was attributed to the aggregate seal covering the distress that was present along the right wheelpath. At the other five sections, the IRI of the right wheelpath increased after the application of the aggregate seal, with an average increase in IRI of 4 inches/mi. For the center of the lane, the aggregate seal caused the IRI to increase at all sections, while for the left wheelpath, the aggregate seal caused the IRI to increase at all sections except for three. The average increase in left wheelpath IRI and CLIRI were 3.3 and 4.7 inches/mi, respectively.

The time-sequence IRI values at section 300119 in Montana that was subjected to an aggregate seal on 7/24/2004 are shown in table 26, while figure 27 shows a plot of the time-sequence IRI values at this section. Evaluation of IRI values obtained before and after the aggregate seal showed the aggregate seal reduced the right wheelpath IRI by 8 inches/mi, increased CLIRI by 4 inches/mi, and caused no change in the left wheelpath IRI.

Table 26. Time-sequence IRI values at section 300119.

Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
11/19/1998	0.1	62	69	60
5/22/1999	0.6	61	66	57
7/10/2000	1.8	64	64	57
8/10/2001	2.9	61	64	59
9/25/2002	4.0	62	65	57
8/27/2003	4.9	63	79	58
7/21/2004	5.8	64	104	59
7/24/2004	Aggregate seal			
8/16/2004	5.9	64	96	63
6/4/2005	6.7	65	103	66
7/26/2008	9.8	70	103	63
7/18/2009	10.8	71	111	66
7/17/2010	11.8	75	109	69

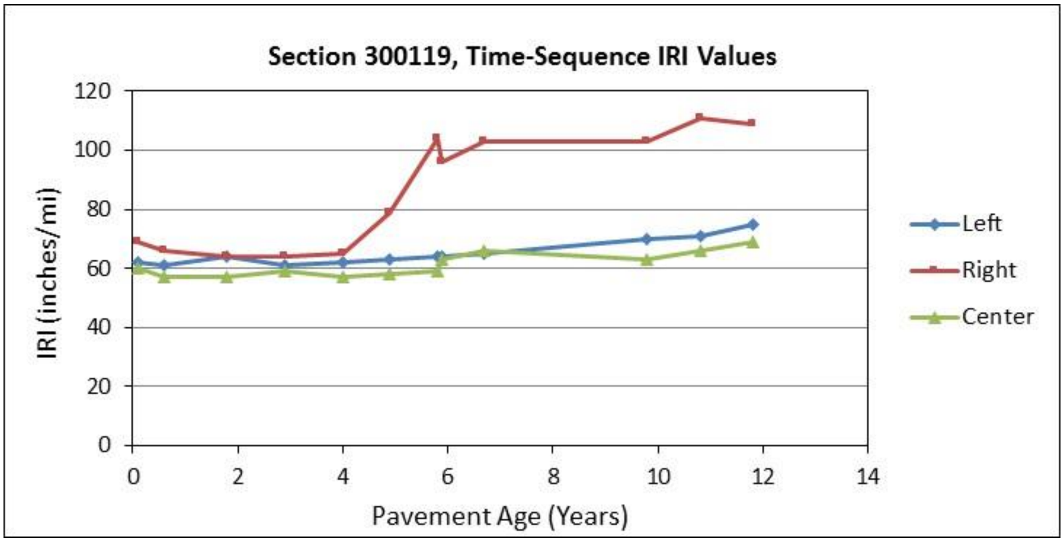

Figure 27. Graph. Time-sequence IRI values at section 300109.

The time-sequence IRI values at section 300123, another section in the Montana SPS-1 project that was subjected to an aggregate seal on 7/24/2004, are shown in table 27, while figure 28 shows a plot of the time-sequence IRI values at this section. Evaluation of IRI values obtained before and after the aggregate seal showed the aggregate seal increased the IRI of all three paths, with an increase in IRI of 6, 4, and 7 inches/mi for the left wheelpath, right wheelpath, and center of the lane, respectively.

Table 27. Time-sequence IRI values at section 300123.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
11/19/1998	0.1	48	55	48
5/22/1999	0.6	49	51	48
7/10/2000	1.8	50	51	48
8/10/2001	2.9	51	52	47
9/25/2002	4.0	54	53	50
8/27/2003	4.9	55	62	50
7/21/2004	5.8	55	63	51
7/24/2004	Aggregate seal			
8/16/2004	5.9	61	67	58
6/4/2005	6.7	61	68	60
7/26/2008	9.8	64	69	65
7/18/2009	10.8	64	69	68
7/17/2010	11.8	65	72	72

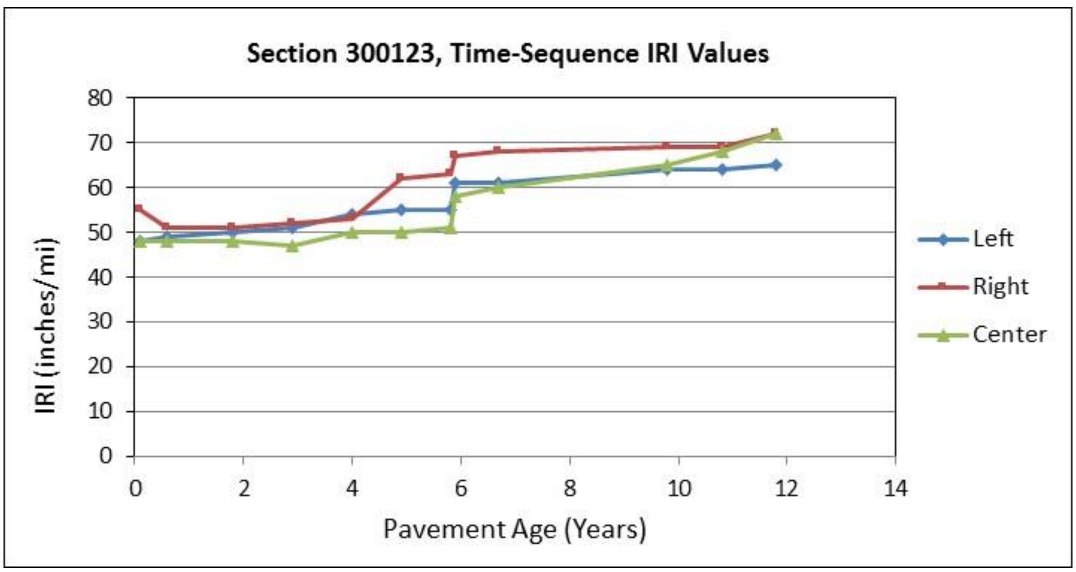

Figure 28. Graph. Time-sequence IRI values at section 300123.

As seen in figure 27 and figure 28, the change in IRI caused by the application of the aggregate seal was small. Therefore, the evaluation of the time-sequence IRI data at these two sections would provide information about the long-term trend of IRI progression. Similar trends were observed for the other sections in the Montana SPS-1 project. Therefore, the research team decided to use all available IRI data for analyzing the IRI changes at all SPS-1 sections in the Montana SPS-1 project.

For the section in Kansas listed in table 24, the aggregate seal had been applied after the section was overlaid. Because only the IRI data up to the overlay were used in the analysis, the application of the aggregate seal had no impact on the data selected for analysis.

For the sections in Texas listed in table 24, the aggregate seal was applied after the second overlay had been placed on the sections. Because data after the second overlay were not analyzed in this study, the application of the aggregate seal had no impact on the data used for analysis.

Variability in the Profiled Path

On a pavement that had significant transverse variability in IRI, variability in the longitudinal path followed by the profiler could have a significant impact on IRI. Also, on a pavement that had cracking along the wheelpaths, transverse variability between runs could cause the distress to be captured or missed, thus affecting IRI. A section that had significant rutting could also result in variability in the IRI values among the runs. Evaluation of time sequence data at SPS-1 sections indicated only a very few cases where the IRI on a particular date would be much higher or lower than that for the preceding and subsequent profile date. Pavements that had cracking along the wheelpaths generally had high IRI values, and although there could be variability among the runs, these differences would get averaged out when the IRI values from repeat runs were averaged. Therefore, for pavements that had an accelerating trend in IRI, the time sequence IRI plots did not typically show an IRI value that did not fit the trend in roughness development.

All sections in the Louisiana SPS-1 project had one data point that clearly had been affected by transverse variability in the profiled path. The time-sequence IRI values at section 220116, which was a test section in the Louisiana SPS-1 project, are shown in table 28, while figure 29 shows a plot of the corresponding time-sequence IRI values.

Table 28. Time-sequence IRI values at section 220116.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
11/17/1997	0.4	45	39	34
10/16/2004	7.3	48	44	45
8/7/2006	9.1	53	46	43
9/25/2007	10.2	49	47	47
4/9/2008	10.8	50	48	46
2/3/2010	12.6	65	68	60
3/16/2011	13.7	52	50	45
1/16/2012	14.6	54	50	48

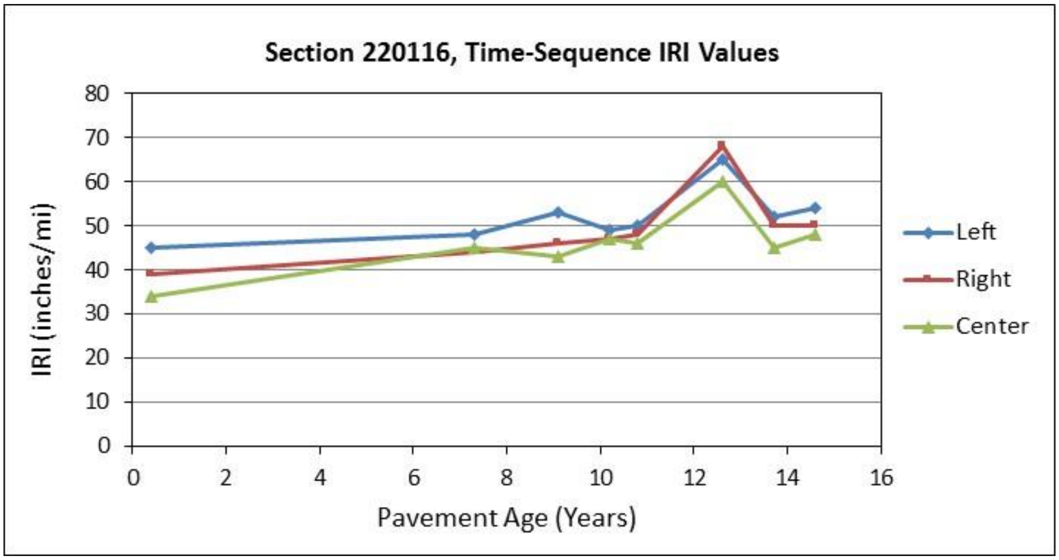

Figure 29. Graph. Time-sequence IRI values at section 220116.

The IRI values on 2/3/2010 for all three paths were higher than the previous and subsequent IRI values. All other sections in the Louisiana SPS-1 project that were profiled on this date showed a similar trend in IRI. No maintenance activities had been performed at this section. This section did not have any distress along the wheelpaths, and rutting on this section was less than 0.25 inches. Evaluation of the profile data did not show any cause for the high IRI values along all three paths on 2/3/2010.

Table 29 shows the IRI values of the nine runs obtained at section 220116 on 2/3/2010, and a plot of these IRI values is shown in figure 30. The IRI values showed considerable variability for all three paths. Therefore, the cause for the high IRI values on 2/3/2010 was attributed to variability in the profiled path that affected the average IRI computed for this date. Runs 7 and 8 were the only runs made on 2/3/2010 that had IRI values that were close to the IRI values obtained for the previous and subsequent profile dates.

Table 29. IRI values obtained at section 220116 on 2/3/2010.

	IRI (Inches/mi)		
Run	**Left**	**Right**	**Center**
1	82	83	85
2	54	57	52
3	58	55	42
4	72	71	68
5	76	81	74
6	73	83	65
7	49	46	45
8	51	54	43
9	75	84	70

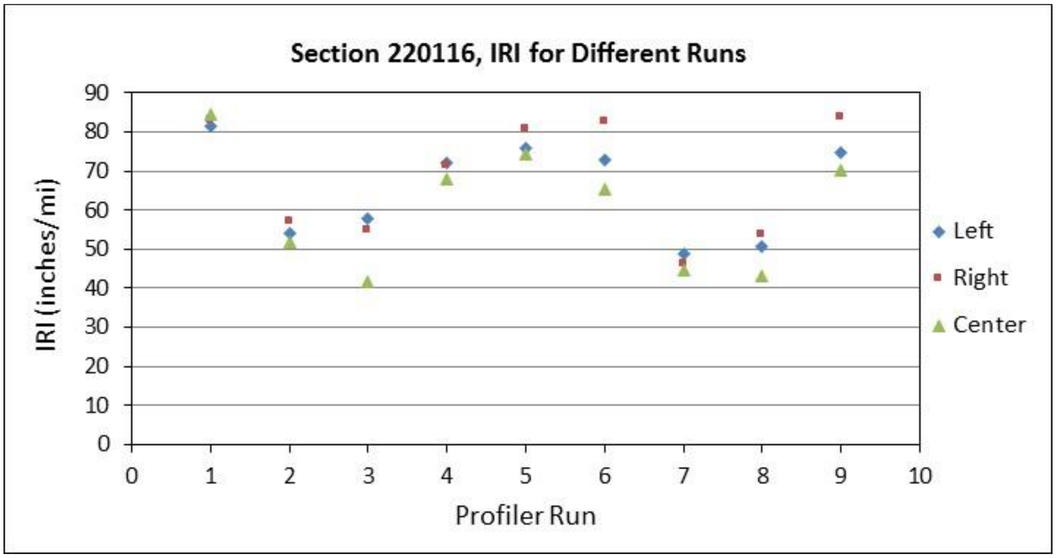

Figure 30. Graph. IRI values obtained at section 220116 for different runs on 2/3/2101.

The IRI data for 2/3/2010 were omitted from analysis at all Louisiana test sections. This was the only case where data were omitted from analysis because of transverse variability in the profiled path. There were several cases where the standard deviation in IRI for the repeat runs for a particular visit was high, and these usually occurred at sections that had high IRI values. However, evaluation of the time-sequence IRI data at these sections did not show an IRI data point that did not fit the trend in IRI progression at the site.

Increase in Distress Affecting Roughness at a Section

Table 30 shows the time sequence IRI values at section 320107, and a rapid increase in IRI was seen at this section for the two wheelpaths after 8/4/2004. The time sequence IRI values at this section are shown in figure 31. Figure 32 shows a continuous IRI plot for the left wheelpath based on a 10-ft base length for the last three profile dates shown in table 30. This plot shows how the roughness progressed for the left wheelpath at this section for the last three profile dates, which caused the overall IRI for the left wheelpath to increase from 63 inches/mi on 8/4/2004 to 119 inches/mi on 6/25/2009. The plot shows there were several localized areas within the section that had very high roughness values, and the roughness at these locations increased with time. Figure 33 shows a plot of the left wheelpath profile data collected at this section on 6/25/2009. The downward spikes in the plot represent transverse cracks, and the data showed that a dip occurred at the crack locations. The high localized roughness areas seen in figure 32 correspond to these cracks seen in figure 33. Hence, the large increase in IRI that was observed at this section along the wheelpaths was attributed to the dips occurring at the crack locations.

Table 30. IRI values obtained at section 320107.

Profile Date	Pavement Age (Years)	IRI (Inches/mi)		
		Left	Right	Center
4/22/1997	1.6	48	59	52
11/18/1997	2.2	48	58	53
8/28/1998	3	47	60	52
10/16/1999	4.1	45	60	52
6/14/2000	4.8	44	59	51
6/19/2001	5.8	46	58	52
6/10/2002	6.8	48	60	53
7/31/2002	6.9	48	60	53
10/13/2003	8.1	55	62	52
4/15/2004	8.6	60	64	54
8/4/2004	8.9	63	67	55
8/27/2006	11	94	84	63
6/25/2009	13.8	119	107	81

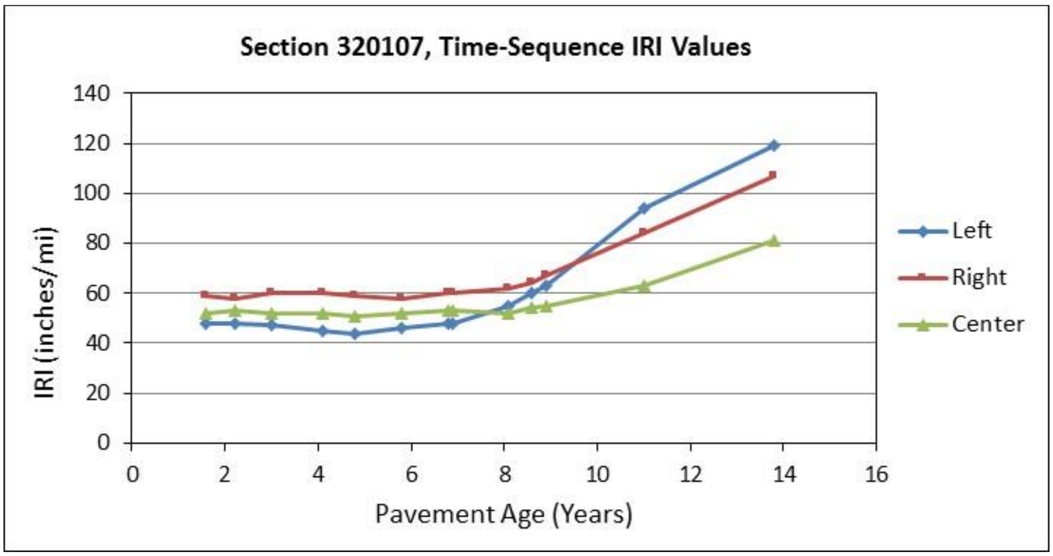

Figure 31. Graph. Time sequence IRI values obtained at section 320107.

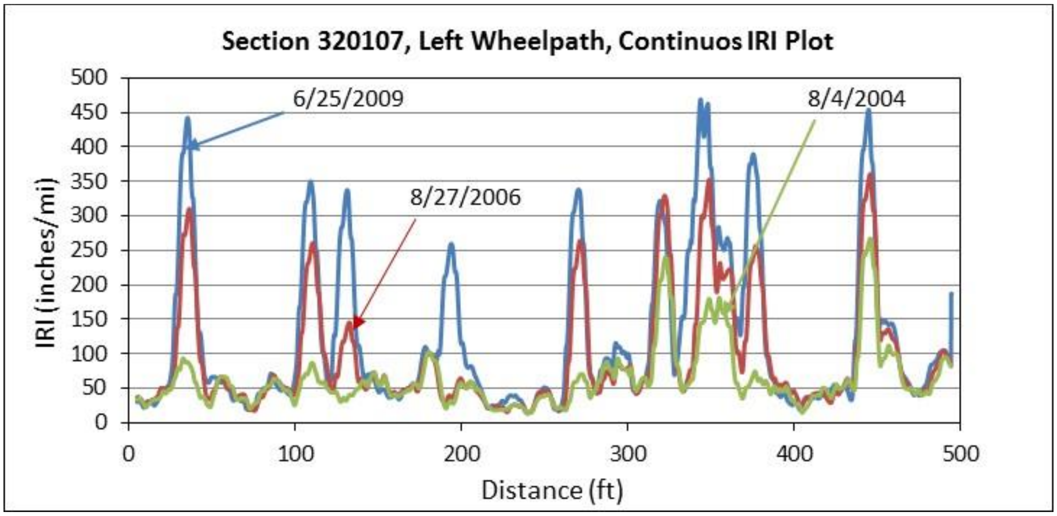

Figure 32. Graph. Continuous IRI plot for left wheelpath of section 320107.

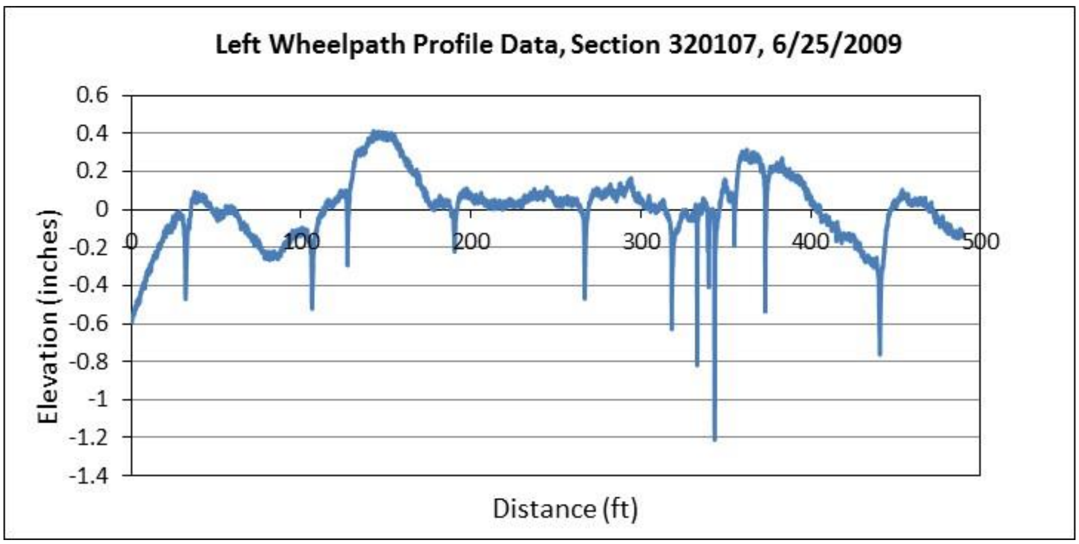

Figure 33. Graph. Left wheelpath profile data collected on 6/25/2009 at section 320107.

Effect of Crack Sealing

Cracks could appear as downward features on the profile data, with the magnitude of the depth of the downward feature depending on the depth of the crack. Although profilers record data at 0.98-inch intervals, the height sensor reading that was used to compute the profile elevation at 0.98-inch intervals was an average elevation over 0.98 inch. Therefore, narrow cracks that were not deep might not appear in the profile because of this averaging. Also, for a narrow and deep crack, the magnitude of the depth of the crack in the profile would be less than the actual depth of the crack because of this averaging.

The effect of cracks on IRI would depend on the width of the crack, depth of the crack, whether a dip occurs at the crack, and the number of cracks traversed when collecting the profile data. Sealing the cracks would eliminate the effect of the crack on the profile data and might result in a reduction in IRI of the section, depending on the depth and width of the crack and the number of cracks traversed when collecting profile data. However, if there was a dip at the crack location, sealing a crack might not have much of an effect in reducing the IRI. The IRI could increase after crack sealing if the cracks were overfilled, which could cause a slight bump at each crack location. Crack sealing of transverse cracks that spanned the entire lane could affect the IRI of the left wheelpath, right wheelpath, and center of the lane. Crack sealing performed on longitudinal cracks or alligator cracks present along a wheelpath could affect the IRI of the wheelpath. Crack sealing performed along longitudinal cracks that are present along the center of the lane could affect CLIRI.

An evaluation was performed at sections that had been subjected to crack sealing to evaluate the impact of crack sealing on IRI. There were not many sections where sealed transverse cracks or sealed cracks along the wheelpath had been recorded. An evaluation of IRI before and after crack sealing at several of these sections did not provide a clear indication that IRI was affected by the crack sealing. Therefore, it was decided to use all available IRI values at sections that had crack sealing performed for analysis.

DATASET FOR ANALYSIS

An IRI dataset that was suitable for analysis was assembled after evaluation of the time-sequence IRI values. For sections where maintenance or rehabilitation affected the IRI as described previously in this chapter, only the IRI data before the maintenance or rehabilitation were considered for analysis.

Data analysis feedback reports were provided to LTPP indicating cases where equipment errors were observed in the data and for cases where data had been assigned to a section from an incorrect location so that the erroneous data could be removed from the PPDB.

As indicated in the previous section entitled Overlay Placed on the Section, the SPS-1 projects in Michigan and Texas have been subjected to two overlays. For these two SPS-1 projects, data up to the first overlay and data after the first overlay up to the second overlay were treated separately.

Appendix B of this report contains a table that shows the details about the dataset that was used for analysis. The following information is shown in this table for each SPS-1 test section:

- State where the section was located and the State code.
- Date when the section was opened to traffic.
- Whether the section was deassigned.
- If the section was deassigned from the LTPP Program, the date when that occurred.
- Date when profile data were first collected at the section.
- Date when center of the lane data were first collected at the section.
- Last profile date used for analysis.

- Number of center of the lane data points available for analysis at the section.
- Time period over which center of the lane data were available (i.e., difference in years between last profile date and date when center of the lane data were first collected at the site).
- Age of the pavement at the last profile date used for analysis (i.e., difference in years between the last profile date and date when section was opened to traffic).

The following observations regarding deassigning of SPS-1 test sections were noted based on the information in the SDR 28 EXPERIMENT SECTION table in the PPDB:

- All test sections at the following 11 SPS-1 projects were deassigned: Alabama, Arizona, Arkansas, Delaware, Florida, Iowa, Kansas, Nebraska, Nevada, New Mexico, and Wisconsin.
- None of the test sections in the SPS-1 projects in Louisiana and Montana were deassigned, while only one test section in the Oklahoma and Virginia SPS-1 projects was deassigned.
- Eight test sections in the Michigan SPS-1 project were not deassigned. However, these test sections had been overlaid twice and therefore were no longer SPS-1 test sections.
- No test sections in the Texas SPS-1 project were deassigned. However, these test sections had been overlaid twice and therefore were no longer SPS-1 test sections.
- All test sections in the Ohio SPS-1 project except three were deassigned.

In an SPS-1 project, all test sections were not necessarily deassigned on the same date. Individual sections could be deassigned at different times when they were rehabilitated. In such projects, the period over which profile data were collected at test sections in the project could vary, with test sections that were deassigned earlier being monitored over a shorter time period when compared with sections that were deassigned later.

As shown in table 2, 18 SPS-1 projects were built. Because each project had 12 test sections, this meant a total of 216 core test sections were constructed for the SPS-1 experiment. Center of the lane data were never collected at 15 test sections because these test sections had been deassigned before the K.J. Law T-6600 profiler that had the capability to collect center of the lane data was used in the LTPP Program. The test sections for which center of the lane data were never collected are shown in table 31.

Table 31. Test sections where center of the lane data were never collected.

State	State Code	Sections
Arkansas	05	19, 20
Kansas	20	1, 2, 5, 6, 7
Michigan	26	13, 14, 19, 22
Ohio	39	1, 2, 5, 7

Table 32 shows the following information for each SPS-1 project: age of the pavement when center of the lane data were first collected at the project, average age of the sections corresponding to the last profile date used for analysis, and the range in age of the sections at the last profile date used for analysis. For sections that were subjected to maintenance or rehabilitation that affected its IRI value, the last profile date used for analysis was the date when data were last collected at the section before the maintenance or rehabilitation activity. For sections that were not subjected to maintenance or rehabilitation, the last profile date used for analysis was the date when data were last collected at the section. The average age of the sections corresponding to the last profile date used for analysis shown in table 32 is the average value for all sections and provides a general idea about the age of the sections in the project at the last profile date used for analysis. The range in age of the sections at the last profile date shown in table 32 indicated the range in age of the test sections in the SPS-1 project at the last profile date used for analysis.

Table 32. Average age of sections in SPS-1 projects at last profile date used for analysis.

SPS-1 Project	Pavement Age When Center of the Lane Data Were First Collected (Years)	Average Age of Sections at Last Profile Date Used for Analysis (Years)	Range of Average Age of Sections at Last Profile Date Used for Analysis (Years)
Alabama	4.3	11.4	4.9–12.2
Arizona	3.5	10.3	8.6–12.7
Arkansas	2.8	12.4	9.6–12.7
Delaware	1.1	10.1	—
Florida	1.2	16.3	—
Iowa	4.3	8.0	—
Kansas	3.3	7.5	—
Louisiana	0.4	14.6	—
Michigan	1.6	6.6	—
Montana	0.1	11.8	—
Nebraska	1.6	4.7	4.6–4.9
Nevada	1.6	12.1	8.6–13.6
New Mexico	1.4	10.5	—
Ohio	3.0	10.1	6.0–10.6
Oklahoma	0.4	13.1	9.8–13.7
Texas	1.3	4.3	—
Virginia	4.6	16.1	8.4–17.4
Wisconsin	0.1	10.4	7.9–10.6

—Indicates all sections were the same age at last profile date.

Table 33 shows the SPS-1 projects classified according to the average age of the sections at last profile date used for analysis. As shown in table 33, the average age of the sections at last profile date used for analysis was less than 8 years for five SPS-1 projects, between 10 and 12 years for seven SPS-1 projects, and between 12 and 18 years for six SPS-1 projects.

Table 33. SPS-1 projects classified based on average age of sections at last profile date.

Average Age of Sections at Last Profile Date Used for Analysis (Years)	SPS-1 Project
4–6	Nebraska, Texas
6–8	Iowa, Kansas, Michigan
8–10	None
10–12	Alabama, Arizona, Delaware, Montana, New Mexico, Ohio, Wisconsin
12–14	Arkansas, Nevada, Oklahoma
14–16	Louisiana
16–18	Florida, Virginia

Figure 34 shows a cumulative frequency distribution of the age of the test sections at last profile date used for analysis. Data for 201 test sections where center of the lane data were collected were used to generate this plot. It shows the pavement age of the test sections at the last profile date used for analysis was less than 6 years for 12 percent of the sections, between 6 and 10 years for 23 percent of the sections, and greater than 10 years for 65 percent of the sections.

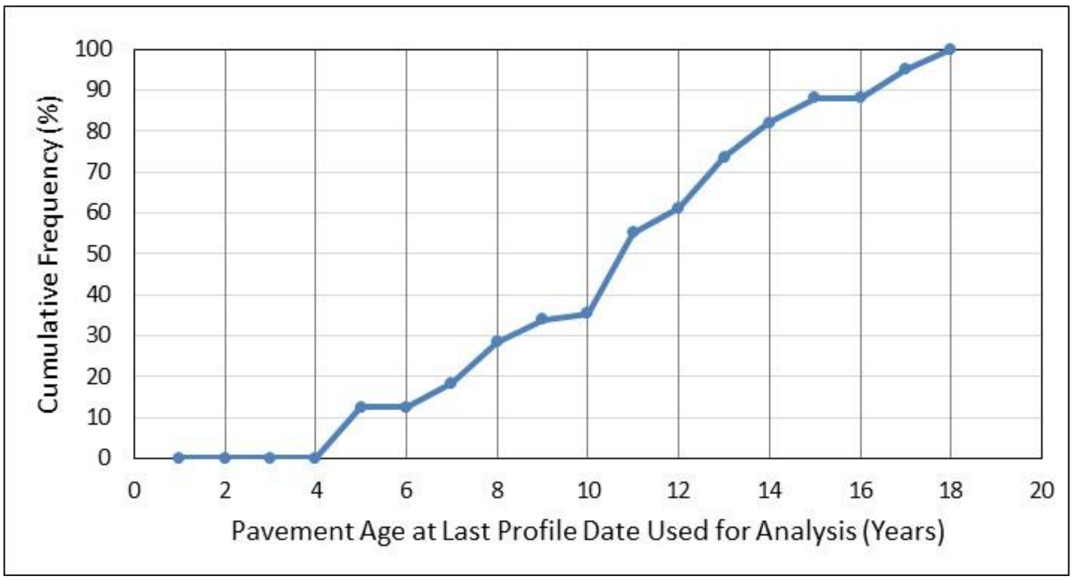

Figure 34. Graph. Cumulative frequency distribution of sections based on pavement age at last profile date used for analysis.

Table 34 shows the average time span over which center of the lane data were collected at each SPS-1 project. The average time span for an SPS-1 project was computed by obtaining the difference in years between the last profile data used for analysis and the first date when center of the lane data were collected at each section in the SPS-1 project and then averaging the values. Table 34 also shows the range in time span when center of the lane data were collected for the sections in the SPS-1 project. As described previously, the time span over which center of the lane data were collected for the various sections in an SPS-1 project could be different because sections could be deassigned at different times, or maintenance or a construction activity that affected the IRI of the section might have occurred for different sections at different times.

Table 34. Time span over which center of the lane data were collected at SPS-1 projects.

SPS-1 Project	Pavement Age When Center of the Lane Data Were First Collected (Years)	Average Time Span Over Which Center of the Lane Data Were Collected (Years)	Range of the Time Span Over Which Center of the Lane Data Were Collected at Sections (Years)
Alabama	4.3	7.0	0.6–7.8
Arizona	3.5	6.8	5.1–9.2
Arkansas	2.8	9.6	6.7–9.9
Delaware	1.1	9.0	—
Florida	1.2	15.1	—
Iowa	4.3	3.7	—
Kansas	3.3	4.2	—
Louisiana	0.4	14.2	—
Michigan	1.6	5.0	3.6–5.1
Montana	0.1	11.7	—
Nebraska	1.6	3.1	—
Nevada	1.6	10.4	7.0–12.6
New Mexico	1.4	9.2	—
Ohio	3.0	7.1	3.0–13.5
Oklahoma	0.4	12.7	9.4–13.3
Texas	1.3	3.0	1.9–3.5
Virginia	4.6	11.4	3.8–12.8
Wisconsin	0.1	10.3	7.8–10.5

—Indicates all sections monitored with center of the lane data over same time span.

Table 35 shows the SPS-1 projects classified according to the average time span over which center of the lane data were available for the project. As shown in table 35, the average time span over which center of the lane data were collected was less than 6 years for five SPS-1 projects, between 6 and 10 years for six SPS-1 projects, and over 10 years for seven SPS-1 projects.

Table 35. SPS-1 projects classified based on average time span over which center of the lane data were available.

Average Period Over Which Center of the Lane Data Collected (Years)	SPS-1 Project
2–4	Iowa, Nebraska, Texas
4–6	Kansas, Michigan
6–8	Alabama, Arizona, Ohio
8–10	Arkansas, Delaware, New Mexico
10–12	Montana, Nevada, Virginia, Wisconsin
12–14	Oklahoma
14–16	Florida, Louisiana

Figure 35 shows a cumulative frequency distribution of time span over which center of the lane data were collected at the test sections. Data for 201 test sections where center of the lane data were available were used to generate this plot. It shows that the time span over which center of the lane data were collected was less than 5 years for about 25 percent of the test sections, between 5 and 10 years for about 35 percent of the test sections, and greater than 10 years for about 40 percent of the test sections.

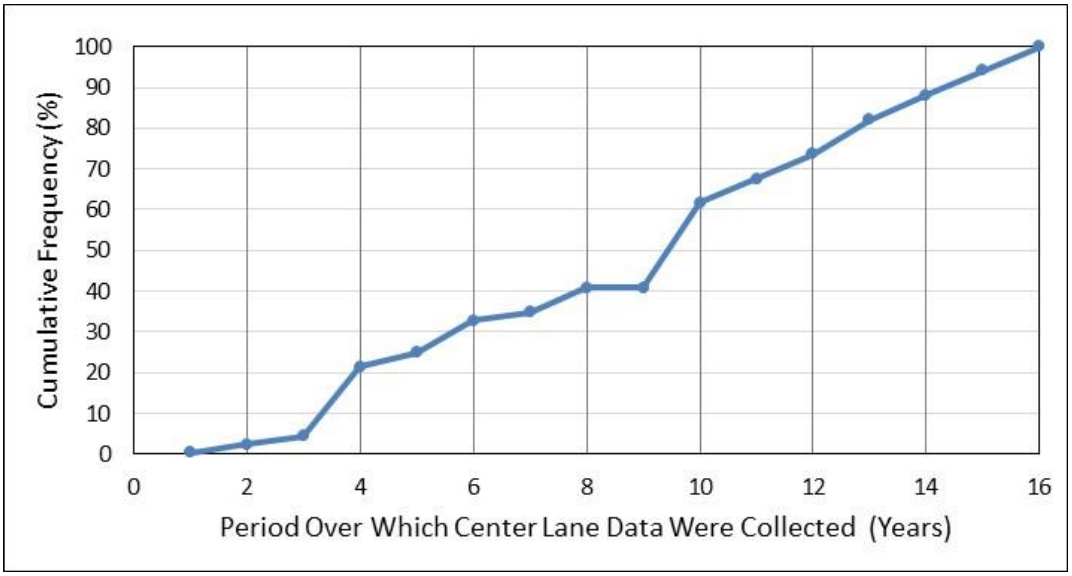

Figure 35. Graph. Cumulative frequency distribution of sections based on time span over which center of the lane data were collected.

CHAPTER 4. CLIMATIC AND SUBGRADE INFORMATION FOR SPS-1 PROJECTS

This chapter discusses the available climatic and subgrade information regarding SPS-1 projects.

CLIMATIC INFORMATION FOR SPS-1 PROJECTS

Climatic information at SPS-1 project locations computed from virtual weather stations data was available in the PPDB. Annual summaries of precipitation information were available in the table entitled CLM VWS PRECIP ANNUAL. The information in this table included total annual precipitation, intense precipitation days per year, wet days per year, and total snowfall per year. An *intense precipitation day* is defined as a day when more than 0.5 inches of precipitation fell, while a *wet day* is defined as a day when precipitation was more than 0.01 inches. Annual summaries of temperature-related information were available in the PPDB table CLM VWS TEMP ANNUAL. The information in this table included mean annual temperature, days above 90 °F per year, days below 32 °F per year, FI per year, and freeze-thaw cycles per year. The annual information in these two tables was averaged for each SPS-1 project over the time period for which IRI data were available for that project. Table 36 shows the average annual values for precipitation, wet days per year, and intense precipitation days per year for each SPS-1 project, and the years over which the data were averaged.

Table 36. Average annual precipitation-related parameters for SPS-1 projects.

Project Location	Years Over Which Data Were Averaged	Average Value Annual Precipitation (Inches)	Average Value Wet Days per Year	Average Value Intense Precipitation Days per Year
Alabama	1993–2005	52	160	32
Arizona	1993–2006	7	56	3
Arkansas	1994–2007	47	129	32
Delaware	1996–2006	48	153	31
Florida	1995–2012	56	168	35
Iowa	1993–2001	41	156	25
Kansas	1993–2001	27	86	16
Louisiana	1997–2012	58	162	36
Michigan	1995–2012	32	142	18
Montana	1998–2010	14	101	6
Nebraska	1995–2000	27	101	17
Nevada	1995–2009	10	77	3
New Mexico	1995–2006	10	73	3
Ohio	1995–2012	42	178	24
Oklahoma	1997–2011	32	96	20
Texas	1997–2007	24	100	13
Virginia	1993–2010	45	143	29
Wisconsin	1997–2008	32	156	16

Table 37 shows the average annual values for mean temperature, days when the maximum temperature was above 90 °F per year, days when the minimum temperature was below 32 °F per year, FI, and the number of freeze-thaw cycles. A freeze-thaw cycle occurs when, during a day, the air temperature goes from less than 32 °F to greater than 32 °F. This table also shows the years over which the data were averaged.

Table 37. Average annual temperature-related parameters for SPS-1 projects.

Project Location	Years over which Data Were Averaged	Average Values				
		Mean Annual Temperature (°F)	Days above 90 °F per Year	Days below 32 °F per Year	FI (°F Days/Year)	Freeze-Thaw Cycles per Year
Alabama	1993–2005	64	51	43	16	43
Arizona	1993–2006	67	138	19	0	19
Arkansas	1994–2007	61	56	63	115	56
Delaware	1996–2006	56	15	81	148	73
Florida	1995–2012	74	87	1	0	1
Iowa	1993–2001	52	14	113	713	76
Kansas	1993–2001	55	56	125	394	105
Louisiana	1997–2012	69	76	11	2	11
Michigan	1995–2012	49	9	136	823	86
Montana	1998–2010	46	19	158	940	124
Nebraska	1995–2000	52	44	137	671	105
Nevada	1995–2009	51	76	167	351	158
New Mexico	1995–2006	62	103	93	11	93
Ohio	1995–2012	52	11	117	578	82
Oklahoma	1997–2011	62	86	72	99	67
Texas	1997–2007	75	158	1	0	1
Virginia	1993–2010	58	39	89	92	86
Wisconsin	1997–2008	43	3	173	1613	99

In the LTPP Program, the boundary between a wet and a dry region was defined as an annual precipitation of 20 inches. An area receiving an annual precipitation of less than or equal to 20 inches was considered to be a dry region, while an area receiving an annual precipitation greater than 20 inches was considered to be a wet region. In the LTPP Program, the boundary between a freezing and a nonfreezing region was defined as an FI of 190 °F days/year. A region having an FI of less than or equal to 190 °F days/year was considered to be a nonfreezing region, while a region having an FI greater than 190 °F days/year was considered to be a freezing region. The SPS-1 projects classified according to the LTPP environmental zones are shown in table 38. This table also shows the average annual values of precipitation, FI, and freeze-thaw cycles at the project location.

Table 38. SPS-1 projects classified according to environmental zones.

Project Location	Climatic Zone	Average Annual Values Precipitation (inches)	FI (°F Days/Year)	Freeze-Thaw Cycles
Alabama	WNF	52	16	43
Arizona	DNF	7	0	19
Arkansas	WNF	47	115	56
Delaware	WNF	48	148	73
Florida	WNF	56	0	1
Iowa	WF	41	713	76
Kansas	WF	27	394	105
Louisiana	WNF	58	2	11
Michigan	WF	32	823	86
Montana	DF	14	940	124
Nebraska	WF	27	671	105
Nevada	DF	10	351	158
New Mexico	DNF	10	11	93
Ohio	WF	42	578	82
Oklahoma	WNF	32	99	67
Texas	WNF	24	0	1
Virginia	WNF	45	92	86
Wisconsin	WF	32	1613	99

SUBGRADE INFORMATION FOR SPS-1 PROJECTS

In the LTPP Program, the subgrade at all test sections was considered as Layer Number 1. The PPDB table entitled SPS-1 Layer provided a description of the subgrade at each test section, the layer type and thickness of any subsurface layers present between the SPS-1 pavement structure and the subgrade, and the layer type and thickness of the various layers of the pavement structure. This table identified that an embankment that was designated as Layer Number 2 was present at four SPS-1 projects. Table 39 shows the projects where an embankment was present and also indicates the subgrade type in the project, the material type of the embankment, and the average thickness of the embankment.

Table 39. SPS-1 projects where an embankment is present.

State	Section Numbers	Subgrade Type	Embankment Layer Number	Material Type	Average Thickness (Inches)
Iowa	1–13	Fine-grained	2	Clay	24
Kansas	1, 2, 5, 9, 10	Fine-grained	2	Silty sand or sandy clay	25
Louisiana	13–24	Fine-grained	2	Silt	9
Nebraska	13–24	Fine-grained	2	Clay	22

The subgrade at six projects was treated. The subgrade at these projects might have been treated to increase the strength of the subgrade or to address constructability issues. Table 40 shows the projects where the subgrade was treated and also indicates the subgrade type in the project, the treatment type, and the average thickness of the treatment. In all of these projects, except at the Nevada project, the SPS-1 pavement sections were placed on the treated subgrade. In the Nevada project, a subbase layer with an average thickness of 20 inches was placed on the treated subgrade, and the SPS-1 pavements sections were placed on the subbase layer.

Table 40. SPS-1 projects where the subgrade was treated.

			Treated Subgrade		
State	**Section Numbers**	**Subgrade Type**	**Layer No.**	**Treatment Type**	**Average Thickness (Inches)**
Louisiana	13–24	Fine-grained	2	Cement treated	6
Nevada	1–12	Coarse-grained	2	Lime treated	12
New Mexico	1–12	Fine-grained	2	Lime treated	6
Oklahoma	13–24	Fine-grained	2	Lime treated	8
Texas	13–24	Coarse-grained	2	Lime treated	12
Virginia	13–24	Fine-grained	2	Lime treated	6

At several projects, a subbase layer was placed on the subgrade before constructing the SPS-1 pavement sections. Table 41 shows the projects where a subbase was placed and also shows the subgrade type of the project, subbase type, and the average thickness of the subbase. In the Nevada project, the subbase was placed on the treated subgrade layer.

Table 41. SPS-1 projects where a subbase was placed.

			Subbase		
State	**Section Numbers**	**Subgrade Type**	**Layer No.[a]**	**Subbase Type**	**Average Thickness (Inches)**
Delaware	1–12	Coarse-grained	2	Coarse-grained soil aggregate mixture	43
Kansas	1–12	Fine-grained	2 or 3	Pozzolanic aggregate mixture	6
Nevada	1–12	Coarse-grained	2	Coarse-grained soil aggregate mixture	20
Wisconsin	13–24	Coarse-grained	2	Coarse-grained soil aggregate mixture	10

[a]For the Kansas project, the Layer No. was 2 for sections that did not have an embankment and 3 for sections that had an embankment.

The results from gradation tests performed on subsurface material were stored in PPDB table TST SS01 UG01 UG02, while the results from hydrometer tests are stored in PPDB table TST SS02 UG03. Gradation information for subgrade was available at one or more test locations at some test sections, while no information was available for other test sections. A similar situation was noted for the results from the hydrometer test. If results from more than one sample were available at a test section, the results were averaged to obtain a single value for a test section.

From the information available in PPDB table TST SS01 UG01 UG02, the median value and the standard deviation of the percentage of material passing through the No. 200 sieve were computed for each project using the test results available at each test section for the subgrade, embankment (if present), and subbase (if present). From the information in PPDB table TST SS02 UG03, the median values of the percent clay material, percent silt material, and combined clay and silt material were computed for each project using the test results available at each test section for the subgrade, embankment (if present), and subbase (if present).

Table 42 shows the following values for the subgrade, embankment (if present), and subbase (if present) for each SPS-1 project: median value and the standard deviation of the material passing through the No. 200 sieve computed from the data at each test section, the number of test sections for which data were available to compute these values, and the material classification based on the median of the material passing through the No. 200 sieve. No information was available in the PPDB for the Delaware project.

Table 42. Percentage of material passing through the No. 200 sieve for subgrade at each SPS-1 project.

Project Location	Layer Type	Material Passing Through No. 200 Sieve (Percent)			Material Type
		Number of Sections That Had Data	Median	Standard Deviation	
Alabama	Subgrade	9	66	4.2	Fine-grained
Arizona	Subgrade	12	17	4.0	Coarse-grained
Arkansas	Subgrade	7	18	7.3	Coarse-grained
Delaware	Subgrade	—	—	—	—
	Subbase	4	13	2.9	Coarse-grained
Florida	Subgrade	5	14	1.6	Coarse-grained
Iowa	Subgrade	7	93	4.3	Fine-grained
	Embankment	10	60	3.4	Fine-grained
Kansas	Subgrade	2	36	7.3	Coarse-grained
	Embankment	3	32	5.8	Coarse-grained
Louisiana	Subgrade	4	94	1.8	Fine-grained
	Embankment	6	88	4.9	Fine-grained
Michigan	Subgrade	7	67	3.6	Fine-grained
Montana	Subgrade	6	22	6.1	Coarse-grained
Nebraska	Subgrade	6	96	3.3	Fine-grained
	Embankment	5	97	1.1	Fine-grained
Nevada	Subgrade	6	45	11.0	Coarse-grained
	Subbase	8	13	6.0	Coarse-grained
New Mexico	Subgrade	10	68	12.5	Fine-grained
Ohio	Subgrade	5	71	1.9	Fine-grained
Oklahoma	Subgrade	5	44	5.5	Coarse-grained
Texas	Subgrade	6	8	4.7	Coarse-grained
Virginia	Subgrade	9	42	7.6	Coarse-grained
Wisconsin	Subgrade	7	10	5.2	Coarse-grained
	Subbase	4	9.2	2.1	Coarse-grained

—Indicates no data available.

Table 43 shows the following values for the subgrade, embankment (if present), and subbase (if present) for each SPS-1 project: median values of the percent silt material, median value for the percent clay material, median value of the combined silt and clay material, number of test sections for which data were available to compute these values, and material classification based on the median value of the combined clay and silt material.

Table 43. Amount of silt and clay in subgrade at SPS-1 projects.

Project Location	Layer Type	Number of Sections That Had Data	Median Value of Material (Percent)			Material Type Based on Silt + Clay Percentage
			Silt	Clay	Silt and Clay	
Alabama	Subgrade	9	40.5	26.0	66.5	Fine-grained
Arizona	Subgrade	12	10.8	5.7	16.5	Coarse-grained
Arkansas	Subgrade	7	12.7	5.4	18.1	Coarse-grained
Delaware	Subgrade	6	16.5	9.0	25.5	Coarse-grained
	Subbase	8	7.2	5.6	12.8	Coarse-grained
Florida	Subgrade	5	13.3	4.6	17.9	Coarse-grained
Iowa	Subgrade	7	56.8	31.1	87.9	Fine-grained
	Embankment	10	37.7	22.4	60.1	Fine-grained
Kansas	Subgrade	8	18.9	11.5	30.4	Coarse-grained
	Embankment	3	16.4	13.0	29.4	Coarse-grained
Louisiana	Subgrade	3	69.5	24.9	94.4	Fine-grained
	Embankment	5	82.9	8.7	91.6	Fine-grained
Michigan	Subgrade	7	39.0	23.7	62.7	Fine-grained
Montana	Subgrade	6	18.5	7.2	25.7	Coarse-grained
Nebraska	Subgrade	6	66.7	32.2	98.9	Fine-grained
	Embankment	5	59.8	39.2	99.0	Fine-grained
Nevada	Subgrade	6	35.7	9.4	45.1	Coarse-grained
	Subbase	6	8.6	2.8	11.4	Coarse-grained
New Mexico	Subgrade	10	35.1	27.3	62.4	Fine-grained
Ohio	Subgrade	5	42.8	28.4	71.2	Fine-grained
Oklahoma	Subgrade	6	23.2	13.7	36.9	Coarse-grained
Texas	Subgrade	6	10.6	1.1	11.7	Coarse-grained
Virginia	Subgrade	9	30.7	12.4	43.1	Coarse-grained
Wisconsin	Subgrade	7	7.1	2.5	9.6	Coarse-grained
	Subbase	1	8.3	4.3	12.6	Coarse-grained

The material classifications shown in table 42 and table 43 for each layer agreed with each other. For the projects where an embankment was present (i.e., Iowa, Kansas, Louisiana, and Nebraska), the material type for the embankment was similar to the material type of the subgrade. For the Delaware, Kansas, Nevada, and Wisconsin projects where a subbase was placed on the subgrade, the material type for the subbase was similar to the material type for the subgrade.

The results from the Atterberg limits tests were stored in the PPDB table TST UG04 SS03. The results for tests on the subgrade were available at one or more test locations at some test sections, while no information was available for other test sections. If results from more than one sample were available at a test section, the results were averaged to obtain a single value for a test section. Table 44 shows the average values for the liquid limit, plastic limit, and PI for the SPS-1 projects that had fine-grained subgrade. This table also shows the number of test sections in each project that had Atterberg test data, which were used for computing the averages.

Table 44. Results from Atterberg limits test for projects built on fine-grained subgrade.

Project Location	Layer Type	Number of Sections That Had Data	Average Values (Percent)			Standard Deviation of PI
			Plastic Limit	Liquid Limit	PI	
Alabama	Subgrade	9	44.7	28.0	16.7	2.2
Iowa	Subgrade	7	43.8	16.1	27.7	9.6
	Embankment	10	32.7	12.0	20.7	3.0
Louisiana	Subgrade	4	38.8	18.8	20.0	4.7
	Embankment	3	24.0	19.0	5.0	0.7
Michigan	Subgrade	7	24.7	14.4	10.3	1.3
Nebraska	Subgrade	6	38.3	18.0	20.3	8.1
	Embankment	5	49.8	15.4	34.4	3.1
New Mexico	Subgrade	10	53.0	23.0	30.0	6.7
Ohio	Subgrade	5	32.0	17.0	15.0	2.9

Results from Atterberg limit tests performed on coarse-grained subgrade were also available in the PPDB table TST UG04 SS03. Some results indicated that the material was not plastic while other results provided a PI value. Table 45 summarizes the test results for the projects that had coarse-grained subgrade and shows the following information: number of test sections in each project where Atterberg limits tests were conducted, number of test sections where the material was not plastic, number of sections for which a PI value was available, and average PI value for the sections where the PI value was greater than 0.

Table 45. Results from Atterberg limits test for projects built on coarse-grained subgrade.

Project Location	Layer Type	Number of Sections Where Atterberg Limits Test Performed	Number of Sections Where PI = 0	Number of Sections Where PI > 0	Average PI of Sections Whose PI > 0
Arizona	Subgrade	12	8	4	6.1
Arkansas	Subgrade	7	7	0	NA
Delaware	Subgrade	4	2	2	5.5
	Subbase	5	5	0	NA
Florida	Subgrade	5	5	0	NA
Kansas	Subgrade	8	4	4	6.8
	Embankment	4	2	2	8.5
	Subbase	5	0	5	2.0
Montana	Subgrade	6	6	0	NA
Nevada	Subgrade	6	3	3	11.0
	Subbase	9	6	3	12.0
Oklahoma	Subgrade	5	0	5	18.4
Texas	Subgrade	6	6	0	NA
Virginia	Subgrade	9	2	7	8.3
Wisconsin	Subgrade	7	7	0	NA
	Subbase	4	4	0	NA

NA = not applicable (there were no sections with PI > 0).

Table 46 summarizes the information presented in table 42 through table 44 and presents the following information for each SPS-1 project: classification of subgrade, embankment (if present), and subbase (if present); average value of percent silt, clay, and silt and clay; and PI (for fine-grained material only).

Table 46. Summary of subsurface information for each SPS-1 project.

Project Location	Layer Type	Material Type	Median Value of Material (Percent)			Average PI for Projects on Fine-Grained Material
			Silt	Clay	Silt and Clay	
Alabama	Subgrade	Fine-grained	40.5	26.0	66.5	16.7
Arizona	Subgrade	Coarse-grained	10.8	5.7	16.5	NA
Arkansas	Subgrade	Coarse-grained	12.7	5.4	18.1	NA
Delaware	Subgrade	Coarse-grained	16.5	9.0	25.5	NA
	Subbase	Coarse-grained	7.2	5.6	12.8	NA
Florida	Subgrade	Coarse-grained	13.3	4.6	17.9	NA
Iowa	Subgrade	Fine-grained	56.8	31.1	87.9	27.7
	Embankment	Fine-grained	37.7	22.4	60.1	20.7
Kansas	Subgrade	Coarse-grained	18.9	11.5	30.4	NA
	Embankment	Coarse-grained	16.4	13.0	29.4	NA
Louisiana	Subgrade	Fine-grained	69.5	24.9	94.4	20.0
	Embankment	Fine-grained	82.9	8.7	91.6	5.0
Michigan	Subgrade	Fine-grained	39.0	23.7	62.7	10.3
Montana	Subgrade	Coarse-grained	18.5	7.2	25.7	NA
Nebraska	Subgrade	Fine-grained	66.7	32.2	98.9	20.3
	Embankment	Fine-grained	59.8	39.2	99.0	34.4
Nevada	Subgrade	Coarse-grained	35.7	9.4	45.1	NA
	Subbase	Coarse-grained	8.6	2.8	11.4	NA
New Mexico	Subgrade	Fine-grained	35.1	27.3	62.4	30.0
Ohio	Subgrade	Fine-grained	42.8	28.4	71.2	15.0
Oklahoma	Subgrade	Coarse-grained	23.2	13.7	36.9	NA
Texas	Subgrade	Coarse-grained	10.6	1.1	11.7	NA
Virginia	Subgrade	Coarse-grained	30.7	12.4	43.1	NA
Wisconsin	Subgrade	Coarse-grained	7.1	2.5	9.6	NA
	Subbase	Coarse-grained	8.3	4.3	12.6	NA

NA = not applicable (project is on a coarse-grained subgrade).

As seen in table 42 through table 44, test data were not available for all test sections in a particular project. Therefore, for analysis purposes, a single value of a test parameter had to be used for all test sections in an SPS-1 project.

CLASSIFICATION OF SPS-1 PROJECTS ACCORDING TO SUBGRADE TYPE AND ENVIRONMENTAL ZONES

Table 47 shows the following information for the SPS-1 projects: environmental zone, subgrade type, average age of the sections in the project at the last profile date used for analysis, and average time span over which center of the lane data were collected at the sections in the project.

Table 47. Summary of subgrade type, environmental region, and time period over which center of the lane data were collected at SPS-1 projects.

Project Location	Section Numbers in Project	Environmental Zone	Subgrade Type	Average Age of Sections at Last Profile Date Used for Analysis (Years)	Average Time Span Over Which Center Lane Data Were Collected (Years)
Alabama	1–12	WNF	Fine-grained	11.4	7.0
Arizona	13–24	DNF	Coarse-grained	10.3	6.8
Arkansas	13–24	WNF	Coarse-grained	12.4	9.6
Delaware	1–12	WNF	Coarse-grained	10.1	9.0
Florida	1–12	WNF	Coarse-grained	16.3	15.1
Iowa	1–12	WF	Fine-grained	8.0	3.7
Kansas	1–12	WF	Coarse-grained	7.5	4.2
Louisiana	13–24	WNF	Fine-grained	14.6	14.2
Michigan	13–24	WF	Fine-grained	6.6	5.0
Montana	13–24	DF	Coarse-grained	11.8	11.7
Nebraska	13–24	WF	Fine-grained	4.7	3.1
Nevada	1–12	DF	Coarse-grained	12.1	10.4
New Mexico	1–12	DNF	Fine-grained	10.5	9.2
Ohio	1–12	WF	Fine-grained	10.1	7.1
Oklahoma	13–24	WNF	Coarse-grained	13.1	12.7
Texas	13–24	WNF	Coarse-grained	4.3	3.0
Virginia	13–24	WNF	Coarse-grained	16.1	11.4
Wisconsin	13–24	WF	Coarse-grained	10.4	10.3

Table 48 shows the SPS-1 projects classified according to the subgrade type and environmental zone. This table shows the SPS-1 projects are not balanced over the subgrade types and the environmental zones. Eleven SPS-1 projects are located on coarse-grained subgrade compared to seven projects that are located on fine-grained subgrade. A third of the SPS-1 projects are located in the WNF zone on a coarse-grained subgrade.

Table 48. SPS-1 projects classified according to subgrade type and environmental region.

Environmental Zone	Subgrade Type	
	Fine-Grained	**Coarse-Grained**
DNF	New Mexico (1–12)	Arizona (13–24)
DF	None	Montana (13–24) Nevada (1–12)
WNF	Alabama (1–12) Louisiana (13–24)	Arkansas (13–24) Delaware (1–12) Florida (1–12) Oklahoma (13–24) Texas (13–24) Virginia (13–24)
WF	Iowa (1–12) Michigan (13–24) Nebraska (13–24) Ohio (1–12)	Kansas (1–12) Wisconsin (13–24)

CHAPTER 5. ROUGHNESS CHANGES AT SPS-1 PROJECTS

This chapter discusses roughness changes at the test sections in each SPS-1 project and presents the change in MIRI and CLIRI as well as the rate of change of MIRI and CLIRI at each test section.

RATE OF CHANGE OF ROUGHNESS

The change in MIRI and CLIRI at each test section was computed by deducting the IRI obtained at the time when the section was first profiled with the K.J. Law T-6600 profiler from the IRI obtained for the last profile date used for analysis. Figure 36 and figure 37 show box plots for the changes in MIRI and CLIRI, respectively, observed for the test sections in each SPS-1 project. Figure 38 is a bar chart that shows the average time span over which IRI data were collected at the sections in each SPS-1 project.

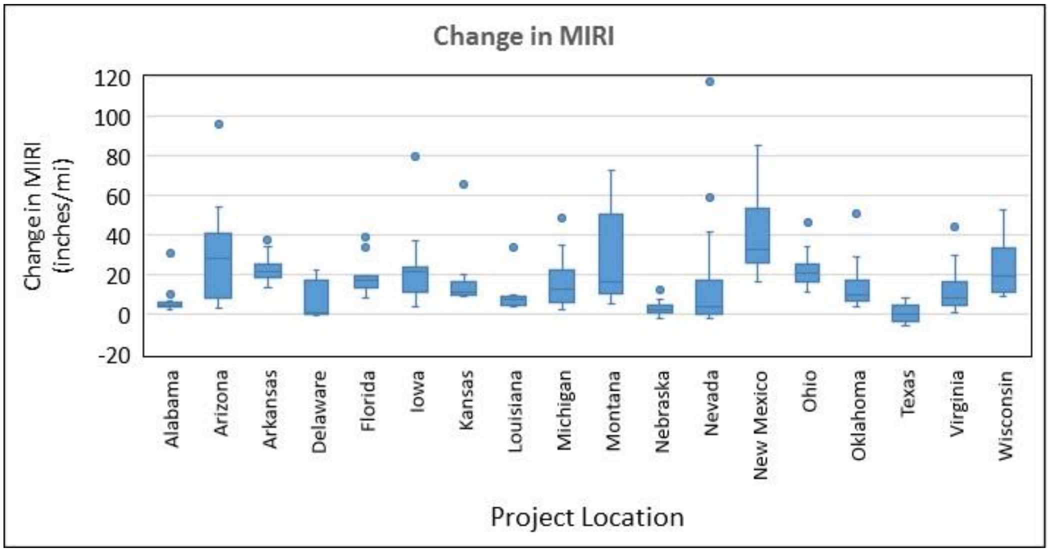

Figure 36. Graph. Box plots showing change in MIRI at test sections in each SPS-1 project.

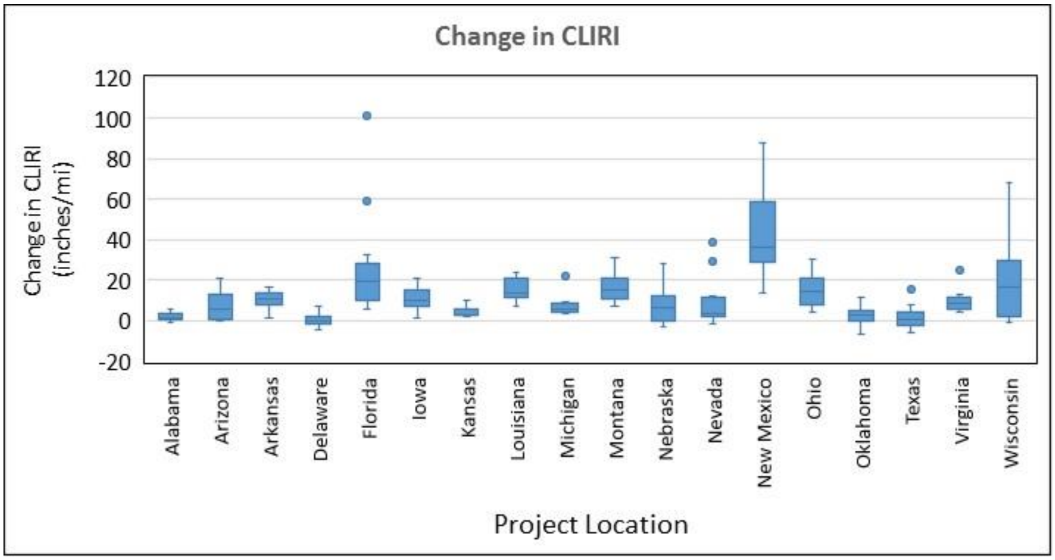

Figure 37. Graph. Box plots showing change in CLIRI at test sections in each SPS-1 project.

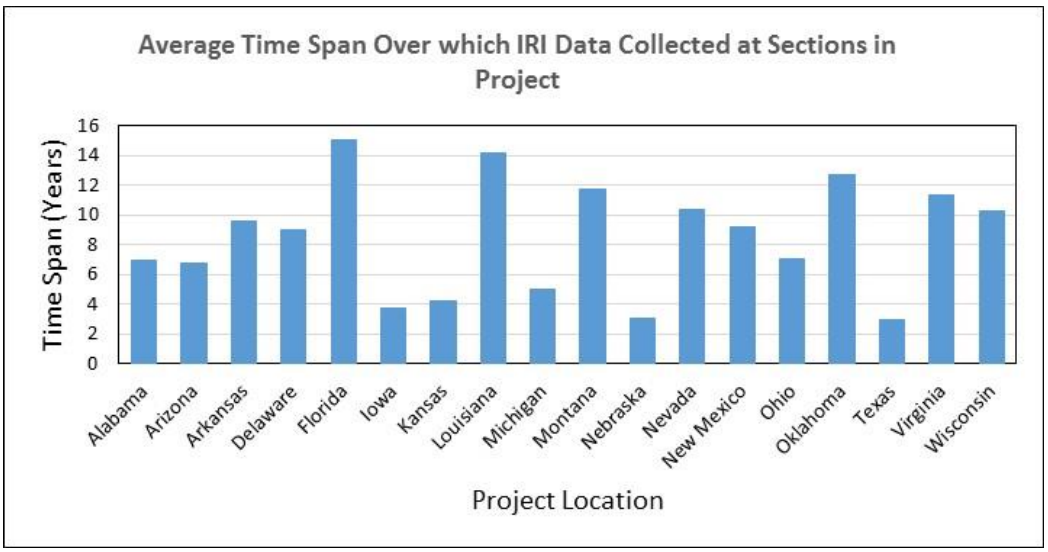

Figure 38. Graph. Average time span over which IRI data have been collected at sections in SPS-1 projects.

A box plot is a simple graphical representation that shows the distribution of data. For each SPS-1 project, the box plot shows the distribution of the change in IRI values for the test sections located in the SPS-1 project. The horizontal line located within the box shows the median of the data. The bottom of the box shows the value of the first quartile of the data (i.e., 25th percentile value), while the top of the box shows the value of the third quartile of the data (i.e., 75th percentile value). The height of the box is equal to the interquartile distance (IQD), which is the difference between the third and the first quartile of the data. The whiskers in the plot at the top and the bottom (i.e., the horizontal lines at the top and the bottom) show the range of the data. A data point that is more than 1.5 times the IQD from the median is defined as an outlier. An outlier is shown as a circle above or below the whiskers.

The bar graph is provided to show the average time span over which data were collected at each SPS-1 project because the change in MIRI and CLIRI could depend on the monitored period. For example, for identical subgrade, traffic, and environmental conditions, a test section monitored over a longer time should show a greater change in MIRI and CLIRI than a test section monitored over a shorter time.

The change in MIRI as well as CLIRI observed at the SPS-1 projects varied. For example, the change in MIRI observed for the sections at the Montana SPS-1 project was much larger than the change in MIRI observed at the Louisiana SPS-1 project, even though the Louisiana project had been monitored over a longer period. Overall, the test sections at the Florida, New Mexico, and Wisconsin SPS-1 projects showed a greater change in CLIRI compared with the other SPS-1 projects.

Evaluation of the IRI versus time plots for the SPS-1 sections showed a linear trend in IRI progression for a majority of the sections except for a few of the weak sections that showed an exponential trend for increase in IRI at the latter years. Because a majority of the sections showed a linear trend for IRI increase, a linear regression analysis between IRI and pavement age was performed on all sections to estimate the rate of increase of MIRI and CLIRI. The box plots in figure 39 and figure 40 show the distribution of the rate of change of MIRI and CLIRI, respectively, obtained for the test sections in each SPS-1 project.

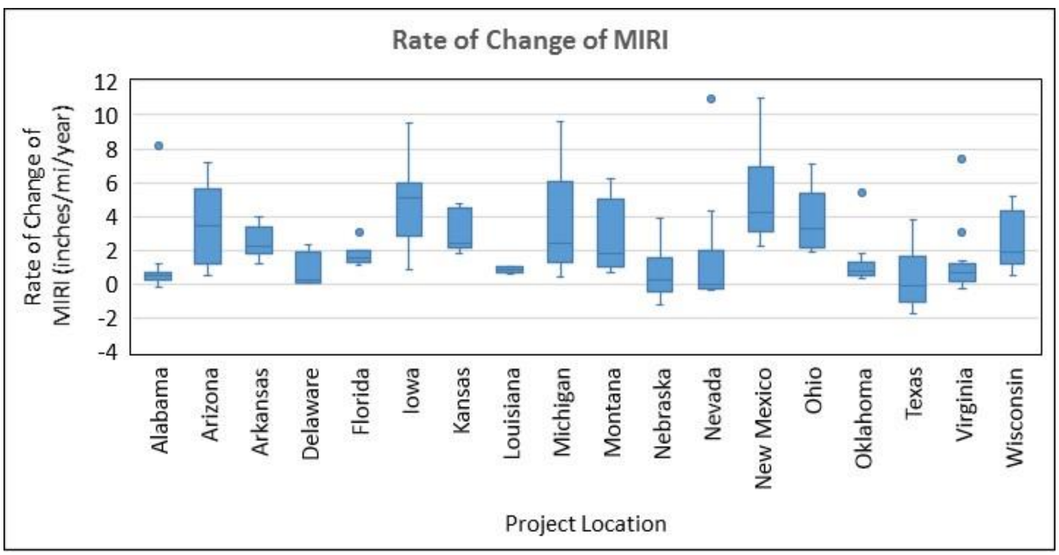

Figure 39. Graph. Rate of change of MIRI at test sections in each SPS-1 project.

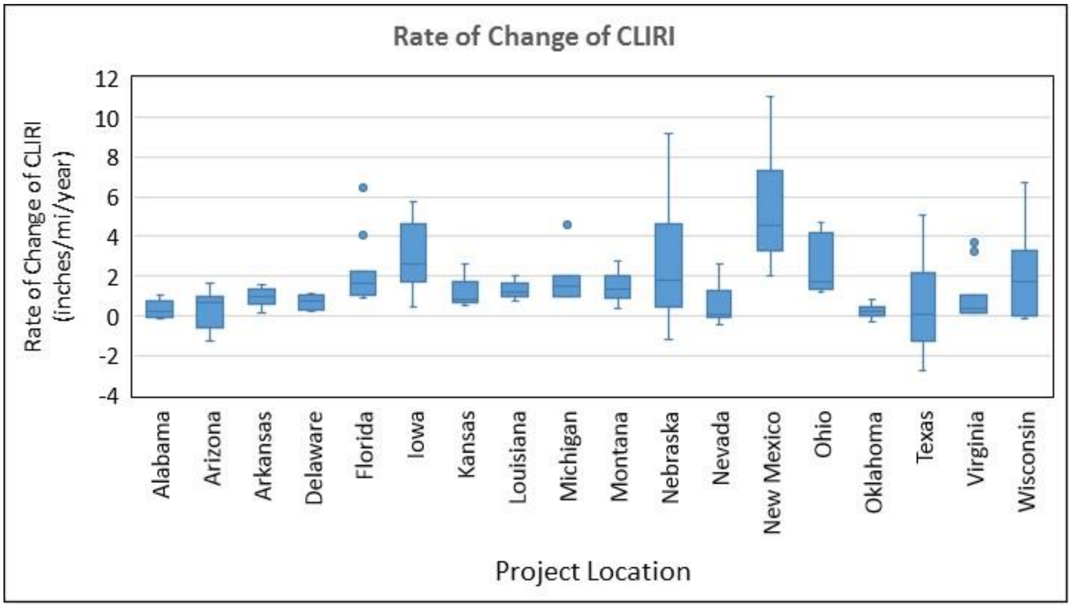

Figure 40. Graph. Rate of change of CLIRI at test sections in each SPS-1 project.

Table 49 shows the median value for the rate of change of MIRI and CLIRI of all test sections in each SPS-1 project. This table also shows the following information for each SPS-1 project: environmental zone, subgrade type, and average time span over which data were collected for all three paths (i.e., wheelpaths and center of the lane).

Table 49. Median values of rate of change of MIRI and CLIRI for SPS-1 projects.

Project Location	Environmental Zone	Subgrade Type	Average Time Span over which Center of the Lane Data Were Collected (Years)	Rate of Change of IRI (Inches/mi/Year)	
				MIRI	CLIRI
Alabama	WNF	Fine-grained	7.0	0.47	0.19
Arizona	DF	Coarse-grained	6.8	3.41	0.66
Arkansas	WNF	Coarse-grained	9.6	2.22	0.97
Delaware	WNF	Coarse-grained	9.0	0.26	0.75
Florida	WNF	Coarse-grained	15.1	1.55	1.65
Iowa	WF	Fine-grained	3.7	5.36	2.58
Kansas	WF	Coarse-grained	4.2	2.48	0.82
Louisiana	WNF	Fine-grained	14.2	0.82	1.18
Michigan	WF	Fine-grained	5.0	2.42	1.47
Montana	DF	Coarse-grained	11.7	1.81	1.35
Nebraska	WF	Fine-grained	3.1	0.26	1.79
Nevada	DF	Coarse-grained	10.4	−0.03	0.08
New Mexico	DNF	Fine-grained	9.2	4.19	4.58
Ohio	WF	Fine-grained	7.1	3.31	1.69
Oklahoma	WNF	Coarse-grained	12.7	0.80	0.19
Texas	WNF	Coarse-grained	3.0	−0.12	0.04
Virginia	WNF	Coarse-grained	11.4	0.66	0.34
Wisconsin	WF	Coarse-grained	10.3	1.85	1.69

PRESENTATION OF RESULTS

In some SPS-1 projects, the time span over which IRI data were available for individual test sections in the SPS-1 project was different. This occurred because maintenance or rehabilitation was conducted that affected the IRI at a test section or because the section was deassigned from the LTPP Program. As described previously, for each SPS-1 project, an average time span over which data were collected was computed by averaging the time spans for which data were available for individual test sections. Table 50 shows the SPS-1 projects divided into four categories based on the average time span over which data were available at the project. All category 1 and category 2 SPS-1 projects had coarse-grained subgrade except for the Louisiana project, which had a fine-grained subgrade.

Table 50. SPS-1 projects categorized according to the availability of data.

Category	Average Time Span over which Center of the Lane Data Were Available (Years)	SPS-1 Project
1	12–16	Florida, Louisiana, Oklahoma
2	10–12	Montana, Nevada, Virginia, Wisconsin
3	6–10	Alabama, Arizona, Arkansas, Delaware, New Mexico, Ohio, Iowa, Kansas, Michigan, Nebraska, Texas
4	Less than 6	

In this chapter, the changes in IRI at SPS-1 projects are presented under each category shown in table 50. The changes in MIRI as well as CLIRI are presented for the test sections in each SPS-1 project. The IRI changes for the test sections in each SPS-1 project are presented graphically as bar charts that show the change in IRI as well as the rate of increase of IRI. The change in IRI was computed by deducting the IRI at the last profile date used for analysis from the IRI obtained when the section was first profiled with the K.J. Law T-6600 profiler. The rate of increase of IRI was the value obtained from the regression analysis.

The structural strengths of test sections in an SPS-1 project were different from each other. The structural number (SN) of each test section was computed by using the following layer coefficients: asphalt concrete—0.42, asphalt-treated base—0.35, permeable asphalt-treated base—0.14, and aggregate base—0.14. The computed SN values are shown in table 51. This table also shows the test sections in a project ranked from 1 through 12, with 1 being the section with the lowest SN and 12 being the test section with the highest SN.

Table 51. Test sections in SPS-1 projects ranked from weakest to strongest based on SN.

SN Rank from Weakest (1) to Strongest (12)	Section Number	AC Thickness (Inches)	Material Type Layer 2	Material Type Layer 3	Thickness (Inches) Layer 2	Thickness (Inches) Layer 3	SN
1	7	4	PATB	DGAB	4	4	2.80
2	2	4	DGAB	—	12	—	3.36
3	5	4	ATB	DGAB	4	4	3.64
4	1	7	DGAB	—	8	—	4.06
5	3	4	ATB	—	8	—	4.48
6	8	7	PATB	DGAB	4	8	4.62
7	10	7	ATB	PATB	4	4	4.90
8	11	4	ATB	PATB	8	4	5.04
9	9	7	PATB	DGAB	4	12	5.18
10	6	7	ATB	DGAB	8	4	6.30
11	12	4	ATB	PATB	12	4	6.44
12	4	7	ATB	—	12	—	7.14
1	13	4	DGAB	—	8	—	2.80
2	20	4	PATB	DGAB	4	8	3.36
3	22	4	ATB	PATB	4	4	3.64
4	21	4	PATB	DGAB	4	12	3.92
5	19	7	PATB	DGAB	4	4	4.06
6	14	7	DGAB	—	12	—	4.62
7	17	7	ATB	DGAB	4	4	4.90
8	18	4	ATB	DGAB	8	4	5.04
9	15	7	ATB	—	8	—	5.74
10	16	4	ATB	—	12	—	5.88
11	23	7	ATB	PATB	8	4	6.30
12	24	7	ATB	PATB	12	4	7.70

—Indicates not applicable.

When presenting the IRI change and rate of increase of IRI in the bar graphs in this report, the test sections are shown according to increasing SN of the test sections.

ROUGHNESS DEVELOPMENT AT CATEGORY 1 SPS-1 PROJECTS

This section describes roughness development at category 1 SPS-1 projects, which are the projects located in Florida, Louisiana, and Oklahoma.

Florida Project

The climatic and subgrade properties and annual thousands of ESALs (KESALs) for the Florida SPS-1 project are shown in table 52. The time period over which center of the lane data were available at the test sections in this project is shown in table 53. All test sections in this project had data for the same time duration. Figure 41 shows the change in IRI at the test sections over the monitored period, while figure 42 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at six test sections. Over the 15.1 years that the sections were monitored, the rate of increase of IRI was less than 2 inches/mi/year at 10 test sections for MIRI and at 8 test sections for CLIRI.

Table 52. Climatic and subgrade properties and traffic level for the Florida SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WNF
	Annual precipitation (inches)	56
	Wet days per year	168
	Intense precipitation days per year	35
	Mean annual temperature (°F)	74
	Days above 90 °F per year	87
	Days below 32 °F per year	1
	FI (°F days/year)	0
	Freeze-thaw cycles per year	1
Subgrade	Subgrade category	Coarse-grained
	Percent material passing through No. 200 sieve	17.9
	Percent silt	13.3
	Percent clay	4.6
Traffic	Average annual KESALs	562

Table 53. Availability of IRI data for the Florida SPS-1 project.

Section Numbers	Age of Pavement (Years)		Time Span for Center of the Lane Data (Years)
	When First Center of the Lane Data Collected	When Last Center of the Lane Data Collected	
1–12	1.2	16.3	15.1

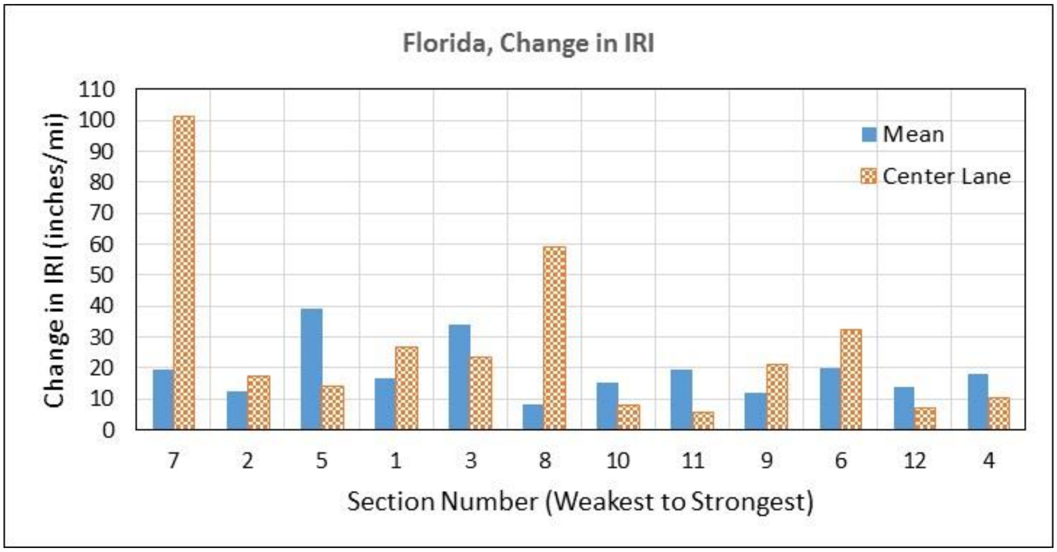

Figure 41. Graph. Change in IRI at test sections in the Florida SPS-1 project.

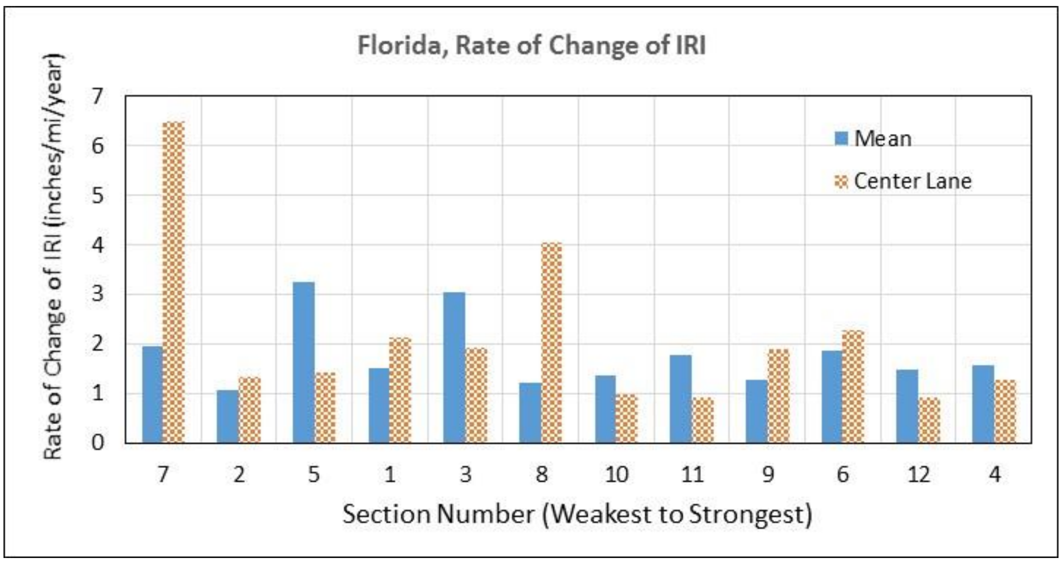

Figure 42. Graph. Rate of change of IRI at test sections in the Florida SPS-1 project.

Louisiana Project

The climatic and subgrade properties and annual KESALs at the Louisiana SPS-1 project are shown in table 54. The time period over which center of the lane data were available at the test sections in this project is shown in table 55. All test sections in this project had data for the same time duration. Figure 43 shows the change in IRI at the test sections over the monitored period, while figure 44 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at only one test section. Over the 14.2 years that the sections were monitored, the rate of increase of IRI was less than 1 inch/mi/year at 11 sections for MIRI and 3 sections for CLIRI. The rate of increase of CLIRI was less than 2 inches/mi/year at 11 test sections. There was no distress along the center of the lane that could have contributed to the increase in CLIRI at the test sections in this project. It appears that the increase in CLIRI was caused by the change in the profile resulting from movements of the subsurface layers (i.e., shrink or swell of the subgrade). Along the wheelpaths, traffic might have smoothed out this effect, which might be the reason the change in CLIRI was more than the change in MIRI.

Table 54. Climatic and subgrade properties and traffic level for the Louisiana SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WNF
	Annual precipitation (inches)	58
	Wet days per year	162
	Intense precipitation days per year	36
	Mean annual temperature (°F)	69
	Days above 90 °F per year	76
	Days below 32 °F per year	11
	FI (°F days/year)	2
	Freeze-thaw cycles per year	11
Subgrade	Subgrade category	Fine-grained
	Percent material passing through No. 200 sieve	94.4
	Percent silt	69.5
	Percent clay	24.9
	Plasticity index	20
Traffic	Average annual KESALs	83

Table 55. Availability of IRI data for the Louisiana SPS-1 project.

Section Numbers	Age of Pavement (Years) When First Center of the Lane Data Collected	Age of Pavement (Years) When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
13–24	0.4	14.6	14.2

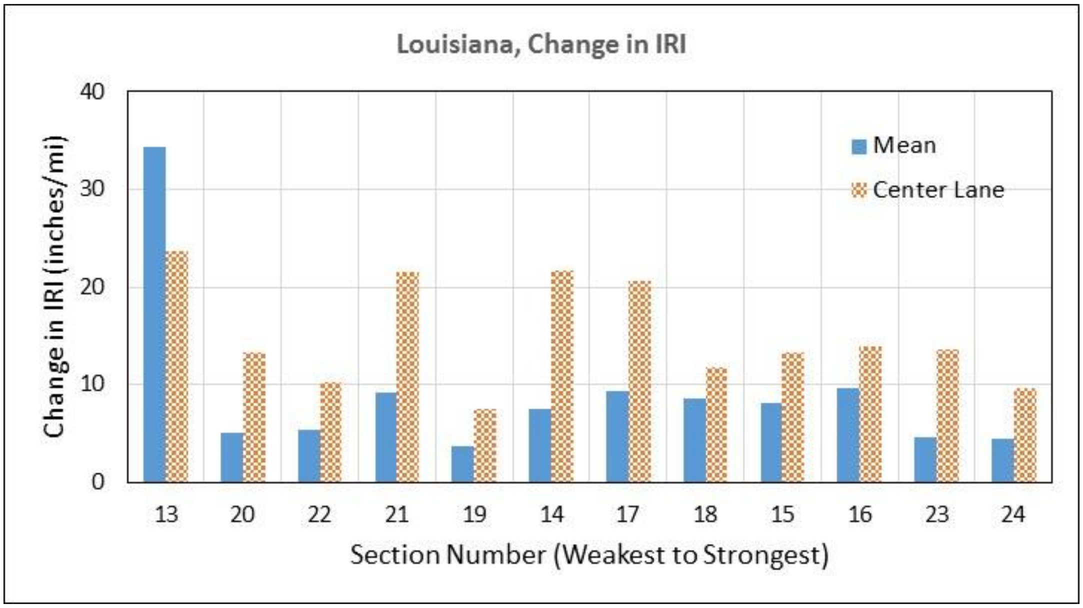

Figure 43. Graph. Change in IRI at test sections in the Louisiana SPS-1 project.

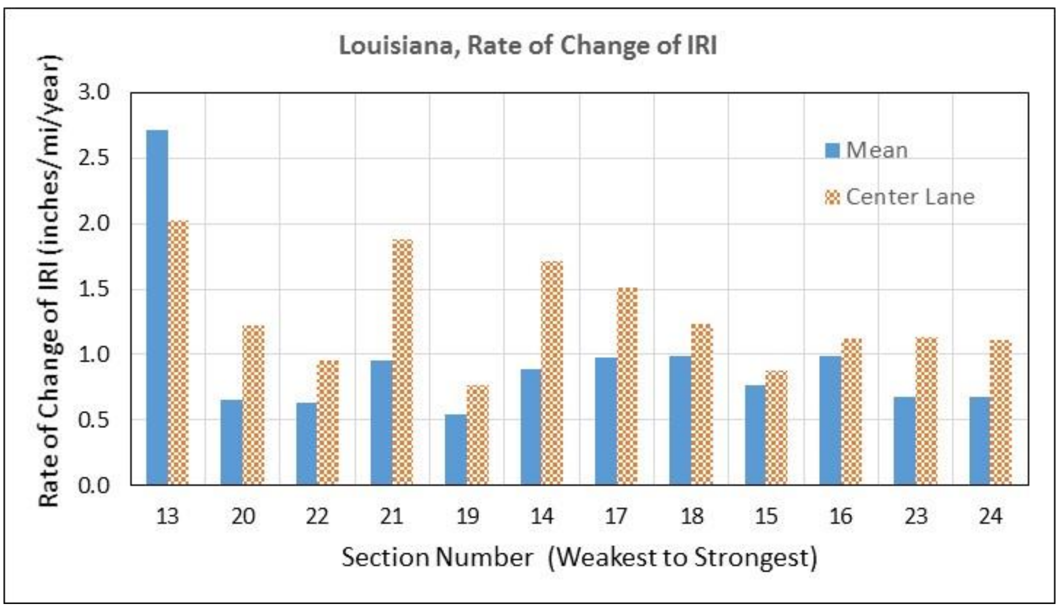

Figure 44. Graph. Rate of change of IRI at test sections in the Louisiana SPS-1 project.

Oklahoma Project

The climatic and subgrade properties and annual KESALs at the Oklahoma SPS-1 project are shown in table 56. The time periods over which center of the lane data were available at the test sections in this project are shown in table 57. Center of the lane data were available over a period of 9.4 years for two test sections and over a period of 13.3 years for 10 test sections. Figure 45 shows the change in IRI at the test sections over the monitored period, while figure 46 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at all test sections. The rate of increase of MIRI was less than 2 inches/mi/year at

11 sections and less than 1 inch/mi/year at 7 test sections. The rate of increase of CLIRI was less than 1 inch/mi/year for all test sections.

Table 56. Climatic and subgrade properties and traffic level for the Oklahoma SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WNF
	Annual precipitation (inches)	32
	Wet days per year	96
	Intense precipitation days per year	20
	Mean annual temperature (°F)	62
	Days above 90 °F per year	89
	Days below 32 °F per year	72
	FI (°F days/year)	99
	Freeze-thaw cycles per year	67
Subgrade	Subgrade category	Coarse-grained
	Percent material passing through No. 200 sieve	36.9
	Percent silt	23.2
	Percent clay	13.7
Traffic	Average annual KESALs	62

Table 57. Availability of IRI data for the Oklahoma SPS-1 project.

Section Numbers	Age of Pavement (Years): When First Center of the Lane Data Collected	Age of Pavement (Years): When Last Center the of Lane Data Collected	Time Span for Center of the Lane Data (Years)
13, 22	0.4	9.8	9.4
14–24	0.4	13.7	13.3

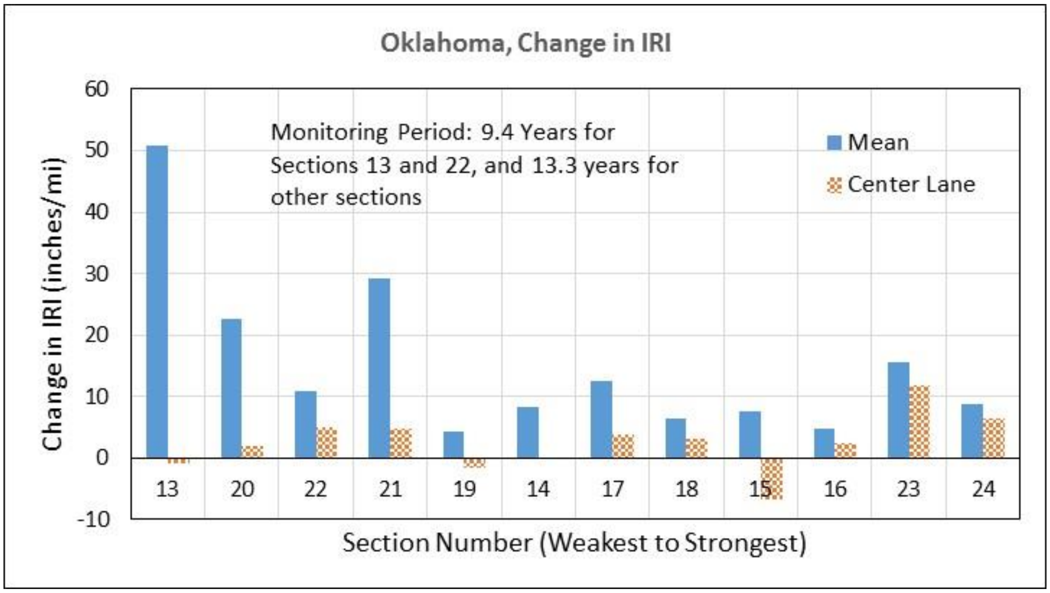

Figure 45. Graph. Change in IRI at test sections in the Oklahoma SPS-1 project.

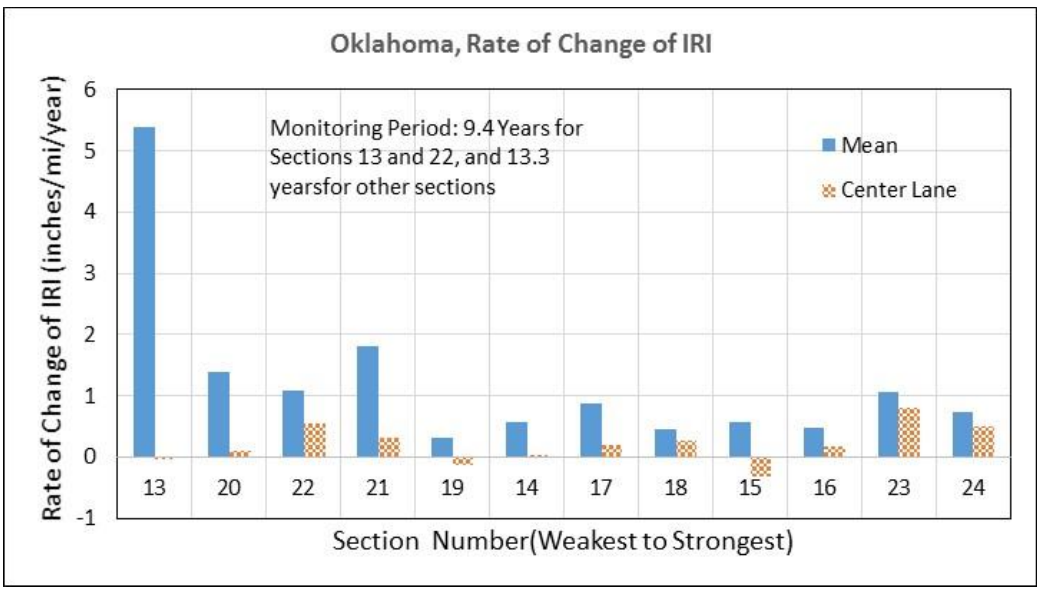

Figure 46. Graph. Rate of change of IRI at test sections in the Oklahoma SPS-1 project.

ROUGHNESS DEVELOPMENT AT CATEGORY 2 SPS-1 PROJECTS

This section describes roughness development at category 2 SPS-1 projects, which are the projects located in Montana, Nevada, Virginia, and Wisconsin.

Montana Project

The climatic and subgrade properties and annual KESALs at the Montana SPS-1 project are shown in table 58. The time period over which center of the lane data were available at the test sections in this project is shown in table 59. All test sections in this project had data for the same time duration. Figure 47 shows the change in IRI at the test sections over the monitored period, while figure 48 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at six test sections. The rate of increase of IRI was less than 2 inches/mi/year at seven sections for MIRI and at nine sections for CLIRI.

Table 58. Climatic and subgrade properties and traffic level for the Montana SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	DF
	Annual precipitation (inches)	14
	Wet days per year	101
	Intense precipitation days per year	6
	Mean annual temperature (°F)	46
	Days above 90 °F per year	19
	Days below 32 °F per year	158
	FI (°F days/year)	940
	Freeze-thaw cycles per year	124
Subgrade	Subgrade category	Coarse-grained
	Percent material passing through No. 200 sieve	25.7
	Percent silt	18.5
	Percent clay	7.2
Traffic	Average annual KESALs	141

Table 59. Availability of IRI data for the Montana SPS-1 project.

Section Numbers	Age of Pavement (Years)		Time Span for Center of the Lane Data (Years)
	When First Center of the Lane Data Collected	When Last Center of the Lane Data Collected	
13–24	0.1	11.8	11.7

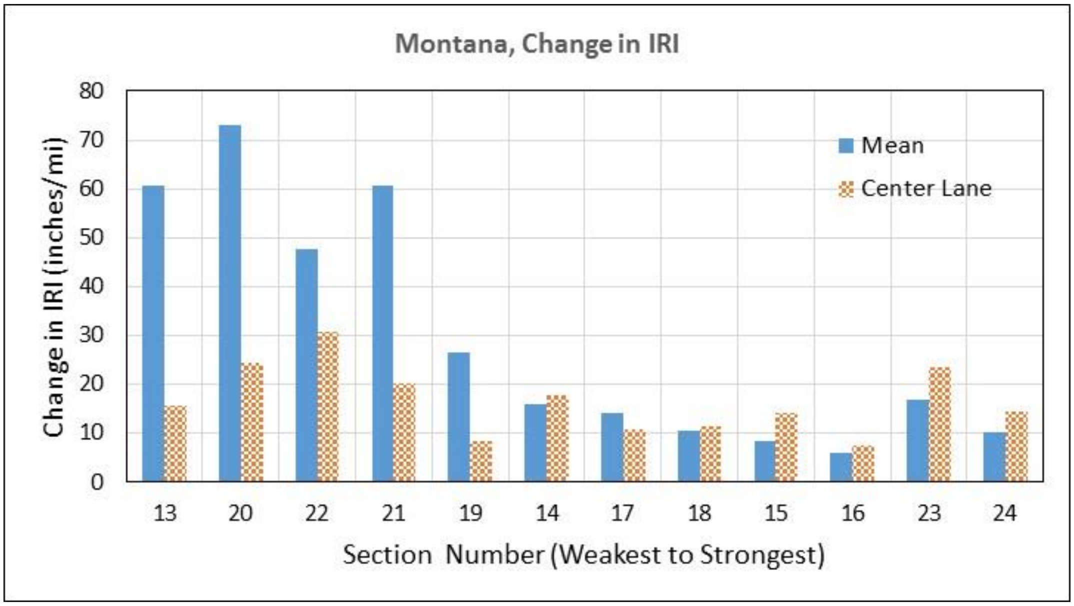

Figure 47. Graph. Change in IRI at test sections in the Montana SPS-1 project.

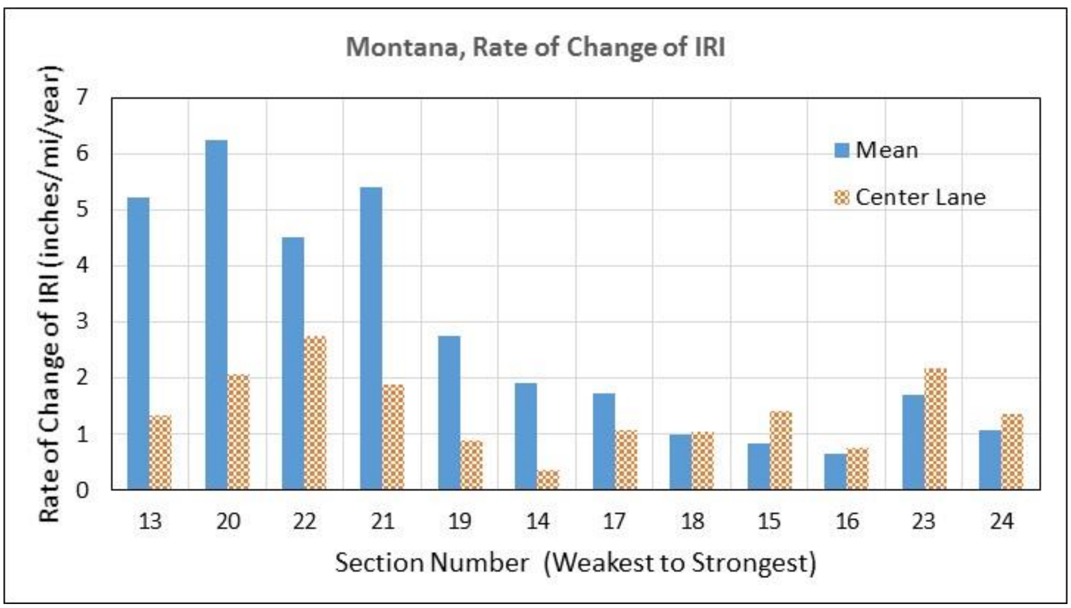

Figure 48. Graph. Rate of change of IRI at test sections in the Montana SPS-1 project.

Nevada Project

The climatic and subgrade properties and annual KESALs at the Nevada SPS-1 project are shown in table 60. The time periods over which center of the lane data were available at the test sections in this project are shown in table 61. As shown in this table, the period over which test sections in this project were monitored varied. Figure 49 shows the change in IRI at the test sections over the monitored period, while figure 50 shows the rate of change of IRI at the test sections. The change in IRI at sections 2, 7, and 9 was much greater than the change in IRI at the other test sections. The change in IRI at the other test sections was less than 15 inches/mi for both MIRI and CLIRI, and the rate of change of IRI for these sections was less than 1 inch/mi/year for MIRI as well as CLIRI.

Table 60. Climatic and subgrade properties and traffic level for the Nevada SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	DF
	Annual precipitation (inches)	10
	Wet days per year	77
	Intense precipitation days per year	3
	Mean annual temperature (°F)	51
	Days above 90 °F per year	76
	Days below 32 °F per year	167
	FI (°F days/year)	351
	Freeze-thaw cycles per year	158
Subgrade	Subgrade category	Coarse-grained
	Percent material passing through No. 200 sieve	45.1
	Percent silt	35.7
	Percent clay	9.4
Traffic	Average annual KESALs	419

Table 61. Availability of IRI data for the Nevada SPS-1 project.

Section Numbers	Age of Pavement (Years): When First Center of the Lane Data Collected	Age of Pavement (Years): When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
2, 3, 5	1.6	8.6	7
8, 12	1.6	11	9.4
1	1.3	13.8	12.5
4, 6, 7, 9, 10, 11	1.6	13.8	12.2

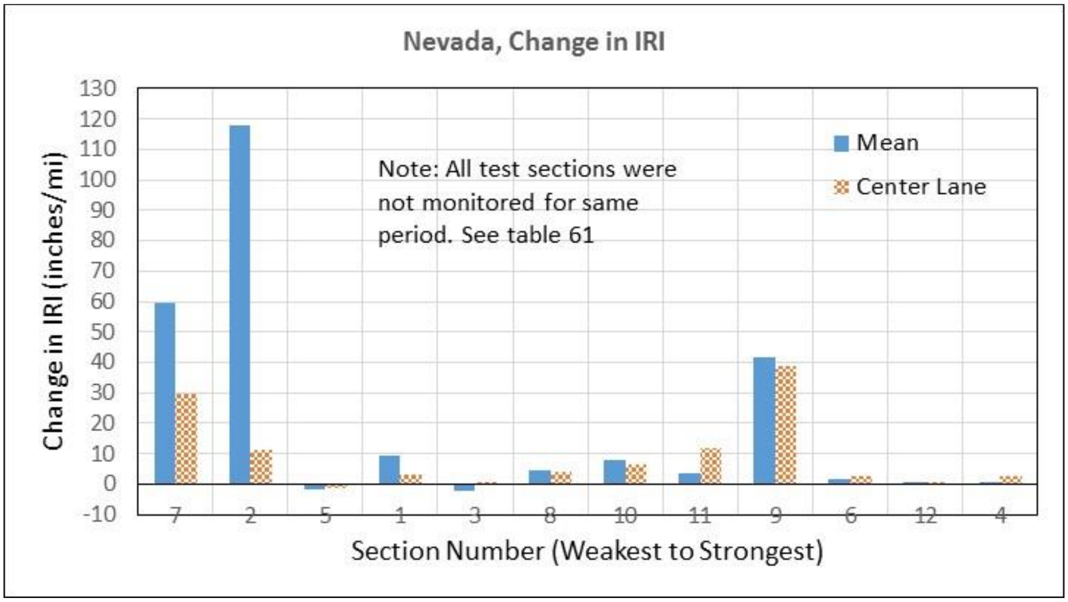

Figure 49. Graph. Change in IRI at test sections in the Nevada SPS-1 project.

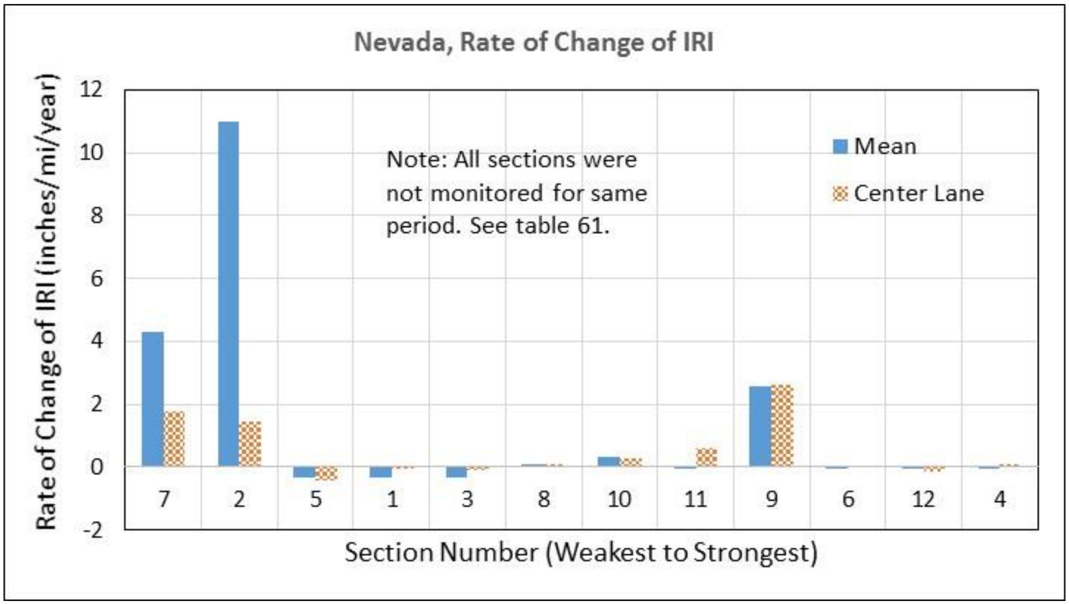

Figure 50. Graph. Rate of change of IRI at test sections in the Nevada SPS-1 project.

Virginia Project

The climatic and subgrade properties and annual KESALs at the Virginia SPS-1 project are shown in table 62. The time periods over which center of the lane data were available at the test sections in this project are shown in table 63. As shown in this table, the period over which test sections in this project were monitored varied. Figure 51 shows the change in IRI at the test sections over the monitored period, while figure 52 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at seven test sections. The rate of increase of IRI was less than 1 inch/mi/year at nine sections for both MIRI and CLIRI.

Table 62. Climatic and subgrade properties and traffic level for the Virginia SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WNF
	Annual precipitation (inches)	45
	Wet days per year	143
	Intense precipitation days per year	29
	Mean annual temperature (°F)	58
	Days above 90 °F per year	39
	Days below 32 °F per year	89
	FI (°F days/year)	92
	Freeze-thaw cycles per year	86
Subgrade	Subgrade category	Coarse-grained
	Percent material passing through No. 200 sieve	43.1
	Percent silt	30.7
	Percent clay	12.4
Traffic	Average annual KESALs	210

Table 63. Availability of IRI data for the Virginia SPS-1 project.

Section Numbers	Age of Pavement (Years) When First Center of the Lane Data Collected	Age of Pavement (Years) When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
13	4.6	8.4	3.8
12–23	4.6	17.4	12.8
24	4.6	10.5	5.9

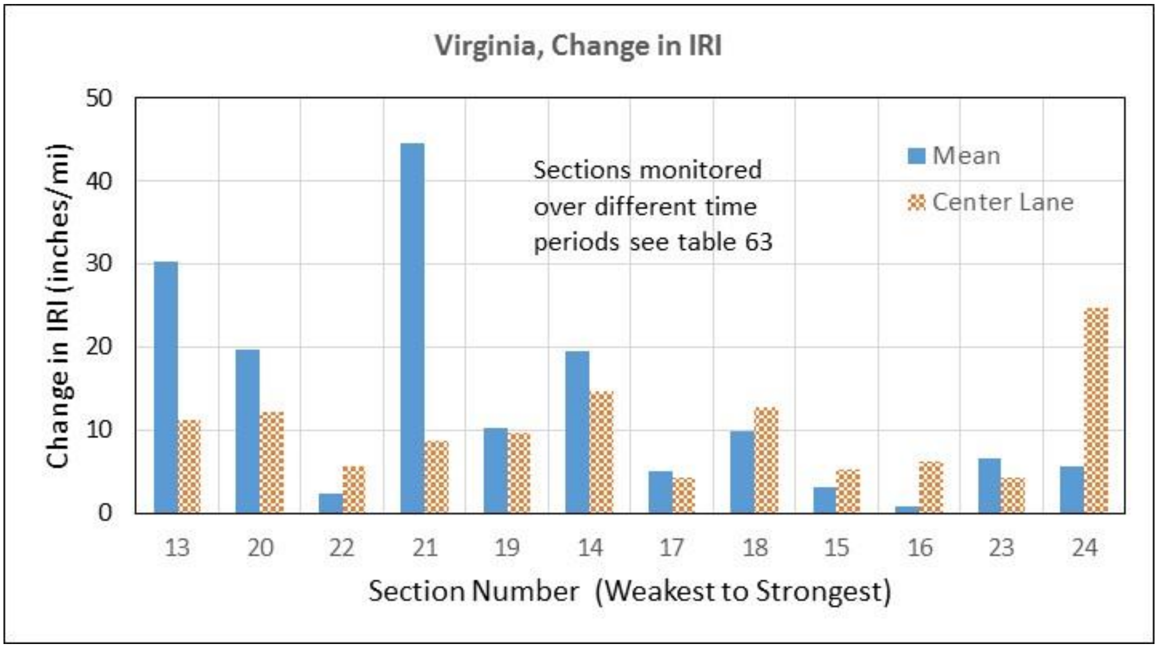

Figure 51. Graph. Change in IRI at test sections in the Virginia SPS-1 project.

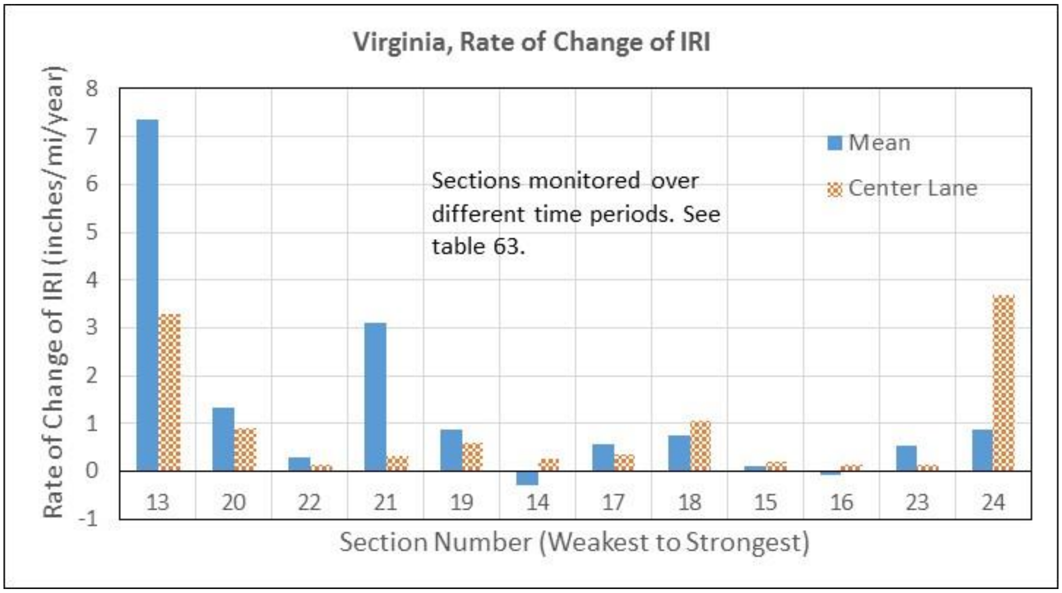

Figure 52. Graph. Rate of change of IRI at test sections in the Virginia SPS-1 project.

Wisconsin Project

The climatic and subgrade properties and annual KESALs at the Wisconsin SPS-1 project are shown in table 64. The time period over which center of the lane data were available at the test sections in this project is shown in table 65. All test sections in this project had data for the same time duration. Figure 53 shows the change in IRI at the test sections over the monitored period, while figure 54 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at seven test sections. In this project, many test sections that were structurally stronger showed a greater increase in IRI than sections that were structurally weaker. The rate of increase of IRI was less than 2 inches/mi/year at seven test sections for MIRI and at eight test sections for CLIRI.

Table 64. Climatic and subgrade properties and traffic level for the Wisconsin SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WF
	Annual precipitation (inches)	32
	Wet days per year	156
	Intense precipitation days per year	16
	Mean annual temperature (°F)	43
	Days above 90 °F per year	3
	Days below 32 °F per year	173
	FI (°F days/year)	1613
	Freeze-thaw cycles per year	99
Subgrade	Subgrade category	Coarse-grained
	Percent material passing through No. 200 sieve	9.6
	Percent silt	7.1
	Percent clay	2.5
Traffic	Average annual KESALs	331

Table 65. Availability of IRI data for the Wisconsin SPS-1 project.

Section Numbers	Age of Pavement (Years)		Time Span for Center of the Lane Data (Years)
	When First Center of the Lane Data Collected	When Last Center of the Lane Data Collected	
14–24	0.1	10.6	10.5

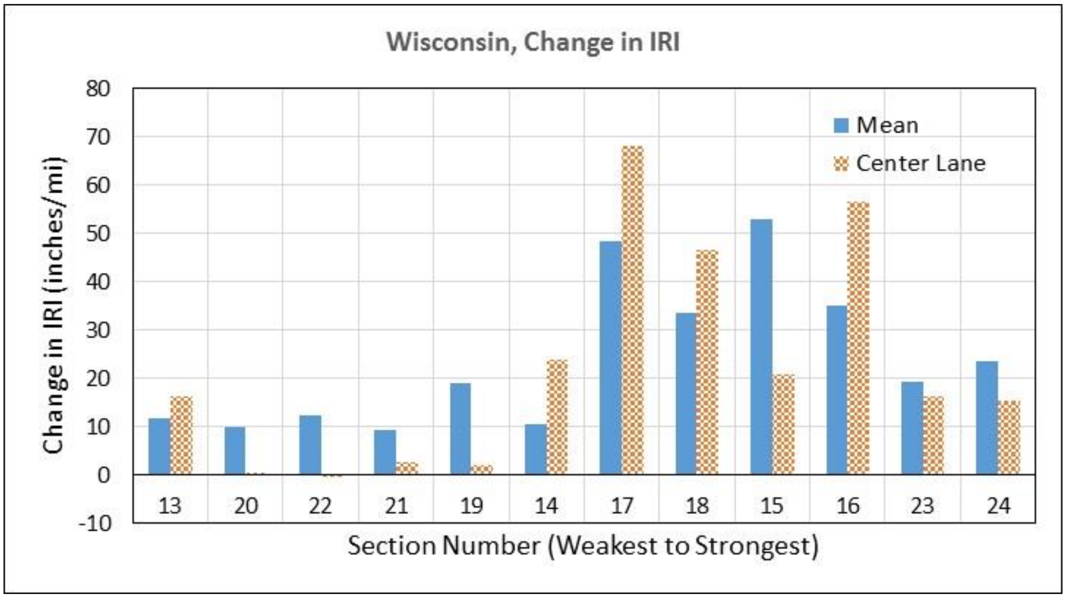

Figure 53. Graph. Change in IRI at test sections in the Wisconsin SPS-1 project.

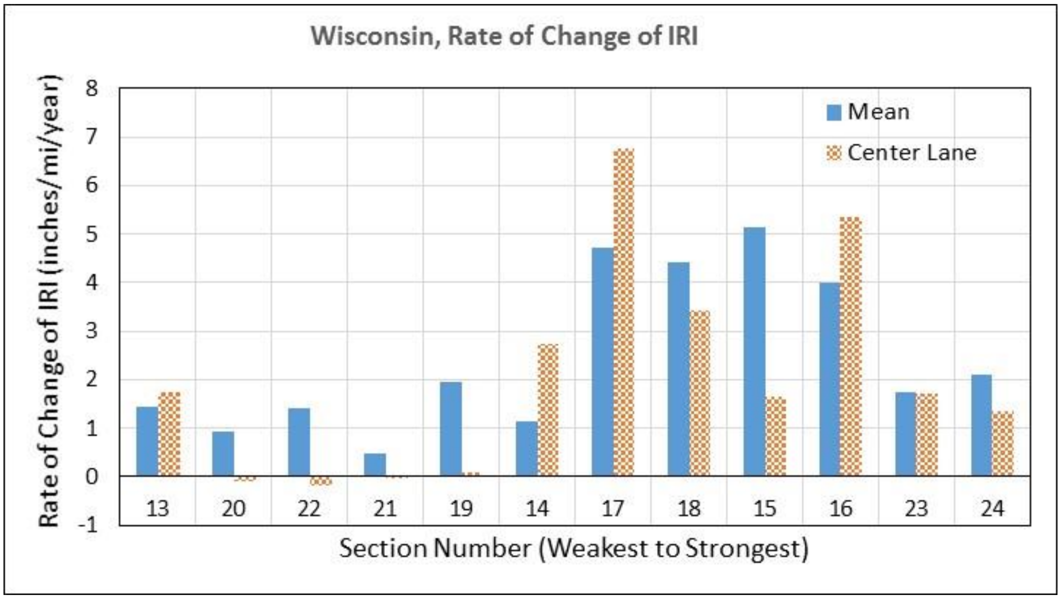

Figure 54. Graph. Rate of change of IRI at test sections in the Wisconsin SPS-1 project.

ROUGHNESS DEVELOPMENT AT CATEGORY 3 SPS-1 PROJECTS

This section describes roughness development at category 3 SPS-1 projects, which are the projects located in Alabama, Arizona, Arkansas, Delaware, New Mexico, and Ohio.

Alabama Project

The climatic and subgrade properties and annual KESALs at the Alabama SPS-1 project are shown in table 66. The time periods over which center of the lane data were available at the test sections in this project are shown in table 67. Only two IRI values were available for section 7, which had been monitored for only 0.6 years. Section 2 had data over a 3.7-year period, while the other sections had data over a 7.8-year period. Figure 55 shows the change in IRI at the test sections over the monitored period, while figure 56 shows the rate of change of IRI at the test sections. Section 7 is not shown in either of these plots. Section 2, which was the weakest section, showed a large change in MIRI compared with other test sections. The change in MIRI was greater than the change in CLIRI at 10 test sections. The rate of increase of IRI was less than 1 inch/mi/year at 9 test sections for MIRI and 10 test sections for CLIRI.

Table 66. Climatic and subgrade properties and traffic level for the Alabama SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WNF
	Annual precipitation (inches)	52
	Wet days per year	160
	Intense precipitation days per year	32
	Mean annual temperature (°F)	64
	Days above 90 °F per year	51
	Days below 32 °F per year	43
	FI (°F days/year)	16
	Freeze-thaw cycles per year	43
Subgrade	Subgrade category	Fine-grained
	Percent material passing through No. 200 sieve	40.5
	Percent silt	26
	Percent clay	66.5
	PI	16.7
Traffic	Average annual KESALs	384

Table 67. Availability of IRI data for the Alabama SPS-1 project.

Section Numbers	Age of Pavement (Years)		Time Span for Center of the Lane Data (Years)
	When First Center of the Lane Data Collected	When Last Center of the Lane Data Collected	
2	4.3	8.0	3.7
7	4.3	4.9	0.6
1, 3–6, 8–12	4.3	12.2	7.9

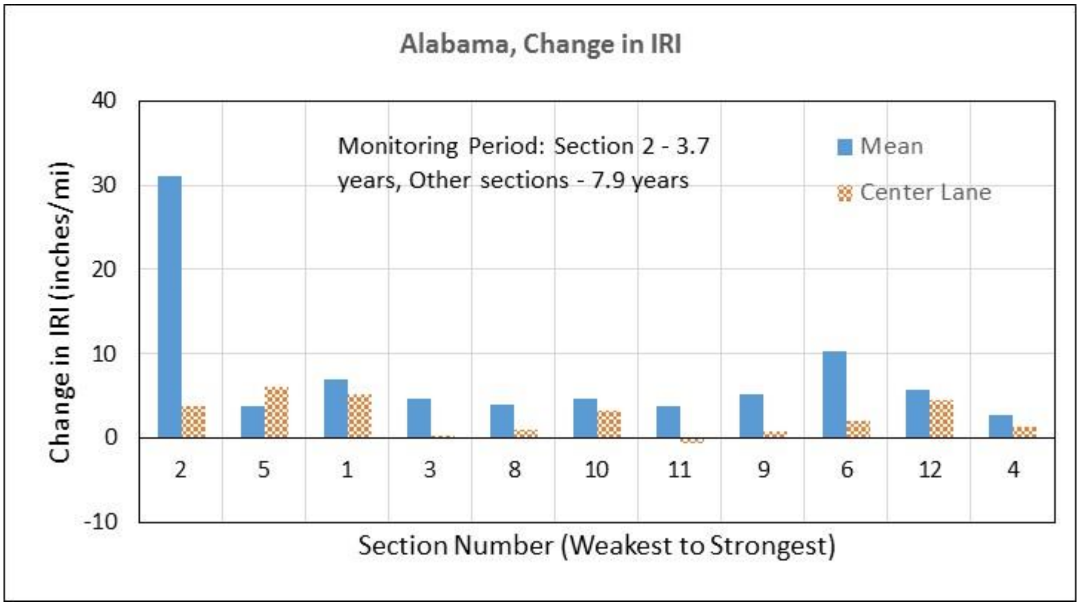

Figure 55. Graph. Change in IRI at test sections in the Alabama SPS-1 project.

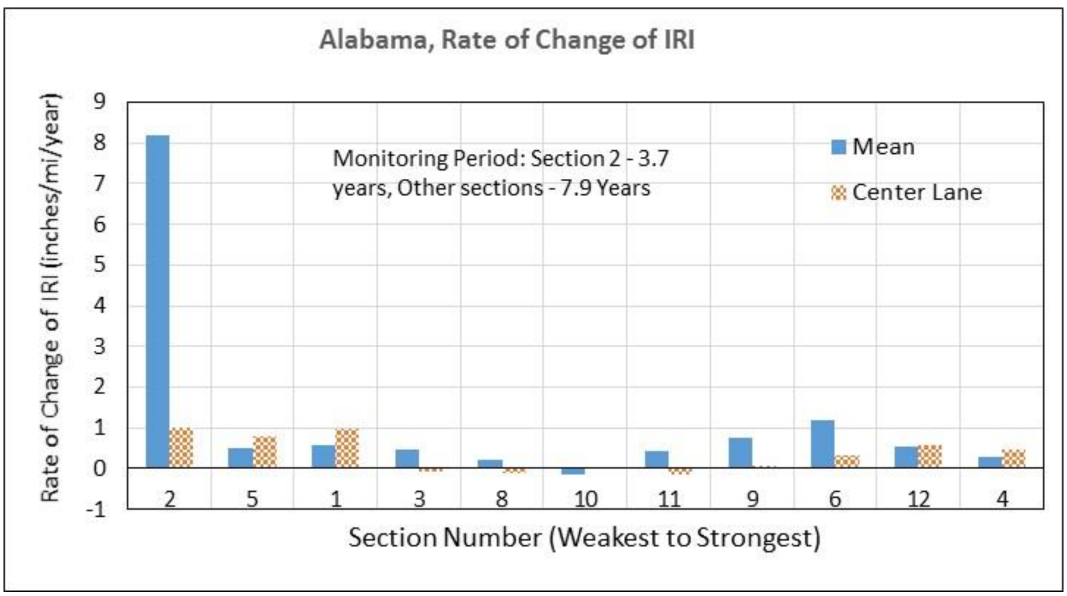

Figure 56. Graph. Rate of change of IRI at test sections in the Alabama SPS-1 project.

Arizona Project

The climatic and subgrade properties and annual KESALs at the Arizona SPS-1 project are shown in table 68. The time periods over which center of the lane data were available at the test sections in this project are shown in table 69. As shown in this table, one group of sections had data over a 5.1-year period, while the other group had data over a 9.2-year period. Figure 57 and figure 58 show the change in IRI for sections that had data over a 5.1-year and 9.2-year period, respectively. Figure 59 and figure 60 show the rate of change of IRI for sections that had data over a 5.1-year and 9.2-year period, respectively. When considering all sections, the change in MIRI was greater than the change in CLIRI at 11 test sections. When considering all sections, the rate of increase of CLIRI was less than 2 inches/mi/year at all test sections and less than 1 inch/mi/year at nine sections.

Table 68. Climatic and subgrade properties and traffic level for the Arizona SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	DNF
	Annual precipitation (inches)	7
	Wet days per year	56
	Intense precipitation days per year	3
	Mean annual temperature (°F)	67
	Days above 90 °F per year	138
	Days below 32 °F per year	19
	FI (°F days/year)	0
	Freeze-thaw cycles per year	19
Subgrade	Subgrade category	Coarse-grained
	Percent material passing through No. 200 sieve	16.5
	Percent silt	10.8
	Percent clay	5.7
Traffic	Average annual KESALs	265

Table 69. Availability of IRI data for the Arizona SPS-1 project.

Section Numbers	Age of Pavement (Years): When First Center of the Lane Data Collected	Age of Pavement (Years): When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
15, 17, 19, 23, 24	3.5	12.7	9.2
13, 14, 16, 18, 21, 22	3.5	8.6	5.1

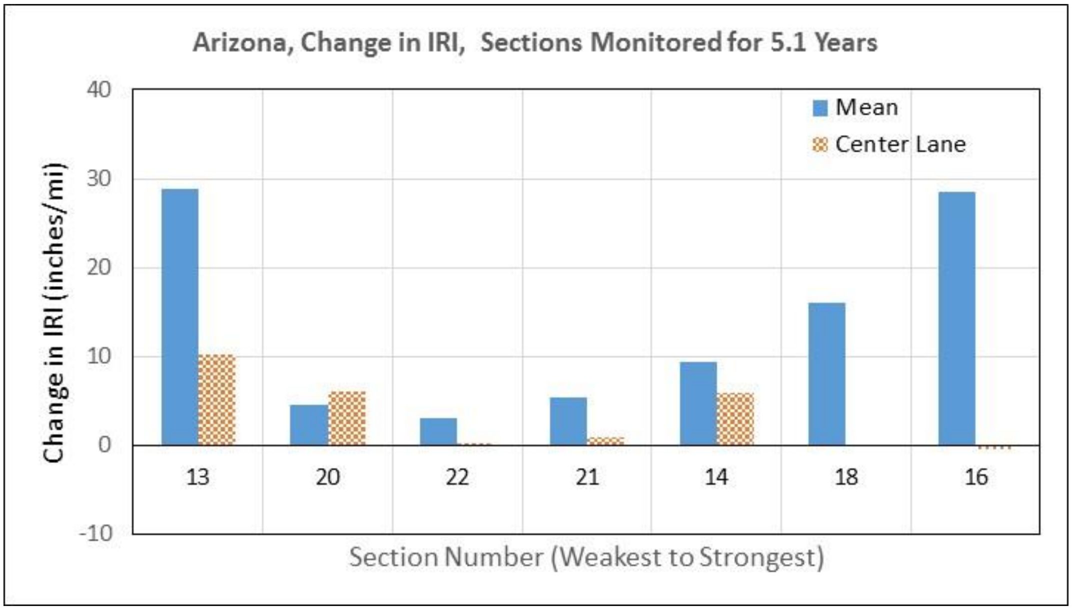

Figure 57. Graph. Change in IRI at test sections in the Arizona SPS-1 project that had data over a 5.1-year period.

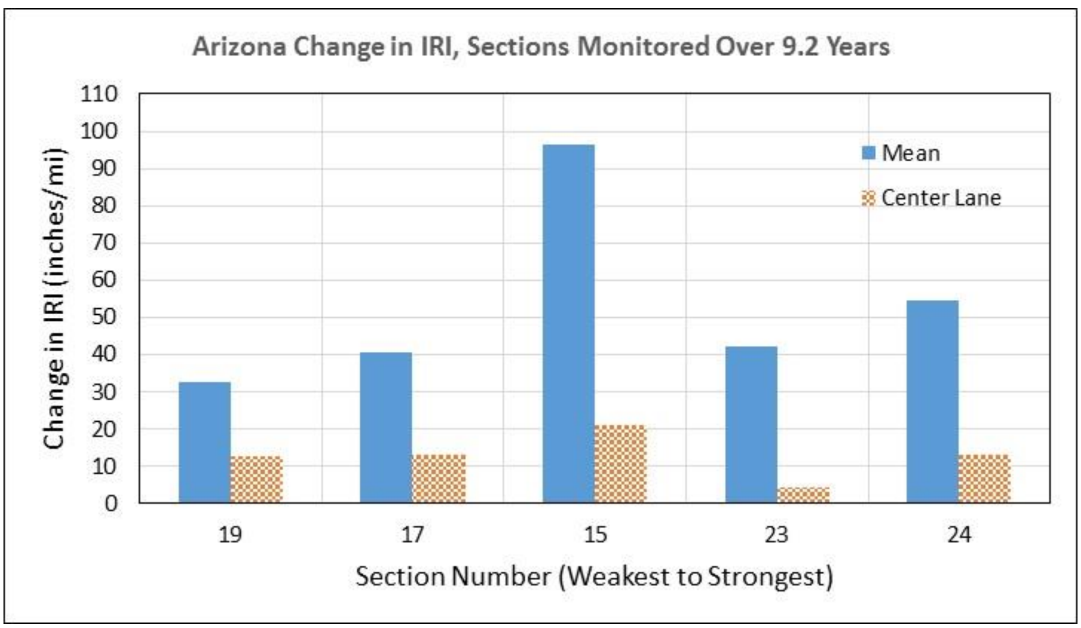

Figure 58. Graph. Change in IRI at test sections in the Arizona SPS-1 project that had data over a 9.2-year period.

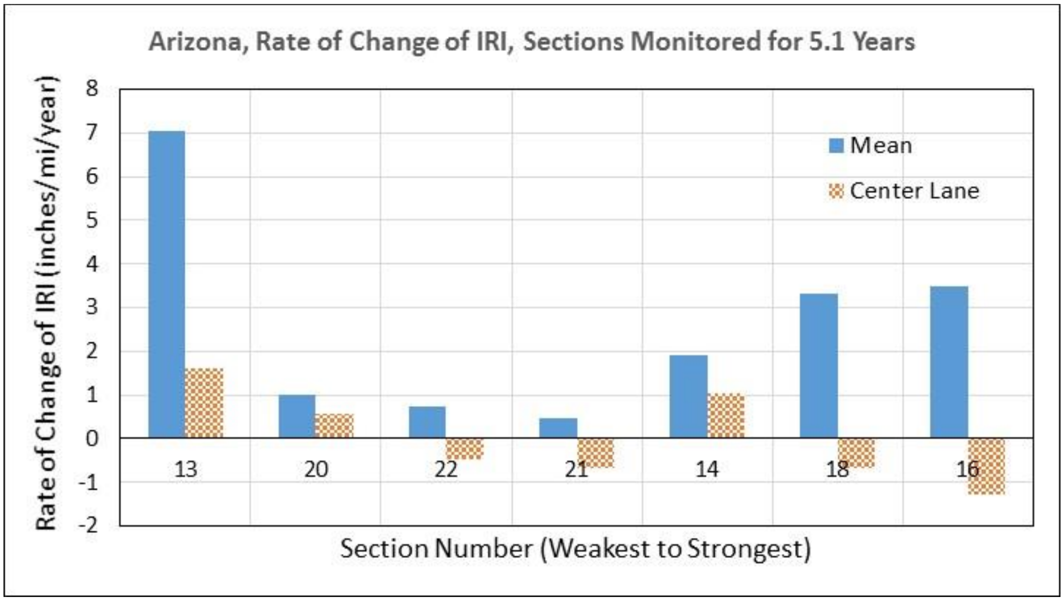

Figure 59. Graph. Rate of change of IRI at test sections in the Arizona SPS-1 project that had data over a 5.1-year period.

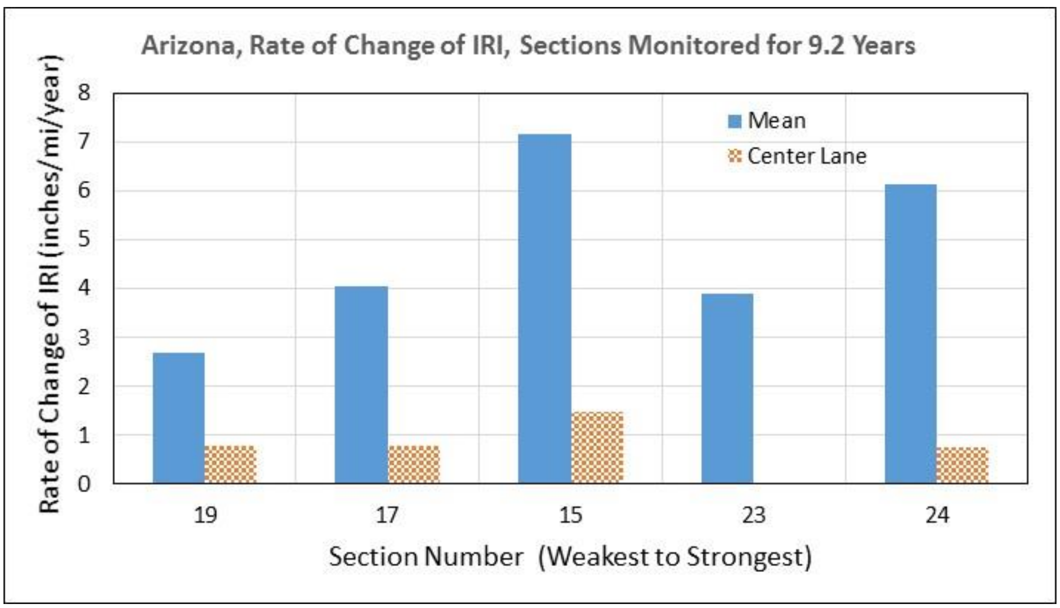

Figure 60. Graph. Rate of change of IRI at test sections in the Arizona SPS-1 project that had data over a 9.2-year period.

Arkansas Project

The climatic and subgrade properties and annual KESALs at the Arkansas SPS-1 project are shown in table 70. The time periods over which center of the lane data were available at the test sections in this project are shown in table 71. As shown in this table, no data were available for sections 19 and 20, section 21 had data over a 6.9-year period, and the other sections had data over a 9.9-year period. Figure 61 shows the change in IRI at the test sections over the monitored period, while figure 62 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at all test sections. The rate of increase of CLIRI was less than 1.6 inches/mi/year at all test sections and less than 1 inch/mi/year at five test sections. The rate of increase of MIRI was less than 2 inches/mi/year for four test sections.

Table 70. Climatic and subgrade properties and traffic level for the Arkansas SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WNF
	Annual precipitation (inches)	47
	Wet days per year	129
	Intense precipitation days per year	32
	Mean annual temperature (°F)	61
	Days above 90 °F per year	56
	Days below 32 °F per year	63
	FI (°F days/year)	115
	Freeze-thaw cycles per year	56
Subgrade	Subgrade category	Coarse-grained
	Percent material passing through No. 200 sieve	18.1
	Percent silt	12.7
	Percent clay	5.4
Traffic	Average annual KESALs	416

Table 71. Availability of IRI data for the Arkansas SPS-1 project.

Section Numbers	Age of Pavement (Years): When First Center of the Lane Data Collected	Age of Pavement (Years): When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
21	2.8	9.6	6.8
13–20 and 22–24	2.8	12.7	9.9

Note: No data for sections 19 and 20.

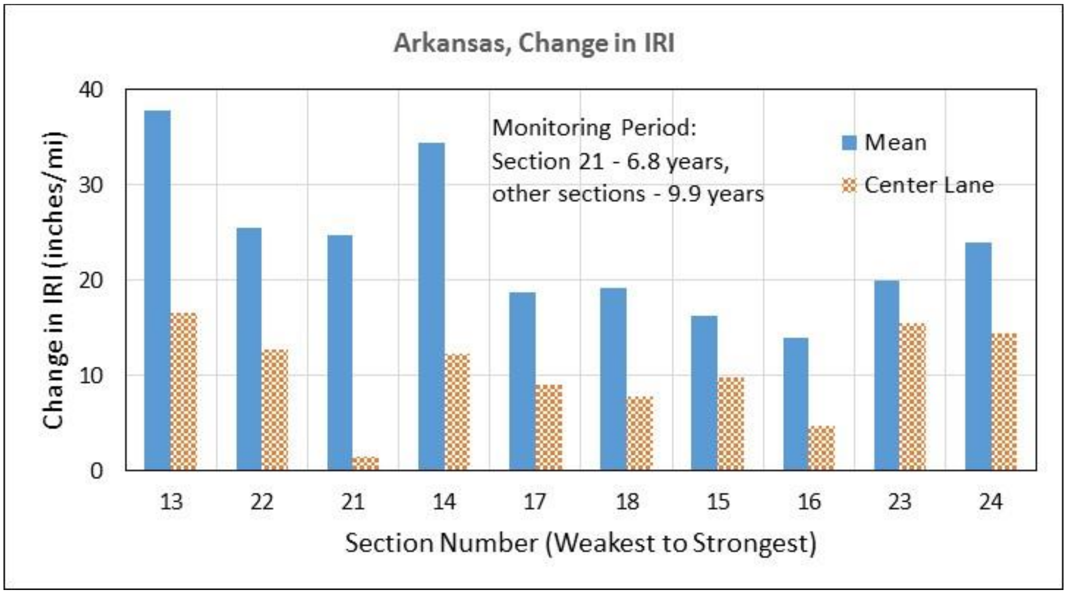

Figure 61. Graph. Change in IRI at test sections in the Arkansas SPS-1 project.

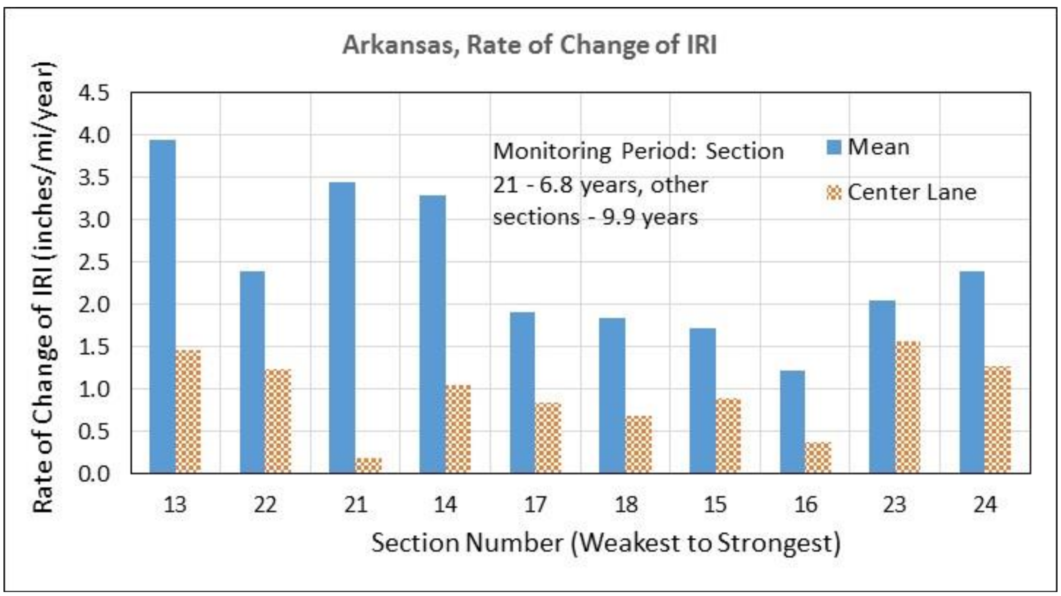

Figure 62. Graph. Rate of change of IRI at test sections in the Arkansas SPS-1 project.

Delaware Project

The climatic and subgrade properties and annual KESALs at the Delaware SPS-1 project are shown in table 72. The time period over which center of the lane data were available at the test sections in this project is shown in table 73. All test sections in this project had data over a 9-year period. Figure 63 shows the change in IRI at the test sections over the monitored period, while figure 64 shows the rate of change of IRI at the test sections. MIRI as well as CLIRI showed variability over the monitored period at all test sections. For example, for section 10, the first and last CLIRI values were both 44 inches/mi. However, over the monitored period, CLIRI ranged from 37 to 51 inches/mi. Hence, for this section, the change in CLIRI over the monitored period was 0; however, the best fit line on the data points indicated the rate of change of CLIRI was 1.03 inches/mi/year. Consequently, in figure 63, MIRI and CLIRI show little change for the structurally strongest eight test sections, but in figure 64, the rate of change of IRI for these test sections shows values up to about 1 inch/mi/year. The absolute change in MIRI was greater than the change in CLIRI at seven test sections. The rate of increase of CLIRI was less than 1.2 inches/mi/year at all test sections, while the rate of increase of MIRI was less than 2 inches/mi/year at 10 test sections.

Table 72. Climatic and subgrade properties and traffic level for the Delaware SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WNF
	Annual precipitation (inches)	48
	Wet days per year	153
	Intense precipitation days per year	31
	Mean annual temperature (°F)	56
	Days above 90 °F per year	15
	Days below 32 °F per year	81
	Freeze Index (°F days/year)	148
	Freeze-thaw cycles per year	73
Subgrade	Subgrade category	Coarse-grained
	Percent material passing through No. 200 sieve	25.5
	Percent silt	16.5
	Percent clay	9
Traffic	Average annual KESALs	384

Table 73. Availability of IRI data for the Delaware SPS-1 project.

Section Numbers	Age of Pavement (Years): When First Center of the Lane Data Collected	Age of Pavement (Years): When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
1–12	1.1	10.1	9

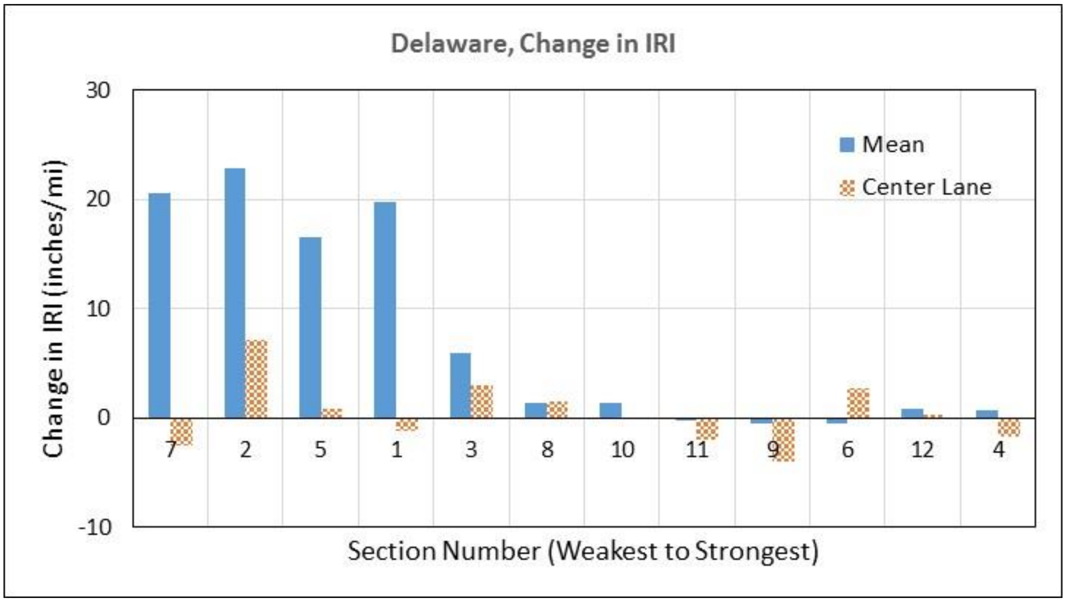

Figure 63. Graph. Change in IRI at test sections in the Delaware SPS-1 project.

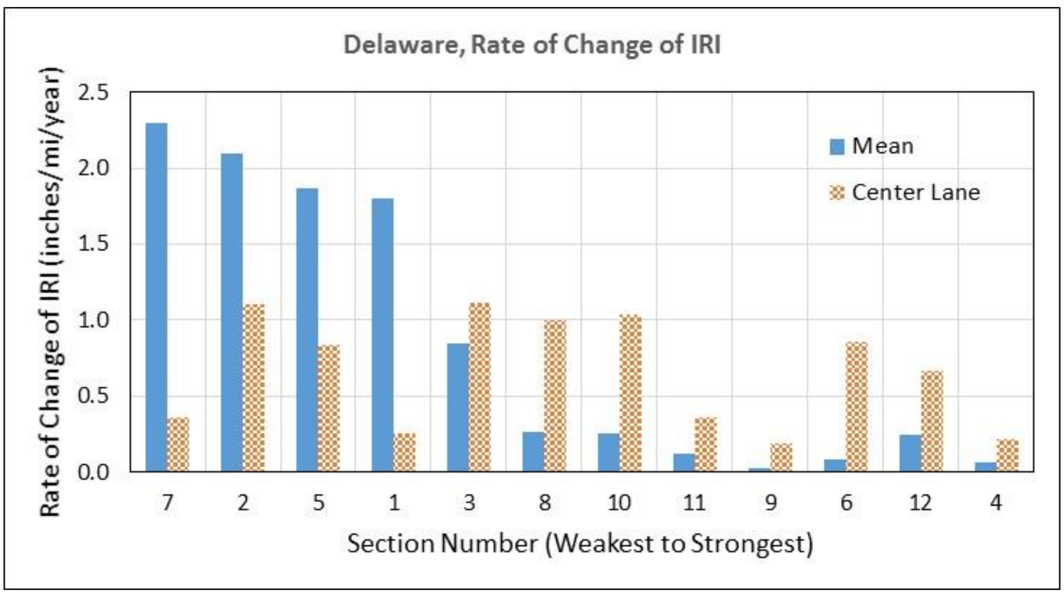

Figure 64. Graph. Rate of change of IRI at test sections in the Delaware SPS-1 project.

New Mexico Project

The climatic and subgrade properties and annual KESALs at the New Mexico SPS-1 project are shown in table 74. The time period over which center of the lane data were available at the test sections in this project is shown in table 75. All test sections in this project had data over a 9.1-year period. Figure 65 shows the change in IRI at the test sections over the monitored period, while figure 66 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at three test sections. The change in MIRI and CLIRI as well as the rate of increase of MIRI and CLIRI were close to each other at all test sections. The rate of change of MRI and CLIRI was greater than 2 inches/mi/year at all test sections. The highest median rate of increase of CLIRI for an SPS-1 project occurred at the New Mexico project (see table 49). Raveling was recorded at all test sections in the New Mexico project during the distress surveys that were performed close to the last profile date. The high rate of increase of CLIRI was attributed to the raveling that was present on the pavement. The first and last dates when center of the lane data were collected at section 12 in this project were 3/11/1997 and 4/24/2006, respectively, and CLIRI for these two dates were 38 and 94 inches/mi, respectively. Figure 67 shows a plot of the profile data collected for these two dates over a portion of the project that were filtered to remove wavelength content greater than 50 ft in order to see details of the profile clearly. The high scatter in the data points in the profile data collected on 4/24/2006 when compared with data collected on 3/11/1997 was attributed to the raveling of the pavement surface. Raveling was believed to be a major contributor to the increases in MIRI and CLIRI at the test sections in this project.

Table 74. Climatic and subgrade properties and traffic level for the New Mexico SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	DNF
	Annual precipitation (inches)	10
	Wet days per year	73
	Intense precipitation days per year	3
	Mean annual temperature (°F)	62
	Days above 90 °F per year	103
	Days below 32 °F per year	93
	FI (°F days/year)	11
	Freeze-thaw cycles per year	93
Subgrade	Subgrade category	Fine-Grained
	Percent material passing through No. 200 sieve	35.1
	Percent silt	27.3
	Percent clay	62.4
	PI	30
Traffic	Average annual KESALs	129

Table 75. Availability of IRI data for the New Mexico SPS-1 project.

Section Numbers	Age of Pavement (Years): When First Center of the Lane Data Collected	Age of Pavement (Years): When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
1–12	1.4	10.5	9.1

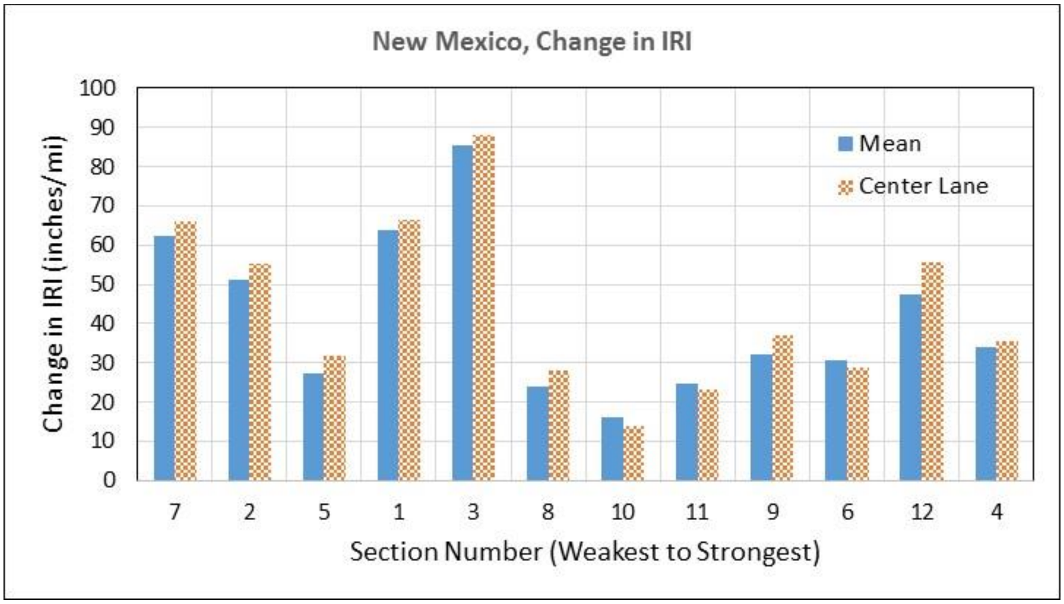

Figure 65. Graph. Change in IRI at test sections in the New Mexico SPS-1 project.

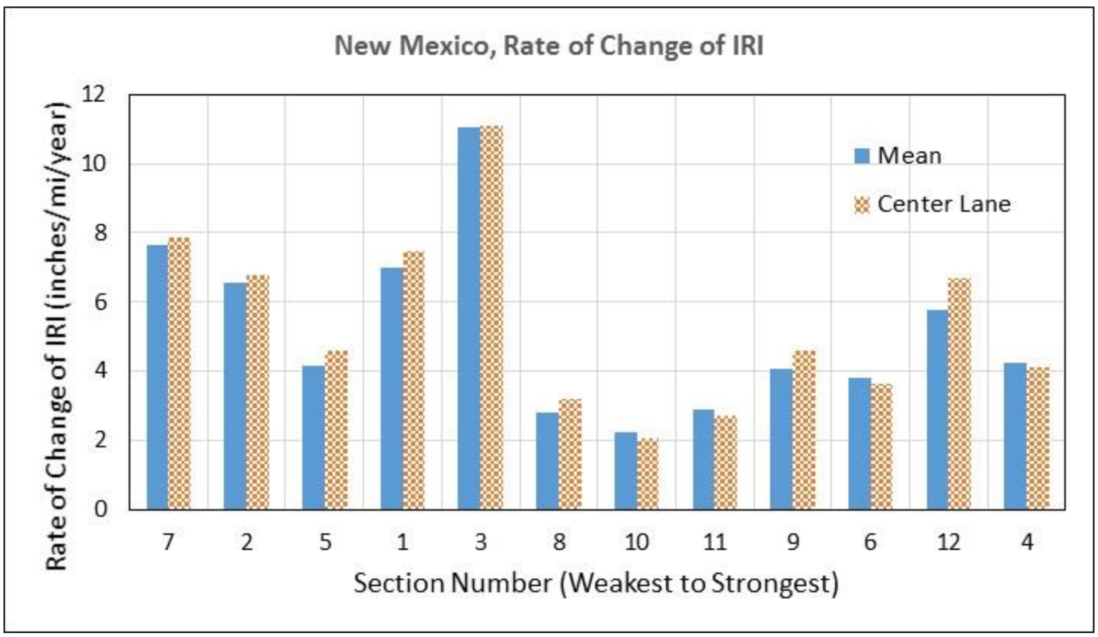

Figure 66. Graph. Rate of change of IRI at test sections in the New Mexico SPS-1 project.

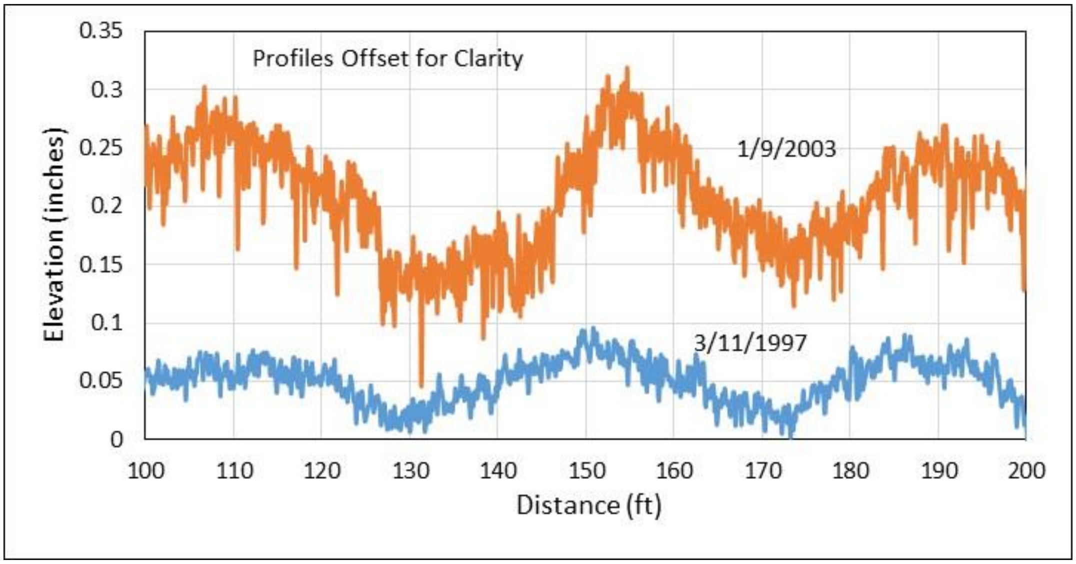

Figure 67. Graph. Center of the lane profile data collected at section 12 in the New Mexico project for two different test dates.

Ohio Project

The climatic and subgrade properties and annual KESALs at the Ohio SPS-1 project are shown in table 76. The time periods over which center of the lane data were available at the test sections in this project are shown in table 77. No data were available for four test sections in this project. The period over which the other sections were monitored ranged from 3 to 13.6 years. Figure 68 shows the change in IRI at the test sections over the monitored period, while figure 69 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at all but one test section. The rate of increase of MIRI and CLIRI was greater than 4 inches/mi/year at all test sections.

Table 76. Climatic and subgrade properties and traffic level for the Ohio SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WF
	Annual precipitation (inches)	42
	Wet days per year	178
	Intense precipitation days per year	24
	Mean annual temperature (°F)	52
	Days above 90 °F per year	11
	Days below 32 °F per year	117
	FI (°F days/year)	578
	Freeze-thaw cycles per year	82
Subgrade	Subgrade category	Fine-grained
	Percent material passing through No. 200 sieve	71.2
	Percent silt	42.8
	Percent clay	28.4
	PI	15
Traffic	Average annual KESALs	485

Table 77. Availability of IRI data for the Ohio SPS-1 project.

Section Numbers	Age of Pavement (Years)		Time Span for Center of the Lane Data (Years)
	When First Center of the Lane Data Collected	When Last Center of the Lane Data Collected	
3, 8–10	3	6	3
11	3	10.8	7.8
6	3	12.7	9.7
4, 12	3	16.6	13.6

Note: No data for sections 1, 2, 5, and 7.

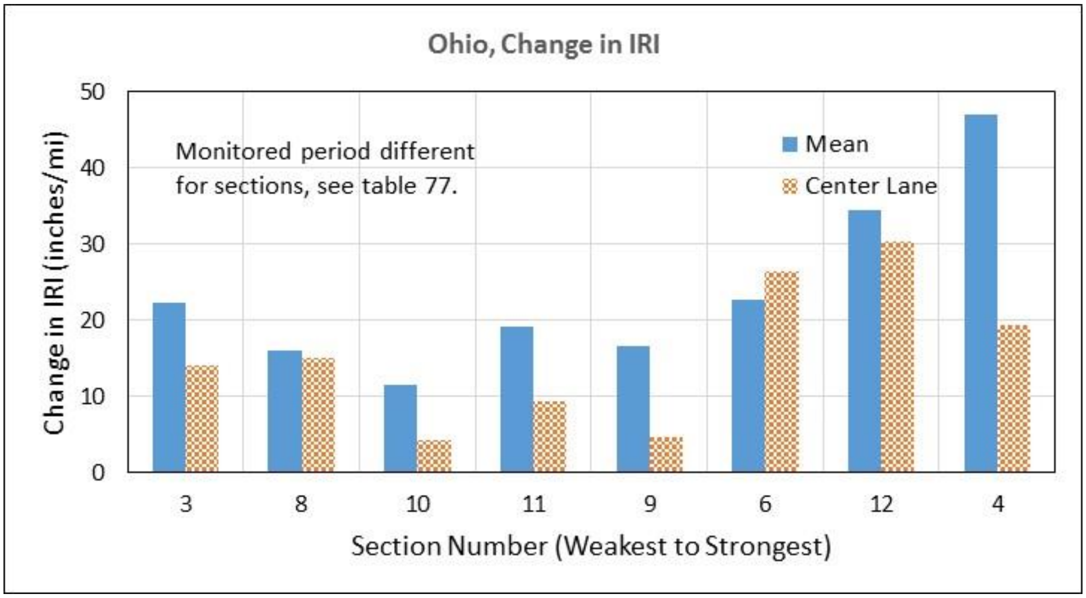

Figure 68. Graph. Change in IRI at test sections in the Ohio SPS-1 project.

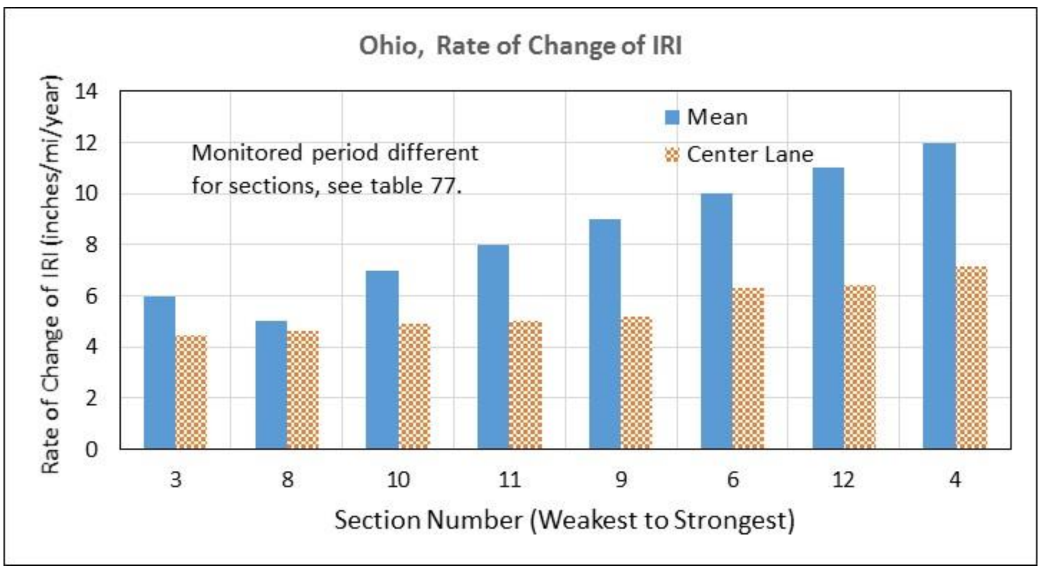

Figure 69. Graph. Rate of change of IRI at test sections in the Ohio SPS-1 project.

ROUGHNESS DEVELOPMENT AT CATEGORY 4 SPS-1 PROJECTS

This section describes roughness development at category 4 SPS-1 projects, which are the projects located in Iowa, Kansas, Michigan, Nebraska, and Texas.

Iowa Project

The climatic and subgrade properties and annual KESALs at the Iowa SPS-1 project are shown in table 78. The time period over which center of the lane data were available at the test sections in this project is shown in table 79. All sections had data for a 3.7-year period. Figure 70 shows the change in IRI at the test sections over this period, while figure 71 shows the rate of change of

IRI at the test sections. The change in MIRI was greater than the change in CLIRI at all test sections. A rate of increase of IRI less than 2 inches/mi/year was noted for MIRI and CLIRI for two and four test sections, respectively. The weakest section in this project (i.e., section 7) had the least change in MIRI as well as CLIRI.

Table 78. Climatic and subgrade properties and traffic level at the Iowa SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WF
	Annual precipitation (inches)	41
	Wet days per year	156
	Intense precipitation days per year	25
	Mean annual temperature (°F)	52
	Days above 90 °F per year	14
	Days below 32 °F per year	113
	FI (°F days/year)	713
	Freeze-thaw cycles per year	76
Subgrade	Subgrade category	Fine-grained
	Percent material passing through No. 200 sieve	87.9
	Percent silt	56.8
	Percent clay	31.1
	PI	27.7
Traffic	Average annual KESALs	133

Table 79. Availability of IRI data for the Iowa SPS-1 project.

Section Numbers	Age of Pavement (Years)		Time Span for Center of the Lane Data (Years)
	When First Center of the Lane Data Collected	When Last Center of the Lane Data Collected	
1–12	4.3	8	3.7

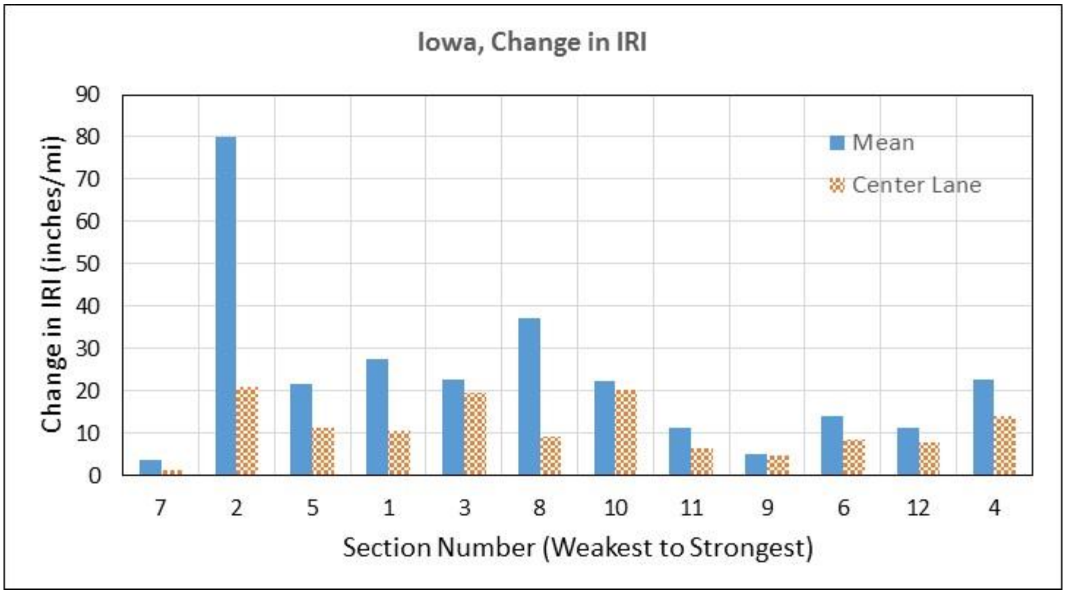

Figure 70. Graph. Change in IRI at the test sections in the Iowa SPS-1 project.

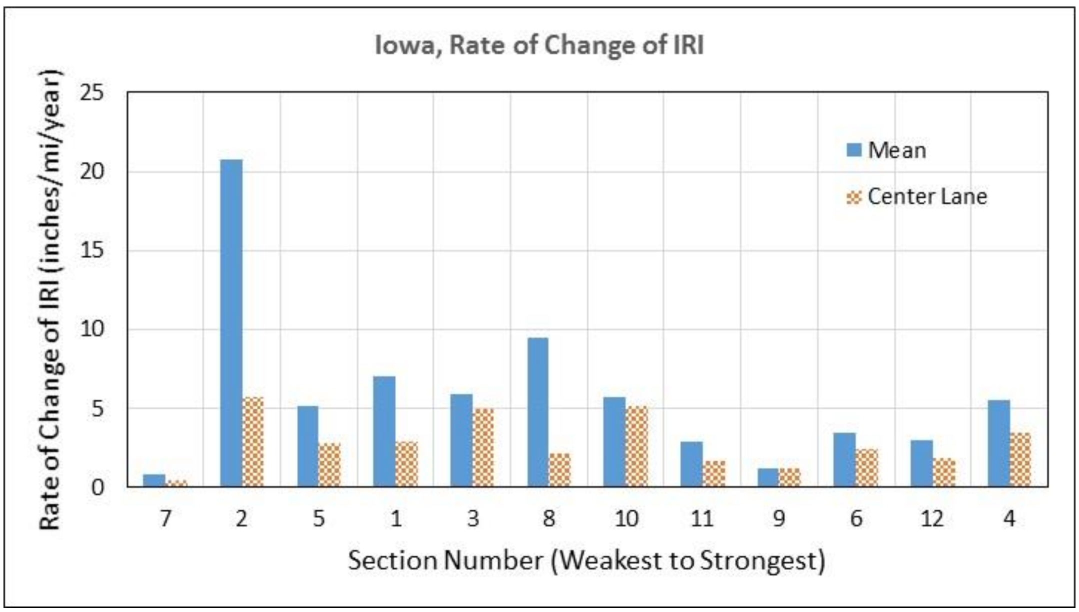

Figure 71. Graph. Rate of change of IRI at test sections in the Iowa SPS-1 project.

Kansas Project

The climatic and subgrade properties and the annual KESALs at the Kansas SPS-1 project are shown in table 80. The time period over which center of the lane data were available at the test sections in this project is shown in table 81. No data were available for sections 1, 2, 5, 6, and 7, while the other sections had data over a 4.2-year period. Figure 72 shows the change in IRI at the test sections over this period, while figure 73 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at all test sections. A rate of increase of IRI less than 2 inches/mi/year was noted for MIRI and CLIRI for one and six test sections, respectively.

Table 80. Climatic and subgrade properties and traffic level at the Kansas SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WF
	Annual precipitation (inches)	27
	Wet days per year	86
	Intense precipitation days per year	16
	Mean annual temperature (°F)	55
	Days above 90 °F per year	56
	Days below 32 °F per year	125
	FI (°F days/year)	394
	Freeze-thaw cycles per year	105
Subgrade	Subgrade category	Coarse-grained
	Percent material passing through No. 200 sieve	30.4
	Percent silt	18.9
	Percent clay	11.5
Traffic	Average annual KESALs	255

Table 81. Availability of IRI data for the Kansas SPS-1 project.

Section Numbers	Age of Pavement (Years) When First Center of the Lane Data Collected	Age of Pavement (Years) When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
3, 4, 8–12	3.3	7.5	4.2

Note: No data for sections 1, 2, 5, 6, and 7.

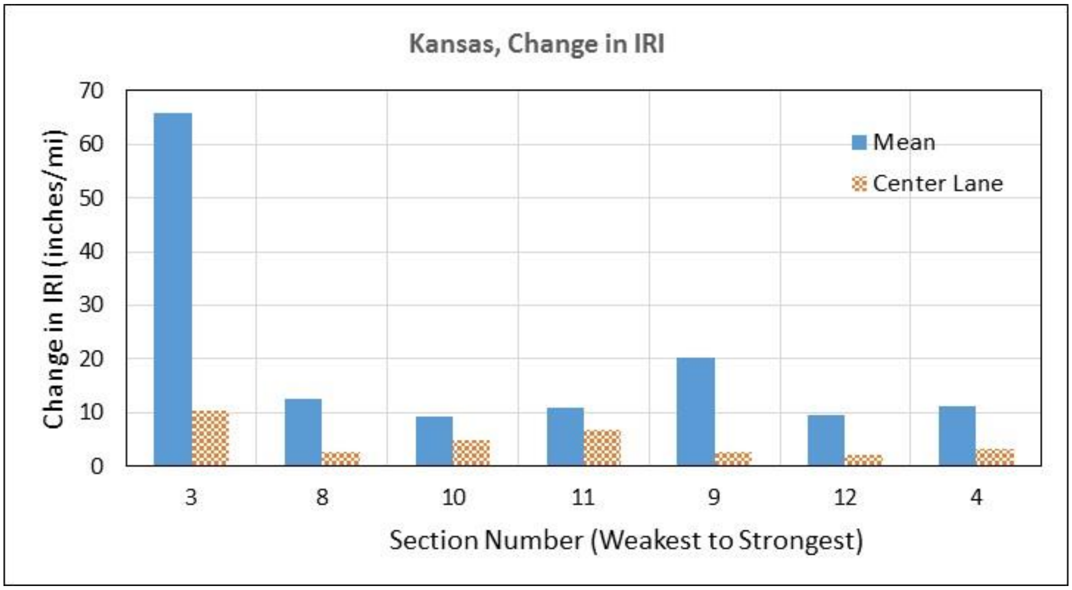

Figure 72. Graph. Change in IRI at test sections in the Kansas SPS-1 project.

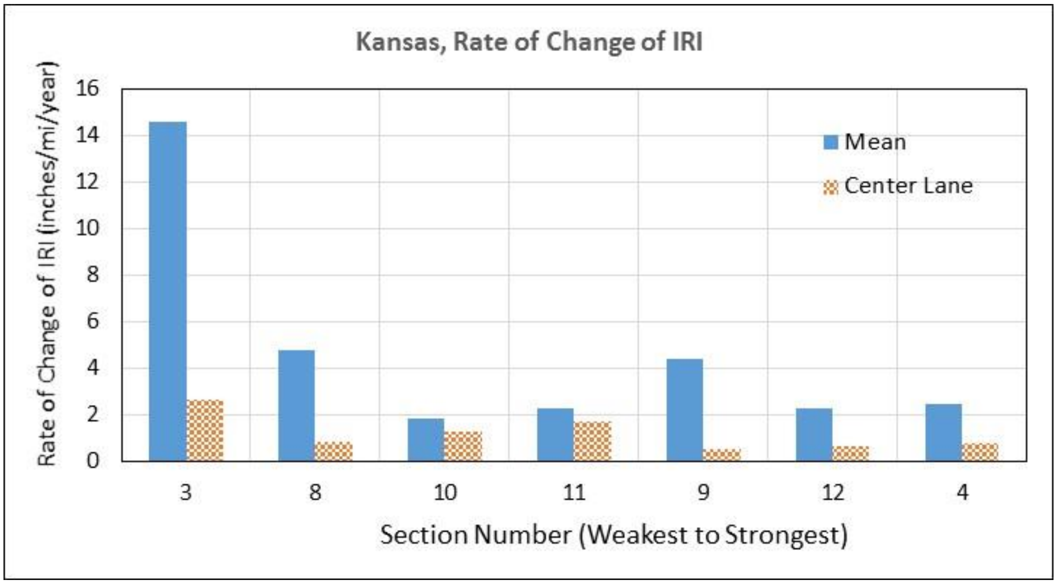

Figure 73. Graph. Rate of change of IRI at test sections in the Kansas SPS-1 project.

Michigan Project

The climatic and subgrade properties and the annual KESALs at the Michigan SPS-1 project are shown in table 82. The time periods over which center of the lane data were available at the test sections in this project are shown in table 83. No data were available for four sections, while seven sections had data over a 5.2-year period, and one test section had data over a 3.6-year period. Figure 74 shows the change in IRI at the test sections over this period, while figure 75 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at six out of the eight test sections. A rate of increase of IRI less than 2 inches/mi/year was noted for MRI and CLIRI for four and six test sections, respectively.

Table 82. Climatic and subgrade properties and traffic level at the Michigan SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WF
	Annual precipitation (inches)	32
	Wet days per year	142
	Intense precipitation days per year	18
	Mean annual temperature (°F)	49
	Days above 90 °F per year	9
	Days below 32 °F per year	136
	FI (°F days/year)	823
	Freeze-thaw cycles per year	86
Subgrade	Subgrade category	Fine-grained
	Percent material passing through No. 200 sieve	62.7
	Percent silt	39
	Percent clay	23.7
	PI	10.3
Traffic	Average annual KESALs	364

Table 83. Availability of IRI data for the Michigan SPS-1 project.

Section Numbers	Age of Pavement (Years): When First Center of the Lane Data Collected	Age of Pavement (Years): When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
15–18, 20, 23, 24	1.4	6.6	5.2
21	3	6.6	3.6

Note: No data for sections 13, 14, 19, and 22.

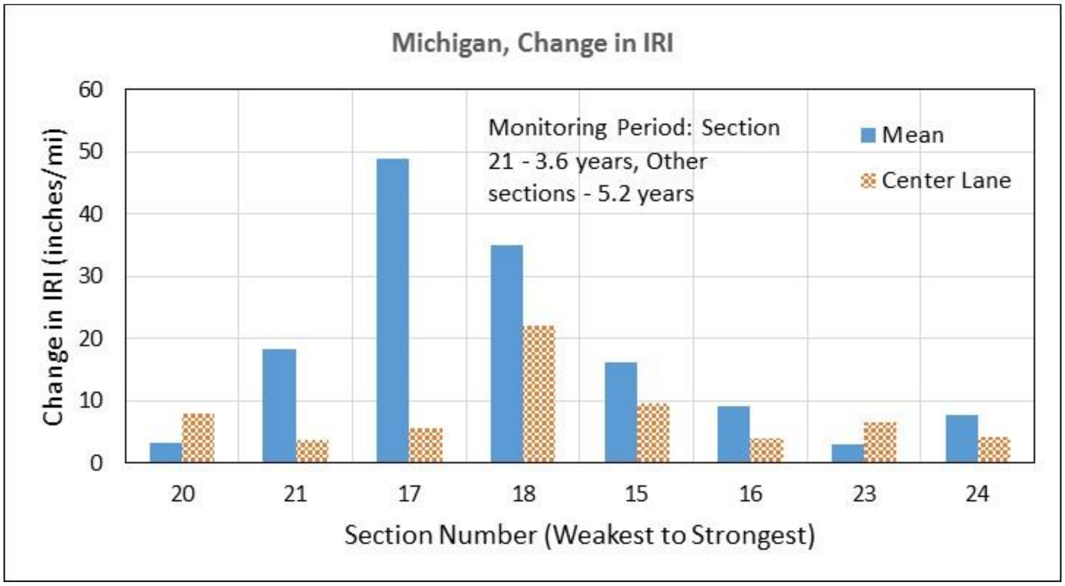

Figure 74. Graph. Change in IRI at test sections in the Michigan SPS-1 project.

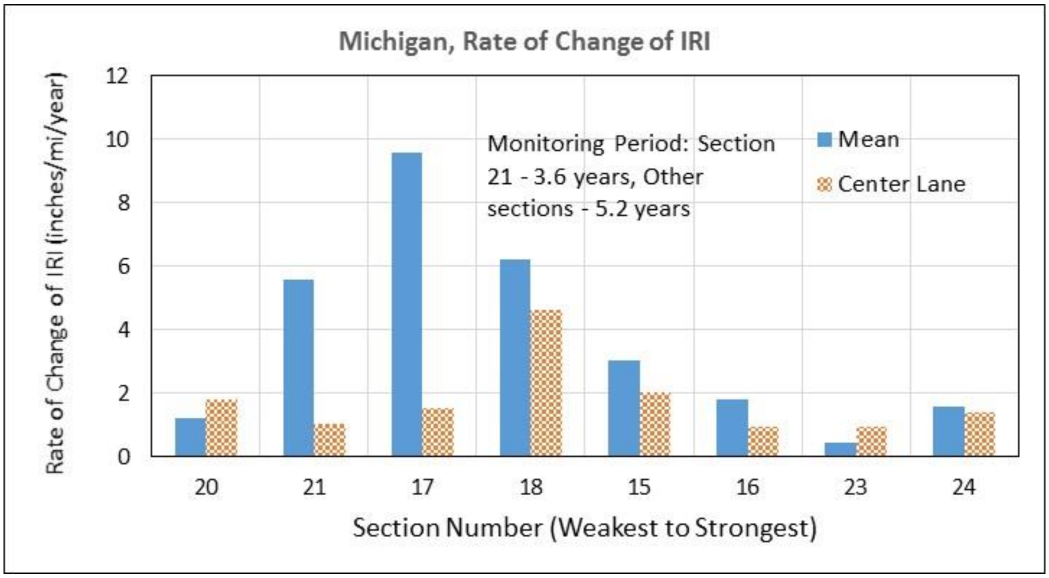

Figure 75. Graph. Rate of change of IRI at test sections in the Michigan SPS-1 project.

Nebraska Project

The climatic and subgrade properties and the annual KESALs at the Nebraska SPS-1 project are shown in table 84. The time period over which center of the lane data were available at the test sections in this project is shown in table 85. All sections had data over a 3-year period, with data collected five times at all test sections during this period. Figure 76 shows the change in IRI at the test sections over this period, while figure 77 shows the rate of change of IRI at the test sections. A rate of increase of IRI less than 2 inches/mi/year was noted for MRI and CLIRI for 10 and 7 test sections, respectively. At some sections, a negative rate of increase of MIRI or CLIRI was noted. The time-sequence data at these sections were variable and showed an overall weak trend of decreasing IRI values. However, the data at these sections were collected over a 3-year period, so the observed trend might simply be the result of variability in the profiled paths and/or due to seasonal variability.

Table 84. Climatic and subgrade properties and traffic level at the Nebraska SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WF
	Annual precipitation (inches)	27
	Wet days per year	101
	Intense precipitation days per year	17
	Mean annual temperature (°F)	52
	Days above 90 °F per year	44
	Days below 32 °F per year	137
	FI (°F days/year)	671
	Freeze-thaw cycles per year	105
Subgrade	Subgrade category	Fine-grained
	Percent material passing through No. 200 sieve	98.9
	Percent silt	66.7
	Percent clay	32.2
	PI	20.3
Traffic	Average annual KESALs	139

Table 85. Availability of IRI data for the Nebraska SPS-1 project.

Section Numbers	Age of Pavement (Years)		Time Span for Center of the Lane Data (Years)
	When First Center of the Lane Data Collected	When Last Center of the Lane Data Collected	
13–24	1.6	4.6	3

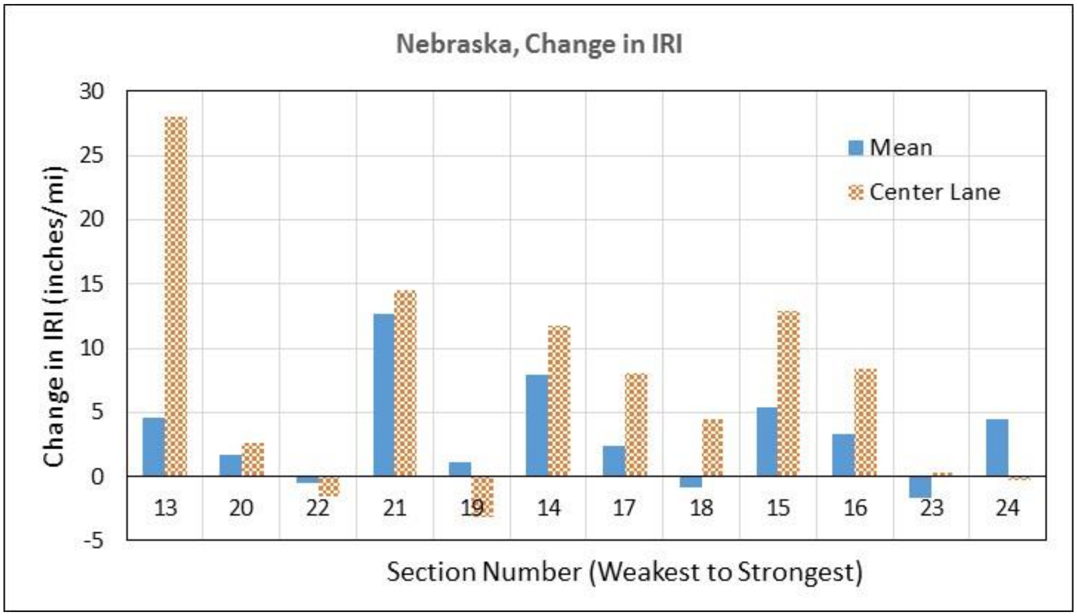

Figure 76. Graph. Change in IRI at test sections in the Nebraska SPS-1 project.

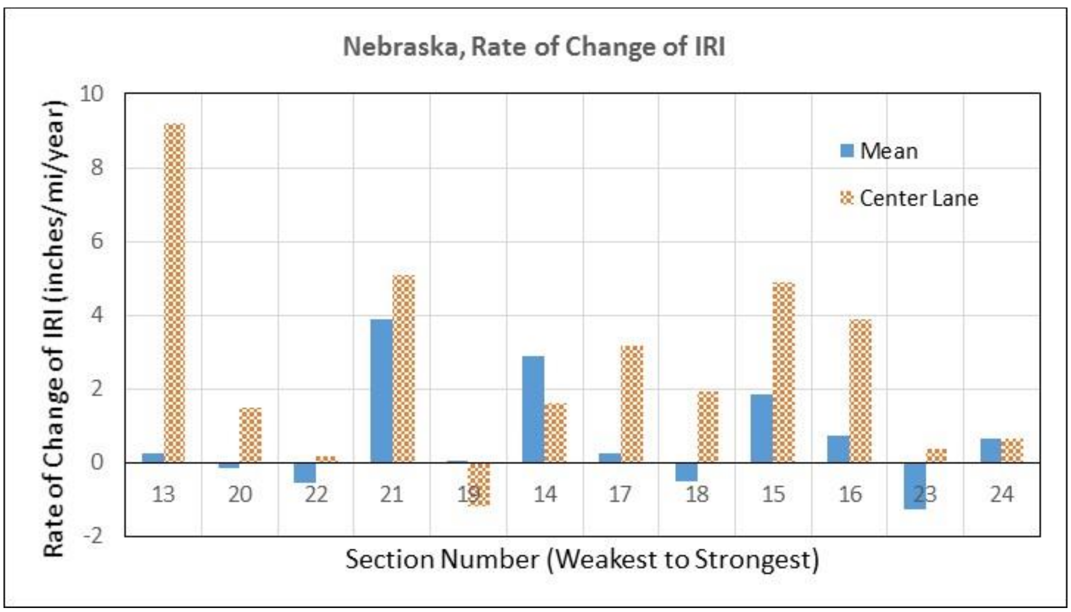

Figure 77. Graph. Rate of change of IRI at test sections in the Nebraska SPS-1 project.

Texas Project

The climatic and subgrade properties and the annual KESALs at the Texas SPS-1 project are shown in table 86. The time periods over which center of the lane data were available at the test sections in this project are shown in table 87. Four test sections had data over a 1.9-year period where the sections were profiled four times, while eight test sections had data over a 3.5-year period where the sections were profiled five times. Figure 78 shows the change in IRI at the test sections over this period, while figure 79 shows the rate of change of IRI at the test sections. Several sections had a lower MIRI as well as a CLIRI at the last date when compared with the first date. This resulted in a negative change in IRI as well as a negative rate of change of IRI. The data at the test sections in this project were collected over a very short time (i.e., 1.9 years or 3.5 years). Hence, the observed trend in the IRI values could be the result of the variability in the profiled path between the visits and/or seasonal variability. The largest change in IRI at the test sections was observed at section 24, where CLIRI increased by 16 inches/mi. MIRI at this section decreased by 6 inches/mi. This section had no distress, and the reason for the increase in CLIRI could not be determined from the profile data.

Table 86. Climatic and subgrade properties and traffic level at the Texas SPS-1 project.

Property	Parameter	Value
Climatic	Climatic region	WNF
	Annual precipitation (inches)	24
	Wet days per year	100
	Intense precipitation days per year	13
	Mean annual temperature (°F)	75
	Days above 90 °F per year	158
	Days below 32 °F per year	1
	FI (°F days/year)	0
	Freeze-thaw cycles per year	1
Subgrade	Subgrade category	Coarse-grained
	Percent material passing through No. 200 sieve	11.7
	Percent silt	10.6
	Percent clay	1.1
Traffic	Average annual KESALs	464

Table 87. Availability of IRI data for the Texas SPS-1 project.

Section Numbers	Age of Pavement (Years): When First Center of the Lane Data Collected	Age of Pavement (Years): When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
13, 17, 18, 20–24	0.8	4.3	3.5
14–16, 19	2.4	4.3	1.9

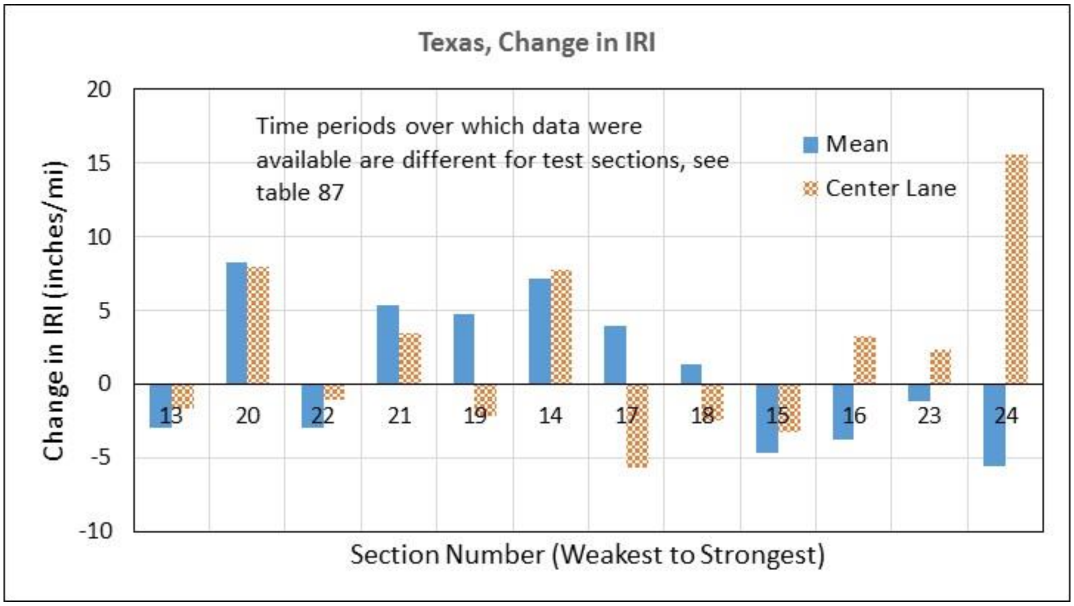

Figure 78. Graph. Change in IRI at test sections in the Texas SPS-1 project.

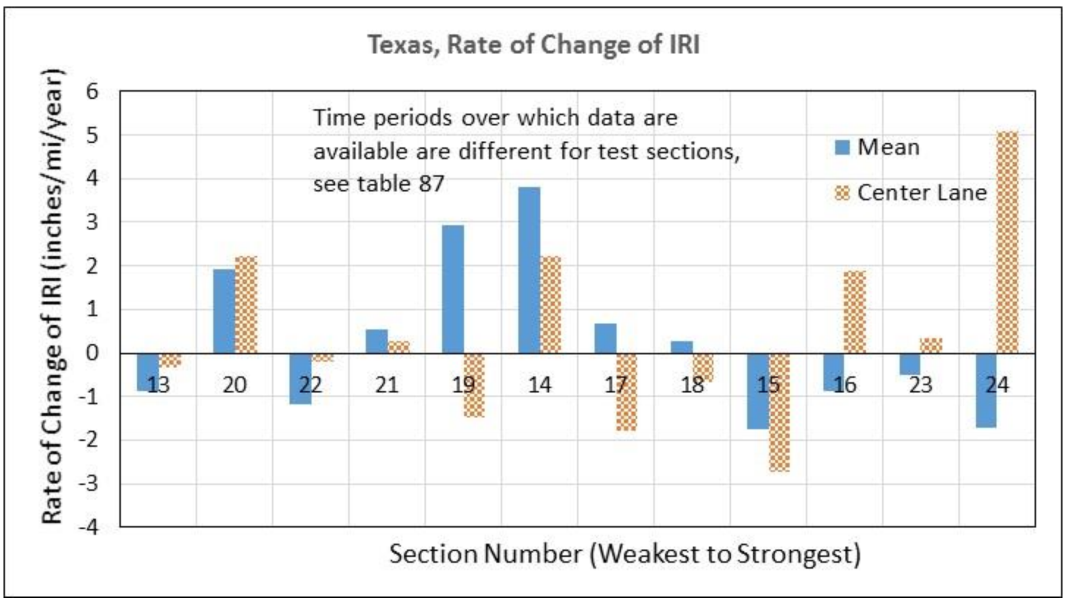

Figure 79. Graph. Rate of change of IRI at test sections in the Texas SPS-1 project.

ROUGHNESS DEVELOPMENT AT OVERLAID SPS-1 PROJECTS

This section describes roughness development at overlaid SPS-1 projects in Michigan and Texas.

Michigan Project After Overlay

The eight test sections in the Michigan SPS-1 project that were not deassigned were overlaid on 10/1/2002. Thereafter, these sections were overlaid again on 6/1/2012. The data collected on the test sections after the first overlay until the second overlay was placed were analyzed. The time period over which center of the lane data were available at the test sections after the overlay for this project is shown in table 88. Figure 80 shows the change in IRI at the test sections over this period, while figure 81 shows the rate of change of IRI at the test sections. Of the eight sections being monitored, the change in MIRI was greater than the change in CLIRI at five test sections.

Table 88. Availability of IRI data for the Michigan SPS-1 project after overlay.

Section Numbers	Age of Pavement (Years): When First Center of the Lane Data Collected	Age of Pavement (Years): When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
15–18, 20, 21, 23, 24	0.5	9.6	9.1

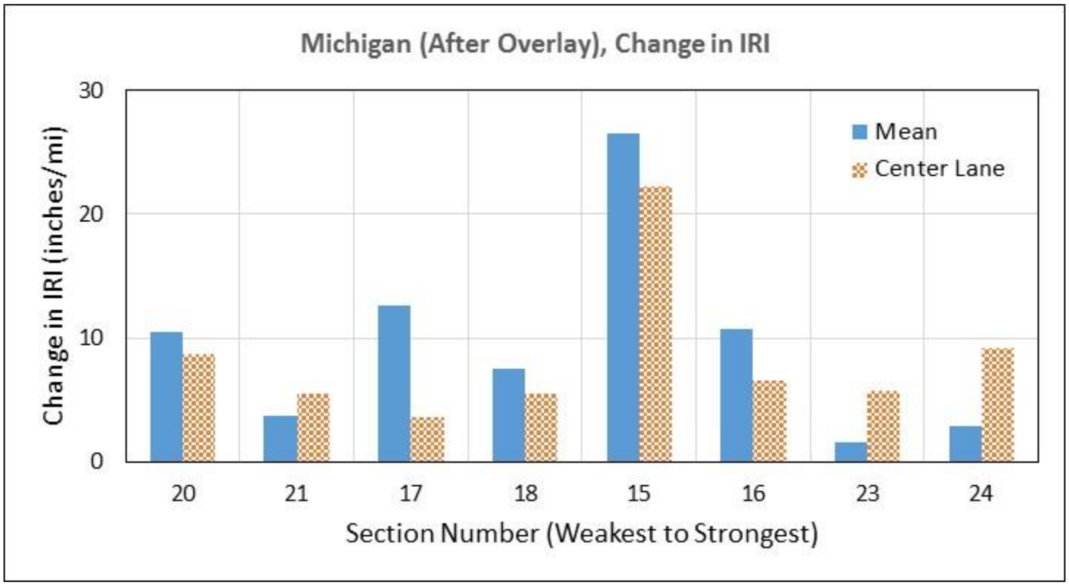

Figure 80. Graph. Change in IRI at the Michigan SPS-1 project after overlay.

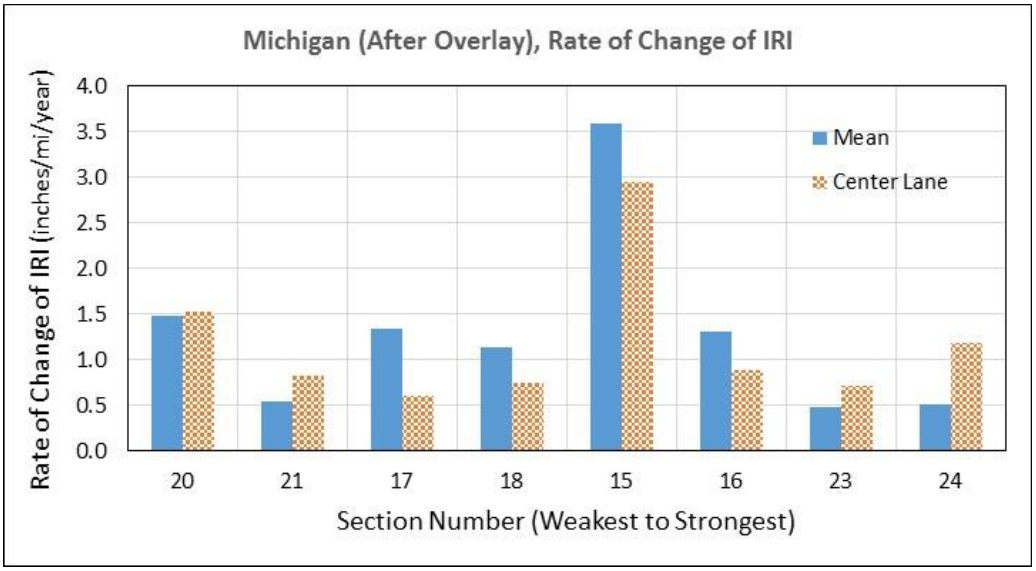

Figure 81. Graph. Rate of change of IRI for sections in the Michigan SPS-1 project after overlay.

Texas Project After Overlay

An overlay was placed on all test sections in the Texas SPS-1 project on 4/29/2002. Thereafter, these sections were overlaid again on 3/31/2007. The data collected at the test sections in this project after the first overlay until the second overlay was placed were analyzed. The time period over which center of the lane data were available at the test sections in this project is shown in table 89. Figure 82 shows the change in IRI at the test sections over this period, while figure 83 shows the rate of change of IRI at the test sections. The change in MIRI was greater than the change in CLIRI at all test sections.

Table 89. Availability of IRI data for the Texas SPS-1 project after the overlay.

Section Numbers	Age of Pavement After Overlay (Years): When First Center of the Lane Data Collected	Age of Pavement After Overlay (Years): When Last Center of the Lane Data Collected	Time Span for Center of the Lane Data (Years)
13–24	1.1	4.9	3.8

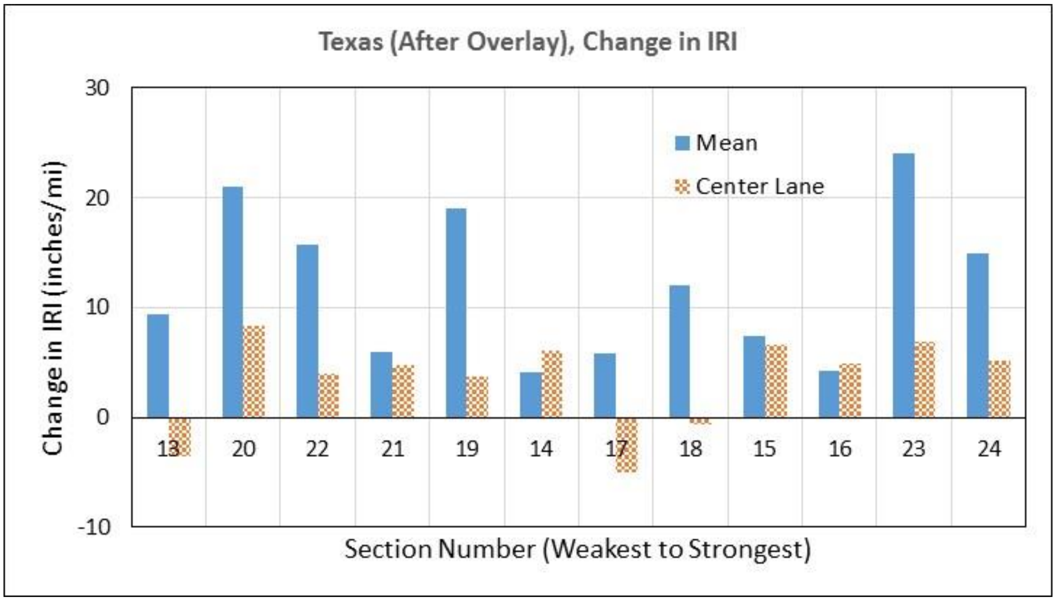

Figure 82. Graph. Change in IRI at the Texas SPS-1 project after overlay.

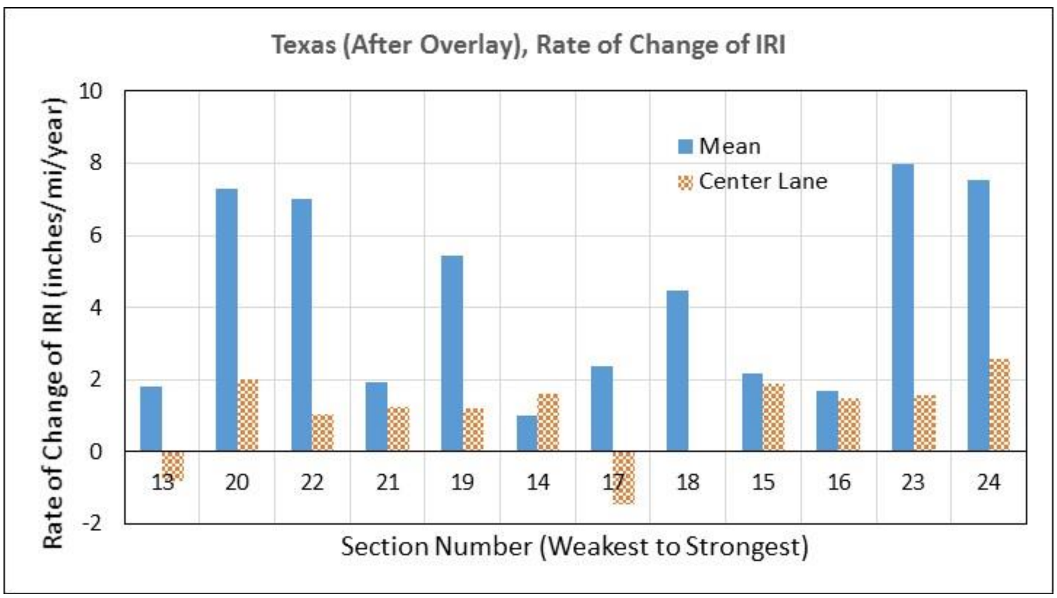

Figure 83. Graph. Rate of change of IRI for sections in the Texas SPS-1 project after overlay.

CHAPTER 6. OVERALL ANALYSIS OF ROUGHNESS CHANGES AT SPS-1 TEST SECTIONS

This chapter presents the overall analysis of roughness changes at SPS-1 test sections, including the relationships between changes in MIRI and CLIRI, changes in IRI and structural strength, changes in IRI and subgrade type, changes in IRI and drainage, and changes in IRI and environmental conditions. This chapter also discusses the effect of PI of subgrade on changes in IRI, the relationship between changes in IRI and transverse cracking, and the effect of seasonal variations on IRI values. The chapter concludes with a detailed investigation of roughness increase at selected sections and a presentation of models for predicting the change in roughness due to environmental effects.

RELATIONSHIP BETWEEN CHANGES IN MIRI AND CLIRI

Figure 84 shows the relationship between the change in MIRI and the change in CLIRI for all SPS-1 test sections. The change in MIRI was greater than the change in CLIRI at 65 percent of the test sections. Figure 85 shows the relationship between the rate of change of MIRI and rate of change of CLIRI that were obtained from the regression analysis. The rate of change of MIRI was greater than the rate of change of CLIRI at 62 percent of the test sections.

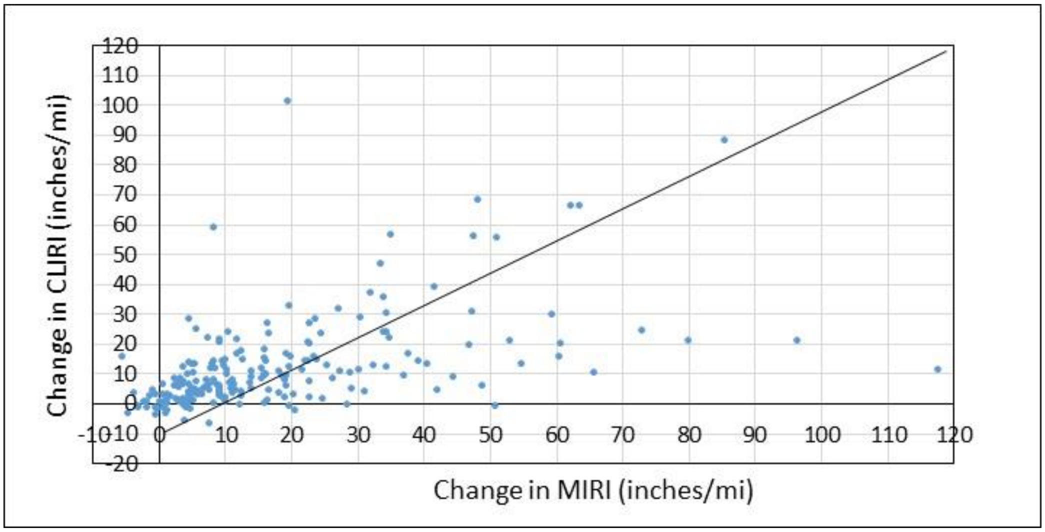

Figure 84. Graph. Change in CLIRI versus change in MIRI.

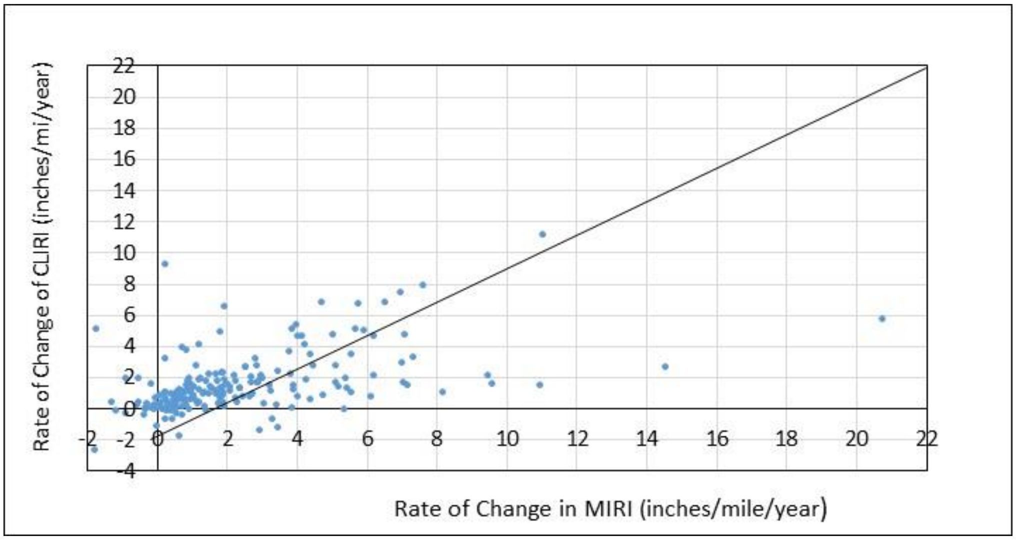

Figure 85. Graph. Rate of change of CLIRI versus rate of change of MIRI.

Figure 86 shows a box plot of the rate of change of MIRI and CLIRI. (See the first subsection of chapter 5 for a description of a box plot.) A rate of change of IRI greater than 10 inches/mi/year was noticed for MIRI at four sections and for CLIRI at one section. A rate of change of IRI less than −2 inches/mi/year was noticed for CLIRI at one section. These data points are not shown in figure 86 or any other plots included in this chapter because if these data points were shown in the plots, it would be difficult to see the changes that affect a majority of the sections. The median, first quartile, and third quartile values for rate of change of MIRI were 1.56, 0.55, and 3.22 inches/mi/year, respectively, while the corresponding values for CLIRI were 1.05, 0.31, and 1.19 inches/mi/year, respectively. A *t*-test indicated the mean value of MIRI was significantly greater than the mean value of CLIRI (significance level = 0.05, *p*-value = 0.002).

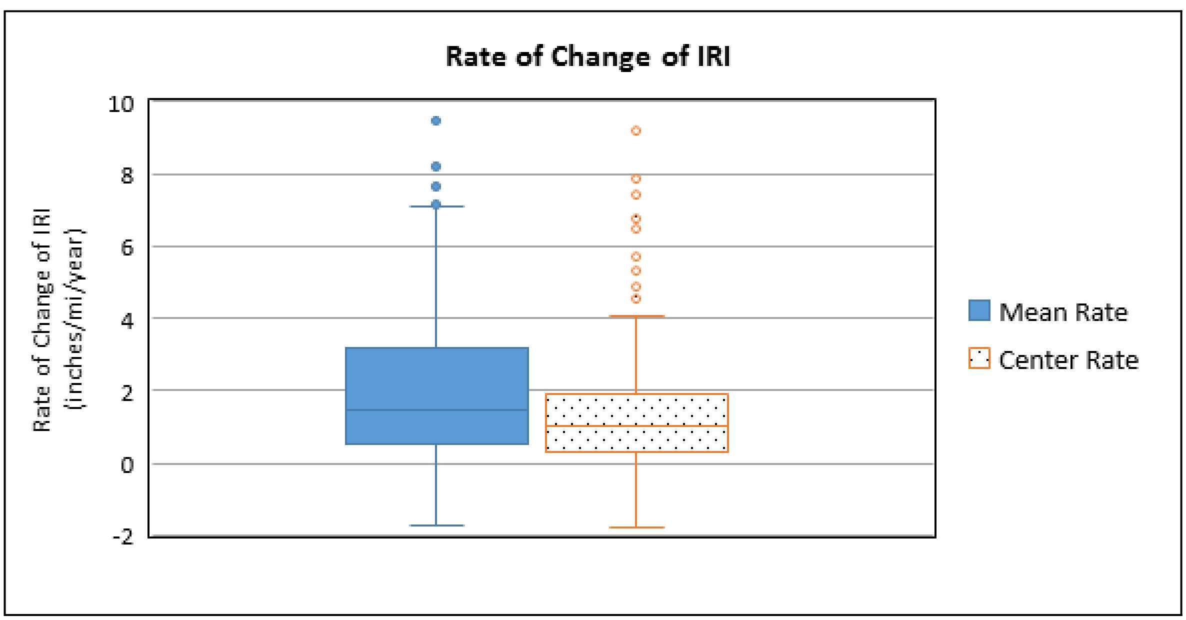

Figure 86. Graph. Box plots showing rate of change of MIRI and CLIRI.

RELATIONSHIP BETWEEN THE CHANGE IN IRI AND STRUCTURAL STRENGTH OF THE TEST SECTION

The relationship between the rate of change of MIRI and SN of the test sections is shown in Figure 87, while this relationship for CLIRI is shown in figure 88. A trend line fitted to each dataset using the method of least squares shows a clear trend of increasing rate of change of MIRI with decreasing SN, while for CLIRI, there was only a slight trend of increasing rate of change of CLIRI with decreasing SN.

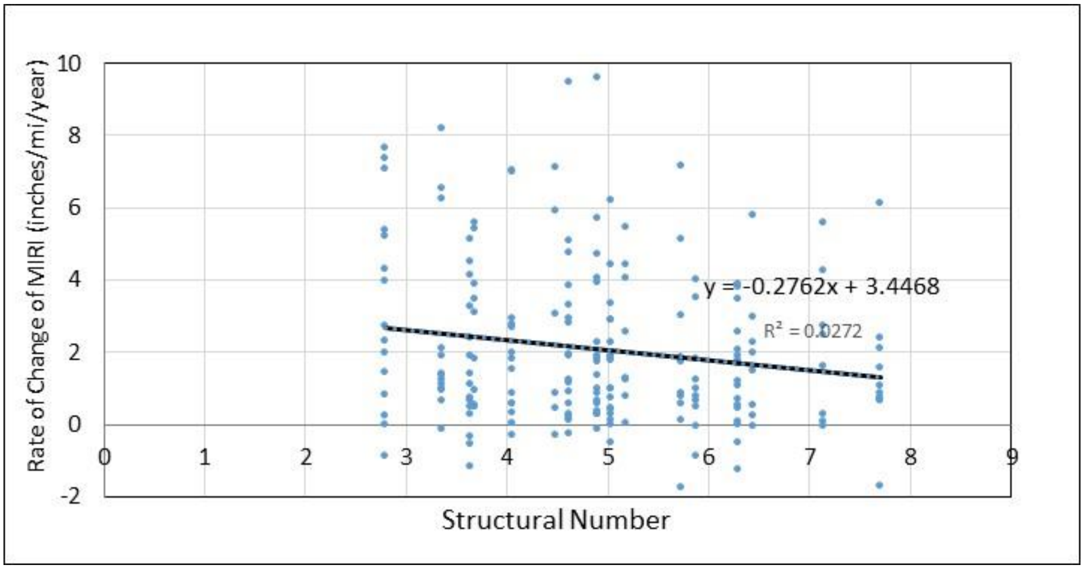

Figure 87. Graph. Relationship between rate of change of MIRI and SN of test sections.

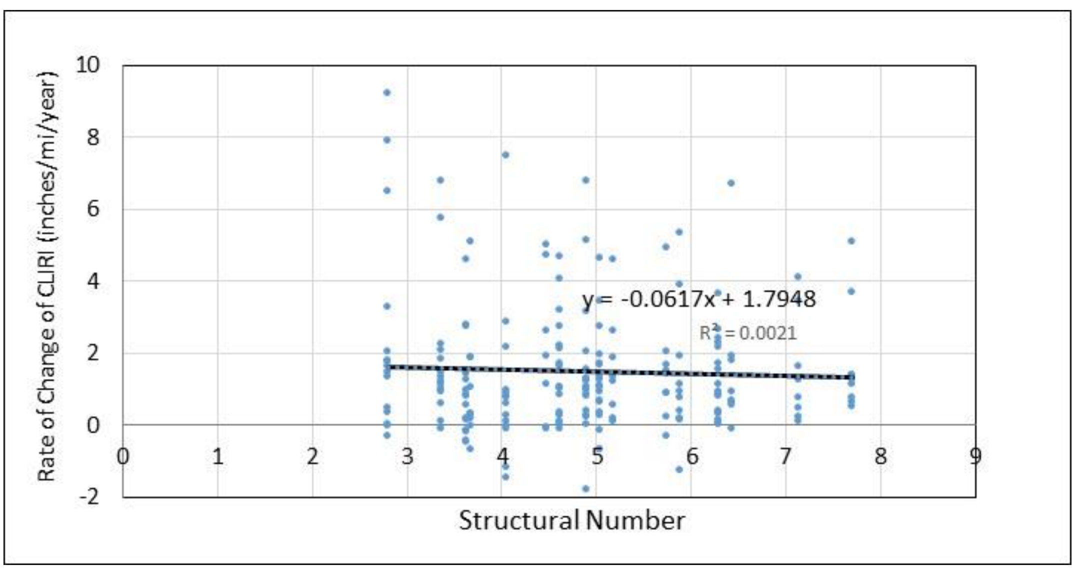

Figure 88. Graph. Relationship between rate of change of CLIRI and SN of test sections.

Test sections 7 and 13, with an SN of 2.8, were the structurally weakest test sections in the SPS-1 experiment, while the next most structurally weak test sections in the SPS-1 experiment were test sections 2 and 20, with an SN of 3.36. For this analysis, test sections 2, 7, 13, and

20 were considered structurally weak test sections, and the other test sections were considered structurally strong test sections. Figure 89 shows a box plot of the rate of change of MIRI and CLIRI for the test sections that were categorized as weak and strong test sections. Table 90 summarizes the following information shown in figure 89 for each dataset: number of test sections; median, first quartile, and third quartile values for the rate of change of IRI; and the range of rate of change of IRI for each dataset excluding outliers. A *t*-test indicated the mean value of the rate of change of MIRI for weak sections was greater than that for the strong sections (significance level = 0.05, *p*-value = 0.039), and the mean value of rate of change of CLIRI for weak sections was greater than that for the strong sections (significance level = 0.05, *p*-value = 0.039).

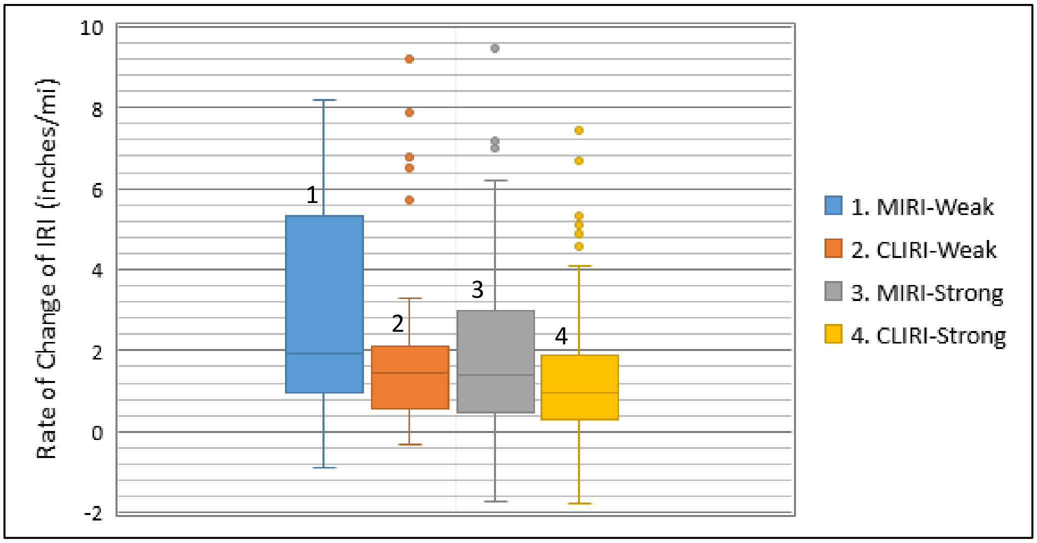

Figure 89. Graph. Box plots showing rate of change of MIRI and CLIRI for weak and strong sections.

Table 90. Median, first quartile, and third quartile values, and data ranges for rate of change of MIRI and CLIRI for weak and strong sections.

Parameter	Number of Test Sections	Rate of Change of IRI (Inches/mi/Year) Median	First Quartile	Third Quartile	Range of Data
MIRI, weak	30	2.02	1.01	6.02	−0.89 to 8.19
MIRI, strong	171	1.49	0.50	3.03	−1.74 to 6.21
CLIRI, weak	30	1.46	0.66	2.06	−0.32 to 3.28
CLIRI, strong	171	0.97	0.28	1.90	−1.79 to 4.09

RELATIONSHIP BETWEEN CHANGES IN IRI AND SUBGRADE TYPE

Figure 90 shows a box plot of the rate of change of MIRI and CLIRI for the test sections based on the subgrade type (i.e., fine- and coarse-grained). Table 91 summarizes the following information shown in figure 90 for each dataset: number of test sections; median, first quartile, and third quartile values for the rate of change of IRI; and the range of rate of change of IRI for each dataset excluding outliers.

A *t*-test indicated the mean value of the rate of change of MIRI for sections on fine-grained subgrade was greater than that for section on coarse-grained subgrade (significance level = 0.05, *p*-value = 0.008), and the mean value of rate of change of CLIRI for sections on fine-grained subgrade was greater than that for sections on coarse-grained subgrade (significance level = 0.05, *p*-value < 0.001). The subgrade is expected to interact with precipitation and FI in affecting the change in IRI. The interaction between environmental conditions and subgrade type is examined later in this chapter in the subsection entitled Relationship Between Changes in IRI and Environmental Conditions.

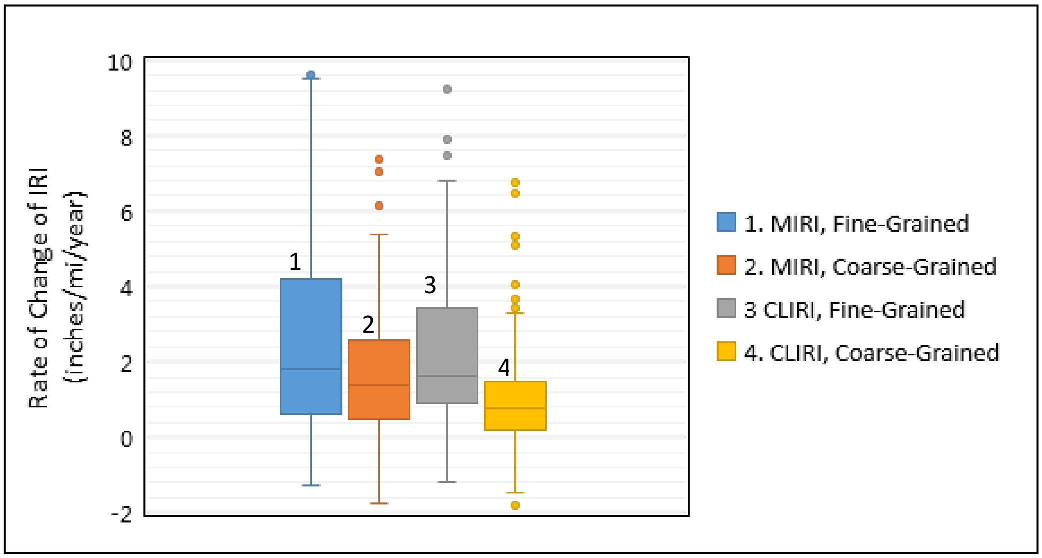

Figure 90. Graph. Box plots showing the rate of change of MIRI and CLIRI for sections on fine- and coarse-grained subgrades.

Table 91. Median, first quartile and third quartile values, and data ranges for rate of change of IRI for fine and coarse subgrades.

Parameter	Number of Test Sections	Rate of Change of IRI (Inches/mi/year) Median	First Quartile	Third Quartile	Range of Data
MIRI, fine	76	1.87	0.65	4.45	−1.27 to 9.49
MIRI, coarse	125	1.43	0.48	2.69	−1.74 to 5.40
CLIRI, fine	76	1.65	0.95	3.49	−1.20 to 6.79
CLIRI, coarse	125	0.78	0.18	1.45	−1.47 to 3.43

RELATIONSHIP BETWEEN CHANGES IN IRI AND DRAINAGE AT TEST SECTIONS

A PATB layer was present in the pavement structure to provide drainage at test sections 7 through 12 and 19 through 24. At sections 7 through 9 and 19 through 21, the PATB layer was located between the AC surface and the DGAB layer. In sections 10 through 12 and 22 through 24, the PATB layer was located between the ATB layer and the subgrade. Figure 91 shows a box plot of the rate of increase of MIRI for sections with and without drainage, categorized according to the subgrade type, while figure 92 shows a similar plot for the rate of increase of CLIRI.

Table 92 summarizes the following information shown in figure 91 and figure 92 for each dataset: number of test sections; median, first quartile, and third quartile values for the rate of change of IRI; and the range of rate of change of IRI for each dataset excluding outliers.

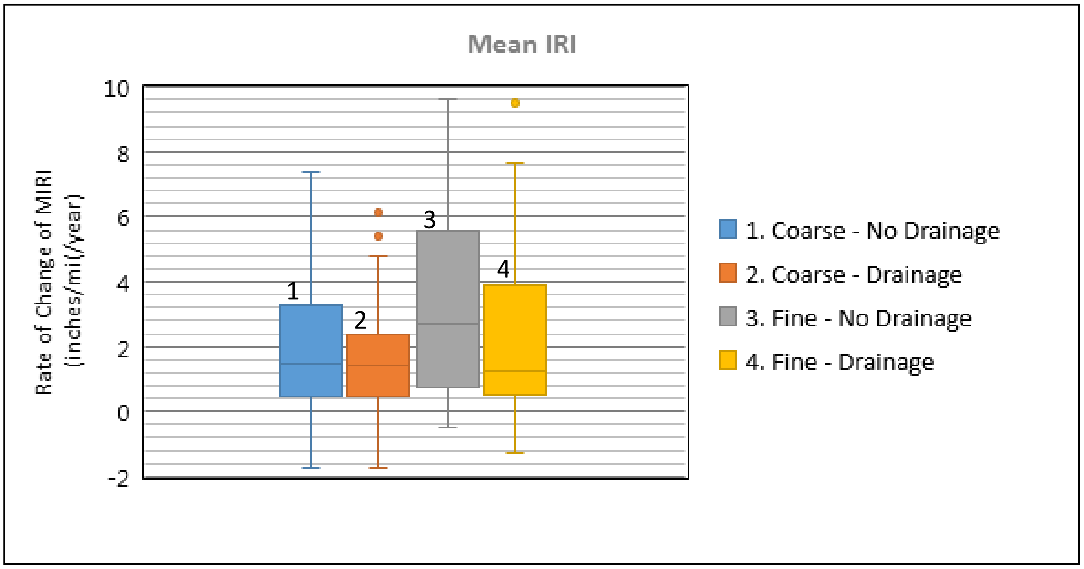

Figure 91. Graph. Box plots showing the rate of change of MIRI for sections with and without drainage, categorized according to subgrade type.

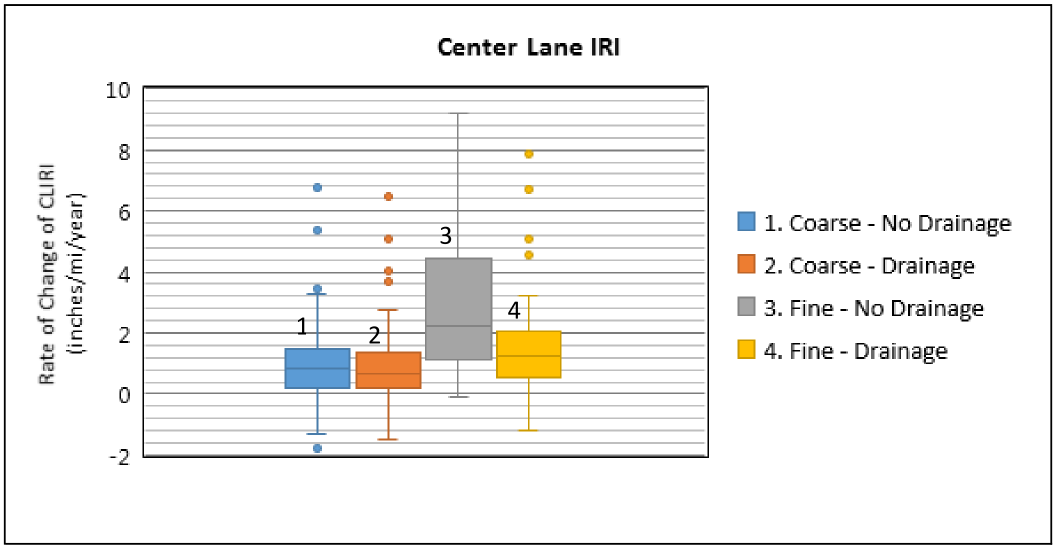

Figure 92. Graph. Box plots showing the rate of change of CLIRI for sections with and without drainage, categorized according to subgrade type.

Table 92. Median, first quartile, and third quartile values, and data ranges for rate of change of IRI for sections with and without drainage, categorized according to subgrade type.

IRI	Parameter	Number of Test Sections	Rate of Change of IRI (Inches/mi/Year)			
			Median	First Quartile	Third Quartile	Range of Data
Mean	Fine, no drainage	37	2.72	0.89	5.92	−0.51 to 9.59
	Fine, drainage	39	1.24	0.53	3.43	−1.27 to 7.64
	Coarse, no drainage	62	1.55	0.50	3.31	1.74 to 7.36
	Coarse, drainage	63	1.40	0.50	2.34	−1.70 to 4.77
Center of the lane	Fine, no drainage	37	2.40	1.23	4.58	−0.51 to 9.59
	Fine, drainage	39	1.23	0.61	1.97	−1.27 to 7.64
	Coarse, no drainage	62	0.85	0.18	1.46	−1.28 to 7.36
	Coarse, drainage	63	0.66	0.19	1.36	−1.70 to 4.77

The analysis showed the following:

- **MIRI, Fine-Grained Subgrade**: The median values of the rate of change of MIRI were 1.24 and 2.71 inches/mi/year for sections with and without drainage, respectively. The third quartile values of the rate of change of MIRI were 3.43 and 5.92 inches/mi/year for sections with and without drainage, respectively. A *t*-test indicated the mean value of the rate of change of MIRI for sections with and without drainage were not different (significance level = 0.05, *p*-value = 0.053). Note that the *p*-value was just over 0.05. However, overall, based on the third quartile value and the spread of the data, sections with drainage performed better in terms of the rate of change of IRI than sections without drainage.

- **CLIRI, Fine-Grained Subgrade**: The median values of the rate of change of CLIRI were 1.23 and 2.40 inches/mi/year for sections with and without drainage, respectively. The third quartile values of rate of change of CLIRI were 1.97 and 4.58 inches/mi/year for sections with and without drainage. A *t*-test indicated that the mean value of the rate of change of CLIRI for sections without drainage was greater than that for sections with drainage (significance level = 0.05, *p*-value = 0.011).

- **MIRI, Coarse-Grained Subgrade:** The median values of the rate of change of CLIRI were 1.40 and 1.55 inches/mi/year for sections with and without drainage, respectively. The third quartile values for the rate of change of MIRI for sections with and without drainage were 2.34 and 3.31 inches/mi/year, respectively. A *t*-test indicated that there was no difference in the mean value of the rate of change of MIRI for sections with and without drainage (significance level = 0.05, *p*-value = 0.30). However, overall, based on the third quartile value and the spread of the data, sections with drainage performed better in terms of the rate of change of IRI than sections without drainage.

- **CLIRI, Coarse-Grained Subgrade:** The median values of the rate of change of CLIRI for sections with and without drainage were 0.66 and 0.85 inches/mi/year, respectively. The third quartile values for the rate of change of CLIRI for sections with and without drainage were 1.36 and 1.46 inches/mi/year, respectively. A *t*-test indicated that there was no difference in the mean value of the rate of change of CLIRI for sections with and without drainage (significance level = 0.05, *p*-value = 0.44). The data shown in the box plots also did not show any clear difference in the rate of change of CLIRI for sections with and without drainage.

Overall, this analysis showed that the provision of drainage on test sections that had fine-grained subgrade reduced the rate of change of IRI. For sections on coarse-grained subgrade, sections with drainage overall showed a lower rate of change of MIRI, but there was no clear difference in the rate of change of CLIRI for sections with and without drainage. Note that subgrades categorized as coarse-grained subgrade would also have material finer than the No. 200 sieve, and drainage characteristics of pavements built on coarse-grained subgrades with a high content of fine material would be improved with the provision of drainage.

An evaluation was performed to determine what method of providing drainage (i.e., PATB over DGAB or PATB under ATB) resulted in a lower rate of change of roughness using the data from test sections constructed on fine-grained subgrade. Figure 93 shows a box plot for the rate of change of MIRI for sections on fine-grained subgrade categorized according to sections without drainage, sections with PATB over DGAB, and sections with PATB below the ATB. Figure 94 shows a similar plot for CLIRI. Table 93 summarizes the following information shown in figure 93 and figure 94 for each dataset: number of test sections; median, first quartile, and third quartile values for the rate of change of IRI; and the range of rate of change of IRI for each dataset excluding outliers.

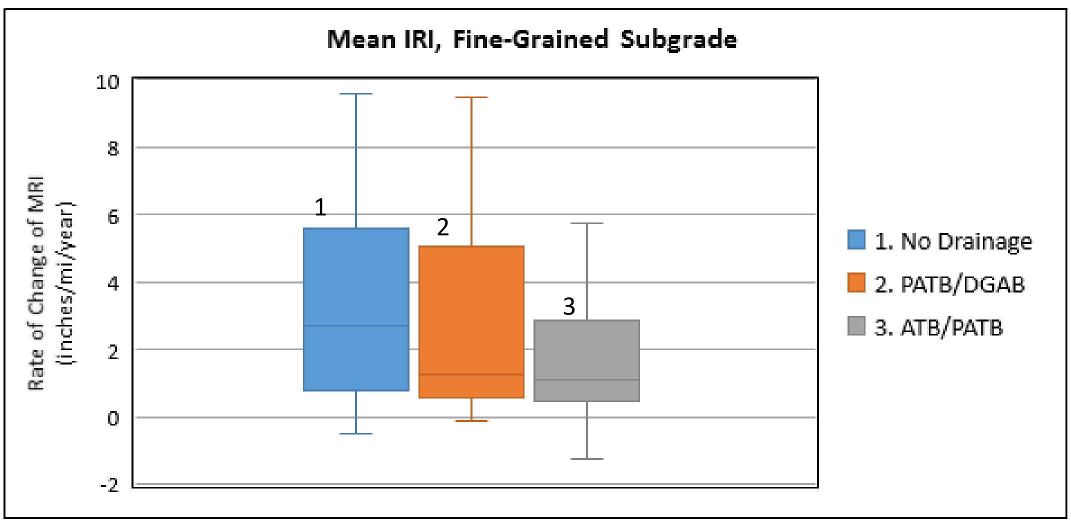

Figure 93. Graph. Box plots showing the rate of change of MIRI for sections on fine-grained subgrade, categorized according to type of drainage.

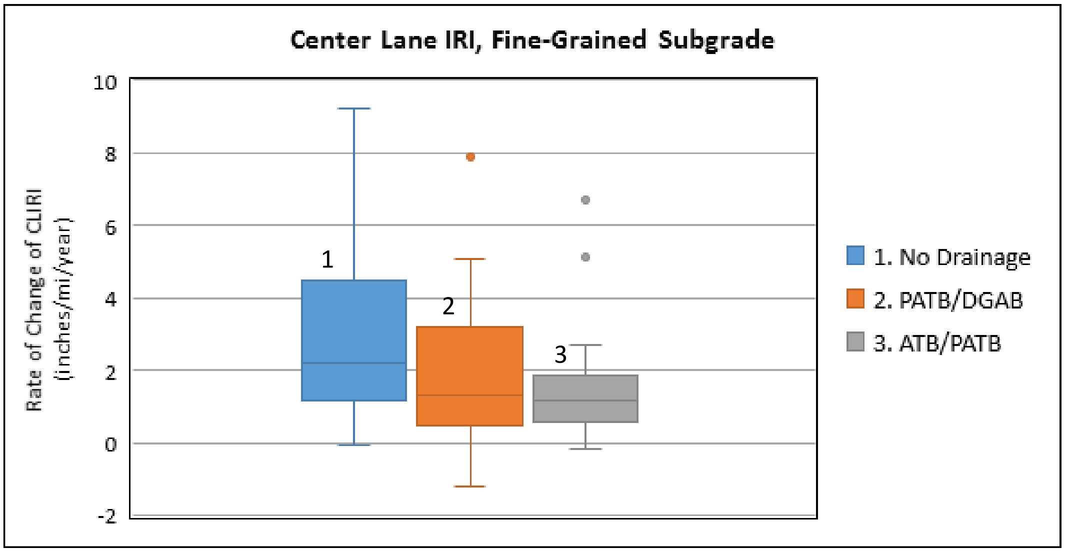

Figure 94. Graph. Box plots showing the rate of change of CLIRI for sections on fine-grained subgrade, categorized according to type of drainage.

Table 93. Median, first quartile and third quartile values, and data ranges for rate of change of IRI for sections on fine-grained subgrade, categorized according to the type of drainage.

IRI	Parameter	Number of Test Sections	Rate of Change of IRI (Inches/mi/Year) Median	First Quartile	Third Quartile	Range of Data
Mean	No drainage	38	2.72	0.89	5.92	−0.51 to 9.59
	PATB/DGAB	20	1.24	0.60	4.55	−0.14 to 9.49
	ATB/PATB	21	1.12	0.50	2.88	−1.27 to 5.78
Center of the lane	No drainage	38	2.40	1.23	4.58	−0.07 to 9.21
	PATB/DGAB	20	1.32	0.61	2.67	−1.20 to 5.07
	ATB/PATB	21	1.16	0.63	1.81	−0.17 to 2.77

The analysis showed the following:

- **MIRI Values**: A *t*-test indicated there was no difference in the mean value of rate of change of MIRI for sections with PATB over DGAB and ATB over PATB (significance level = 0.05, *p*-value = 0.11). The median value for the rate of change of MIRI for sections with no drainage, PATB over DGAB, and PATB below ATB were 2.72, 1.24, and 1.12 inches/mi/year, respectively. The third quartile values for the rate of change of MIRI for sections with no drainage, PATB over DGAB, and PATB below ATB were 5.92, 4.55, and 2.88 inches/mi/year, respectively. Although the *t*-test indicated there was no difference in the mean values for the rate of change of MIRI for sections with PATB over DGAB and PATB below ATB, the third quartile values showed that the sections with PATB below ATB performed better than the sections with PATB over DGAB.

- **CLIRI Values**: A *t*-test indicated there was no difference in the mean value of the rate of change of CLIRI for sections with PATB over DGAB and ATB over PATB (significance level = 0.05, *p*-value = 0.26). The median value for the rate of change of CLIRI for sections with no drainage, PATB over DGAB, and PATB below ATB were 2.40, 1.32, and 1.16 inches/mi, respectively. The third quartile values for the rate of change of MIRI for sections with no drainage, PATB over DGAB, and PATB below ATB were 4.58, 2.67, and 1.81 inches/mi/year, respectively. Although the *t*-test indicated there was no difference in the mean values for the rate of change of CLIRI for sections with PATB over DGAB and PATB below ATB, the third quartile values showed that the sections with PATB below ATB performed better than the sections with PATB over DGAB.

RELATIONSHIP BETWEEN CHANGES IN IRI AND ENVIRONMENTAL CONDITIONS

This subsection first categorizes the data used to analyze the relationship between changes in IRI and environmental conditions and discusses the results for changes in roughness for different environmental zones, interaction between environmental zone and subgrade type for roughness development, and interaction between provision of drainage and environmental zone.

Categorization of Data

Table 94 shows the SPS-1 projects categorized according to the environmental zone and subgrade type. In addition to the number of projects, this table also shows the number of SPS-1 test sections available in each category for analysis. As seen in table 94, the number of projects available in each category was not equal. For example, of the eight SPS-1 projects in the WNF zone, two projects were located on fine-grained subgrade, while six projects were located on coarse-grained subgrade. In the DNF zone, there were two projects, with one project located on fine-grained subgrade and the other located on coarse-grained subgrades. Only one SPS-1 project was constructed in the DF zone, and it was constructed on a coarse-grained subgrade. When comparing performance of test sections among the different environmental zones, there could be a bias because of unequal projects in each category. For cases where there were only one or two projects, the analysis could be heavily influenced by the poor performance of test sections in a specific project.

Table 94. SPS-1 projects classified according to subgrade type and environmental zone.

Environmental Zone	Subgrade Types			
	Fine-Grained		Coarse-Grained	
	SPS-1 Projects	Sections for Analysis	SPS-1 Projects	Sections for Analysis
DNF	1	12	1	12
DF	—	—	2	24
WNF	2	24	6	70
WF	4	40	2	19

Changes in Roughness for Different Environmental Zones

Figure 95 and figure 96 show box plots for the rate of change of MIRI and CLIRI, respectively, classified according to the four environmental zones. Table 95 summarizes the following information shown in these two figures for each dataset: number of test sections; median, first quartile, and third quartile values for the rate of change of IRI; and the range of rate of change of IRI for each dataset excluding outliers.

For MIRI as well as CLIRI, the environmental zones in the order of increasing median values for the rate of change of IRI were WNF, DF, WF, and DNF. The number of SPS-1 projects that were located in the WNF, DF, WF, and DNF zones were eight, two, six, and two, respectively. The SPS-1 projects in the DNF zone were located in Arizona and New Mexico. All test sections in the New Mexico project had a relatively high rate of change of MIRI as well as CLIRI because of raveling. Hence, the high rate of change of MIRI and CLIRI for the DNF zone was not necessarily a reflection of the environment on pavement performance but was likely an AC mix related issue that caused the raveling.

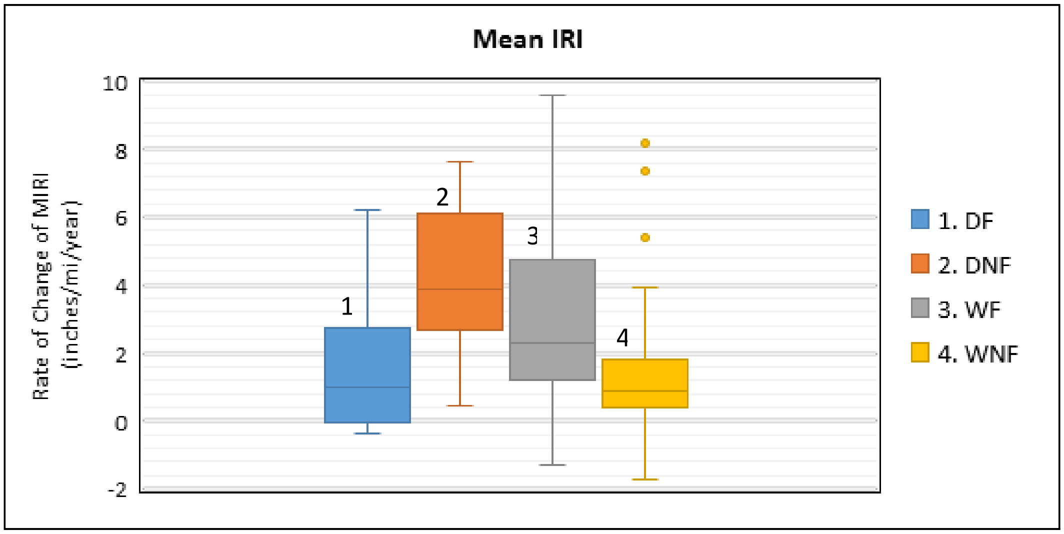

Figure 95. Graph. Box plots showing the rate of change of MIRI at SPS-1 sections according to environmental zone.

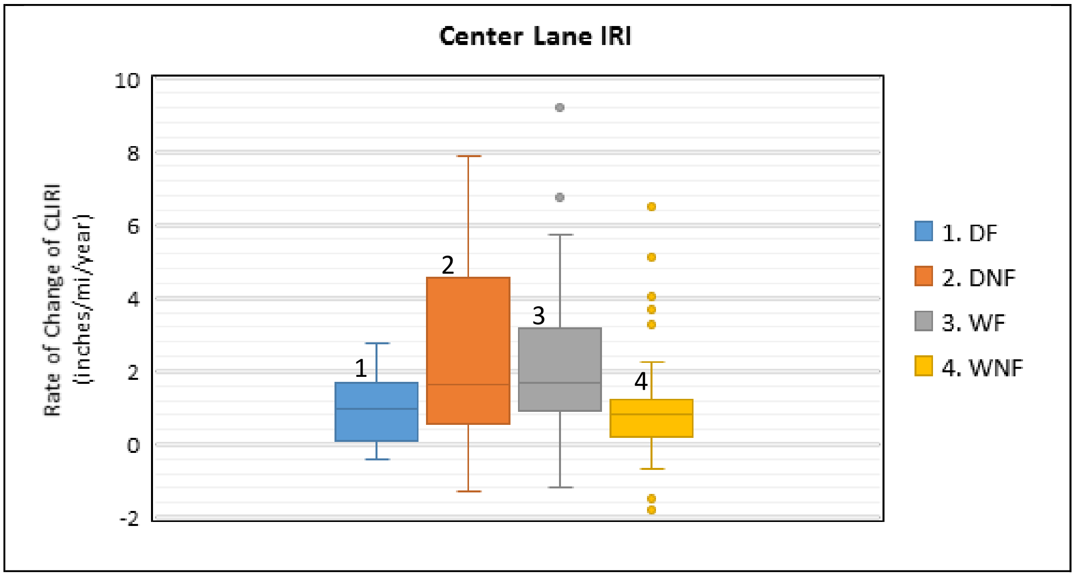

Figure 96. Graph. Box plots showing the rate of change of CLIRI at SPS-1 sections according to environmental zone.

Table 95. Median, first quartile, and third quartile values, and data ranges for rate of change of IRI for sections classified according to environmental zone.

IRI	Parameter	Number of Test Sections	Rate of Change of IRI (Inches/mi/Year) Median	First Quartile	Third Quartile	Range of Data
Mean	DF	24	1.03	-0.02	3.13	−0.35 to 6.24
	DNF	24	3.97	2.79	6.23	−0.47 to 7.64
	WF	59	2.48	1.24	4.91	−1.27 to 9.59
	WNF	94	0.86	0.43	1.80	−1.74 to 3.94
Center of the lane	DF	24	0.96	0.08	1.53	−0.43 to 0.97
	DNF	24	1.83	0.70	4.58	−1.28 to 7.88
	WF	59	1.70	0.99	3.01	−1.20 to 5.72
	WNF	94	0.80	0.20	1.23	−0.69 to 2.27

A clear difference in the performance of test sections in the WF and WNF zones, which had six and eight projects, respectively, were observed in the data. The third quartile values for the rate of change of MIRI for the WF and WNF zones were 4.91 and 1.80 inches/mi/year, respectively, while the third quartile values for the rate of change of CLIRI for the WF and WNF zones were 3.01 and 1.23 inches/mi/year, respectively. A *t*-test also indicated that the mean values of MIRI as well as CLIRI for the WF region were greater than the corresponding values for the WNF zone (significance level = 0.05, p-value < 0.001).

Interaction Between Environmental Zone and Subgrade Type for Roughness Development

Of the eight SPS-1 projects in the WNF zone, two were located on fine-grained subgrade and six on coarse-grained subgrade. Of the six SPS-1 projects in the WF zone, four were located on fine-grained subgrade and two on coarse-grained subgrade. In the DNF zone, there was one SPS-1 project each located on fine- and coarse-grained subgrade, while both SPS-1 projects in the DF zone were located on coarse-grained subgrade. The change in IRI for the projects in the DNF, WF, and WNF zones classified according to subgrade type was examined to investigate the effect of subgrade type on the change in IRI.

The box plots in figure 97 and figure 98 show the rate of change of MIRI and CLIRI, respectively, classified according to subgrade type and environmental zone. Table 96 summarizes the following information shown in these two figures for each dataset: number of test sections, and median, first quartile, and third quartile values for the rate of change of IRI.

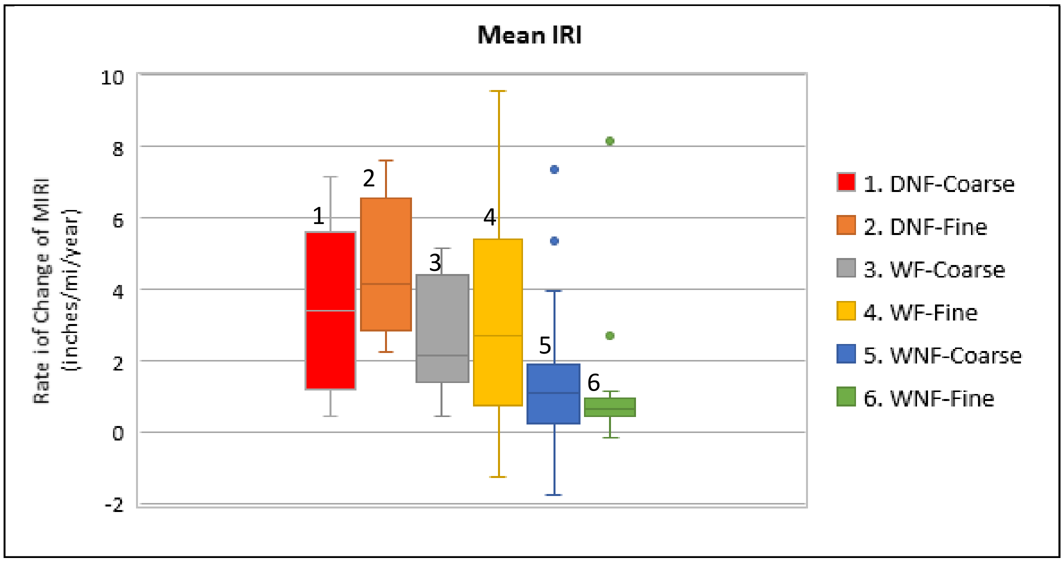

Figure 97. Graph. Box plots showing the rate of change of MIRI at sections in DNF, WNF, and WF zones, categorized according to subgrade type.

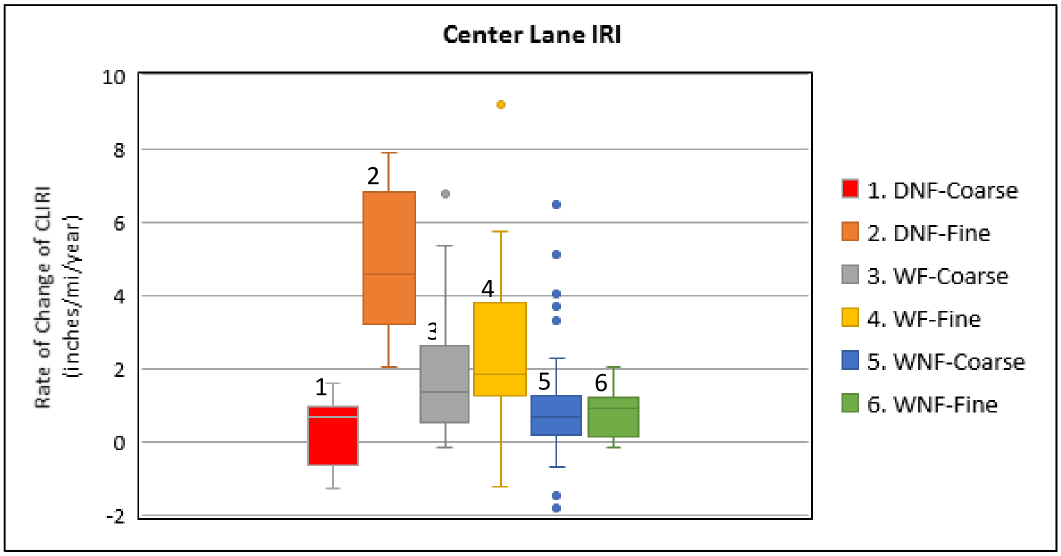

Figure 98. Graph. Box plots showing the rate of change of CLIRI for sections in DNF, WNF, and WF zones, categorized according to subgrade type.

Table 96. Median, first quartile and third quartile values, and data ranges for rate of change of IRI for sections classified according to environmental zone and subgrade type.

IRI	Environmental Zone	Subgrade	Number of Test Sections	Rate of Change of IRI (Inches/mi/Year)		
				Median	First Quartile	Third Quartile
MIRI	DNF	Coarse	12	3.41	1.69	4.57
		Fine	12	4.19	3.56	6.66
	WF	Coarse	19	2.26	1.59	4.42
		Fine	40	2.80	0.81	5.47
	WNF	Coarse	70	1.09	0.29	1.90
		Fine	24	0.67	0.48	0.96
CLIRI	DNF	Coarse	12	0.66	-0.52	0.84
		Fine	12	4.58	3.53	6.95
	WF	Coarse	19	1.36	0.59	2.18
		Fine	40	1.86	1.29	3.56
	WNF	Coarse	70	0.67	0.20	1.26
		Fine	24	0.92	0.25	1.15

The analysis showed the following:

- **DNF Zone**: Overall, the box plots show the sections on fine-grained subgrade had a higher rate of change of IRI for MIRI as well as CLIRI when compared with sections on coarse-grained subgrade. In the fine-grained subgrade project, which was the New Mexico SPS-1 project, the MIRI as well as the CLIRI at test sections showed a high rate of change of IRI because of raveling of the AC surface. Hence, the differences in the changes between the sections on fine- and coarse-grained subgrade could not be attributed to the subgrade.

- **WF Zone**: A *t*-test indicated there was no difference in the mean values of the rate of change of MIRI as well as CLIRI for the two subgrade types in the WF zone. The third quartile values for the rate of change of MIRI for sections in the WF zone on coarse- and fine-grained subgrade were 4.42 and 5.47 inches/mi/year, respectively. For CLIRI, the third quartile values for the rate of change of CLIRI for sections in the WF zone that were on coarse- and fine-grained subgrade were 2.18 and 3.56 inches/mi/year, respectively. Based on these third quartile values, the sections on coarse-grained subgrade appear to have performed better than the sections on fine-grained subgrade with respect to the rate of change of IRI.

- **WNF Zone**: A *t*-test indicated there was no difference in the mean values of the rate of change of MIRI as well as CLIRI for the two subgrade types. The third quartile values for the rate of change of MIRI for sections on coarse- and fine-grained subgrade were 1.90 and 0.96 inches/mi/year, respectively. The third quartile values for the rate of change of CLIRI for sections on coarse- and fine-grained subgrade were 1.26 and 1.15 inches/mi/year, respectively. It was expected that the rate of change of IRI would be higher for sections on fine-grained subgrade. The two SPS-1 projects in the WNF zone located on fine-grained subgrade were in Alabama and Louisiana. The rate of change of MIRI as well as CLIRI for the Alabama project were very low, which resulted in low values being computed for the third quartile value for the rate of change of MIRI and CLIRI for sections on fine-grained subgrade.

Figure 99 shows the rate of change of CLIRI plotted versus the percent of subgrade passing through the No. 200 sieve for test sections in the WF zone. In this plot, the vertical series of data points shown for a specific value of percent material passing through the No. 200 sieve for the subgrade are for test sections in a specific SPS-1 project. A trend line fitted to the data shows that there was a weak trend of the rate of change of CLIRI increases with increasing fines content.

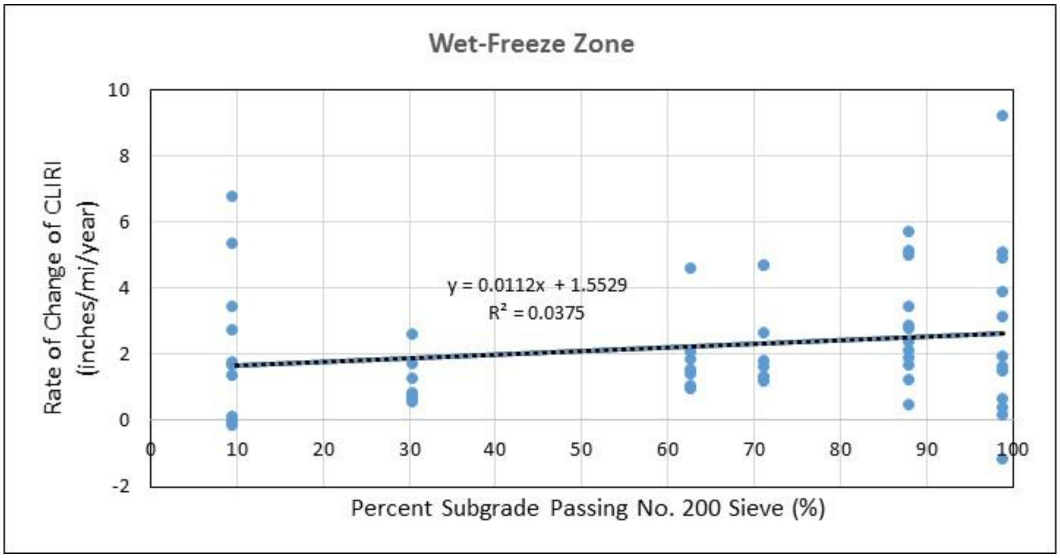

Figure 99. Graph. Rate of change of CLIRI versus percent subgrade passing through the No. 200 sieve for SPS-1 sections in the WF zone.

Figure 100 shows the rate of change of CLIRI plotted versus the percent of subgrade passing through the No. 200 sieve for test sections in the WNF zone. A trend line fitted to the data shows that the rate of change of CLIRI did not appear to be influenced by the fines content in the subgrade.

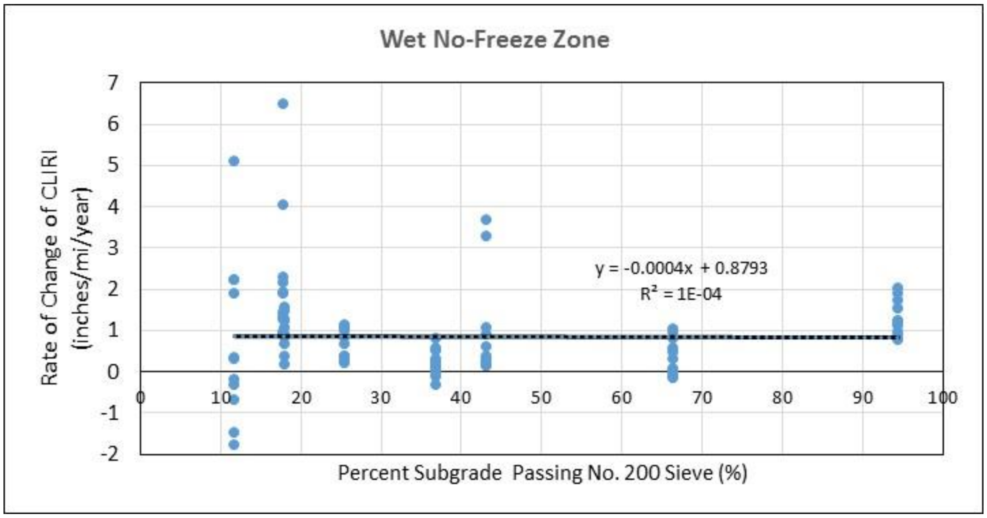

Figure 100. Graph. Rate of change of CLIRI versus percent material passing through the No. 200 sieve for SPS-1 sections in the WNF zone.

Interaction Between Provision of Drainage and Environmental Zone

Previously, a clear difference was observed in roughness progression rates for sections on fine-grained subgrade without drainage and drainage provided through a PATB layer incorporated into the pavement structure. The impact of drainage on test sections located on fine-grained subgrades in the different environmental zones was studied. Figure 101 and figure 102 show box plots of the rate of change of MIRI and CLIRI for sections with and without drainage located on fine-grained subgrade for different environmental zones. An SPS-1 project on fine-grained subgrade was not constructed in the DF zone; therefore, there is no data for the DF zone in these plots. The number of SPS-1 projects that were constructed on fine-grained subgrade in the DNF, WNF, and WF zones were one, two, and four, respectively. Table 97 summarizes the following information shown in figure 101 and figure 102 for each dataset: number of test sections and median, first quartile, and third quartile values for the rate of change of IRI.

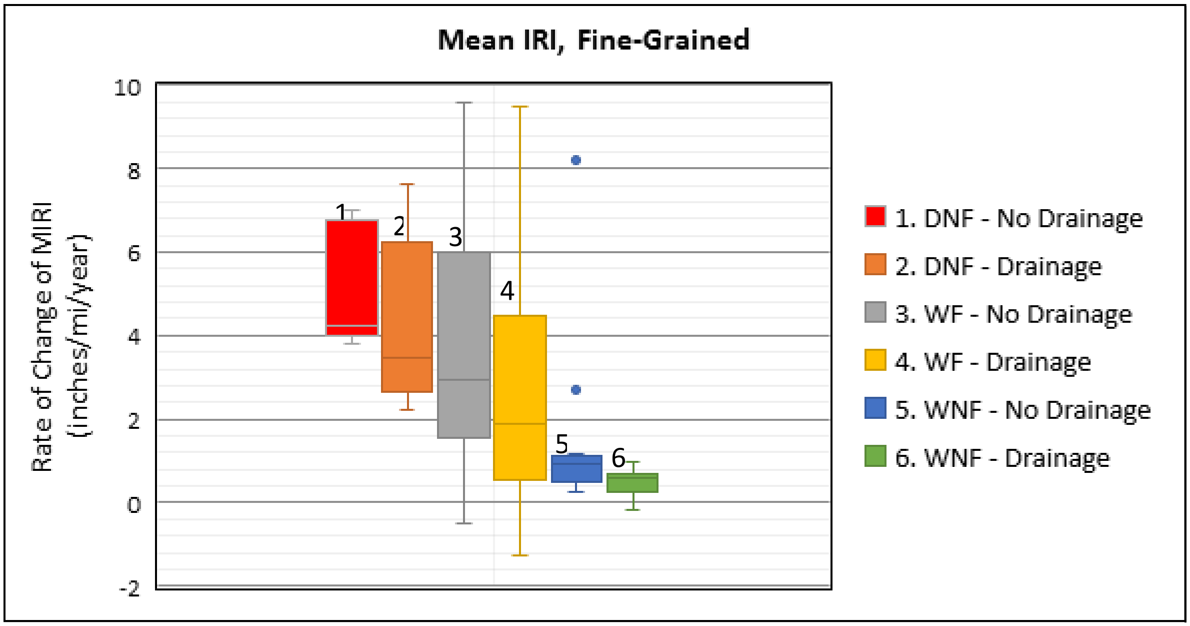

Figure 101. Graph. Box plots showing rate of change of MIRI for sections on fine-grained subgrade, categorized according to environmental zone and provision of drainage.

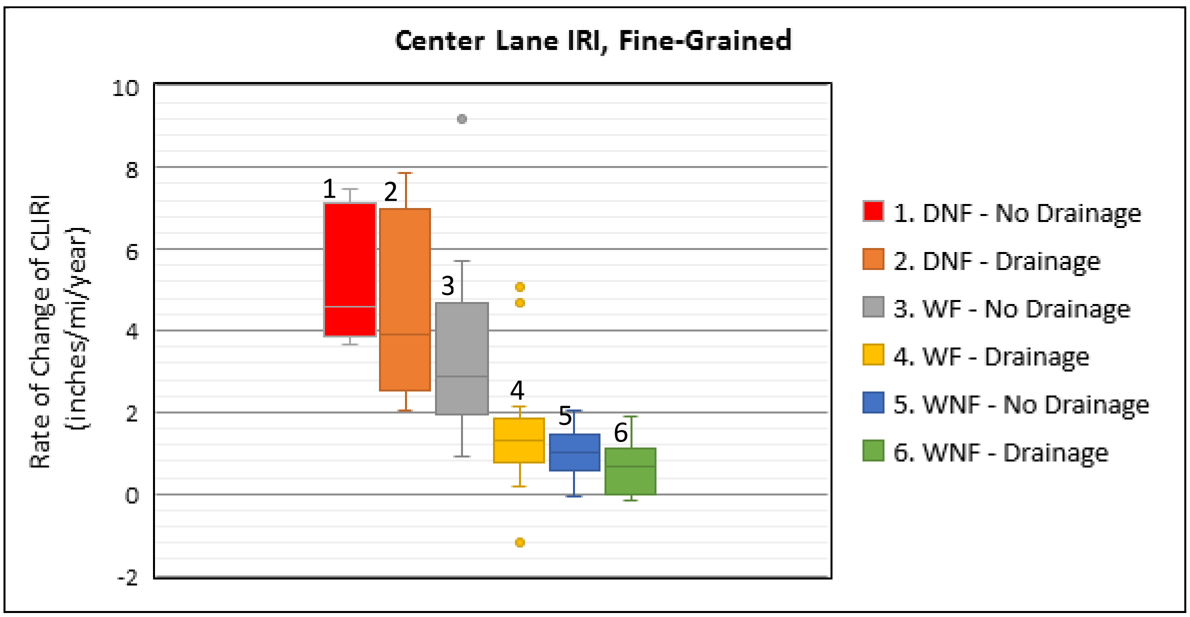

Figure 102. Graph. Box plots showing rate of change of CLIRI for sections on fine-grained subgrade, categorized according to environmental zone and provision of drainage.

Table 97. Median, first quartile, and third quartile values for rate of change of IRI for sections on fine-grained subgrade classified according to environmental zone and provision of drainage.

IRI	Environmental Zone	Provision of Drainage	Number of Test Sections	Rate of Change of IRI (Inches/mi/Year) Median	First Quartile	Third Quartile
MIRI	DNF	No Drainage	6	5.39	4.17	6.88
		Drainage	6	3.47	2.84	5.34
	WF	No Drainage	19	3.01	1.83	6.07
		Drainage	21	1.90	0.65	3.91
	WNF	No Drainage	12	0.93	0.56	1.03
		Drainage	12	0.59	0.36	0.67
CLIRI	DNF	No Drainage	6	5.68	4.21	7.29
		Drainage	6	3.89	2.84	6.17
	WF	No Drainage	19	2.88	2.00	4.66
		Drainage	21	1.33	0.93	1.82
	WNF	No Drainage	12	0.99	0.72	1.30
		Drainage	12	0.66	0.01	1.12

In each environmental zone, the median as well as the third quartile value for the rate of change of IRI for MIRI and CLIRI was higher for sections without drainage when compared with the sections with drainage.

Only one project was on fine-grained subgrade in the DNF zone—the project in New Mexico. As described previously in this report, all sections in that project had a high rate of change of IRI for MIRI as well as for CLIRI because of raveling of the AC surface.

The difference in the third quartile values for sections with and without drainage was highest for the WF zone for both MIRI and CLIRI, which indicated provision of drainage had a major impact on the rate of change of IRI for pavements constructed on fine-grained subgrades in the WF zone.

EFFECT OF PI OF SUBGRADE ON CHANGES IN IRI

The swelling potential of a fine-grained subgrade depends on the PI of the subgrade, with subgrades with higher PI values being more susceptible to swelling. Seven SPS-1 projects were located on fine-grained subgrade. The relationship between the PI of the subgrade and rate of change of MIRI and CLIRI for these projects was examined. Table 98 shows the SPS-1 projects constructed on fine-grained subgrade, the PI of the subgrade, and the median value of the rate of change of MIRI and CLIRI for the test sections in the project.

Table 98. SPS-1 projects constructed on fine-grained subgrade.

Project Location	Environmental Zone	PI of Subgrade (percent)	Median Rate of Change of IRI of Test Sections (Inches/mi/Year)	
			MIRI	CLIRI
Alabama	WNF	17	0.47	0.19
Iowa	WF	28	5.36	2.58
Louisiana	WNF	20	0.82	1.18
Michigan	WF	10	2.42	1.47
Nebraska	WF	20	0.26	1.79
New Mexico	DNF	30	4.19	4.58
Ohio	WF	15	3.31	1.69

Figure 103 and figure 104 show the rate of change of MIRI and CLIRI, respectively, for all test sections in these projects plotted with the PI of the subgrade. The IRI values shown vertically for a specific value of PI are the IRI of the test sections contained within a specific SPS-1 project. A trend line fitted to the data points shows a trend of increasing rate of change of IRI with increasing PI values for both MIRI and CLIRI.

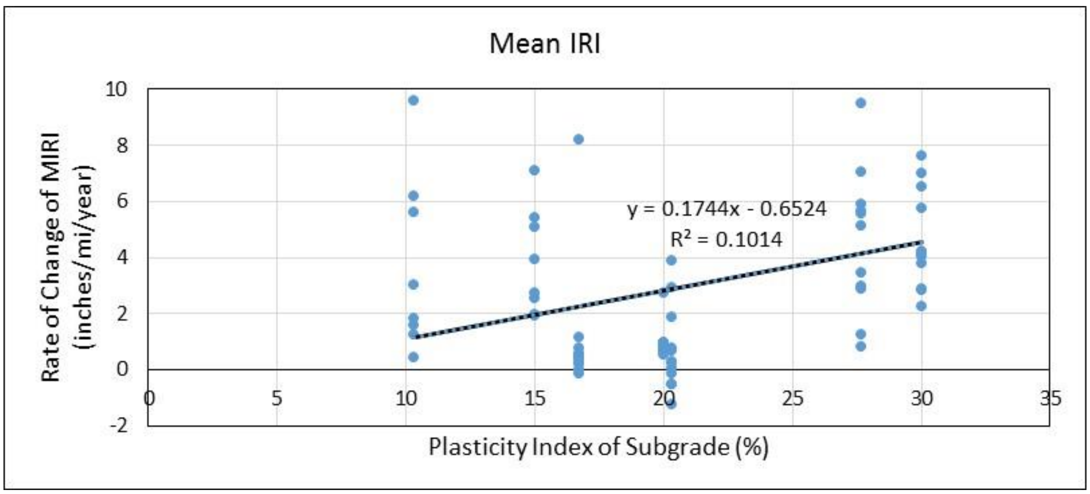

Figure 103. Graph. Rate of change of MIRI of test sections located on fine-grained subgrade versus the PI of the subgrade.

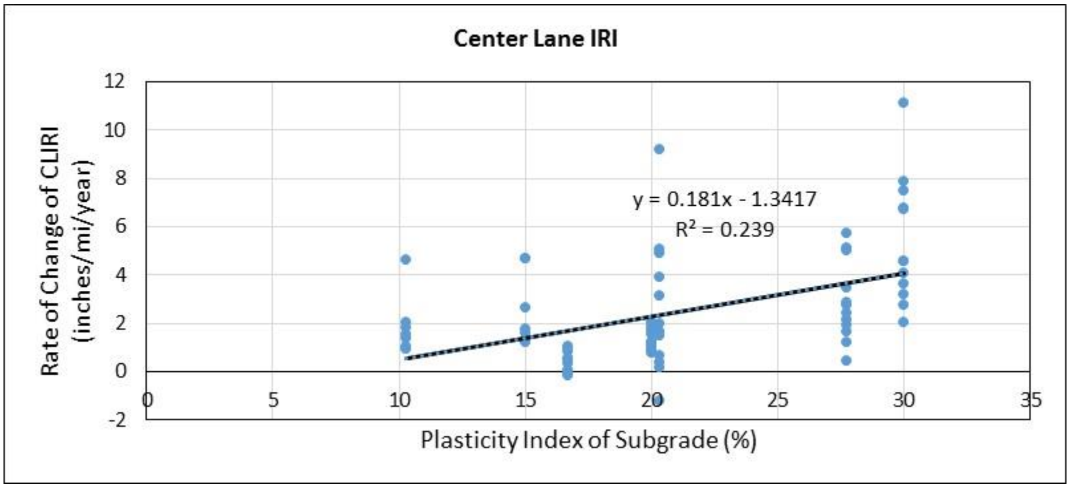

Figure 104. Graph. Rate of change of CLIRI of test sections located on fine-grained subgrade versus the PI of the subgrade.

RELATIONSHIP BETWEEN CHANGES IN IRI AND TRANSVERSE CRACKING

Von Quintus et. al. identified transverse cracking as a factor contributing to the increase in IRI of pavements and presented models for predicting the IRI of flexible pavements that included the total length of transverse cracks as an input to the model.(7) The smoothness model for flexible pavements included in the AASHTO MEPDG software includes the total length of transverse cracking as a parameter for predicting the increase in IRI.(3) In both of these models, the total length of transverse cracking within a section is summed up irrespective of the severity level of the transverse crack (i.e., low, medium, and high).

A transverse crack that extends across the center of the lane might affect CLIRI depending on the severity of the transverse crack. An analysis was performed to investigate the relationship between the change in CLIRI and the total length of transverse cracking at a section. The change in CLIRI at each section was computed by deducting the first CLIRI value from the last CLIRI value. Then, the distress survey date that was closest to the last date when IRI data were collected at the section was identified from the data in the MON DIS AC REV table in PPDB. Then, the total length of transverse cracking (i.e., all severity levels) corresponding to this date was summed for each test section. Figure 105 plots the change in CLIRI against the total length of transverse cracking within the section for all SPS-1 sections. The plot shows no relationship between these two parameters.

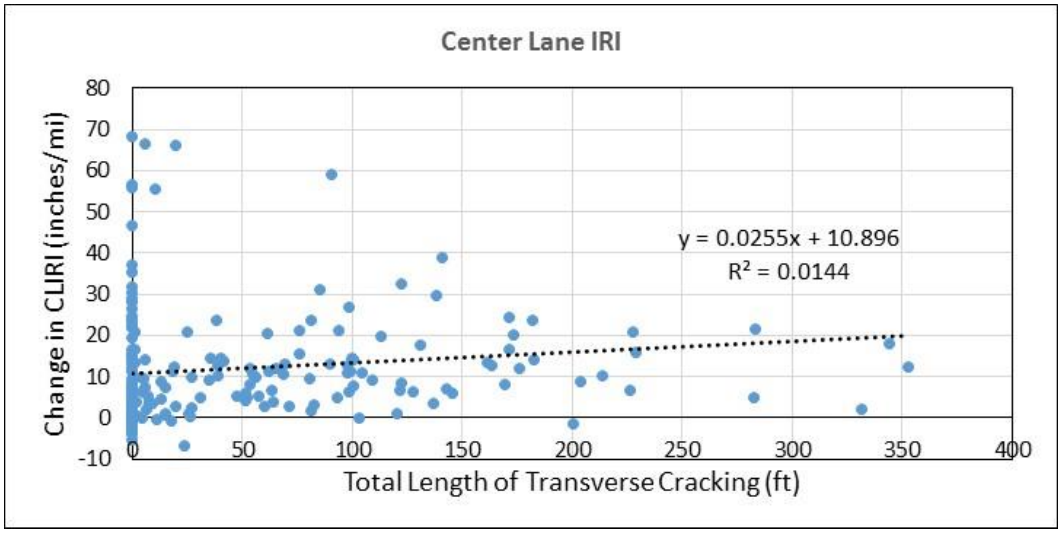

Figure 105. Graph. Relationship between the change in CLIRI and length of transverse cracking at test sections.

For a crack to affect CLIRI, that crack must extend across the center of the lane. Some of the transverse cracks located within a section might not have extended across the center of the lane. Such cracks would not have had an impact on CLIRI. Also, the impact of a crack on IRI was expected to depend on the severity level of the crack. Low severity level cracks might not have much of an impact on CLIRI. A crack would have a major impact on the IRI if there was a dip associated with the crack at the crack location. Such cracks are expected to be either medium or high severity level cracks. An example of how high severity level cracks that have a dip associated with the crack-affected CLIRI (SPS-1 section 300122) is described later in this chapter in the section entitled Detailed Investigation of Roughness Increase at Selected Sections.

THE EFFECT OF SEASONAL VARIATIONS ON IRI VALUES

Five SPS-1 test sections were part of the LTPP SMP program. These test sections were usually profiled four times a year to collect data during each season while the SMP program was in place. Table 99 shows the test sections that were in the SMP program and also indicates the climatic zone where the test section was located, the type of subgrade at the test section, and the percent material passing through the No. 200 sieve for subgrade.

Table 99. SPS-1 test sections that were in the seasonal monitoring program.

State	LTPP Section Number	Environmental Zone	Subgrade Type	Material Passing Through No. 200 Sieve for Subgrade (Percent)
Arizona	040113	DNF	Coarse-grained	17
Arizona	040114	DNF	Coarse-grained	17
Montana	300114	DF	Coarse-grained	22
Nevada	320101	DF	Coarse-grained	45
Virginia	510114	WNF	Coarse-grained	42

The two test sections in the Arizona SPS-1 project were profiled five times in 1998. Table 100 shows the CLIRI values obtained at these two test sections. At section 040113, CLIRI was 80 inches/mi for the first profile date, and thereafter the CLIRI values were between 85 and 89 inches/mi. It was not possible to identify the reason CLIRI at the first profile date was lower than the other CLIRI values by evaluating the profile data. At section 040114, the CLIRI values ranged from 50 to 53 inches/mi for the five profile dates, with this range being typically within the range of IRI associated with lateral wander during data collection. The CLIRI of these two sections located in the DNF region on a coarse-grained subgrade did not exhibit any seasonal effects.

Table 100. CLIRI values at section 040113 and 040114 in the Arizona SPS-1 project.

Profile Date	CLIRI (Inches/mi)	
	Section 040113	Section 040114
1/14/1998	80	53
4/8/1998	85	52
7/8/1998	88	50
10/1/1998	89	50
12/4/1998	89	50

Figure 106 shows the CLIRI values over a 4-year period at section 300114 in the Montana SPS-1 project. Profile data at this site were collected five times a year in 2001, 2002, and 2003; three times a year in 2000; and four times a year in 2004. CLIRI over this period ranged from 45 to 49 inches/mi except on 8/16/2004 when CLIRI was 55 inches/mi. The variations in CLIRI between 45 to 49 inches/mi were typically within the range of IRI that could occur as a result of lateral variations in the profiled path. The reason for the higher CLIRI value on 8/16/2004 when compared with the other years could not be determined from the profile data. CLIRI values of this section, which was located in the DF region on a coarse-grained subgrade, did not exhibit any seasonal effects.

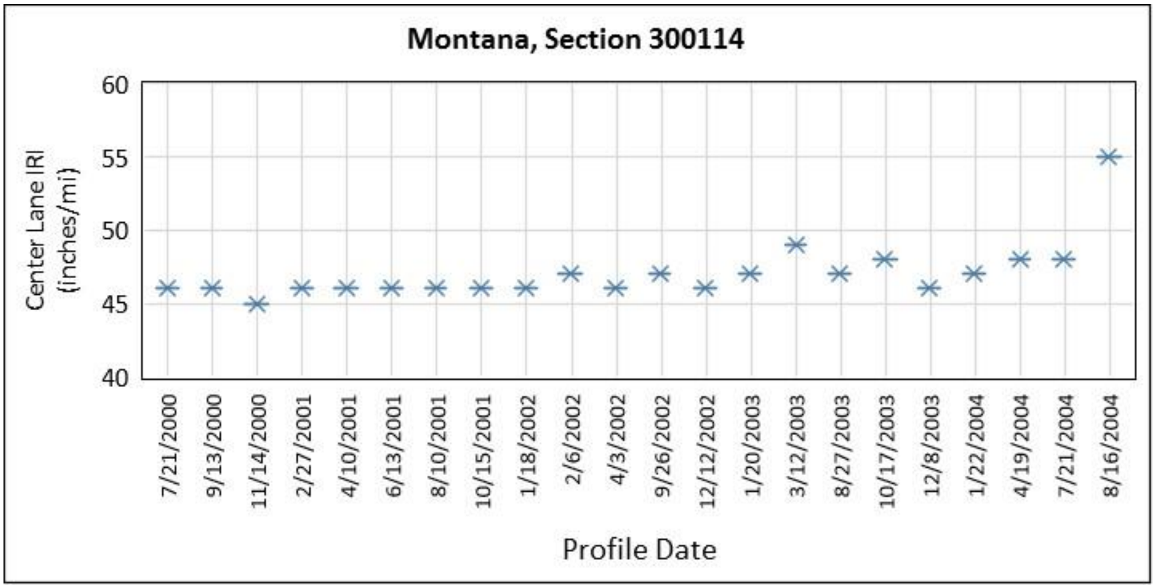

Figure 106. Graph. CLIRI values at section 300114 in Montana.

Section 320101 in the Nevada SPS-1 project was profiled five times a year in 1997, 2000, 2001, and 2002. Figure 107 shows the CLIRI values for the profile dates, which ranged from 50 to 52 inches/mi except for one occasion when CLIRI was 54 inches/mi. The CLIRI of this section, which was located in the DF region on a coarse-grained subgrade, did not appear to have been affected by any seasonal effects.

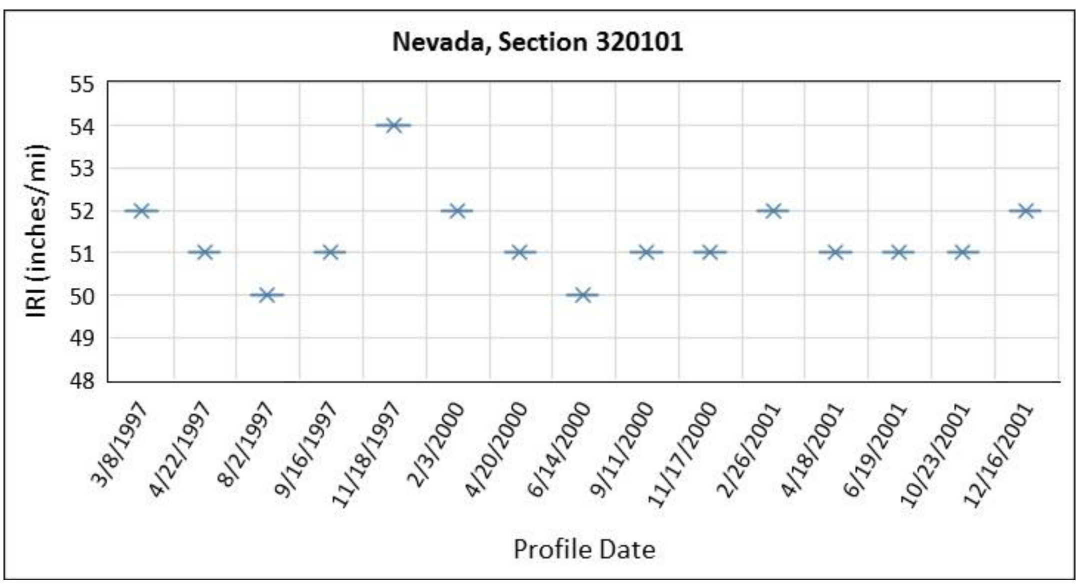

Figure 107. Graph. CLIRI values at section 320101 in Nevada.

Section 510114 in the Virginia SPS-1 project was profiled five times a year in 1998 and 2002 and four times a year in 2001 and 2003. Figure 108 shows the CLIRI values for the profile dates, which ranged from 63 to 66 inches/mi. This range is within the range of IRI typically expected as a result of lateral variations in the profiled path. The CLIRI of this section, which was located in the WNF region on a coarse-grained subgrade, did not appear to have been affected by any seasonal effects.

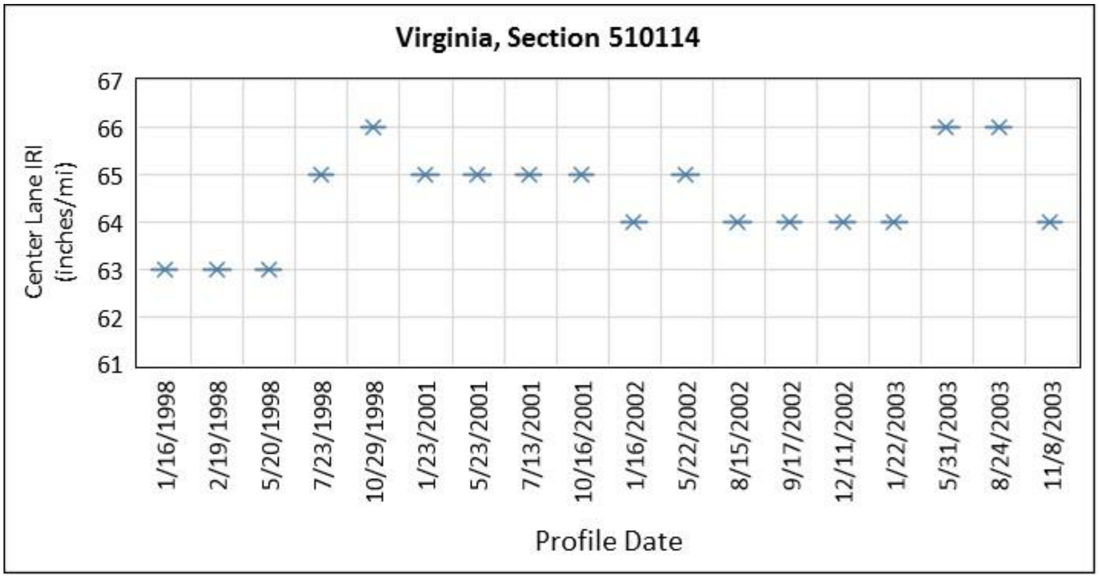

Figure 108. Graph. CLIRI values at section 510114 in Virginia.

For the test sections that were studied, which were all located on a coarse-grained subgrade and were situated in DF, DNF, and WNF environmental zones, the IRI values did not show any changes associated with seasonal influences.

DETAILED INVESTIGATION OF ROUGHNESS INCREASE AT SELECTED SECTIONS

The increase in CLIRI could be attributed to the change in the profile of the pavement that occurred as a result of environmental effects as well as cracks that traverse the center of the lane (i.e., transverse cracks) and cracking present along the center of the lane (i.e., block cracking and longitudinal cracking).

A detailed investigation of how roughness changes along the center of the lane was performed by evaluating the profile data collected at a select group of sections. One aim of this investigation was to see whether specific wavelengths that contributed to the increase in CLIRI could be identified. Test sections where no distresses were present as well as sections where cracking that could influence CLIRI was present were selected for this analysis.

Evaluation of Roughness Increases at Selected Sections

This subsection presents the results of evaluation of roughness increase on selected sections in New Mexico, Louisiana, Montana, Ohio, Arizona, and Oklahoma SPS-1 projects.

Section 350105

All sections in the New Mexico SPS-1 project showed a large change in CLIRI, with the average change in CLIRI of all sections in the New Mexico project being the highest of all SPS-1 projects. At section 350105 in the New Mexico SPS-1 project, CLIRI increased from 34 to 65 inches/mi from 3/11/1997 to 4/24/2006. The increase in MIRI during this period at this section was from 37 to 64 inches/mi. The distress survey that was performed on 3/28/2006 indicated that the section did not have any transverse or block cracking that could have affected CLIRI. The distress survey noted that approximately 40 percent of the surface was raveled. Figure 109 shows a continuous IRI plot (25-ft base length) for CLIRI from a profiler run performed on 3/11/1997 and 4/24/2006. This plot shows CLIRI increased throughout the section between these two dates. A PSD plot of the profile data shows the distribution of wavelengths in the profile. Figure 110 shows a PSD plot for these data collection runs and shows the increase in IRI occurred for all wavelengths less than 80 ft, and a specific range of wavelengths that contributed to the increase in IRI could not be identified. It appears that the raveling of the pavement was a major contributor to increasing CLIRI at this section.

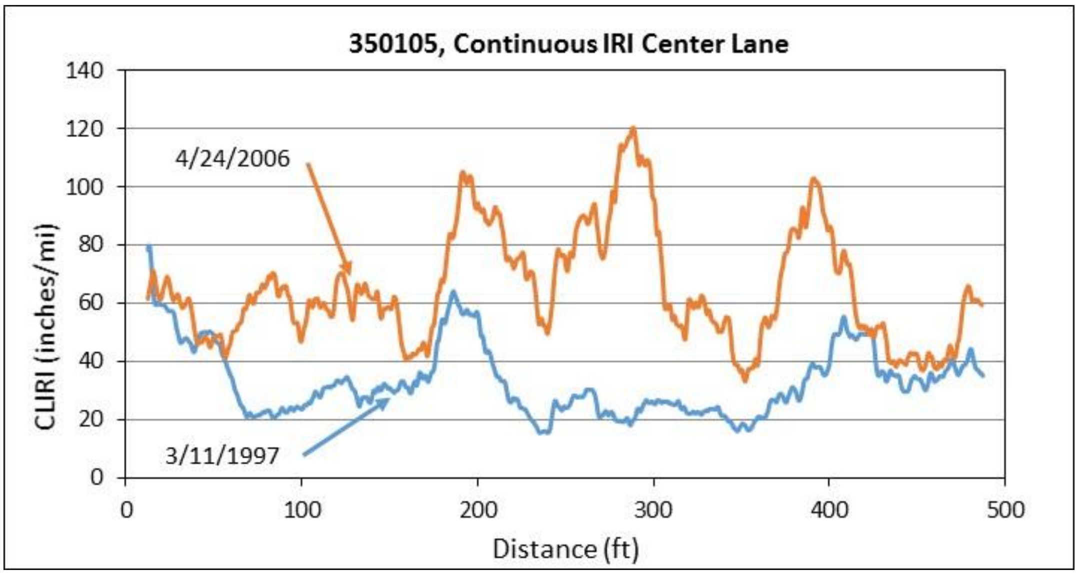

Figure 109. Graph. Continuous IRI plot showing the change in IRI along the center of the lane at section 350105.

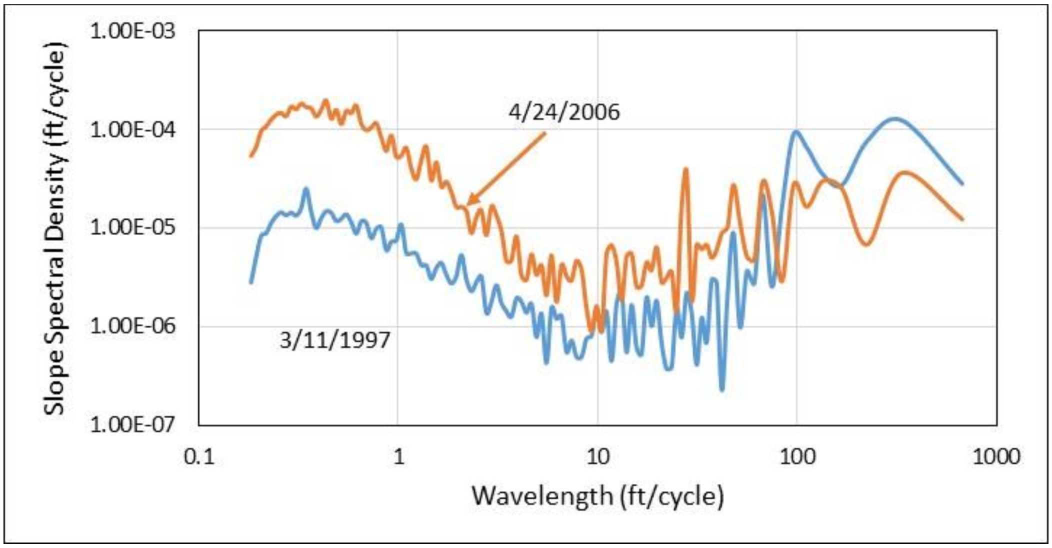

Figure 110. Graph. PSD plot for center of the lane data at section 350105.

Section 220114

At all sections, except for one, at the Louisiana SPS-1 project, the change in CLIRI was higher than the change in MIRI. At section 220114 in the Louisiana SPS-1 project, CLIRI increased from 31 to 52 inches/mi from 11/17/1997 to 1/16/2012. The increase in MIRI during this period at this section was from 40 to 48 inches/mi. The only distress recorded at this section at the last profile date was 85 ft of longitudinal nonwheelpath cracking that was of low severity; this cracking was located at the edge of the lane close to the inside lane. Hence, this cracking would not have had an impact on CLIRI. Figure 111 shows a continuous IRI plot for CLIRI (25-ft base length) from a profiler run that was collected on 11/17/1997 and 1/16/2012. This plot shows the IRI increased throughout the section between these two dates. Figure 112 shows a PSD plot of the data collected for these two dates, and the plot shows the increase in IRI occurred for most wavelengths, and a specific range of wavelengths that contributed to the increase in IRI could not be identified. The Louisiana SPS-1 project was on a fine-grained subgrade that had a PI of 20. Because there was no distress at this section, the increase in CLIRI appeared to have been caused by the change in the profile due to movement of subsurface layers (i.e., swelling or shrinkage of subgrade).

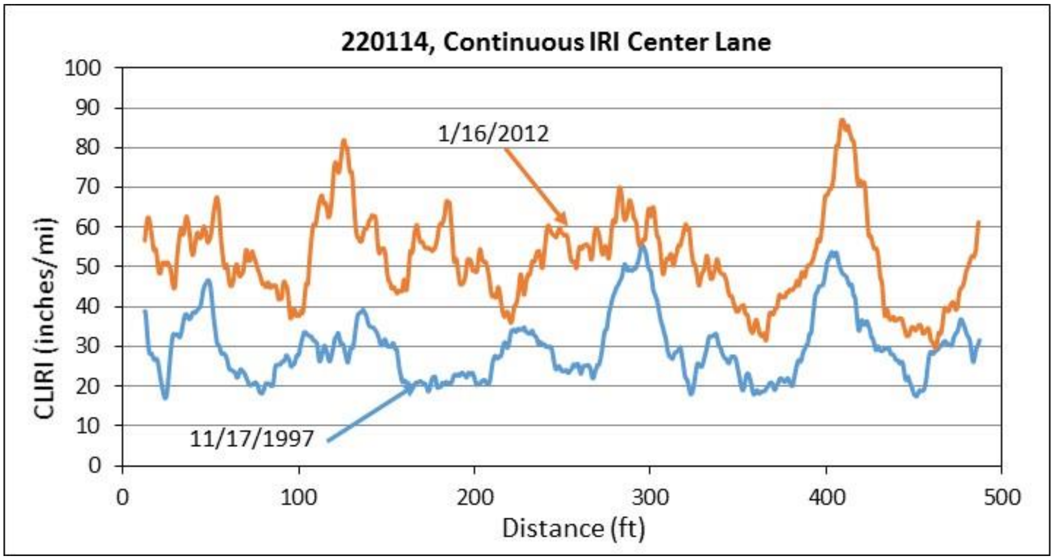

Figure 111. Graph. Continuous IRI plot showing the change in IRI along the center of the lane at section 220114.

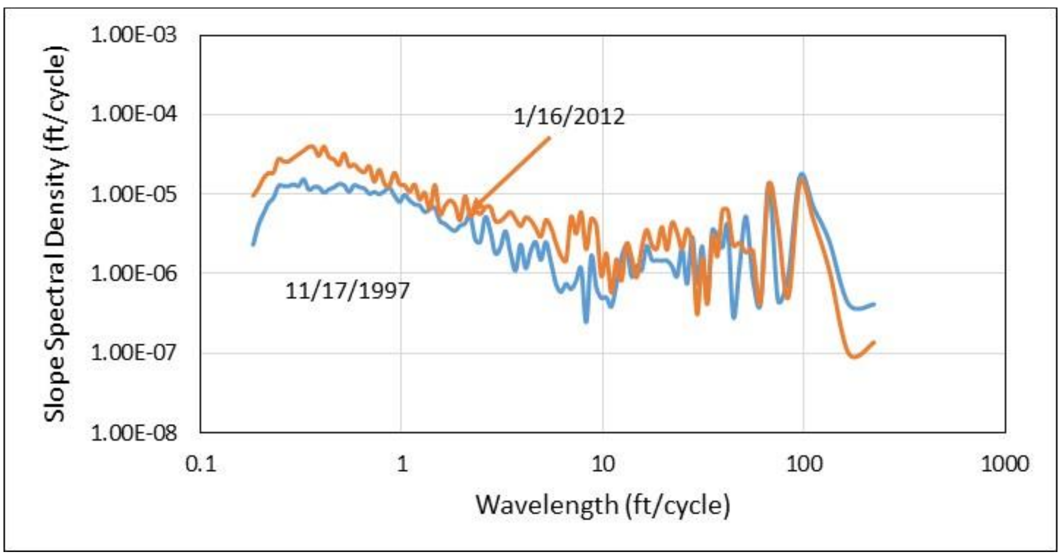

Figure 112. Graph. PSD plot for center of the lane data at section 220114.

Section 300122

At section 300122 in Montana, CLIRI increased from 47 to 77 inches/mi from 11/19/1998 to 7/17/2010. Figure 113 shows a plot of the center of the lane profile data collected at this section on 7/17/2010. Figure 114 shows a continuous IRI plot of CLIRI (25-ft base length) for the data collected on 11/19/1998 and 7/17/2010. The profile data plot shows there are three sharp downward features at 128, 247, and 465 ft, which are high severity transverse cracks, with a depression occurring adjacent to the cracks. The continuous CLIRI plot shows that a significant increase in CLIRI had occurred at the locations of these three transverse cracks between 11/19/1998 and 7/17/2010. In this section, the roughness associated with these three cracks was a major contributor to the increase in overall CLIRI of the section.

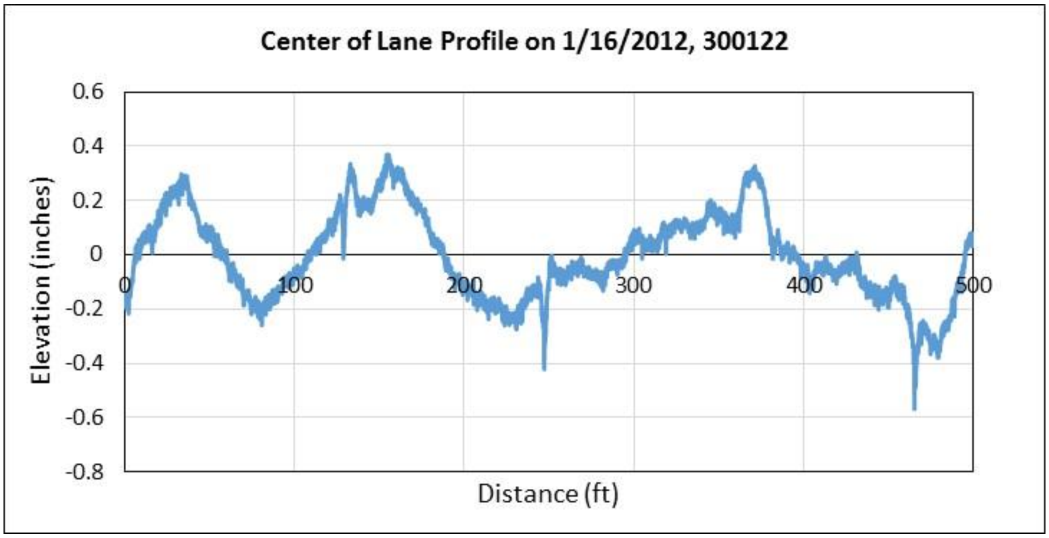

Figure 113. Graph. Center of the lane profile plot at section 300122.

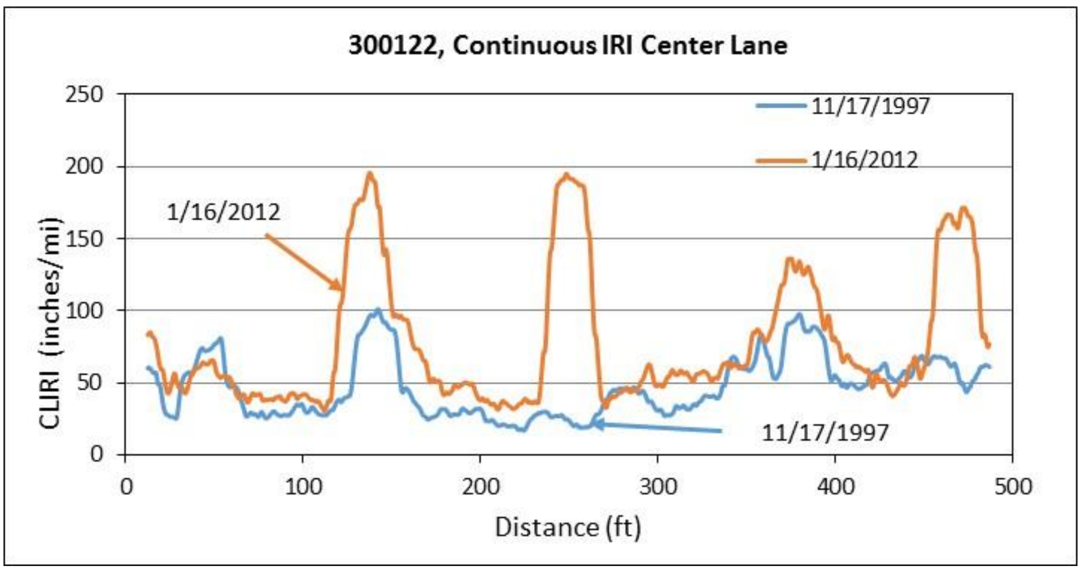

Figure 114. Graph. Continuous IRI plot showing the change in IRI along the center of the lane at section 300122.

Section 390112

Overall, only a few SPS-1 sections had block cracking, but many sections in the Ohio SPS-1 project had block cracking. Section 390112 had 43 percent of the area recorded as having high severity block cracking on the date closest to the last profile date. This block cracking was present along the center of the lane. CLIRI of section 390112 increased from 95 to 126 inches/mi from 11/12/1998 to 5/23/2012. Figure 115 shows a plot of the center of the lane profile data collected at this section on 5/23/2012 for one run, while figure 116 shows the continuous IRI plot of CLIRI (25-ft base length) for one run from the data collected on 11/12/1998 and 5/23/2012.

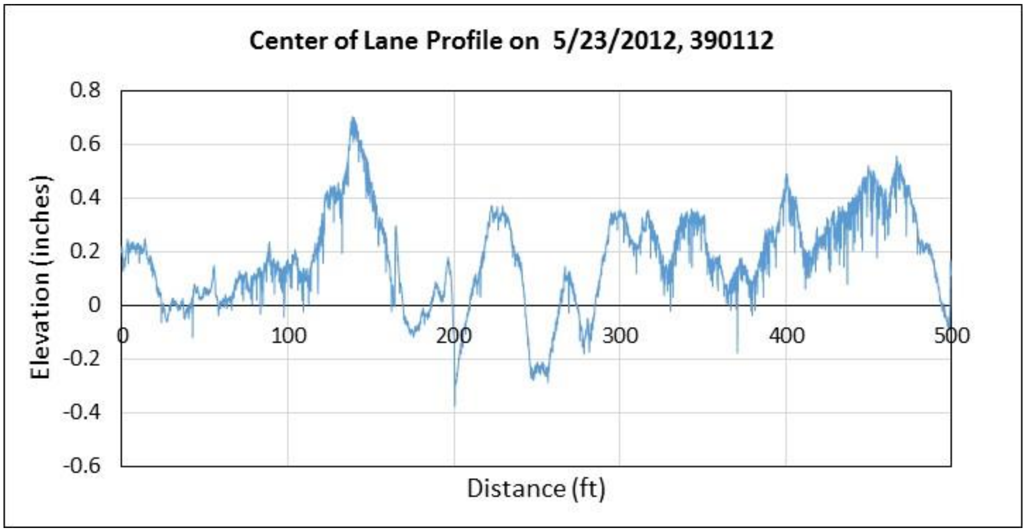

Figure 115. Graph. Center of the lane profile at section 390112.

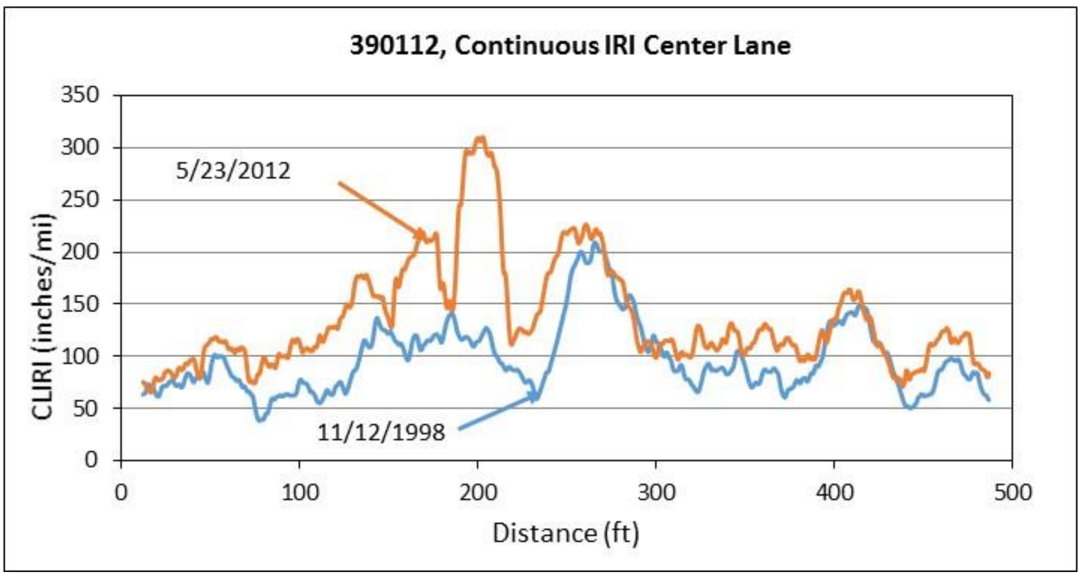

Figure 116. Graph. Continuous IRI plot showing the change in IRI along the center of the lane at section 390112.

The downward features in the profile plot represent the cracks associated with the block cracks that were present along the center of the lane. As seen from the continuous IRI plot, CLIRI of this section increased throughout the section from 11/12/1998 to 5/23/2012. A large increase in IRI is seen in the continuous IRI plot close to 200 ft, where a dip in the pavement was noted in the profile data. The block cracking that was present along the center of the lane was expected to have been a major contributor to the increase in CLIRI at this section.

Section 040119

CLIRI of section 040119 in the Arizona SPS-1 project increased from 49 to 62 inches/mi from 1/23/1997 to 3/27/2006. Figure 117 shows a plot of the center of the lane profile data collected at this section for the first run on 3/27/2006, while figure 118 shows a continuous IRI plot of CLIRI

(25-ft base length) for the first data collection runs performed on 1/23/1997 and 3/27/2006. The profile plot shows some sharp downward spikes, which represent transverse cracks. The distress survey performed closest to the last profile date at this section indicated the section had 70 transverse cracks. The number of cracks with low, medium, and high severity were 50, 16, and 4, respectively. The total length of transverse cracks was 164 ft, and the distress maps showed several of these cracks traversed the center of the lane. No longitudinal cracking along the center of the lane or block cracking along the center of the lane that could have affected CLIRI was present at this section. The continuous IRI plot shows IRI had increased over a majority of the distance within the section from 1/23/1997 to 3/27/1996, with most of the increase in IRI occurring between 70 and 200 ft. No clear relationship between the transverse cracks in the profile plot and the increase in IRI from the continuous IRI plot could be observed.

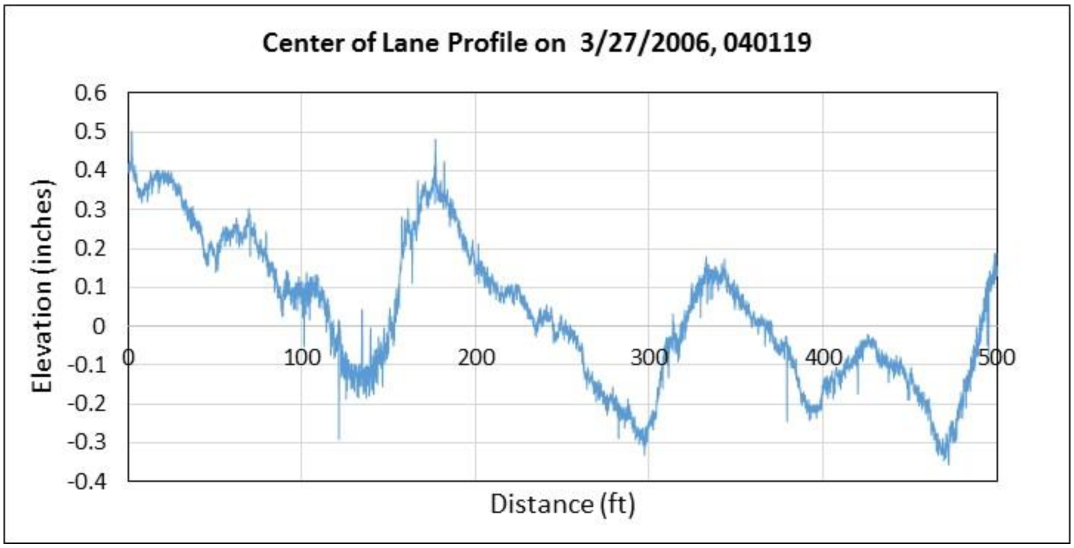

Figure 117. Graph. Center of the lane profile plot at section 040119.

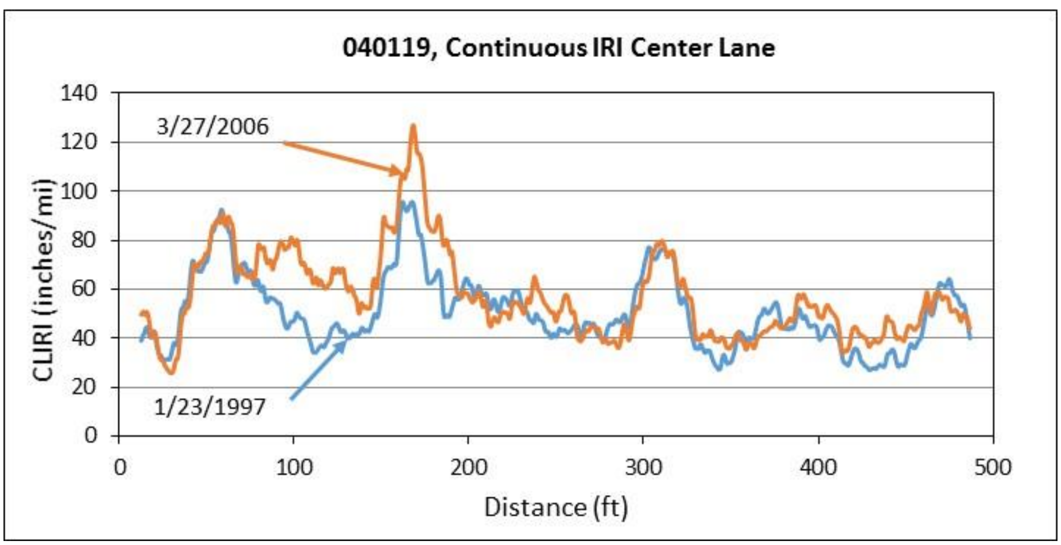

Figure 118. Graph. Continuous IRI plot showing the change in IRI along the center of the lane at section 040119.

Section 400121

CLIRI of section 400121 located in the Oklahoma SPS-1 project increased from 66 to 71 inches/mi from 11/19/1997 to 3/5/2011. The distress survey carried out on this section on the date closest to the last profile date indicated this section had 78 transverse cracks. The total length of the transverse cracks was 302 ft, with 97 percent of these transverse cracks classified as low severity. The distress survey map showed that several of these transverse cracks traversed the center of the lane. However, based on the increase in IRI, the transverse cracks do not seem to have had much of an effect on CLIRI.

Summary

Raveling of the AC surface contributed to the increase in IRI. Evaluation of the effect of low- and medium-severity cracks in increasing the IRI by studying profile plots and continuous IRI plots at a few sections did not show an increase in IRI that could be attributed to the cracking. The IRI computation algorithm includes a moving average meant to mimic tire enveloping, and a downward spike measured on a narrow crack will have little effect on the IRI because of the moving average applied to the profile data in the IRI algorithm before computing the IRI. Hence, a low or medium severity crack might not have much of an impact on the IRI. However, a deformation on the pavement associated with the crack, such as a depression on either side of the crack, could have a significant effect on increasing the IRI. It was also observed that high-severity block cracking would cause an increase in IRI.

MODELS FOR PREDICTING THE CHANGE IN ROUGHNESS DUE TO ENVIRONMENTAL EFFECTS

Figure 119 shows a box plot of the change in CLIRI that occurred at the test sections that were analyzed in this study classified according to the subgrade type (i.e., fine-grained or coarse-grained).

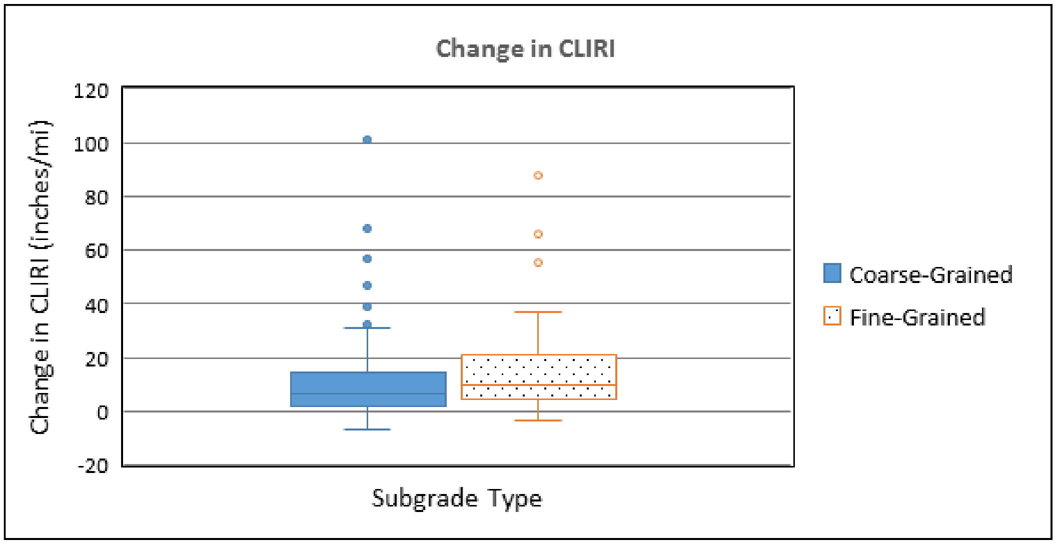

Figure 119. Graph. Box plots showing the change in CLIRI classified according to the subgrade type.

Figure 120 shows a box plot of the time period over which CLIRI values were obtained at the test sections classified according to the subgrade type. Figure 121 shows a box plot of the age of the pavement at the last profile date that was used for analysis.Table 101 through table 103 summarize the information shown in figure 119 through figure 121, respectively. The range of the data shown in these tables excludes outliers.

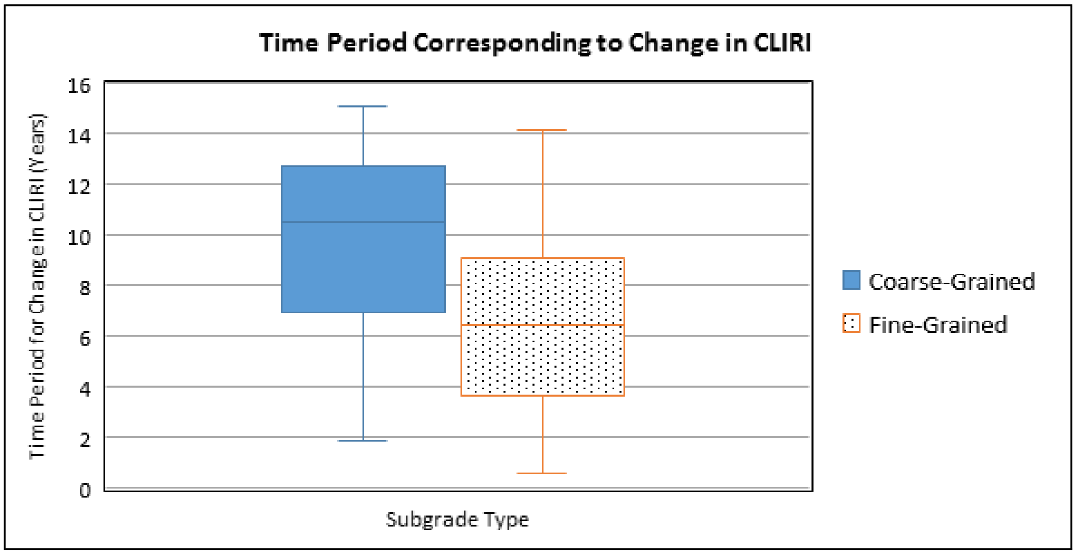

Figure 120. Graph. Box plots showing the period over which CLIRI was collected at the test sections, classified according to the subgrade type.

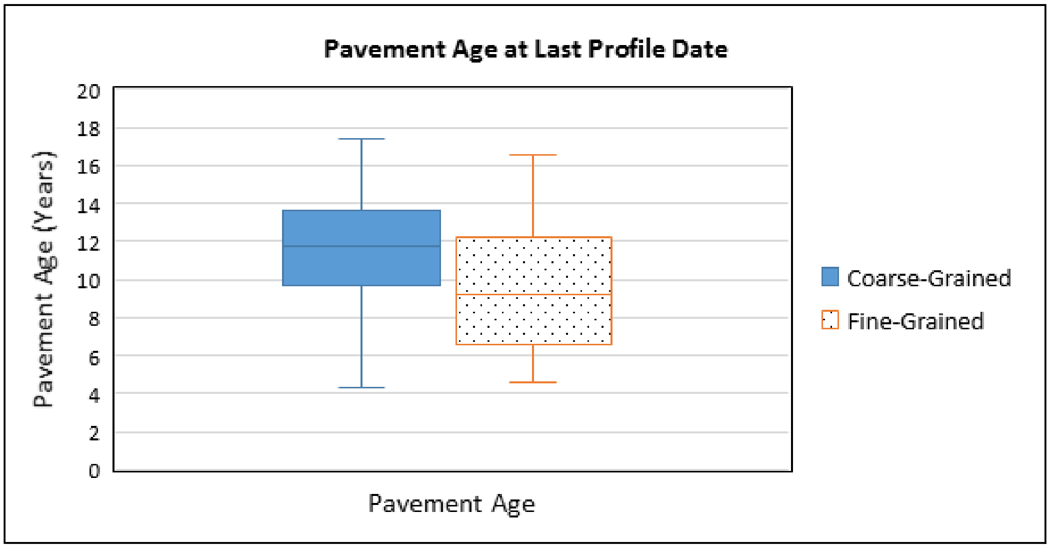

Figure 121. Graph. Box plots showing the age of the pavement at the last profile date used for analysis classified according to subgrade type.

Table 101. Median, first quartile, and third quartile values, and range of data for the change in CLIRI classified according to the subgrade type.

Subgrade Type	Number of Test Sections	Change in CLIRI (Inches/mi)			
		Median	First Quartile	Third Quartile	Range of Data
Coarse-grained	125	6.5	2.0	14.1	−6.8 to 31
Fine-grained	76	9.9	4.4	20.6	−3.0 to 37

Table 102. Median, first quartile, and third quartile values, and range of data for the time period over which CLIRI was obtained at test sections classified according to the subgrade type.

Subgrade Type	Number of Test Sections	Time Period Over which CLIRI was Obtained at Test Sections (Years)			
		Median	First Quartile	Third Quartile	Range of Data
Coarse-grained	125	11.0	7.0	12.8	1.9 to 15.1
Fine-grained	76	6.0	3.7	9.1	0.6 to 14.2

Table 103. Median, first quartile, and third quartile values, and range of data for the pavement age at last profile date classified according to the subgrade type.

Subgrade Type	Number of Test Sections	Age of Pavement at Last Profile Date (Years)			
		Median	First Quartile	Third Quartile	Range of Data
Coarse-grained	125	11.8	9.8	13.7	4.3 to 17.4
Fine-grained	76	9.3	6.6	12.2	4.6 to 16.6

As shown in table 101, the median values for the change in CLIRI for sections on coarse- and fine-grained subgrade were 6.5 and 9.9 inches/mi, with the third quartile values for the change in CLIRI values for sections on coarse- and fine-grained subgrade being 14.1 and 20.6 inches/mi, respectively. The median value of the change in CLIRI for sections on both coarse- and fine-grained subgrade was not large, and therefore, developing models capable of predicting small changes in CLIRI could be very challenging.

The environmental parameters that could influence the increase in IRI were annual precipitation and FI. The subgrade parameters that could influence the increase in IRI were the percentage of subgrade passing through the No. 200 sieve (fines content) and the PI of the subgrade. Freezing would cause frost heave that could increase the IRI, while the PI of the subgrade would influence the swelling potential of the subgrade. Provision of a drainage layer was also a factor that affected the rate of change of IRI.

A model for predicting the change in CLIRI was first developed using linear regression by using all of the available data (i.e., sections on fine-grained and coarse-grained subgrade). Thereafter, separate models were developed for predicting the change in CLIRI for pavements on coarse-and fine-grained subgrade. Different combinations of the previously mentioned parameters were used to obtain the maximum R^2 value.

The model developed considering all data is shown in figure 122.

$$\Delta CLIRI = 0.420 \times Elapsed\ Time \times \text{Ln}[\text{Ln}(Precip + 1) \times P200 \text{ x } (FI + 1) + (PI + 1) \text{ x } \text{Ln}(Precip + 1)]$$

Figure 122. Equation. Formula for model developed for predicting the change in CLIRI considering all data.

Where:

$\Delta CLIRI$ = change in center of the lane IRI, inches/mi
Elapsed Time = period corresponding to the change in CLIRI, years
Precip = average annual precipitation, inches
*P*200 = subgrade passing the No. 200 sieve, percentage
FI = average annual FI, °F days/year

For the model in figure 122, R^2 equals 0.43, standard error equals 14.9 inches/mi, and the number of data points equals 201.

The model developed considering sections on coarse-grained subgrade is shown in figure 123.

$$\Delta CLIRI = 0.4522 \times Elapsed\ Time \times \text{Ln}[\text{Ln}(Precip + 1) \times P200 \times (FI + 1)]$$

Figure 123. Equation. Formula for model developed considering data for sections on coarse-grained subgrade.

For the model in figure 123, R^2 equals 0.37, standard error equals 14.2 inches/mi, and the number of data points equals 125.

The model developed considering sections on fine-grained subgrade is shown in figure 124.

$$\Delta CLIRI = 0.420 \times Elapsed\ Time \times \text{Ln}[\text{Ln}(Precip + 1) \times P200 \text{ x } (FI + 1)] + (PI + 1) \text{ x } \text{Ln}(Precip + 1)]$$

Figure 124. Equation. Formula for model developed considering data for sections on fine-grained subgrade.

For the model in figure 124, R^2 equals 0.48, standard error equals 16 inches/mi, and the number of data points equals 76.

In all of these models, the R^2 values were low, and the standard error values were relatively high. Therefore, the change in CLIRI predicted by the models due to environmental effects can have a significant error. Including the total length of transverse cracking in the regression analysis did not result in a noticeable improvement in R^2 or a reduction in the standard error for all models.

The environmental parameters (i.e., precipitation and FI) for all test sections within an SPS-1 project are the same. The subgrade parameters (i.e., passing No. 200 and PI) for all test sections within a specific SPS-1 project were not available. Therefore, an average value for these parameters was computed by averaging the values that were available at the test sections that had data to compute an average value for the SPS-1 project. (See the subsection in chapter 4 entitled Subgrade Information for SPS-1 Projects.) This average value was assigned for all test sections in the project for the regression analysis. As shown in chapter 5, the change in CLIRI was different for different test sections in an SPS-1 project. However, although CLIRI for test sections in a specific project was different, in the regression analysis, the subgrade and environmental parameters for all test sections in an SPS-1 project were assumed to be the same. Therefore, for a specific SPS-1 project, the same set of parameters was being associated with different CLIRI values. This is likely one reason the standard error of the models shown in figure 122 through figure 124 are high and the R^2 values are low

CHAPTER 7. SUMMARY AND CONCLUSIONS

Eighteen SPS-1 projects were constructed for the LTPP SPS-1 experiment. The number of projects located on coarse- and fine-grained subgrade were 11 and 7, respectively. The distribution of the projects according to the environmental zones were: DNF—two projects, DF—two projects, WNF—eight projects, and WF—six projects. Data from 201 test sections were analyzed, with 125 of these test sections located on a coarse-grained subgrade and the other 76 sections located on a fine-grained subgrade. Because this was not a balanced experiment, some biases could be present when comparisons are performed between subgrade types and environmental zones.

The median ages of the test sections that were analyzed were 11.8 and 9.3 years for the sections on coarse- and fine-grained subgrade, respectively. The third quartile values for the age of the test sections were 13.7 and 12.2 years for the sections on coarse- and fine-grained subgrade, respectively.

CLIRI

In this project, the increase in roughness that occurred along the center of the lane was assumed to be due to environmental factors. A rate of change of CLIRI was computed for each test section using liner regression using the time-sequence CLIRI data. The following conclusions were drawn from the analysis of the data:

- The median values for the change in CLIRI over the monitored period for the sections on fine- and coarse-grained subgrade were 6.5 and 9.9 inches/mi, respectively. The third quartile values for the change in CLIRI over the monitored period for the sections on fine- and coarse-grained subgrade were 14.1 and 20.6 inches/mi, respectively. As shown by the median value for the change in CLIRI, the change in CLIRI that had occurred over the monitored period for many sections was small.

- The median and the third quartile values of the rate of change of CLIRI when all SPS-1 test sections were considered were 1.05 and 1.19 inches/mi/year, respectively.

- Overall, sections on fine-grained subgrade showed a greater rate of change of CLIRI compared with sections on coarse-grained subgrade. When all SPS-1 sections were considered, the median values for the rate of change of CLIRI for sections on fine- and coarse-grained subgrade were 1.65 and 0.78 inches/mi/year, respectively, while the third quartile values for rate of change of CLIRI for the two subgrade types were 3.49 and 1.45 inches/mi/year, respectively. Sufficient projects were available to compare the performance of the sections on fine- and coarse-grained subgrade in the WF and WNF environmental zones. In the WF zone, the median values for the rate of change of CLIRI for sections on fine- and coarse-grained subgrade were 1.86 and 1.36 inches/mi/year, respectively, while the third quartile values for rate of change of CLIRI for the two subgrade types were 3.56 and 2.18 inches/mi/year, respectively. In the WNF zone, the median values for the rate of change of CLIRI for sections on fine- and coarse-grained subgrade were 0.92 and 0.67 inches/mi/year, respectively, while the third quartile values for rate of change of CLIRI for the two subgrade types were 1.15 and 1.26 inches/mi/year, respectively.

- The provision of drainage through use of a PATB layer reduced the rate of change of CLIRI for sections on fine-grained subgrade. In the WF zone, the median values for the rate of change of CLIRI for sections on fine-grained subgrade with and without drainage were 1.33 and 2.88 inches/mi/year, respectively, while the third quartile values for rate of change of CLIRI for sections with and without drainage were 1.82 and 4.66 inches/mi/year, respectively. In the WNF zone, the median values for the rate of change of CLIRI for sections on fine-grained subgrade with and without drainage were 0.66 and 0.99 inches/mi/year, respectively, while the third quartile values for rate of change of CLIRI for sections with and without drainage were 1.12 and 1.30 inches/mi/year, respectively. This information shows it is very important to provide drainage for pavements built over fine-grained subgrade in the WF zone to reduce the rate of change of IRI.

- The effect of drainage on the rate of change of CLIRI for sections located on coarse-grained subgrade was less than was observed for sections on fine-grained subgrade. For sections on coarse-grained subgrade, when all SPS-1 sections were considered, the median values for the rate of change of CLIRI for sections with and without drainage were 0.66 and 0.85 inches/mi/year, respectively, while the third quartile values for the rate of change of CLIRI for these two cases were 1.36 and 1.46 inches/mi/year, respectively.

- For sections on fine-grained subgrade, the sections where the PATB layer was below the ATB layer (i.e., ATB/PATB) had an overall lower rate of change of CLIRI when compared with sections where the PATB layer was placed over the DGAB layer (i.e., PATB/DGAB). The median values for the rate of change of CLIRI where drainage was provided by ATB/PATB and PATB/DGAB were 1.16 and 1.32 inches/mi/year, respectively, while the third quartile values for these two cases were 1.81 and 2.67 inches/mi/year, respectively. For sections on fine-grained subgrade where no drainage was provided, the median and the third quartile values for the rate of change of CLIRI were 2.40 and 4.58 inches/mi/year, respectively.

- For sections on fine-grained subgrade, a trend of increasing rate of increase of CLIRI with increasing PI values of the subgrade was observed.

- Evaluation of data collected at five sections that were located on coarse-grained subgrade showed no seasonal effects on the IRI values. Two of these sections were in the DNF zone, two in the DF zone, and one in the WNF zone.

MIRI

The profile of the pavement can change due to environmental effects such as frost heave and swelling of the subgrade. Along the wheelpaths, the profile of the pavement can change due to traffic effects. Therefore, the changes in MIRI on a pavement can be due to both environmental and traffic effects. It is possible that the traffic may counteract the upward movements caused in the profile due to environmental effects by smoothing the profile. In addition to evaluating the changes in IRI along the center of the lane, the changes in MIRI were also studied in this project.

A rate of change of MIRI was computed using liner regression analysis using the available time-sequence MIRI data at each test section, and the results were used for analysis. The following observations were noted from the analysis of the data:

- The rate of change of MIRI was greater than the rate of change of CLIRI at 62 percent of the projects. Therefore, at 38 percent of the projects, the rate of change of IRI at the center of the lane (which received no traffic) was higher than the rate of change of IRI along the wheelpaths.

- When considering all SPS-1 test sections, the median values of the rate of change of MIRI and CLIRI were 1.56 and 1.05 inches/mi/year, respectively, while the third quartile values for these parameters were 3.22 and 1.19 inches/mi/year, respectively.

- Overall, sections on fine-grained subgrade showed a higher rate of change of MIRI when compared with sections on coarse-grained subgrade. When all SPS-1 sections were considered, the median values for the rate of change of MIRI for sections on fine- and coarse-grained subgrade were 1.87 and 1.43 inches/mi/year, respectively, while the third quartile values for rate of change of MIRI for the two subgrade types were 2.69 and 4.45 inches/mi/year, respectively. Sufficient projects were available to compare the performance of the sections on fine- and coarse-grained subgrade in the WF and WNF environmental zones. In the WF zone, the median values for the rate of change of MIRI for sections on fine- and coarse-grained subgrade were 2.80 and 2.26 inches/mi/year, respectively, while the corresponding values for the rate of change of CLIRI were 1.86 and 1.36 inches/mi/year, respectively. The third quartile values for rate of change of MIRI for the two subgrade types in the WF zone were 5.47 and 4.42 inches/mi/year, respectively, while the corresponding values for the rate of change of CLIRI were 3.36 and 2.18 inches/mi/year, respectively. In the WNF zone, the median values for the rate of change of MIRI for sections on fine- and coarse-grained subgrade were 0.67 and 1.09 inches/mi/year, respectively, while the corresponding values for the rate of change of CLIRI were 0.92 and 0.67 inches/mi/year, respectively. In the WNF zone, the third quartile values for the rate of change of MIRI for sections on fine- and coarse-grained subgrade were 0.96 and 1.90 inches/mi/year, respectively, while the corresponding values for the rate of change of CLIRI were 1.15 and 1.26 inches/mi/year, respectively.

- The provision of drainage through a PATB layer had a major effect in reducing the rate of change of MIRI for sections on fine-grained subgrade in the WF zone, while in the WNF zone the provision of drainage also reduced the rate of rate of change of MIRI. In the WF zone, the median values for the rate of change of MIRI for sections on fine-grained subgrade with and without drainage were 1.90 and 3.01 inches/mi/year, respectively, while the corresponding values for the rate of change of CLIRI were 1.33 and 2.88 inches/mi/year, respectively. The third quartile values for rate of change of MIRI for sections on fine-grained subgrade in the WF zone with and without drainage were 3.91 and 6.07 inches/mi/year, respectively, while the corresponding values for the rate of change of CLIRI were 1.82 and 4.66 inches/mi/year, respectively. In the WNF zone, the median values for the rate of change of MIRI for sections on fine-grained subgrade with and without drainage was 0.59 and 0.93 inches/mi/year, respectively, while the corresponding values for the rate of change of CLIRI were 0.66 and

0.99 inches/mi/year, respectively. The third quartile values for rate of change of MIRI for sections on fine-grained subgrade in the WNF zone with and without drainage were 0.67 and 1.03 inches/mi/year, respectively, while the corresponding values for the rate of change of CLIRI were 1.12 and 1.30 inches/mi/year, respectively.

- On coarse-grained subgrades, the provision of drainage also reduced the rate of change of MIRI. A coarse-grained subgrade could have a fines content up to 50 percent, and the effect of drainage for sections on a coarse-grained subgrade could vary depending on the amount of fines content in the subgrade. When all SPS-1 sections were considered, the median value of the rate of change of MIRI for sections on coarse-grained subgrade with and without drainage were 1.40 and 1.55 inches/mi/year, respectively, while the corresponding values for the rate of change of CLIRI were 0.66 and 0.85 inches/mi/year, respectively. The third quartile values for the rate of change of MIRI for sections on coarse-grained subgrade with and without drainage were 2.34 and 3.31 inches/mi/year, respectively, while the corresponding values for the rate of change of CLIRI were 1.36 and 1.46 inches/mi/year, respectively.

- For sections on fine-grained subgrade, the sections where the PATB layer was below the ATB layer (i.e., ATB/PATB) had an overall lower rate of change of MIRI when compared with sections where the PATB layer was placed over the DGAB layer (i.e., PATB/DGAB). The median values for the rate of change of MIRI where drainage was provided by ATB/PATB and PATB/DGAB were 1.12 and 1.24 inches/mi/year, respectively, while the rate of change of CLIRI for these two cases were 1.16 and 1.32 inches/mi/year, respectively. The third quartile values for the rate of change of MIRI where drainage was provided by ATB/PATB and PATB/DGAB were 2.88 and 4.55 inches/mi/year, respectively, while the corresponding values for the rate of change of CLIRI were 1.81 and 2.67 inches/mi/year, respectively. The median and third quartile values for the rate of change of MIRI for sections on fine-grained subgrade where no drainage was provided were 2.72 and 5.92 inches/mi/year, respectively. The median and third quartile values for the rate of change of CLIRI for sections on fine-grained subgrade where no drainage was provided were 1.23 and 4.58 inches/mi/year, respectively.

- For sections on fine-grained subgrade, a trend of increasing rate of increase of MIRI with increasing PI values of the subgrade was observed.

- No relationship between the total length of cracking and the change in MIRI was noted for the analyzed data. Cracks that had a depression associated with the crack had a large impact on the IRI.

Other Observations

- Raveling of the pavement surface contributed to the increase in roughness of the pavement.

- In many cases, construction of patches on the pavement increased the IRI of the pavement significantly. This implies more care should be taken when constructing patches to ensure that the resulting pavement is smooth and adequately compacted.

Benefits of Collecting Profile Data Along the Center of the Lane

State transportation departments can obtain network-level profile data along the two wheelpaths of the travel lane and use MIRI values computed from the collected data to track the roughness of their highway network. Collecting profile data along the center of the lane could provide information on how the profile along the center of the lane, which is mainly influenced by environmental effects, would change over time. This information could be used to modify or improve the agency's pavement design procedure to minimize large increases in IRI in areas where the combination of environmental and subgrade conditions caused such increases in the center lane. This information could also be used by the agency to build better models for predicting the change in IRI due to environmental conditions. If an agency collects network-level data using the services of a vendor, collection of the center of the lane profile data in addition to the wheelpath data would be expected to increase the cost minimally. If the agency used its own equipment to collect data, there would be a cost associated with upgrading existing equipment with an additional sensor to collect the profile data along the center of the lane. However, if the agency purchased new equipment, it could obtain equipment with an additional sensor that could collect data along the center of the lane at a small increase in cost.

APPENDIX A. PROFILE DATA AVAILABILITY AT SPS-1 TEST SECTIONS

Table 104 shows the profile data availability at SPS-1 test sections.

Table 104. Profile data availability at SPS-1 test sections.

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	Date First Profiled With T-6600	Last Profile Date	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date (Years)[2]
Alabama (01)	3/1/1993	1	Yes	6/15/2005	10/30/1995	7/3/1997	5/4/2005	12	7.8	12.2
		2	Yes	6/15/2005	8/25/1994	7/3/1997	5/4/2005	12	7.8	12.2
		3	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	8	7.8	12.2
		4	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	10	7.8	12.2
		5	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	8	7.8	12.2
		6	Yes	6/15/2005	8/25/1994	7/3/1997	5/4/2005	8	7.8	12.2
		7	Yes	8/21/2001	8/24/1994	7/3/1997	3/4/2001	4	3.7	8.0
		8	Yes	6/15/2005	8/24/1994	7/3/1997	5/4/2005	9	7.8	12.2
		9	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	8	7.8	12.2
		10	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	9	7.8	12.2
		11	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	7	7.8	12.2
		12	Yes	6/15/2005	8/25/1994	7/3/1997	5/4/2005	8	7.8	12.2
Arizona (04)	8/1/1993	13	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	27	9.2	12.7
		14	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	27	9.2	12.7
		15	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		16	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		17	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		18	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		19	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		20	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		21	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		22	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		23	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		24	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	Date First Profiled With T-6600	Last Profile Date	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date (Years)[2]
Arkansas (05)	9/1/1994	13	Yes	11/15/2008	7/7/1995	7/1/1997	9/21/2008	8	11.2	14.1
		14	Yes	11/15/2008	7/7/1995	7/1/1997	9/21/2008	8	11.2	14.1
		15	Yes	11/15/2008	7/7/1995	7/1/1997	9/21/2008	8	11.2	14.1
		16	Yes	11/15/2008	7/7/1995	7/1/1997	9/21/2008	8	11.2	14.1
		17	Yes	11/15/2008	7/7/1995	7/1/1997	9/21/2008	8	11.2	14.1
		18	Yes	11/15/2008	7/7/1995	7/1/1997	9/21/2008	8	11.2	14.1
		19	Yes	6/15/2004	7/8/1995	7/1/1997	3/19/2004	6	6.7	9.6
		20	Yes	6/15/2004	7/8/1995	7/1/1997	3/19/2004	6	6.7	9.6
		21	Yes	6/15/2004	7/8/1995	7/1/1997	3/19/2004	5	6.7	9.6
		22	Yes	11/15/2008	7/8/1995	7/1/1997	9/21/2008	8	11.2	14.1
		23	Yes	11/15/2008	7/8/1995	7/1/1997	9/21/2008	8	11.2	14.1
		24	Yes	11/15/2008	7/7/1995	7/1/1997	9/21/2008	8	11.2	14.1
Delaware (10)	5/1/1996	1	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		2	Yes	5/1/2008	2/24/1996	6/10/1997	6/13/2006	15	9.0	10.1
		3	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	15	9.0	10.1
		4	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		5	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		6	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		7	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		8	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		9	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		10	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		11	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		12	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	Date First Profiled With T-6600	Last Profile Date	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date (Years)[2]
Florida (12)	11/1/1995	1	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
		2	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	15	15.1	16.3
		3	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
		4	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	15	15.1	16.3
		5	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
		6	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
		7	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
		8	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	15	15.1	16.3
		9	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
		10	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	15	15.1	16.3
		11	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
		12	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
Iowa (19)	6/1/1993	1	Yes	8/1/2007	10/15/1993	9/25/1997	9/22/2004	8	7.0	11.3
		2	Yes	8/1/2007	10/15/1993	9/25/1997	9/22/2004	8	7.0	11.3
		3	Yes	8/1/2007	10/15/1993	9/25/1997	9/22/2004	8	7.0	11.3
		4	Yes	8/1/2007	10/15/1993	9/25/1997	9/22/2004	8	7.0	11.3
		5	Yes	8/1/2007	10/15/1993	9/25/1997	9/22/2004	8	7.0	11.3
		6	Yes	8/1/2007	10/15/1993	9/25/1997	9/22/2004	8	7.0	11.3
		7	Yes	8/1/2007	2/15/1995	9/25/1997	9/22/2004	8	7.0	11.3
		8	Yes	8/1/2007	10/15/1993	9/25/1997	9/22/2004	8	7.0	11.3
		9	Yes	8/1/2007	10/15/1993	9/25/1997	9/22/2004	8	7.0	11.3
		10	Yes	8/1/2007	10/15/1993	9/25/1997	9/22/2004	8	7.0	11.3
		11	Yes	8/1/2007	10/15/1993	9/25/1997	9/22/2004	8	7.0	11.3
		12	Yes	8/1/2007	10/15/1993	9/25/1997	9/22/2004	8	7.0	11.3

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	Date First Profiled With T-6600	Last Profile Date	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date (Years)[2]
Kansas (20)	11/1/1993	1	Yes	7/25/1996	5/13/1994	2/13/1997	4/23/1996	0	N/A	2.5
		2	Yes	7/25/1996	5/13/1994	2/13/1997	4/23/1996	0	N/A	2.5
		3	Yes	12/31/2003	5/13/1994	2/13/1997	3/15/2004	6	7.1	10.4
		4	Yes	12/31/2003	5/13/1994	2/13/1997	3/15/2004	6	7.1	10.4
		5	Yes	12/31/2003	5/13/1994	2/13/1997	3/15/2004	6	7.1	10.4
		6	Yes	12/31/2003	5/13/1994	2/13/1997	3/15/2004	5	7.1	10.4
		7	Yes	7/25/1996	5/13/1994	2/13/1997	4/23/1996	0	N/A	2.5
		8	Yes	12/31/2003	5/13/1994	2/13/1997	3/15/2004	5	7.1	10.4
		9	Yes	12/31/2003	5/13/1994	2/13/1997	3/15/2004	6	7.1	10.4
		10	Yes	12/31/2003	5/13/1994	2/13/1997	3/15/2004	6	7.1	10.4
		11	Yes	12/31/2003	5/13/1994	2/13/1997	3/15/2004	6	7.1	10.4
		12	Yes	12/31/2003	5/13/1994	2/13/1997	3/15/2004	6	7.1	10.4
Louisiana (22)	7/1/1997	13	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		14	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		15	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		16	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		17	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		18	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		19	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		20	No	ND	11/17/1997	11/17/1997	1/16/2012	7	14.2	14.6
		21	No	ND	11/17/1997	11/17/1997	1/16/2012	7	14.2	14.6
		22	No	ND	11/17/1997	11/17/1997	1/16/2012	7	14.2	14.6
		23	No	ND	11/17/1997	11/17/1997	1/16/2012	7	14.2	14.6
		24	No	ND	11/17/1997	11/17/1997	1/16/2012	7	14.2	14.6

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	Date First Profiled With T-6600	Last Profile Date	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date (Years)[2]
Michigan (26)	11/1/1995	13	Yes	10/1/1995	No Data Collected				N/A	N/A
		14	Yes	10/1/1995	No Data Collected				N/A	N/A
		15	No	ND	12/30/1996	12/30/1996	9/11/2012	16	15.7	16.9
		16	No	ND	12/30/1996	12/30/1996	9/11/2012	16	15.7	16.9
		17	No	ND	12/30/1996	12/30/1996	9/11/2012	16	15.7	16.9
		18	No	ND	12/30/1996	12/30/1996	9/11/2012	15	15.7	16.9
		19	Yes	10/1/1995	No Data Collected				N/A	N/A
		20	No	ND	12/30/1996	12/30/1996	9/11/2012	15	15.7	16.9
		21	No	ND	12/30/1996	12/30/1996	9/11/2012	16	15.7	16.9
		22	Yes	10/1/1995	No Data Collected				N/A	N/A
		23	No	ND	12/30/1996	12/30/1996	9/11/2012	16	15.7	16.9
		24	No	ND	12/30/1996	12/30/1996	9/11/2012	16	15.7	16.9
Montana (30)	10/1/1998	13	No	ND	11/19/1998	11/19/1998	9/15/2012	14	13.8	14.0
		14	No	ND	11/19/1998	11/19/1998	9/15/2012	32	13.8	14.0
		15	No	ND	11/19/1998	11/19/1998	9/15/2012	14	13.8	14.0
		16	No	ND	11/19/1998	11/19/1998	9/15/2012	14	13.8	14.0
		17	No	ND	11/19/1998	11/19/1998	9/15/2012	14	13.8	14.0
		18	No	ND	11/19/1998	11/19/1998	9/15/2012	14	13.8	14.0
		19	No	ND	11/19/1998	11/19/1998	9/15/2012	14	13.8	14.0
		20	No	ND	11/19/1998	11/19/1998	9/15/2012	14	13.8	14.0
		21	No	ND	11/19/1998	11/19/1998	9/15/2012	14	13.8	14.0
		22	No	ND	11/19/1998	11/19/1998	9/15/2012	14	13.8	14.0
		23	No	ND	11/19/1998	11/19/1998	9/15/2012	14	13.8	14.0
		24	No	ND	11/19/1998	11/19/1998	9/15/2012	14	13.8	14.0

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Nebraska (31)	8/1/1995	13	Yes	7/12/2000	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6
		14	Yes	9/27/2002	11/1/1995	2/18/1997	5/20/2002	18	5.3	6.8
		15	Yes	9/27/2002	11/1/1995	2/18/1997	4/24/2002	7	5.2	6.7
		16	Yes	9/27/2002	11/1/1995	2/18/1997	4/24/2002	7	5.2	6.7
		17	Yes	9/27/2002	11/1/1995	2/18/1997	4/24/2002	7	5.2	6.7
		18	Yes	9/27/2002	11/1/1995	2/18/1997	4/24/2002	7	5.2	6.7
		19	Yes	9/27/2002	11/1/1995	2/18/1997	4/24/2002	7	5.2	6.7
		20	Yes	9/27/2002	11/1/1995	2/18/1997	4/24/2002	7	5.2	6.7
		21	Yes	9/27/2002	11/1/1995	2/18/1997	4/24/2002	7	5.2	6.7
		22	Yes	9/27/2002	11/1/1995	2/18/1997	4/24/2002	7	5.2	6.7
		23	Yes	9/27/2002	11/1/1995	2/18/1997	4/24/2002	7	5.2	6.7
		24	Yes	9/27/2002	11/1/1995	2/18/1997	4/24/2002	7	5.2	6.7
Nevada (32)	9/1/1995	1	Yes	7/1/2009	12/3/1996	12/3/1996	6/24/2009	30	12.6	13.8
		2	Yes	5/1/2004	4/22/1997	4/22/1997	4/15/2004	10	7.0	8.6
		3	Yes	5/1/2004	4/22/1997	4/22/1997	4/15/2004	10	7.0	8.6
		4	Yes	7/1/2009	4/22/1997	4/22/1997	6/24/2009	12	12.2	13.8
		5	Yes	5/1/2004	4/22/1997	4/22/1997	4/15/2004	10	7.0	8.6
		6	Yes	7/1/2009	4/22/1997	4/22/1997	6/24/2009	13	12.2	13.8
		7	Yes	7/1/2009	4/22/1997	4/22/1997	6/25/2009	13	12.2	13.8
		8	Yes	7/1/2009	4/22/1997	4/22/1997	6/25/2009	13	12.2	13.8
		9	Yes	7/1/2009	4/22/1997	4/22/1997	6/25/2009	13	12.2	13.8
		10	Yes	7/1/2009	4/22/1997	4/22/1997	6/24/2009	13	12.2	13.8
		11	Yes	7/1/2009	4/22/1997	4/22/1997	6/25/2009	13	12.2	13.8
		12	Yes	7/1/2009	4/22/1997	4/22/1997	6/25/2009	13	12.2	13.8

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	Date First Profiled With T-6600	Last Profile Date	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date (Years)[2]
New Mexico (35)	11/1/1995	1	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
		2	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
		3	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
		4	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
		5	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
		6	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
		7	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
		8	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
		9	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
		10	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
		11	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
		12	Yes	6/15/2009	3/11/1997	3/11/1997	5/15/2008	8	11.2	12.5
Ohio (39)	11/1/1995	1	Yes	9/27/1997	8/14/1996	12/27/1996	12/27/1996	1	0.0	1.2
		2	Yes	9/2/1996	8/14/1996	12/27/1996	8/29/1996	0	N/A	0.8
		3	Yes	6/19/2002	12/27/1996	12/27/1996	11/4/2001	6	4.9	6.0
		4	No	ND	8/14/1996	12/27/1996	11/5/2012	17	15.9	17.0
		5	Yes	9/7/1998	8/14/1996	12/27/1996	12/8/1997	2	0.9	2.1
		6	Yes	8/1/2008	8/14/1996	12/27/1996	7/14/2008	12	11.6	12.7
		7	Yes	9/2/1996	8/14/1996	12/27/1996	8/30/1996	0	N/A	0.8
		8	Yes	6/19/2002	8/14/1996	12/27/1996	11/4/2001	6	4.9	6.0
		9	Yes	6/19/2002	8/14/1996	12/27/1996	11/4/2001	6	4.9	6.0
		10	Yes	6/19/2002	8/14/1996	12/27/1996	11/4/2001	6	4.9	6.0
		11	No	ND	8/14/1996	12/27/1996	11/5/2012	17	15.9	17.0
		12	No	ND	8/14/1996	12/27/1996	11/5/2012	6	15.9	17.0

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Oklahoma (40)	7/1/1997	13	Yes	6/15/2008	11/19/1997	11/19/1997	4/30/2008	9	10.5	10.8
		14	No	ND	11/19/1997	11/19/1997	3/5/2011	11	13.3	13.7
		15	No	ND	11/19/1997	11/19/1997	3/5/2011	11	13.3	13.7
		16	No	ND	11/19/1997	11/19/1997	3/5/2011	11	13.3	13.7
		17	No	ND	11/19/1997	11/19/1997	3/5/2011	11	13.3	13.7
		18	No	ND	11/19/1997	11/19/1997	3/5/2011	11	13.3	13.7
		19	No	ND	11/19/1997	11/19/1997	3/5/2011	11	13.3	13.7
		20	No	ND	11/19/1997	11/19/1997	3/5/2011	11	13.3	13.7
		21	No	ND	11/19/1997	11/19/1997	3/5/2011	11	13.3	13.7
		22	Yes	6/15/2008	11/19/1997	11/19/1997	4/30/2008	9	10.5	10.8
		23	No	ND	11/19/1997	11/19/1997	3/5/2011	11	13.3	13.7
		24	No	ND	11/19/1997	11/19/1997	3/5/2011	11	13.3	13.7
Texas (48)	7/1/1997	13	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7
		14	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7
		15	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7
		16	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7
		17	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7
		18	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7
		19	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7
		20	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7
		21	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7
		22	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7
		23	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7
		24	No	ND	9/8/1997	9/8/1997	3/28/2002	13	4.6	4.7

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	Date First Profiled With T-6600	Last Profile Date	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date (Years)[2]
Virginia (51)	3/1/1993	13	Yes	10/1/2001	4/24/1996	10/9/1997	7/13/2001	13	3.8	8.4
		14	No	ND	4/24/1996	10/9/1997	3/27/2012	29	14.5	19.1
		15	No	ND	4/24/1996	10/9/1997	3/27/2012	21	14.5	19.1
		16	No	ND	4/24/1996	10/9/1997	3/27/2012	21	14.5	19.1
		17	No	ND	4/25/1997	10/9/1997	3/27/2012	21	14.5	19.1
		18	No	ND	4/24/1996	10/9/1997	3/27/2012	21	14.5	19.1
		19	No	ND	4/24/1996	10/9/1997	3/27/2012	21	14.5	19.1
		20	No	ND	4/24/1996	10/9/1997	3/27/2012	21	14.5	19.1
		21	No	ND	4/25/1997	10/9/1997	3/27/2012	21	14.5	19.1
		22	No	ND	4/24/1996	10/9/1997	3/27/2012	21	14.5	19.1
		23	No	ND	4/24/1996	10/9/1997	3/27/2012	21	14.5	19.1
		24	No	ND	4/24/1996	10/9/1997	3/27/2012	20	14.5	19.1
Wisconsin (55)	11/1/1997	13	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		14	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		15	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		16	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		17	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		18	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		19	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		20	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		21	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		22	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		23	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		24	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6

[1]Number of times center lane data that have been collected.
[2]Age of the pavement at last profile date.
ND = not deassigned; N/A = not applicable.

APPENDIX B. DATASET USED FOR ANALYSIS

Table 105 shows the dataset used for analysis in this study.

Table 105. Dataset used for analysis.

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	First Center Date for Analysis	Last Center Date for Analysis	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date Years[2]
Alabama (01)	3/1/1993	1	Yes	6/15/2005	10/30/1995	7/3/1997	5/4/2005	10	7.8	12.2
		2	Yes	6/15/2005	8/25/1994	7/3/1997	3/14/2001	7	3.7	8.0
		3	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	7	7.8	12.2
		4	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	8	7.8	12.2
		5	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	7	7.8	12.2
		6	Yes	6/15/2005	8/25/1994	7/3/1997	5/4/2005	7	7.8	12.2
		7	Yes	8/21/2001	8/24/1994	7/3/1997	1/27/1998	2	0.6	4.9
		8	Yes	6/15/2005	8/24/1994	7/3/1997	5/4/2005	8	7.8	12.2
		9	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	7	7.8	12.2
		10	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	8	7.8	12.2
		11	Yes	6/15/2005	1/10/1996	7/3/1997	5/4/2005	7	7.8	12.2
		12	Yes	6/15/2005	8/25/1994	7/3/1997	5/4/2005	7	7.8	12.2
Arizona (04) Sections With No Aggregate Seal	8/1/1993	15	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		17	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		19	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		23	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
		24	Yes	6/1/2006	1/27/1994	1/23/1997	3/27/2006	11	9.2	12.7
Arizona (04) Sections With Aggregate Seal Up to Seal	8/1/1993	13	Yes	6/1/2006	1/27/1994	1/23/1997	3/14/2002	13	5.1	8.6
		14	Yes	6/1/2006	1/27/1994	1/23/1997	3/14/2002	13	5.1	8.6
		16	Yes	6/1/2006	1/27/1994	1/23/1997	2/20/2002	13	5.1	8.6
		18	Yes	6/1/2006	1/27/1994	1/23/1997	2/20/2002	13	5.1	8.6
		20	Yes	6/1/2006	1/27/1994	1/23/1997	2/20/2002	13	5.1	8.6
		21	Yes	6/1/2006	1/27/1994	1/23/1997	2/20/2002	13	5.1	8.6
		22	Yes	6/1/2006	1/27/1994	1/23/1997	2/20/2002	13	5.1	8.6

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	First Center Date for Analysis	Last Center Date for Analysis	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date Years[2]
Arizona (04) Sections With Aggregate Seal After Seal	5/1/2002	14	Yes	6/1/2006	10/11/2002	10/11/2002	3/27/2006	13	3.5	3.9
		16	Yes	6/1/2006	3/2/2003	3/2/2003	3/27/2006	3	3.1	3.9
		18	Yes	6/1/2006	3/2/2003	3/2/2003	3/27/2006	4	3.1	3.9
		20	Yes	6/1/2006	3/2/2003	3/2/2003	3/27/2006	4	3.1	3.9
		21	Yes	6/1/2006	3/2/2003	3/2/2003	3/27/2006	4	3.1	3.9
		22	Yes	6/1/2006	3/2/2003	3/2/2003	3/27/2006	4	3.1	3.9
Arkansas (05)	9/1/1994	13	Yes	11/15/2008	7/7/1995	7/1/1997	5/22/2007	7	9.9	12.7
		14	Yes	11/15/2008	7/7/1995	7/1/1997	5/22/2007	7	9.9	12.7
		15	Yes	11/15/2008	7/7/1995	7/1/1997	5/22/2007	7	9.9	12.7
		16	Yes	11/15/2008	7/7/1995	7/1/1997	5/22/2007	7	9.9	12.7
		17	Yes	11/15/2008	7/7/1995	7/1/1997	5/22/2007	7	9.9	12.7
		18	Yes	11/15/2008	7/7/1995	7/1/1997	5/22/2007	7	9.9	12.7
		19	Yes	6/15/2004	7/8/1995	N/A	N/A	N/A	N/A	N/A
		20	Yes	6/15/2004	7/8/1995	N/A	N/A	N/A	N/A	N/A
		21	Yes	6/15/2004	7/8/1995	7/1/1997	3/19/2004	5	6.7	9.6
		22	Yes	11/15/2008	7/8/1995	7/1/1997	5/22/2007	7	9.9	12.7
		23	Yes	11/15/2008	7/8/1995	7/1/1997	5/22/2007	7	9.9	12.7
		24	Yes	11/15/2008	7/7/1995	7/1/1997	5/22/2007	7	9.9	12.7
Delaware (10)	5/1/1996	1	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		2	Yes	5/1/2008	2/24/1996	6/10/1997	6/13/2006	15	9.0	10.1
		3	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	15	9.0	10.1
		4	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		5	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		6	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		7	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		8	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		9	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		10	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		11	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1
		12	Yes	5/1/2008	6/10/1997	6/10/1997	6/13/2006	14	9.0	10.1

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	First Center Date for Analysis	Last Center Date for Analysis	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date Years[2]
Florida (12)	11/1/1995	1	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	11	15.1	16.3
		2	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
		3	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	9	15.1	16.3
		4	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
		5	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	9	15.1	16.3
		6	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	9	15.1	16.3
		7	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	9	15.1	16.3
		8	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
		9	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	9	15.1	16.3
		10	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	12	15.1	16.3
		11	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	9	15.1	16.3
		12	Yes	7/13/2012	1/27/1997	1/27/1997	2/24/2012	9	15.1	16.3
Iowa (19)	6/1/1993	1	Yes	8/1/2007	10/15/1993	9/25/1997	5/29/2001	5	3.7	8.0
		2	Yes	8/1/2007	10/15/1993	9/25/1997	5/29/2001	5	3.7	8.0
		3	Yes	8/1/2007	10/15/1993	9/25/1997	5/29/2001	5	3.7	8.0
		4	Yes	8/1/2007	10/15/1993	9/25/1997	5/29/2001	5	3.7	8.0
		5	Yes	8/1/2007	10/15/1993	9/25/1997	5/29/2001	5	3.7	8.0
		6	Yes	8/1/2007	10/15/1993	9/25/1997	5/29/2001	5	3.7	8.0
		7	Yes	8/1/2007	2/15/1995	9/25/1997	5/29/2001	5	3.7	8.0
		8	Yes	8/1/2007	10/15/1993	9/25/1997	5/29/2001	5	3.7	8.0
		9	Yes	8/1/2007	10/15/1993	9/25/1997	5/29/2001	5	3.7	8.0
		10	Yes	8/1/2007	10/15/1993	9/25/1997	5/29/2001	5	3.7	8.0
		11	Yes	8/1/2007	10/15/1993	9/25/1997	5/29/2001	5	3.7	8.0
		12	Yes	8/1/2007	10/15/1993	9/25/1997	5/29/2001	5	3.7	8.0

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	First Center Date for Analysis	Last Center Date for Analysis	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date Years[2]
Kansas (20)	11/1/1993	1	Yes	7/25/1996	5/13/1994	N/A	N/A	N/A	N/A	N/A
		2	Yes	7/25/1996	5/13/1994	N/A	N/A	N/A	N/A	N/A
		3	Yes	12/31/2003	5/13/1994	2/13/1997	5/12/2001	5	4.2	7.5
		4	Yes	12/31/2003	5/13/1994	2/13/1997	5/12/2001	5	4.2	7.5
		5	Yes	12/31/2003	5/13/1994	N/A	N/A	N/A	N/A	N/A
		6	Yes	12/31/2003	5/13/1994	N/A	N/A	N/A	N/A	N/A
		7	Yes	7/25/1996	5/13/1994	N/A	N/A	N/A	N/A	N/A
		8	Yes	12/31/2003	5/13/1994	2/13/1997	5/12/2001	4	4.2	7.5
		9	Yes	12/31/2003	5/13/1994	2/13/1997	5/12/2001	5	4.2	7.5
		10	Yes	12/31/2003	5/13/1994	2/13/1997	5/12/2001	5	4.2	7.5
		11	Yes	12/31/2003	5/13/1994	2/13/1997	5/12/2001	5	4.2	7.5
		12	Yes	12/31/2003	5/13/1994	2/13/1997	5/12/2001	5	4.2	7.5
Louisiana (22)	7/1/1997	13	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		14	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		15	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		16	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		17	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		18	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		19	No	ND	11/17/1997	11/17/1997	1/16/2012	8	14.2	14.6
		20	No	ND	11/17/1997	11/17/1997	1/16/2012	7	14.2	14.6
		21	No	ND	11/17/1997	11/17/1997	1/16/2012	7	14.2	14.6
		22	No	ND	11/17/1997	11/17/1997	1/16/2012	7	14.2	14.6
		23	No	ND	11/17/1997	11/17/1997	1/16/2012	7	14.2	14.6
		24	No	ND	11/17/1997	11/17/1997	1/16/2012	7	14.2	14.6

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	First Center Date for Analysis	Last Center Date for Analysis	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date Years[2]
Michigan (26) Up to First Overlay	11/1/1995	13	Yes	10/1/1995	N/A	N/A	N/A	N/A	N/A	N/A
		14	Yes	10/1/1995	N/A	N/A	N/A	N/A	N/A	N/A
		15	No	ND	12/30/1996	4/6/1997	5/29/2002	6	5.1	6.6
		16	No	ND	12/30/1996	4/6/1997	5/29/2002	6	5.1	6.6
		17	No	ND	12/30/1996	4/6/1997	5/29/2002	6	5.1	6.6
		18	No	ND	12/30/1996	4/6/1997	5/29/2002	6	5.1	6.6
		19	Yes	10/1/1995	N/A	N/A	N/A	N/A	N/A	N/A
		20	No	ND	12/30/1996	4/6/1997	5/29/2002	5	5.1	6.6
		21	No	ND	12/30/1996	10/27/1998	5/29/2002	4	3.6	6.6
		22	Yes	10/1/1995	N/A	N/A	N/A	N/A	N/A	N/A
		23	No	ND	12/30/1996	4/6/1997	5/29/2002	6	5.1	6.6
		24	No	ND	12/30/1996	4/6/1997	5/29/2002	6	5.1	6.6
Michigan (26) From First to Second Overlay	10/1/2002	15	No	ND	12/30/1996	4/10/2003	4/25/2012	7	9.0	9.6
		16	No	ND	12/30/1996	4/10/2003	4/25/2012	7	9.0	9.6
		17	No	ND	12/30/1996	4/10/2003	4/25/2012	7	9.0	9.6
		18	No	ND	12/30/1996	4/21/2005	4/25/2012	6	7.0	9.6
		20	No	ND	12/30/1996	4/21/2005	4/25/2012	6	7.0	9.6
		21	No	ND	12/30/1996	4/21/2005	4/25/2012	6	7.0	9.6
		23	No	ND	12/30/1996	4/10/2003	4/25/2012	7	9.0	9.6
		24	No	ND	12/30/1996	4/10/2003	4/25/2012	7	9.0	9.6

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	First Center Date for Analysis	Last Center Date for Analysis	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date Years[2]
Montana (30)	10/1/1998	13	No	ND	11/19/1998	11/19/1998	7/16/2010	12	11.7	11.8
		14	No	ND	11/19/1998	11/19/1998	7/16/2010	30	11.7	11.8
		15	No	ND	11/19/1998	11/19/1998	7/16/2010	12	11.7	11.8
		16	No	ND	11/19/1998	11/19/1998	7/16/2010	12	11.7	11.8
		17	No	ND	11/19/1998	11/19/1998	7/16/2010	12	11.7	11.8
		18	No	ND	11/19/1998	11/19/1998	7/16/2010	12	11.7	11.8
		19	No	ND	11/19/1998	11/19/1998	7/17/2010	12	11.7	11.8
		20	No	ND	11/19/1998	11/19/1998	7/17/2010	12	11.7	11.8
		21	No	ND	11/19/1998	11/19/1998	7/17/2010	12	11.7	11.8
		22	No	ND	11/19/1998	11/19/1998	7/17/2010	12	11.7	11.8
		23	No	ND	11/19/1998	11/19/1998	7/17/2010	12	11.7	11.8
		24	No	ND	11/19/1998	11/19/1998	7/17/2010	12	11.7	11.8
Nebraska (31)	8/1/1995	13	Yes	7/12/2000	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6
		14	Yes	9/27/2002	11/1/1995	2/18/1997	7/1/2000	11	3.4	4.9
		15	Yes	9/27/2002	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6
		16	Yes	9/27/2002	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6
		17	Yes	9/27/2002	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6
		18	Yes	9/27/2002	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6
		19	Yes	9/27/2002	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6
		20	Yes	9/27/2002	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6
		21	Yes	9/27/2002	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6
		22	Yes	9/27/2002	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6
		23	Yes	9/27/2002	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6
		24	Yes	9/27/2002	11/1/1995	2/18/1997	3/20/2000	5	3.1	4.6

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	First Center Date for Analysis	Last Center Date for Analysis	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date Years[2]
Nevada (32)	9/1/1995	1	Yes	7/1/2009	12/3/1996	12/3/1996	6/24/2009	30	12.6	13.8
		2	Yes	5/1/2004	4/22/1997	4/22/1997	4/15/2004	10	7.0	8.6
		3	Yes	5/1/2004	4/22/1997	4/22/1997	4/15/2004	10	7.0	8.6
		4	Yes	7/1/2009	4/22/1997	4/22/1997	6/24/2009	12	12.2	13.8
		5	Yes	5/1/2004	4/22/1997	4/22/1997	4/15/2004	10	7.0	8.6
		6	Yes	7/1/2009	4/22/1997	4/22/1997	6/24/2009	13	12.2	13.8
		7	Yes	7/1/2009	4/22/1997	4/22/1997	6/25/2009	13	12.2	13.8
		8	Yes	7/1/2009	4/22/1997	4/22/1997	8/27/2006	12	9.4	11.0
		9	Yes	7/1/2009	4/22/1997	4/22/1997	6/25/2009	13	12.2	13.8
		10	Yes	7/1/2009	4/22/1997	4/22/1997	6/24/2009	13	12.2	13.8
		11	Yes	7/1/2009	4/22/1997	4/22/1997	6/25/2009	13	12.2	13.8
		12	Yes	7/1/2009	4/22/1997	4/22/1997	8/27/2006	12	9.4	11.0
New Mexico (35)	11/1/1995	1	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5
		2	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5
		3	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5
		4	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5
		5	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5
		6	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5
		7	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5
		8	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5
		9	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5
		10	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5
		11	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5
		12	Yes	6/15/2009	3/11/1997	3/11/1997	4/24/2006	7	9.1	10.5

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	First Center Date for Analysis	Last Center Date for Analysis	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date Years[2]
Ohio (39)	11/1/1995	1	Yes	9/27/1997	8/14/1996	N/A	N/A	N/A	N/A	N/A
		2	Yes	9/2/1996	8/14/1996	N/A	N/A	N/A	N/A	N/A
		3	Yes	6/19/2002	12/27/1996	11/12/1998	11/4/2001	4	3.0	6.0
		4	No	ND	8/14/1996	11/12/1998	5/23/2012	13	13.5	16.6
		5	Yes	9/7/1998	8/14/1996	N/A	N/A	N/A	N/A	N/A
		6	Yes	8/1/2008	8/14/1996	11/12/1998	7/14/2008	10	9.7	12.7
		7	Yes	9/2/1996	8/14/1996	N/A	N/A	N/A	N/A	N/A
		8	Yes	6/19/2002	8/14/1996	11/12/1998	11/4/2001	4	3.0	6.0
		9	Yes	6/19/2002	8/14/1996	11/12/1998	11/4/2001	4	3.0	6.0
		10	Yes	6/19/2002	8/14/1996	11/12/1998	11/4/2001	4	3.0	6.0
		11	No	ND	8/14/1996	11/12/1998	8/9/2006	9	7.7	10.8
		12	No	ND	8/14/1996	11/12/1998	5/23/2012	12	13.5	16.6
Oklahoma (40)	7/1/1997	13	Yes	6/15/2008	11/19/1997	11/19/1997	4/11/2007	5	9.4	9.8
		14	No	ND	11/19/1997	11/19/1997	3/5/2011	9	13.3	13.7
		15	No	ND	11/19/1997	11/19/1997	3/5/2011	9	13.3	13.7
		16	No	ND	11/19/1997	11/19/1997	3/5/2011	9	13.3	13.7
		17	No	ND	11/19/1997	11/19/1997	3/5/2011	9	13.3	13.7
		18	No	ND	11/19/1997	11/19/1997	3/5/2011	9	13.3	13.7
		19	No	ND	11/19/1997	11/19/1997	3/5/2011	9	13.3	13.7
		20	No	ND	11/19/1997	11/19/1997	3/5/2011	9	13.3	13.7
		21	No	ND	11/19/1997	11/19/1997	3/5/2011	9	13.3	13.7
		22	No	ND	11/19/1997	11/19/1997	4/11/2007	9	9.4	9.8
		23	No	ND	11/19/1997	11/19/1997	3/5/2011	9	13.3	13.7
		24	No	ND	11/19/1997	11/19/1997	3/5/2011	9	13.3	13.7
		24	No	ND	11/19/1997	11/19/1997	3/5/2011	9	13.3	13.7

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	First Center Date for Analysis	Last Center Date for Analysis	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date Years[2]
Texas (48) Until First Overlay	7/1/1997	13	No	ND	9/8/1997	4/2/1998	10/17/2001	5	3.5	4.3
		14	No	ND	9/8/1997	12/10/1999	10/17/2001	4	1.9	4.3
		15	No	ND	9/8/1997	12/10/1999	10/17/2001	4	1.9	4.3
		16	No	ND	9/8/1997	12/10/1999	10/17/2001	4	1.9	4.3
		17	No	ND	9/8/1997	4/2/1998	10/17/2001	5	3.5	4.3
		18	No	ND	9/8/1997	4/2/1998	10/17/2001	5	3.5	4.3
		19	No	ND	9/8/1997	12/10/1999	10/17/2001	4	1.9	4.3
		20	No	ND	9/8/1997	4/2/1998	10/17/2001	5	3.5	4.3
		21	No	ND	9/8/1997	4/2/1998	10/17/2001	5	3.5	4.3
		22	No	ND	9/8/1997	4/2/1998	10/17/2001	5	3.5	4.3
		23	No	ND	9/8/1997	4/2/1998	10/17/2001	5	3.5	4.3
		24	No	ND	9/8/1997	4/2/1998	10/17/2001	5	3.5	4.3
Texas (48) After First Overlay	4/29/2002	13	No	ND	9/8/1997	5/21/2003	3/19/2007	4	3.8	4.9
		14	No	ND	9/8/1997	5/21/2003	3/19/2007	5	3.8	4.9
		15	No	ND	9/8/1997	5/21/2003	3/19/2007	5	3.8	4.9
		16	No	ND	9/8/1997	5/21/2003	3/19/2007	5	3.8	4.9
		17	No	ND	9/8/1997	5/21/2003	3/19/2007	5	3.8	4.9
		18	No	ND	9/8/1997	5/21/2003	3/19/2007	5	3.8	4.9
		19	No	ND	9/8/1997	5/21/2003	3/19/2007	5	3.8	4.9
		20	No	ND	9/8/1997	5/21/2003	3/19/2007	5	3.8	4.9
		21	No	ND	9/8/1997	5/21/2003	3/19/2007	5	3.8	4.9
		22	No	ND	9/8/1997	5/21/2003	3/19/2007	5	3.8	4.9
		23	No	ND	9/8/1997	5/21/2003	3/19/2007	5	3.8	4.9
		24	No	ND	9/8/1997	1/21/2005	3/19/2007	3	2.2	4.9

State and Code	Traffic Open Date	Section Number	Out of Study?	Deassign Date (if Deassigned)	Date First Profiled	First Center Date for Analysis	Last Center Date for Analysis	Center Lane Profiles[1]	Time Span for Center Lane Data (Years)	Age at Last Profile Date Years[2]
Virginia (51)	3/1/1993	13	Yes	10/1/2001	4/24/1996	10/9/1997	7/13/2001	13	3.8	8.4
		14	No	ND	4/24/1996	10/9/1997	7/13/2010	29	12.8	17.4
		15	No	ND	4/24/1996	10/9/1997	7/13/2010	19	12.8	17.4
		16	No	ND	4/24/1996	10/9/1997	7/13/2010	19	12.8	17.4
		17	No	ND	4/25/1997	10/9/1997	7/13/2010	19	12.8	17.4
		18	No	ND	4/24/1996	10/9/1997	7/13/2010	19	12.8	17.4
		19	No	ND	4/24/1996	10/9/1997	7/13/2010	19	12.8	17.4
		20	No	ND	4/24/1996	10/9/1997	7/13/2010	19	12.8	17.4
		21	No	ND	4/25/1997	10/9/1997	7/13/2010	19	12.8	17.4
		22	No	ND	4/24/1996	10/9/1997	7/13/2010	19	12.8	17.4
		23	No	ND	4/24/1996	10/9/1997	7/13/2010	19	12.8	17.4
		24	No	ND	4/24/1996	10/9/1997	8/24/2003	13	5.9	10.5
Wisconsin (55)	11/1/1997	13	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		14	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		15	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		16	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		17	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		18	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		19	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		20	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		21	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		22	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		23	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6
		24	Yes	9/1/2008	12/1/1997	12/1/1997	6/7/2008	10	10.5	10.6

[1]Number of times that center lane data have been collected.
[2]Age of the pavement at last profile date.
ND = not deassigned; N/A = not available.

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