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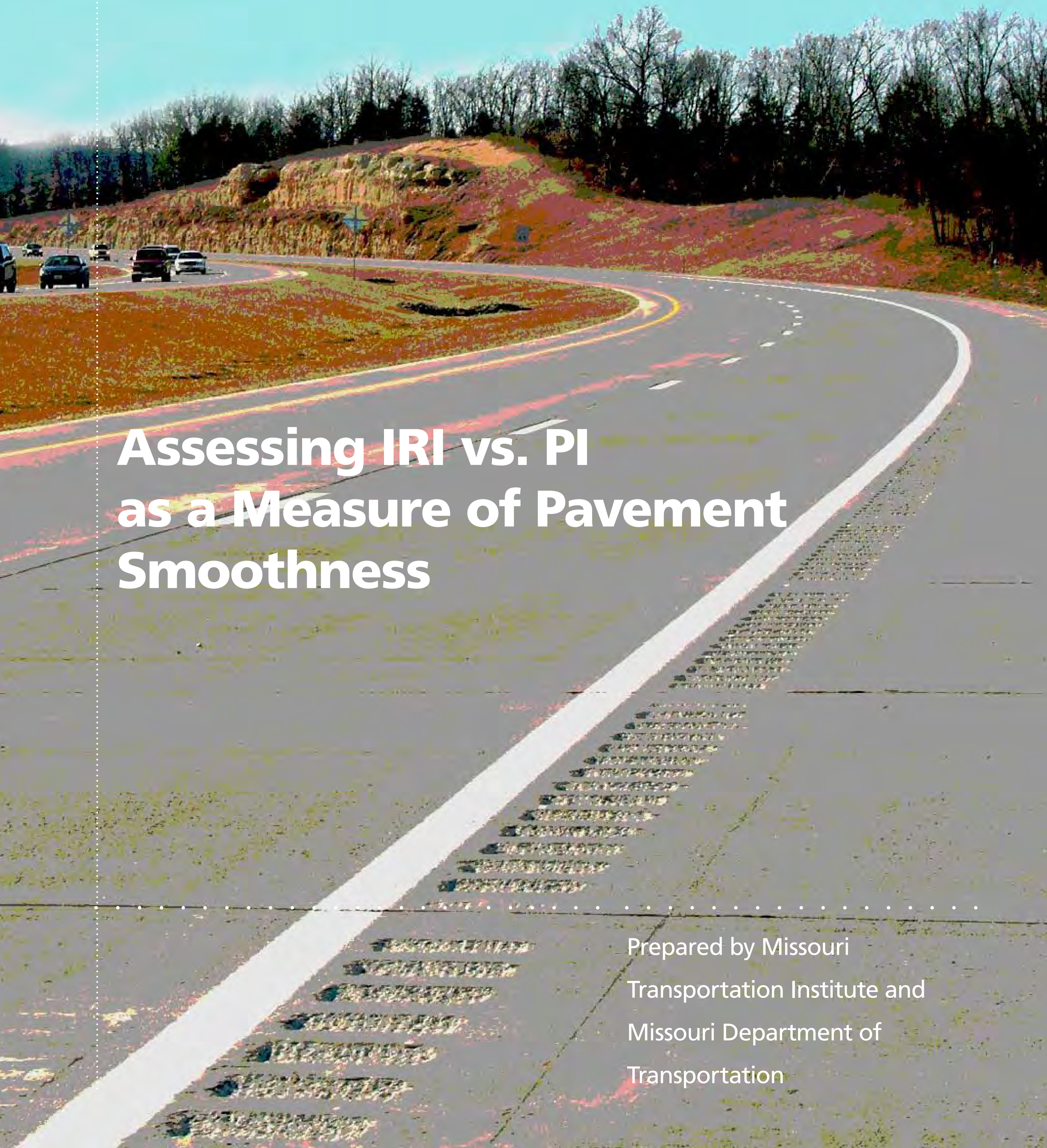

Assessing IRI vs. PI as a Measure of Pavement Smoothness

Prepared by Missouri Transportation Institute and Missouri Department of Transportation

FINAL REPORT

RI06-003

Assessing IRI vs. PI as a Measurement of Pavement Smoothness

Prepared for the
Missouri Department of Transportation
Organizational Results

by

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16. Abstract

A Pavement smoothness specification that allows either the International Roughness Index (IRI) or Profile Index (PI) to measure pavement smoothness would be advantageous to both industry and MoDOT. This brief study provides for MoDOT an understanding of the relationship between IRI and PI, an analysis comparing the two systems, a review of potential specifications and offers a "smoothness adjustment table" that would fit into Section 502.15.3 of the Missouri specifications. Furthermore safeguards against the potential manipulation of the data within both IRI and PI systems are discussed. With proper certification procedures for equipment and operators and a random verification program on the measurement of smoothness, it is unlikely that the state DOT will encounter a problem with systematic alterations of inertial profiling data. Sample specifications from Connecticut DOT, Ohio DOT and Minnesota DOT are included in the report as they are good examples of specifications that MoDOT may wish to use as a pattern for their specification.

17. Key Words International Roughness Index (IRI), Profile Index (PI) inertial measurements, profilometer, pavement smoothness, pavement roughness, blanking bands, California profilometer	18. Distribution Statement No restrictions. This document is available to the public through National Technical Information Center, Springfield, Virginia 22161

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Executive Summary

A Pavement smoothness specification that allows either the International Roughness Index (IRI) or Profile Index (PI) to measure pavement smoothness would be advantageous to both industry and MoDOT. This brief study provides for MoDOT an understanding of the relationship between IRI and PI, an analysis comparing the two systems, and a review of the current state of the practice. Sample specifications from Connecticut DOT, Ohio DOT and Minnesota DOT are included in the report as they are good examples of specifications that MoDOT may wish to use as a pattern for their specification.

To assist MoDOT we drew from the recent research and provide smoothness adjustment tables for pay factors that would fit into Section 502.15.3 of the Missouri DOT specifications. For example:

PI and IRI (in/mi) Pay Factors

Pay Factors for roads with speed limit of >45mph

PI (in/mi)	IRI (in/mi)	Percent
0-10	0-40	105%
10.1-15	40.1-54	103%
15.1-25	54.1-80	100%
25.1 +	80.1 +	100%

Furthermore we held informal discussions with several IRI and PI users from several states concerning safeguards against the potential manipulation of the data within both IRI and PI systems. As a result we report that with proper certification procedures for equipment and operators, a random verification program on the measurement of smoothness, stiff penalties for cheating, regular calibration of the measuring equipment and both the data and the results provided to the state it is unlikely that the state DOT will encounter a problem with systematic alterations of inertial profiling or profilometer data.

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Introduction

This report describes the International Roughness Index (IRI), current users, sample specifications, current issues, and its relationship with the Profile Index(PI). A suggested set of pay-factor tables are presented. Missouri DOT has a specification addressing the requirements for use of California profilograph equipment and the computation of profile index to compute pay factor. Multiple Appendices, containing detailed information, are provided for easy reference and may be used to support the preparation of a new set of specifications for inertial profiling and international roughness index. The Appendices are:

- A – Database of State DOT Concrete Pavement Practices
- B – State agency smoothness specifications for asphalt pavements
- C – IRI vs. PI and also PI (asphalt) to PI (concrete) Relationships
- D – Pavement Smoothness Pay Factor, Incentive/Disincentive Specifications
- E – Example Specifications from Connecticut DOT (Inertial Profiler and IRI)
- F – Example Specifications from Ohio DOT (CA profilograph and IRI)
- G – Example Specifications from Minnesota DOT (Inertial Profiler and IRI)
- H – Collecting Smoothness Data for Pay Factors Flowchart

Appendices A, B-1, and B-2 are included for background information. The others provide examples and substantive information for the preparation of inertial profiling and IRI-based specifications. When necessary, a description of the information is provided with the appendix. Missouri's (wet – freeze and 0.0 blanking band) equations are highlighted for easy reference.

Brief Description of Profilograph / Performance Index

(Please note the following description is taken from the American Concrete Pavement Association (ACPA) website www.pavement.com.)

A California profilograph is a rolling straight edge. It measures vertical deviations from a moving 25-foot reference plane.

A sensing or recording wheel located at the center of the frame moves freely in the vertical direction, giving the machine the ability to record surface deviations. The surface profile is logged into a computer or traced onto graph paper as the profilograph travels along the pavement. The profile is termed a profile trace and shows the location and height of bumps and dips. The profile trace of a pavement built perfectly smooth would be a straight line on graph paper.

To meet the minimum smoothness requirements of the specification, contractors use a diamond grinding machine to remove bumps in the surface which are identified on the profile trace. The trace is also used to produce a profile index expressed in inches per mile (or millimeters per kilometer). When contractors and agency engineers talk about ride numbers or "the ride" they are referring to the profile index. A lower profile index represents a smoother surface than a higher profile index. Many states, including Missouri, also successfully use incentive and disincentive payments for the degree of smoothness as presented in Appendices A, B-1, and B-2.

Brief Description of International Roughness Index (IRI)

IRI measurements are used by some highway agencies to measure pavement smoothness and also to determine pay factors on new highway construction and highway rehabilitation projects. The IRI (also referred to as inertial profile) estimates total vertical up and down movement of a quarter car simulation model in response to a stimulus input over a given distance. IRI units are inches/mile, or meters/kilometer or millimeters/kilometer. The quarter car simulation model is composed of a body (sprung) mass, suspension spring and damper, axle/tire (unsprung) mass, and tire spring with internationally defined parameters and with an assumed vehicle speed of 50 miles per hour. The defined model parameters and quarter car model is often referred to as *The Golden Car*. The stimulus input to the model is the vertical profile of the roadway. See reference [1] for additional details on one-dimensional Inertial Profiling and IRI computations.

The IRI quarter car simulation model is essentially a filter of the roadway vertical profile. The quarter car model is primarily influenced by wavelengths ranging from 1.2 to 30 meters (3.9 to 98.4 feet). Maximum sensitivity is at wavelengths of 2.4 to 15 meters (7.9 to 49.2 feet). An accurate vertical profile that encompasses the entire range of wavelengths of interest is required as input to the IRI model. To make full use of the IRI output, the location of IRI values outside an acceptable ride quality value must be also known for identification of the cause of the problem and for remedial repairs. This value is most off tied to the pay factor specification of “x” in/mi.

The profile estimation algorithm as typically used in Pavement Management System (PMS) vehicles assumes that the vehicle never stops and maintains a relatively stable speed, preferably between 30 to 60 mph. A portion of the recursion equation that generates the inertial profile has a term that includes the speed parameter squared in the denominator. Low speed values can generate false peaking in the computed inertial profile and therefore create false spikes in the IRI parameter.

The tables and figures in Appendix A showing which states are using IRI for measuring construction quality are taken from references that are four years old. This is the latest national information as no entity keeps an up-to-date list of each of the states practices. The use of IRI is increasing in popularity for a number of reasons presented below.

One reason for using IRI is the concept of using the same pavement condition index from “cradle to grave”. The IRI index is used by almost all states for monitoring the condition of pavements from year-to-year. This is one of the pavement performance indices that states use for maintenance and rehabilitation scheduling. It is also one of the indices that FHWA uses in monitoring the condition of the nations highways as part of the HPMS database.

Another reason is that the profilograph is limited in the wavelengths it can measure due to its fixed length, typically 25 feet. Therefore, it cannot record longer wavelengths that also effect ride-quality. For example: sag in string lines can occur in concrete pavement construction due to improper installation or due to an improperly adjusted feeler gauge on the paver, resulting in 50 foot (typical mount point intervals) peak-to-peak waves. This construction problem, if missed, will result in a poor ride quality. The mechanical design of the profilograph can result in inaccurate profile readings and PI values. The IRI encompasses larger wavelengths missed by the profilograph that are influential on ride quality.

Inertial profilers collect more accurate and detailed pavement profiles used in computing IRI. When the profile information is collected and saved for later analysis, the profile contains a wealth of information that can be extracted for diagnosing the causes of poor ride-quality. Knowing the extracted road features that cause poor ride quality leads to improved construction practices and pavement design. There are signal processing methods currently being evaluated that can decompose the profile into its constituent parts. For example, when this method was applied to a segment of I-80 (concrete construction), string line sag and slab warp and curl profiles were individually extracted from the profile. What were left were the texture, joints, cracks, and faults. Since the IRI is a linearly additive measurement, the IRI introduced by string line sag, warp and curl, and the other features can be computed for each of these extracted components. Simply stated, by using IRI the causes of poor ride quality can be ascertained, and therefore corrective actions undertaken.

These are several of the main reasons many states are considering moving to IRI for all pavement surface - ride measurements.

IRI and Smoothness Specifications

Highway agencies specify both smoothness (profilograph-PI) and roughness (inertial profilers-IRI) measurement specifications in the construction of highway pavements. The equipment and specifications can vary from state to state. Appendix A contains tables generated from the American Concrete Pavement Association's website (www.pavement.com) "Database of State DOT Concrete Pavement Practices". These tables present: 1) Smoothness Specification - Measurement Requirements; 2) Smoothness Specification - Measuring Equipment Used and Roughness Index; 3) Smoothness Specification - Pay Factors and Limits; 4) Smoothness Specification - Blanking Band and Must-Grind Bump Requirement; and 5) Tining Dimensions. It should be noted that PI values are dependent on the size of the blanking band and that different states use different blanking band sizes in their specifications.

The profilograph does have some limitations due to its physical design. One of its problem areas is on horizontal curves with superelevation transitions and on the banked horizontal curves. Scofield [2] reports on these profilograph limitations.

An effort has been under way to have all highway agencies switch to the IRI (inertia profilers) measurement for QC/QA. A primary reason for this desired switch is that profilographs measures only wavelengths within the range of 0.3 to 23 m (1 to 75 feet) and because it amplifies wavelengths that are a factor of its length (i.e. 7.6 m [25 feet]). Also, different states used different blanking band sizes (0.0, 2.5. and 5.0 mm), causing a systematic inconsistency in the data from state to state.

Pavement Smoothness Index Relationships

An FHWA report [3], "Pavement Smoothness Index Relationships, Final Report", Publication FHWA-RD-02-57, attempts to provide answers to agencies wanting to switch from PI to IRI. Previous small studies by a number of agencies and universities developed relationships between IRI and PI which did not compare well among these small studies.

The FHWA study performed a more comprehensive analysis using the time history smoothness data collected for the Long-Term Pavement Performance (LTPP) program. Both PI and IRI performance indices were computed from the surface profile data contained within the LTPP database. Data was also categorized by pavement type (6) and climatic zone (4), and model type (6). PI values were computed with 0.0, 2.5. and 5mm blanking bands. Models of IRI vs $PI_{0.0mm}$, $PI_{2.5mm}$, $PI_{5.0mm}$ and models amongst the PI's with the different blanking bands was desired.

A single model of IRI vs. PI contains too much variance in the data. A model for each pavement type by climatic zone and blanking band would require a total of 144 models. An analysis was performed to determine which factorial cells of the model matrix could be combined to reduce the number of models. Fifteen models were developed for the PI-IRI relationship and 18 models were developed for the PI-PI relationships for Asphalt - Concrete. For PCC-surfaced pavements, 9 and 12 models were developed for the PI-IRI and PI-PI relationships, respectively. R-squared was typically above 70 percent with reasonable levels of error. This is generally considered a good level of correlation.

The state agency smoothness specifications for asphalt and concrete pavements are included in Appendices B-1 and B-2. These tables were used to develop models of recommended Initial IRI and $PI_{0.0}$ Level for each of the states full-pay PI limits.

IRI Issues

Though inertial profiling has been in use for more than twenty years, a number of issues still exist and are being investigated.

FHWA Accelerometer Study, SEQS-21 and SEQS-48

In 2002 and 2003, FHWA conducted a study on accelerometer sensitivity requirements for inertial profiling [4, 5]. It was found that changing grades and cross slopes negatively impacted profile precision and accuracy on high-speed profilers operating at lower speeds. This was reaffirmed in a following study with light-weight profilers at the same test site. The acceleration errors introduced when the vertical axis accelerometers were not truly vertical on grades and cross slopes were found to be of approximately the same magnitude as the vertical profile's input to the accelerometer. Small changes in speed (accelerations) of only a few miles per hour at slow speeds also introduced error. At high speeds, the effects of grades and cross slope on the vertical accelerometer measurements were minor. The issue is how to best account for the grade, cross slope, and changes in speed at low operating speeds. Use of lower speed profilers for construction smoothness testing aggravates this concern. For construction measurements the use of high speed profilers run at a constant speed of 40mph is recommended.

2005 ACPA Profiler Repeatability Tests, UMTRI-2005-35

Karamihas [6] reported that IRI measurement of textured concrete pavements (longitudinal and transverse tining, surface drag, diamond ground) indicated that a problem of repeatability and reproducibility exists. Currently, this issue is being addressed by the development and use of displacement lasers that have either a larger dot size or use a line scan to basically average out the surface texturing. The use of these lasers has shown significant improvements in profiler repeatability. Good results were obtained on transversely tined pavement and a pavement with a drag texture. One vendor obtained good results on a longitudinally tined pavement. Pavement with smooth diamond ground surface was the most challenging surface type to measure, and only one device demonstrated good repeatability.

For longitudinally tined pavement and diamond ground pavement, repeatability depended on the use of a large-footprint height sensor and consistent lateral tracking of the profiler.

Ultra-Light Inertial Profiler

The FHWA TFHRC is developing a prototype Ultra-Light Inertial Profiler (ULIP) [7] based on equipping a Segway HT with sensors for inertial profiling and texture measurements. Initial results showed a problem with profile repeatability in the longer wavelengths. It was believed that pitch and roll of the Segway was a source of this error. Using the longitudinally aligned accelerometer data, an estimate of the pitch was computed. The estimated pitch was used to adjust the vertical axis accelerometer measurement. A significant improvement in profile repeatability was observed proving that pitch movement of a vehicle influences the vertical accelerometer data and that roll movement would also have an effect on inertial profile estimates. A six degrees-of-freedom gyroscope has been added to the ULIP. This research is in-progress.

Filters

Longwave filters are applied to inertial profiles to eliminate wavelengths of a length greater than those that influence ride quality. The filters are also used because profilers are unable to adequately record the longer wavelengths as their effect on vertical accelerometers are small relative to the wavelengths of interest. Butterworth and moving average filters are the most common filters used with inertial profile roughness measurement. Due to the nature of these filters and their implementation on equipment from different vendors the results need to be carefully assessed. The resulting IRI numbers are generally comparable; however, the resulting profiles produced are not quite as comparable even if the same filter and parameters are applied. This information means that the size of the “bumps” will be generally the same (so IRI number is comparable) but the location of the “bumps” (profile) may be within a somewhat larger range of several feet longitudinally along the pavement.

Reference Profiler

Many highway construction and rehabilitation projects have incentive/disincentive pay factors related to pavement smoothness/roughness. Inertial Profilers to be used in QC/QA therefore need to be accurate, repeatable, and reproducible. Highway agencies require that inertial profilers be certified to meet specific standards. Certification is performed at profile certification sites where the “true profile” is known by the highway agency and to which the inertial profiler results are compared within the wavelengths of interest. Establishing the *true profile* is a time consuming process. What is desired is a *reference profiling device* which provides a measurement of profile as a standard for verifying the measurements of the other devices.

A report entitled “Critical Profiler Accuracy Requirements” by S. Karamihas [8] specifies the requirements of a reference profiler and recommends a procedure for comparing the “Reference Profile” with the output of the production profilers. This new approach may have limitations and should be carefully reviewed.

Robustness of Pavement Smoothness Measurements

With the progress made in the industry during the past five years on repeatability and accuracy of inertial profilers, there is an increasing level of confidence in the technology. Currently, the Federal Highway Administration’s contractor Starodub, Inc. is performing additional research on the topic of one-dimensional inertial profiling, three-dimensional, and six degrees-of-freedom inertial profiling. This research project was awarded at the end of April 2006 and should be completed by the end of the year. The primary objective of the study is to quantify the sources of error beyond the current knowledge base.

Security of PI and IRI data **(freedom from manipulation)**

Informal discussions with several IRI and PI users from several states concerning safeguards against the potential manipulation of the data within both IRI and PI systems were held during the last few months. As a result we learned that there is no way to guarantee a tamper proof system. Several suggested that PI may be more vulnerable than IRI but with good procedures most concerns can be minimized for both PI and IRI. With proper certification procedures for equipment and operators, a random verification program on the measurement of smoothness, stiff penalties for cheating, regular calibration of the measuring equipment and both the data and the results provided to the state at the time of collection it is unlikely that the state DOT will encounter a problem with systematic alterations of inertial profiling or profilometer data.

It is suggested that a random verification program on the measurement of smoothness be performed on about 10% of the projects by third parties. If significant differences are found between results from two independent sources, there now exist signal processing technologies that allow detailed comparisons of the data.

If someone would try to falsify IRI data, the most likely areas of falsification are in the filtering step on the measured inertial profiles and the distance ranging sensors. If the specifications require that a copy of the inertial profile data is delivered with the IRI results, the Missouri DOT can perform additional analysis if a doubt is raised on the integrity of the results. The FHWA has developed a software package named PROVAL that can provide a starting evaluation step in the review of questionable profiles.

In Appendix H, we have provided a flowchart for improving the security when collecting smoothness data for pay factors.

Summary

In this report we have discussed the relationship between IRI and PI and discussed the relative advantages and disadvantages of both systems. In general we find that the trend (while slow) is toward the IRI inertial system. The fact that it is already the system of choice for system wide smoothness / roughness inventorying and with growing acceptance of the inertial measuring systems we see more and more states moving to IRI for project related measurements. About seven State DOTs have integrated the inertial profiling and IRI technologies into their practice.

Additional information on inertial profiling technology for certification and operations can be found in the following standard AASHTO specifications:

- A - Standard Equipment Specification for Inertial Profiler – AASHTO Designation: MP 11-03
- B - Standard Practice for Certification of Inertial Profiling Systems – AASHTO Designation: PP 49-03
- C- Standard Practice for Operating Inertial Profilers and Evaluating Pavement Profiles – AASHTO Designation: PP 50-03 (Highlighted for Missouri)
- D - Standard Practice for Pavement Ride Quality When Measured Using Inertial Profiling Systems – AASHTO Designation: PP 51-03

There is not one state specification that can be called “the best” as they are tied to the pavement types and technologies of each state. However we have included the specifications from Connecticut, Minnesota and Ohio as these are three types of specifications that can support the needs of Missouri. These are included in the following Appendices:

- E – Example Specifications from Connecticut DOT (Inertial Profiler and IRI)
- F – Example Specifications from Ohio DOT (CA profilograph and IRI)
- G – Example Specifications from Minnesota DOT (Inertial Profiler and IRI)

The current Missouri Specifications in **502.15.3.2 Deductions** includes two tables with Pay Factors for roads with speed limits greater than 45mph and less than 45mph. We have used this information and the data from the, FHWA-RD-02-057 study “Pavement Smoothness Index Relationships” and developed the following set of tables that are appropriate for Missouri DOT. Shown below are PI and IRI tables for > 45mph and <45mph: (See Appendix C for supporting information found in FHWA-RD-02-057 study)

Current PI 0mm/ PI 0in. Pay Factors

Table I. Pay Factors for roads with speed limit of >45mph

PI0mm (mm/km)	Percent	PI0.0in (in/mi)	Percent
0 - 158	105%	0 - 10	105%
159 - 237	103%	10.1 - 15	103%
238 - 395	100%	15.1 - 25	100%
396 +	100%*	25.1 +	100%*

* After Correction to 395 or less   *After Correction to 25 or less

Table II. Pay Factors for roads with speed limit of <=45mph

PI0mm (mm/km)	Percent	PI0.0in (in/mi)	Percent
0 - 316	103%	0 - 20	103%
317 - 711	100%	20.1 - 45	100%
712 +	100%*	45.1 +	100%*

* After Correction to 711 or less   *After Correction to 45 or less

Potential IRI (mm/km) (in/mi) Pay Factors

Table I. Pay Factors for roads with speed limit of >45mph

IRI (mm/km)	Percent	IRI (in/mi)	Percent
0 - 634	105%	0 - 40	105%
637 - 845	103%	40.1 - 54	103%
847 - 1266	100%	54.1 - 80	100%
1267 +	100%*	80.1 +	100%*

* After Correction to 1267 or less   *After Correction to 80 or less

Table II. Pay Factors for roads with speed limit of <=45mph

IRI (mm/km)	Percent	IRI (in/mi)	Percent
0 - 1055	103%	0 - 67	103%
1058 - 2108	100%	67.1 - 134	100%
2111 +	100%*	134.1 +	100%*

* After Correction to 2111 or less   *After Correction to 134 or less

Above tables are for incentives.
Any corrective area is considered a marred area, and is subject to a 20% reduction.

References

[1] Sayers, M. W., and Karamihas, S. M., “The Little Book of Profiling” UMTRI (September 1998)

[2] Scofield, L., “Profilograph Limitations, Correlations and Calibration Criteria for Effective Performance Based Specifications”, National Cooperative Highway Research Program Project 20-57, Task 53 (1992)

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[4] Gagarin, N., Mekemson, J.R., and Lineman, L., “Effect of Accelerometer Accuracy on Inertial Profile Measurements for Proposed Certification Procedure,” Task Order 21, Turner-Fairbank Highway Research Center, Federal Highway Administration (November 2002, Revised September 2003)

[5] Gagarin, N., Mekemson, J.R., and Lineman, L., “Accelerometer Study: Lightweight Experiment at Northern Virginia Sites,” Final report Task Order SEQS-48, Turner-Fairbank Highway Research Center, Federal Highway Administration (July 2003)

[6] Karamihas. S. M., “2005 ACPA Profiler Repeatability Tests”, UMTRI-2005-35 (November 2005)

[7] Gagarin, N., Mekemson, J. R., and Crowley, C. B., “Development of an Ultra-Light Inertial Profiler Prototype,” Task Order SEQS-49, Turner-Fairbank Highway Research Center, Federal Highway Administration (March 2004)

[8] Karamihas, S. M., “Critical Profiler Accuracy Requirements”, UMTRI-2005-24 (September 2005)

Appendix A: Database of State DOT Concrete Pavement Practices

Smoothness Specification - Measurement Requirements

State	Profile measurement location	Length of section evaluated	How profile index calculated	Acceptance measurement by
AL				
AK				
AZ	both wheel paths	0.1 mile	by hand or computer	State
AR	center of lane	0.1 mile	by hand or computer	contractor, State
CA	both wheel paths	0.1 mile	by hand or computer	contractor
CO	both wheel paths	0.1 mile	by hand or computer	State
CT	both wheel paths	1000 ft min	by hand	State
DE	both wheel paths	0.1 mile	computer	State
FL	both wheel paths	0.1 mile	computer	State
GA	outer wheelpath	0.25 mile	by hand	contractor
HI	both wheel paths	0.1 mile	by hand	State
ID	right wheel path	0.1 mile	by hand, computer	contractor
IL	center, outer	0.1 mile	digital scan	State, contractor
IN	outer wheel path	0.1 mile	by hand	contractor
IA	center of lane	0.1 mile	by hand, computer, digital scan	contractor
KS	both wheel paths	0.1 mile	computer, digital scan	contractor
KY	both wheel paths	1.5 km	computer	State
LA	both wheel paths	depends on lot	0 - 6 in / mile / lot	State

ME				
MD	outer wheel path	0.1 mile	computer	contractor
MA				
MI	outer wheel path	Mile	by hand or computer	contractor
MN	center of lane	0.1 mile	computer, digital scan	contractor
MS	both wheel paths	0.1 mile	by hand or computer	contractor
MO	both wheel paths	0.1 mile	by hand or computer	contractor, State
MT	outer wheel path	0.1 mile	by hand or computer	State
NE	outer wheel path	0.1 mile	computer	contractor
NV				
NH				
NJ	center of lane			State
NM	both wheel paths	0.1 mile	by hand or computer	contractor
NY	both wheel paths	0.25 mile	by hand	contractor
NC	both wheel paths	600 ft	by hand	contractor
ND	outer wheel paths	0.1 mile	computer	State
OH	both wheel paths	0.1 mile	by hand or computer	contractor
OK	both wheel paths	0.1 mile	computer, digital scan	
OR	either wheelpath	0.1 mile	by hand or computer	contractor
PA	both wheel paths	0.1 mile	by hand, computer, digital scan	contractor
PR	outer wheel path	0.1 mile	computer	State
RI	random	random		State

SC	both wheel paths	0.25 mile	by hand	State
SD	both wheel paths	0.1 mile	computer	contractor
TN	both wheel paths	0.1 mile	by hand	State
TX	both wheel paths	0.1 mile	by hand	contractor, State
UT	outer wheel path	0.1 mile	computer	contractor
VT				
VA				
WA	right wheel path	all	computer	contractor
WV	both wheel paths	0.1 mile	computer	State
WI	both wheel paths	0.1 mile	computer	contractor
WY	both wheel paths	0.1 mile		State

Source: American Concrete Pavement Association

Smoothness Specification - Measuring Equipment Used and Roughness Index

State	Smoothness Measuring Equipment	Roughness Index
AL		
AK		
AZ	CA profilograph	Profile Index (in/mile)
AR	CA profilograph	Profile Index (in/mile)
CA	CA profilograph	Profile Index (in/mile)
CO	CA profilograph	Profile Index (in/mile)
CT	CA profilograph	Profile Index (in/mile)
DE	CA profilograph	Profile Index (in/mile)
FL	CA profilograph	Profile Index (in/mile)
GA	Rainhart profilograph	Profile Index (in/mile)
HI	CA profilograph, 12-ft straightedge	Profile Index (in/mile)
ID	CA profilograph 10-ft straightedge	Profile Index (in/0.1 mile)
IL	CA profilograph	IRI
IN	CA profilograph, 10-ft straightedge	Profile Index (in/0.1 mile)
IA	CA profilograph	Profile Index (in/mile)
KS	CA profilograph, others	Profile Index (in/mile)
KY	noncontact profilometer	IRI
LA	CA profilograph	Profile Index (in/mile)
ME	10-ft straightedge	
MD	CA profilograph	Profile Index (in/mile)
MA		
MI	CA profilograph, GM Profilometer	Ride Quality Index
MN	CA profilograph	Profile Index (in/mile)
MS	CA profilograph	Profile Index (in/mile)
MO	CA profilograph	Profile Index (in/mile)
MT	CA profilograph	Profile Index (in/mile)
NE	CA profilograph	Profile Index (in/mile)

NV	CA profilograph	
NH		
NJ	10-ft straightedge	none
NM	CA profilograph	Profile Index (in/mile)
NY	CA profilograph	IRI
NC	Rainhart profilograph	Profile Index (in/mile)
ND	CA profilograph	inch / 0.10 mile
OH	CA profilograph, 10-ft straightedge	Profile Index (in/mile)
OK	CA profilograph, straightedge	Profile Index (in/mile)
OR	CA profilograph	Profile Index (in/mile)
PA	CA profilograph, others	Profile Index (in/mile)
PR	CA profilograph	Profile Index (in/mile)
RI	10-ft straightedge	
SC	Rainhart profilograph	Profile Index (in/mile)
SD	CA profilograph	Profile Index (in/mile)
TN	Rainhart profilograph	Profile Index (in/mile)
TX	CA profilograph, others	Profile Index (in/mile)
UT	CA profilograph, 10-ft straightedge	Profile Index (in/mile)
VT		
VA		
WA	CA profilograph	Profile Index (in/mile), IRI
WV	Mays Meter	Mays ride number
WI	CA profilograph	Profile Index (in/mile)
WY	CA profilograph	Profile Index (in/mile)

Source: American Concrete Pavement Association

Smoothness Specification - Pay Factors and Limits

State	Index range for 100% payment	Index for maximum incentive	Max incentive possible	Worst roughness index allowable	Acceptance measurement by
AL					
AK					
AZ	7 - 9				
AR	6-7 in/mile	2 in/mile or less	105% sq yd price	7 in/mile	
CA	5 - 7				
CO	7 - 12				
CT	10 - 12	0 – 6	106% cy unit price	18 - 20	92% cy unit price
DE		< 40 mm / km	$1.50 / m2	175 mm / km	
FL			103% sy unit price	7 in/mile	
GA				7 in/mile	
HI	7 - 10			10	70% sy unit price
ID					
IL	4.25 - 10	< 2.25	103% sy unit price	15	90% sy unit price
IN	30 mm / 1.6 km	< 13 mm / 1.6 km	103% sm unit price	30 mm / 1.6 km	
IA	3.1 - 7.0	0 - 1.0	$200-650 per segment	10.1	$100-300 per segment
KS	18 - 40, 25 - 65	6, 15	$1200, $1000 / 0.1 mile	25, 45	$750 per 0.1 mile
KY	3.55 - 4.04		103% sy unit price	3.45 - 3.49	98% sy unit price
LA				8 in / mile / lot	95% sy unit price
ME					

MD	4 - 12	< 2	105% sy unit price		90% sy unit price
MA					
MI	4 - 10	0	100% sy unit price	10	
MN	4 - 6	0 - 4	$/sy formula	6 - 8	$/sy formula
MS	< 7				
MO	18.1 -30	< 10	107% sy unit price	30	95% sy unit price
MT	6 - 10	< 6	$0.50 / sy	10 - 15	$1.00 / sy
NE	7 - 10	0 - 2	105% sy unit price	15	90% sy unit price
NV					
NH					
NJ					5% per lot
NM	4 - 7				
NY	5	0-1	105% sy unit price	12	to be determined
NC	4				
ND	0.3 to 0.5 / 0.1 mile	< 0.3 inch / 0.1 mile	$0.50 / sy	0.9 inch / 0.1 mile	unit price - $4.00/sy
OH	5 - 7	< 3	105% sy unit price	12	90% sy unit price
OK					
OR	5 - 7	2.5	101.5% sy unit price	7	
PA	< 36	< 18	107% sy unit price	36	100% sy unit price
PR	20 - 30		formula		formula
RI					
SC			100% sy unit price	10	
SD	25 - 35	< 10	104% sy	40	98% sy unit

			unit price		price
TN	< 10			10, 15	
TX	4 - 6	< 1.5	$90 per 0.1 mile section	12	$140 per 0.1 mile section
UT	7		$1.00 / sy		60% sy unit price
VT					
VA					
WA	7	< 1	104% half mile section	7	98% half mile section
WV	< 100			100	
WI	19.1 - 32	< 10	$1.00 per foot per lane	45	$8300 per mile per lane
WY	6 - 7			7	

Source: American Concrete Pavement Association

Appendix B-1: State agency smoothness specifications for asphalt pavements – Table 14 of Publication FHWA-RD-02-057

State	Testing Device	Index	Testing Interval	Bonus Range	Full Pay Range	Penalty Range	Correction Range
AL	California-type profilograph	$PI_{5\text{-mm}}$	0.16 km[a] (0.1 mi)	<32 mm/km (<2 inches per mile)	32 - 63 mm/km (2 - 3.9 inches per mile)	64 - 160 mm/km (4 - 10 inches per mile)	>160 mm/km (<10 inches per mile)
AK	--	--	--	--	--	--	--
AZ	GM-type profiler	MRN	0.16 km[a] (0.1 mi)	<520 mm/km[a] (<33 inches per mile)	520 - 710 mm/km[a] (33 - 45 inches per mile)	711 - 1578 mm/km[a] (46 - 100 inches per mile)	<1578 mm/km[a] (>100 inches per mile)
AR	California-type profilograph, lightweight profiler	$PI_{5\text{-mm}}$	0.2 km (0.1 mi)	</= 45 mm/km (</= 3 inches per mile)	46 - 75 mm/km (3.1 - 5 inches per mile)	76 - 110 mm/km (5.1 - 7 inches per mile)	>110 mm/km (< 7 inches per mile)
CA	California-type profilograph	$PI_{5\text{-mm}}$	0.16 km (0.1 mi)[a]	--	</= 80 mm/km (</= 5 inches per mile)[a]	--	>80 mm/km (>5 inches per mile)[a]
CO	California-type profilograph	$PI_{2.5\text{-mm}}$	0.15 km (0.095 mi)	</= 222 mm/km (</= 14 inches per mile)	222.1 - 252 mm/km (14.1 - 16 inches per mile)	252.1 - 378 mm/km (16.1 - 24 inches per mile)	>378 mm/km (>24 inches per mile)
CT	ARAN inertial profiler	IRI	0.16 km[a] (0.1 mi)	>950 mm/km[a] (<60 inches per mile)	950 - 1260 mm/km[a] (60 - 80 inches per mile)	1261 - 1894 mm/km[a] (80.1 - 120 inches per mile)	>1894 mm/km[a] (>120 inches per mile)
DE	Rolling straightedge	--	--	--	--	--	--
FL	Rolling	--	--	--	--	--	--

	straightedge						
GA	Inertial profiler	IRI	1.6 km(1.0 mi)	--	</= 750 mm/km (</= 47.5 inches per mile)[a]	--	>750 mm/km (>47.5 inches per mile)[a]
HI	--	--	--	--	--	--	--
ID	California-type profilograph	$PI_{5\text{-}mm}$	0.1 km (0.1 mi)	--	</= 8 mm/0.1km (</= 0.5 in/0.1mi)	--	>8 mm/0.1km (>0.5 in/0.1 mi)
IL	California-type profilograph	$PI_{5\text{-}mm}$	0.16 km (0.1 mi)	</= 8 mm/km (</= 0.5 inches per mile)[b]	9 - 160 mm/km (0.6 - 10 inches per mile)	161 - 235 mm/km (10.1 - 15 inches per mile)	>235 mm/km (>15 inches per mile)
IN	California-type profilograph	$PI_{5\text{-}mm}$	0.16 km (0.1 mi)	--	</= 30 mm/0.16 km (</= 1.2 in/0.1 mi)	31 - 38 mm/0.16 km (1.21 - 1.5 in/0.1 mi)	>38 mm/0.16 km (>1.5 in/0.1 mi)
IA	California-type profilograph	$PI_{5\text{-}mm}$	0.16 km (0.1 mi)	</= 48 mm/km (</= 3 inches per mile)	49 - 110 mm/km (3.1 - 7 inches per mile)	111 - 160 mm/km (7.1 - 10 inches per mile)	>160 mm/km (>10 inches per mile)
KS	California-type profilograph	$PI_{0.0}$	0.1 km (0.1 mi)	</= 160 mm/km (</= 10 inches per mile)	161 - 475 mm/km (10.1 - 30 inches per mile)	476 - 630 mm/km (30.1 - 40 inches per mile)[c]	>630 mm/km (>40 inches per mile)
KY	Inertial profiler	RI	1.6 km[a] (1.0 mi)	RI >/= 4.05	3.70 </= RI < 4.05	3.45 </= RI < 3.70	RI < 3.45
LA	California-type profilograph	$PI_{5\text{-}mm}$	Lot	--	</= 47 mm/km (</= 3 inches per mile)	48 - 95 mm/km (3.1 - 6 inches per mile)	>95 mm/km (>6 inches per mile)
ME	Rolling dipstick profiler	IRI	0.2 km (0.12 mi)	</= 945 mm/km[a] (</= 60 inches per mile)	946 - 1105 mm/km[a] (60.1 - 70 inches per mile)	1106 - 1260 mm/km[a] (70.1 - 80 inches per mile)	>1260 mm/km[a] (>80 inches per mile)

MD	California-type profilograph	PI_{5-mm}	0.16 km[a] (0.1 mi)	</= 63 mm/km[a] (</= 4.0 inches per mile)	64 - 110 mm/km[a] (4.1 - 7 inches per mile)	111 - 190 mm/km[a] (7.1 - 12 inches per mile)	>191 mm/km[a] (>12 inches per mile)
MA	Inertial Profiler	IRI	0.2 km (0.12 mi)[a]	*	*	*	*
MI	California-type profilograph or GM-type inertial profiler	PI_{5-mm}RQI[d]	0.16 km[a] (0.1 mi)	</= 63 mm/km[a] (</= 4 inches per mile)or RQI <45	64 - 158 mm/km[a] (4.1 - 10 inches per mile) or 45 </= RQI </= 53	--	>158 mm/km[a] (>10 inches per mile)or RQI > 53
MN	California-type profilograph	PI_{5-mm}	0.1 km (0.1 mi)	</= 38.7 mm/km (</= 2.4 inches per mile)	38.8 - 78.9 mm/km (2.5 - 5 inches per mile)	79 - 118.3 m/km (5.1 - 7.5 inches per mile)	>118.3 mm/km (>7.5 inches per mile)
MS	California-type profilograph	PI_{5-mm}	0.16 km[a] (0.1 mi)	</= 79 mm/km[a] (</= 5 inches per mile)	80 - 110 mm/km[a] (5.1 - 7 inches per mile)	111 - 158 m/km[a] (7.1 - 10 inches per mile)	>158 mm/km[a] (>10 inches per mile)
MO	California-type profilograph	$PI_{0.0}$	0.1 km (0.1 mi)	</= 284 mm/km (</= 18 inches per mile)	285 - 395 mm/km (18.1 - 25 inches per mile)	396 - 711 m/km (25.1 - 45 inches per mile)	>712 mm/km (>45 inches per mile)
MT	--	--	--	--	--	--	--
NE	California-type profilograph	PI_{5-mm}	0.2 km (0.1 mi)	</= 75 mm/km (</= 5 inches per mile)	76 - 110 mm/km (5.1 - 7 inches per mile)	111 - 155 mm/km (7.1 - 10 inches per mile)	>155 mm/km (>10 inches per mile)
NV	California-type profilograph	PI_{5-mm}	0.1 km (0.1 mi)	--	</= 80 mm/km (</= 5 inches per mile)	--	>80 mm/km (>5 inches per mile)
NH	GM-type	RN	0.16	**	**	**	**

	inertial profiler		km[a] (0.1 mi)				
NJ	Rolling straightedge	--	--	--	--	--	--
NM	California-type profilograph	$PI_{5\text{-}mm}$	0.1 km (0.1 mi)	</= 65 mm/km (</= 4 inches per mile)	66 - 80 mm/km (4.1 - 5 inches per mile)	81 - 160 m/km (5.1 - 10 inches per mile)	>160 mm/km (>10 inches per mile)
NC	Hearne straightedge	CSI	0.76 km (0.47 mi)	CSI=10,20	CSI=30,40	CSI=11,21,31,41,50,51,60,61	--
ND	--	--	--	--	--	--	--
OH	California-type profilograph	$PI_{5\text{-}mm}$	0.16 km[a] (0.1 mi)	</= 63 mm/km[a] (</= 4 inches per mile)	64 - 110 mm/km[a] (4.1 - 7 inches per mile)	111 - 190 m/km[a] (7.1 - 12 inches per mile)	>190 mm/km[a] (>12 inches per mile)
OK	California-type profilograph	$PI_{5\text{-}mm}$	0.16 km[a] (0.1 mi)	</= 79 mm/km[a] (</= 5 inches per mile)	80 - 110 mm/km[a] (5.1 - 7 inches per mile)	111 - 190 m/km[a] (7.1 - 12 inches per mile)	>190 mm/km[a] (>12 inches per mile)
OR	California-type profilograph	$PI_{5\text{-}mm}$	016 km[a] (0.1 mi)	</= 80 mm/km[a] (</= 5 inches per mile)	81 - 110 mm/km[a] (5.1 - 7 inches per mile)	111 - 155 mm/km[a] (7.1 - 10 inches per mile)	>155 mm/km[a] (>10 inches per mile)
PA	California-type profilograph	$PI_{0.0}$	0.16 km[a] (0.1 mi)	</= 442 mm/km[a] (</= 28 inches per mile)	443 - 536 mm/km[a] (28.1 - 34 inches per mile)	537 - 726 mm/km[a] (34.1 - 46 inches per mile)	>726 mm/km[a] (>46 inches per mile)
PR	California-type profilograph	$PI_{5\text{-}mm}$	0.16 km[a] (0.1 mi)	</= 110 mm/km[a] (</= 7 inches per mile)	111 - 205 mm/km[a] (7.1 - 13 inches per mile)	-	>205 mm/km[a] (>13 inches per mile)
RI	--	--	--	--	--	--	--
SC	Maysmeter	MRN	1.6 km[a] (1.0 mi)	</= 552 mm/km[a] (</= 35	553 - 630 mm/km[a] (35.1 - 40	631 - 868 mm/km[a] (40.1 - 55 inches per mile)	>868 mm/km[a] (>55

				inches per mile)	inches per mile)		inches per mile)
SD	Inertial profiler	IRI	0.16 km[a] (0.1 mi)	</= 868 mm/km[a] (</= 55 inches per mile)	869 - 1105 mm/km[a] (55.1 - 70 inches per mile)	1106 - 1262 mm/km[a] (70.1 - 80 inches per mile)	>1262 mm/km[a] (>80 inches per mile)
TN	Maysmeter	MRN	1.6 km[a] (1.0 mi)	</= 315 mm/km a (</= 20 inches per mile)	316 - 475 mm/km[a] (20.1 - 30 inches per mile)	476 - 950 mm/km[a] (30.1 - 60 inches per mile)	>950 mm/km[a] (>60 inches per mile)
TX	California-type profilograph	$PI_{0.0}$	0.16 km[a] (0.1 mi)	</= 237 mm/km[a] (</= 15 inches per mile)	238 - 315 mm/km[a] (15.1 - 20 inches per mile)	316 - 630 m/km[a] (20.1 - 40 inches per mile)	>630 mm/km[a] (>40 inches per mile)
UT	California-type profilograph	$PI_{5\text{-mm}}$	0.2 km (0.12 mi) a	--	</= 110 mm/km (</=7 inches per mile) a	--	>110 mm/km (>7 inches per mile)[a]
VT	Maysmeter	IRI	0.32 km[a] (0.2 mi)	<950 mm/km[a] (<60 inches per mile)	950 - 1090 mm/km[a] (60 - 69 inches per mile)	1091 - 1500 mm/km[a] (70 - 95 inches per mile)	>1500 mm/km[a] (>95 inches per mile)
VA	South Dakota-type profiler	IRI	0.16 km[a] (0.1 mi)	</= 868 mm/km[a] (</= 55 inches per mile)	869 - 1105 mm/km[a] (55.1 - 70 inches per mile)	1106 - 1578 km[a] (70.1 - 100 inches per mile)	>1578 mm/km[a] (>100 inches per mile)
WA[e]	Lightweight inertial profiler	IRI	0.1 km (0.1 mi)[a]	</= 946 mm/km[a] (</= 60 inches per mile)	947 - 1500 mm/km[a] (60.1 - 95 inches per mile)	1501 - 1815 mm/km[a] (95.1 - 115 inches per mile)	>1815 mm/km[a] (>115 inches per mile)
WV	Maysmeter or inertial profiler	MRN	0.16 km (0.1 mi)	--	</= 1000 mm/km (</= 65 inches per mile)	1001 - 1500 mm/km (66 - 97.5 inches per mile)	>1500 mm/km (>97.5 inches per mile)
WI	California-	$PI_{5\text{-mm}}$	0.16	--	</= 158	159 - 237 m/km[a] (10.1 - 15	>237

	type profilograph		km[a] (0.1 mi)		mm/km[a] (</= 10 inches per mile)	inches per mile)	mm/km[a] (>15 inches per mile)
WY	Inertial profiler	IRI	0.16 km[a] (0.1 mi)	***	***	***	***

*Percent Within Limits Specification: Upper Spec Limit = 1500 m/km (95 inches per mile)
**Percent Within Limits Specification: Lower Spec Limit = RN = 4.1
***Statistical Based Specification: Full Pay approximately equal to 868-1105 mm/km (55-70 inches per mile)
[a] Limits are a direct English-Metric conversion from counterpart limits. Actual limits given by the Agency were not available.
[b] Based on average profile index for entire project.
[c] For PI between 476 mm/km (30.1 inches per mile) and 630 mm/km (40 inches per mile), must also grind to 475 mm/km (30 inches per mile) or below.
[d] RQI: Ride quality index.
[e] Draft specification.

Appendix B-2: State agency smoothness specifications for concrete pavements – Table 15 of Publication FHWA-RD-02-057

State	Testing Device	Index	Testing Interval	Bonus Range	Full Pay Range	Penalty Range	Correction Range
AL	California-type profilograph	$PI_{5\text{-mm}}$	0.16 km (0.1 mi)	<45 mm/km (<3 inches per mile)	45 -- 94 mm/km (3 -- 5.9 inches per mile)	95 - 160 mm/km (6 - 10 inches per mile)	>160 mm/km (>10 inches per mile)
AK	--	--	--	--	--	--	--
AZ	California-type profilograph	$PI_{5\text{-mm}}$	0.16 km[a](0.1 mi)	<110 mm/km[a](<7 inches per mile)	110 -- 142 mm/km[a](7 - 9 inches per mile)	--	>142 mm/km[a](>9 inches per mile)
AR	California-type profilograph, lightweight profiler	$PI_{5\text{-mm}}$	0.2 km (0.1 mi)	</= 90 mm/km (</= 6 inches per mile)	91 - 110 mm/km (6.1 - 7 inches per mile)	--	>110 mm/km (>7 inches per mile)
CA	California-type profilograph	$PI_{5\text{-mm}}$	0.1 km (0.06 mi)[a]	--	</= 110 mm/km (</= 7 inches per mile)[a]	--	>110 mm/km (>7 inches per mile)[a]
CO	California-type profilograph	$PI_{2.5\text{-mm}}$	0.15 km (0.095 mi)	</= 222 mm/km[a] (</= 14 inches per mile)	222.1 - 252 mm/km[a] (14.1 - 16 inches per mile)	252.1 - 378 mm/km[a] (16.1 - 24 inches per mile)	>378 mm/km[a] (>24 inches per mile)
CT	California-type profilograph	$PI_{5\text{-mm}}$	0.15 km (0.1 mi)[a]	</=160 mm/km (10 inches per mile)[a]	161 - 190 mm/km (10.1 - 12 inches per mile)[a]	191 - 315 mm/km (12.1 - 20 inches per mile)[a]	>315 mm/km (>20 inches per mile)[a]
DE	CA profilograph or rolling straightedge	$PI_{5\text{-mm}}$	0.16 km[a](0.1 mi)	<50 mm/km[a](<3.2 inches per mile)	50 - 200 mm/km[a](3.2 - 12.7 inches per mile)	--	>200 mm/km[a](>12.7 inches per mile)
FL	California-type profilograph	$PI_{5\text{-mm}}$	0.1 km (0.1 mi)	</= 80 mm/km (</= 5 inches per mile)	81 - 95 mm/km (5.1 - 6 inches per mile)	96 - 110 mm/km (6.1 - 7 inches per mile)	>110 mm/km (>7 inches per mile)
GA	Rainhart	$PI_{2.5\text{-}}$	0.4	--	</= 110	--	>110

	profilograph	mm	km[a](0.25 mi)		mm/km[a](</= 7 inches per mile)		mm/km[a](>7 inches per mile)
HI	California-type profilograph	$PI_{5\text{-mm}}$	0.16 km[a](0.1 mi)	--	</= 157 mm/km[a](</= 10 inches per mile)	158 - 236 mm/km[a](10.1 - 15 inches per mile)	>236 mm/km[a](>15 inches per mile)
ID	California-type profilograph	$PI_{5\text{-mm}}$	0.1 km (0.1 mi)	--	</= 8 mm/0.1 km (</= 0.5 in/0.1mi)	--	>8 mm/0.1 km (>0.5 in/0.1mi)
IL	California-type profilograph	$PI_{5\text{-mm}}$	0.16 km (0.1 mi)	</= 67 mm/km (</= 4.25 inches per mile) b	68 - 160 mm/km (4.26 - 10 inches per mile)	161 - 235 mm/km (10.01 - 15 inches per mile)	>235 mm/km (>15 inches per mile)
IN	California-type profilograph	$PI_{5\text{-mm}}$	0.16 km (0.1 mi)	</= 23mm/0.16 km (</= 0.9 in/0.1mi)	23 - 25 mm/0.16km (0.9 - 1.0 in/0.1 mi)	--	>25 mm/0.16 km (>1.0 in/0.1 mi)
IA	California-type profilograph	$PI_{5\text{-mm}}$	0.16 km (0.1 mi)	</= 48 mm/km (£3 inches per mile)	49 - 110 mm/km (3.1 - 7 inches per mile)	111 - 160 mm/km (7.1 - 10 inches per mile)	>160 mm/km (>10 inches per mile)
KS	California-type profilograph	$PI_{0.0}$	0.1 km (0.1 mi)	</= 285 mm/km (</= 18 inches per mile)	286 -- 475 mm/km (18.1 -- 30 inches per mile)	476 -- 630 mm/km (30.1 -- 40 inches per mile)[c]	>630 mm/km (>40 inches per mile)
KY	Rainhart profilograph and inertial profiler	$PI_{2.5\text{-mm}}$RI	0.3 km[a](0.19 mi)	RI >/= 4.05	</=125 mm/km[a] (</= 8 inches per mile)	126 - 190 mm/km[a](8.1 - 12 inches per mile)	>190 mm/km[a](>12 inches per mile)
LA	California-type profilograph	$PI_{5\text{-mm}}$	Lot	-	£94 mm/km (</= 6 inches per mile)	95 - 126 mm/km (6.1 - 8 inches per mile)	>126 mm/km (>8 inches per mile)
ME	--	--	--	--	--	--	--
MD	California-type profilograph	$PI_{5\text{-mm}}$	0.16 km[a](0.1 mi)	</= 63 mm/km[a] (</= 4.0 inches per mile)	64 - 110 mm/km[a](4.1 - 7 inches per mile)	111 - 190 mm/km[a](7.1 - 12 inches per mile)	>191 mm/km[a](>12 inches per mile)
MA	--	--	--	--	--	--	--
MI	California-type	$PI_{5\text{-}}$	0.16	</= 63	64 - 158	--	>158

	profilograph or GM-type inertial profiler	$_{mm}$RQI d	km[a](0.1 mi)	mm/km[a] (</= 4 inches per mile)or RQI < 45	mm/km[a] (4.1 - 10 inches per mile)or 45 </=RQI </= 53		mm/km[a](>10 inches per mile)or RQI > 53
MN	California-type profilograph	PI_{5-mm}	0.16 km (0.1 mi)	</= 63 mm/km (</= 4 inches per mile)	64 - 94 mm/km (4.1 - 6 inches per mile)	95 - 126 m/km (6.1 - 8 inches per mile)	>126 mm/km (>8 inches per mile)
MS	California-type profilograph	PI_{5-mm}	0.16 km[a](0.1 mi)	--	</= 110 mm/km[a](</= 7 inches per mile)	111 - 190 m/km[a](7.1 - 12 inches per mile)	>190 mm/km[a](>12 inches per mile)
MO	California-type profilograph	$PI_{0.0}$	0.1 km (0.1 mi)	</= 284 mm/km (</= 18 inches per mile)	285 - 395 mm/km (18.1 - 25 inches per mile)	396 - 711 m/km (25.1 - 45 inches per mile)	>712 mm/km (>45 inches per mile)
MT	California-type profilograph	PI_{5-mm}	0.16 km[a](0.1 mi)	</= 94 mm/km[a](£6 inches per mile)	95 - 158 mm/km[a](6.1 - 10 inches per mile)	159 - 237 m/km[a] (10.1 - 15 inches per mile)	>237 mm/km[a](>15 inches per mile)
NE	California-type profilograph	PI_{5-mm}	0.2 km (0.1 mi)	</= 75 mm/km (</= 5 inches per mile)	76 - 155 mm/km (5.1 - 10 inches per mile)	156 - 230 mm/km (10.1 - 15 inches per mile)	>230 mm/km (>15 inches per mile)
NV	California-type profilograph	PI_{5-mm}	0.1 km (0.1 mi)	--	</= 80 mm/km (</= 5 inches per mile)	--	>80 mm/km (>5 inches per mile)
NH	--	--	--	--	--	--	--
NJ	Rolling straightedge	--	--	--	--	--	--
NM	California-type profilograph	PI_{5-mm}	0.1 km (0.1 mi)	</= 80 mm/km (</= 5 inches per mile)	81 - 110 mm/km (5.1 - 7 inches per mile)	111 - 190 m/km (7.1 - 12 inches per mile)	>190 mm/km (>12 inches per mile)
NY	California-type profilograph	PI_{5-mm}	0.16 km (0.1 mi)[a]	</= 79 mm/km[a](</= 5 inches per mile)	80 - 190 mm/km[a](5.1 - 12 inches per mile)	--	>190/km[a](>12 inches per mile)
NC	Rainhart profilograph	PI_{5-mm}	0.18 km[a](0.11 mi)	--	</= 63 mm/km[a](</= 4 inches per	--	>63 mm/km[a](>4 inches per

					mile)		mile)
ND	California-type profilograph	$PI_{5\text{-}mm}$	0.16 km[a](0.1 mi)	<8mm/0.16 km[a](<0.3 in/0.1mi)	8 - 13 mm/0.16 km[a](0.3 - 0.5 in/0.1mi)	14 -- 23 mm/0.16 km[a](0.51 - 0.9 in/0.1mi)	>23 mm/0.16 km[a](>0.9 in/0.1mi)
OH	California-type profilograph	$PI_{5\text{-}mm}$	0.16 km[a](0.1 mi)	</= 78 mm/km[a](</= 5 inches per mile)	79 - 110 mm/km[a](5.1 - 7 inches per mile)	111 - 190 m/km[a](7.1 - 12 inches per mile)	>190 mm/km[a](>12 inches per mile)
OK	California-type profilograph	$PI_{5\text{-}mm}$	0.16 km[a](0.1 mi)	</= 79 mm/km[a](</= 5 inches per mile)	80 - 110 mm/km[a](5.1 - 7 inches per mile)	111 - 190 m/km[a](7.1 - 12 inches per mile)	>190 mm/km[a](>12 inches per mile)
OR	California-type profilograph	$PI_{5\text{-}mm}$	0.2 km (0.1 mi)[a]	</= 80 mm/km (</= 5 inches per mile)[a]	81 - 110 mm/km (5.1 - 7 inches per mile)[a]	--	>110 mm/km (>7 inches per mile)[a]
PA	California-type profilograph	$PI_{0.0}$	0.16[a](0.1 mi)	</= 568 mm/km[a](</= 36 inches per mile)	--	--	>568 mm/km[a](>36 inches per mile)
PR	California-type profilograph	$PI_{5\text{-}mm}$	0.16 km[a](0.1 mi)	</= 110 mm/km[a](</= 7 inches per mile)	111 - 205 mm/km[a](7.1 - 13 inches per mile)	--	>205 mm/km[a](>13 inches per mile)
RI	--	--	--	--	--	--	--
SC	Rainhart profilograph	$PI_{5\text{-}mm}$	0.4 km[a](0.25 mi)	--	</= 158 mm/km[a](</= 10 inches per mile)	--	>158 mm/km[a](>10 inches per mile)
SD	California-type profilograph	$PI_{0.0}$	0.1 km (0.1 mi)	</= 395 mm/km (</= 25 inches per mile)	396 - 550 mm/km (25.1 - 35 inches per mile)	551 - 630 mm/km (35.1 - 40 inches per mile)	>630 mm/km (>40 inches per mile)
TN	Rainhartprofilograph	$PI_{2.5\text{-}mm}$	0.1 km (0.1 mi)	--	</= 160 mm/km (</= 10 inches per mile)	161 - 235 mm/km (10.1 - 15 inches per mile)	>235 mm/km (>15 inches per mile)
TX	California-type profilograph	$PI_{0.0}$	0.16 km[a](0.1 mi)	237 mm/km[a](</= 15 inches per mile)	238 - 315 mm/km[a](15.1 - 20 inches per mile)	316 -- 630 m/km[a](20.1 - 40 inches per mile)	>630 mm/km[a](>40 inches per mile)

UT	California-type profilograph	$PI_{5\text{-}mm}$	0.2 km (0.12 mi)[a]	--	</= 110 mm/km (</= 7 inches per mile)[a]	--	>110 mm/km (>7 inches per mile) a
VT	--	--	--	--	--	--	--
VA	South Dakota-type profiler	IRI	0.16 km[a] (0.1 mi)	</= 946 mm/km[a] (</= 60 inches per mile)	947 - 1262 mm/km[a] (60.1 - 80 inches per mile)	1263 - 1578 km a(80.1 - 100 inches per mile)	>1578 mm/km[a] (>100 inches per mile)
WA	California-type profilograph	$PI_{7.5\text{-}mm}$	0.1 km (0.1 mi) a	</= 60 mm/km (</= 3.8 inches per mile)[a]	61 -- 100 mm/km (3.9 - 6.3 inches per mile) a	>100 mm/km (>6.3 inches per mile) a,e	--
WV	Maysmeter or inertial profiler	MRN	0.16 km (0.1 mi)	--	</= 1000 mm/km (</= 65 inches per mile)	1001 - 1500 mm/km (66 - 97.5 inches per mile)	>1500 mm/km (>97.5 inches per mile)
WI	California-type profilograph	$PI_{01\text{-}inch}$	0.16 km[a] (0.1 mi)	</= 400 mm/km[a] (</= 25.3 inches per mile)	401 - 700 mm/km[a] (25.4 - 44.3 inches per mile)	701 - 800 m/km[a] (44.4 - 50.7 inches per mile) f	>800 mm/km[a] (>50.7 inches per mile)
WY	California-type profilograph	$PI_{5\text{-}mm}$	*	*	*	*	*

* Perf. Related Spec (PCC thickness, strength, smoothness) >80 mm/km (>5.0 inches per mile).
[a] Limits are a direct English-Metric conversion from counterpart limits. Actual limits given by the agency were not available.
[b] Based on average profile index for entire project.
[c] For PI between 476 mm/km (30.1 inches per mile) and 630 mm/km (40 inches per mile), must also grind to 475 mm/km (30 inches per mile) or below.
[d] RQI: Ride quality index.
[e] For PI greater than 100 mm/km (6.3 inches per mile), must also grind to 100 mm/km (6.3 inches per mile) or less.
[f] For PI greater than 700 mm/km (44.3 inches per mile), must also grind to 700 mm/km (44.3 inches per mile) or less.

Appendix C: IRI vs. PI and PI to PI (Asphalt to Concrete) Relationships

In FHWA Report FHWA-RD-02-057, "Pavement Smoothness Index Relationships, Final Report", equations where developed for converting from PI to IRI based on pavement type and climatic region using the LTPP profile data base. Tables C1, C2, C3 and C4 summarize the conversion equations. Information on PI to IRI relationships relevant to Missouri are highlighted in the tables and noted in the figure captions.

Table C1. PI to IRI equations for Asphaltic Concrete

PI to IRI for Asphaltic Concrete						
Pavement Type	**Climate[a]**	**Blanking Band (mm)**	**Correlation Equation (IRI = mm/km, PI = mm/km)**	**N**	**SEE**	**R^2**
AC	***1,2,3,4***	***0***	***$IRI = 2.66543*PI_{0.0} + 213.01$***	***14,170***	***200.2***	***0.89***
AC	1,2,3,4	2.5	$IRI = 2.97059*PI_{2.5\text{-mm}} + 638.74$	14,160	231.7	0.86
AC	1,2,3,4	5	$IRI = 3.78601*PI_{5\text{-mm}} + 887.51$	13,775	292.3	0.77
AC/AC	1	0	$IRI = 2.74599*PI_{0.0} + 265.42$	1,854	192	0.91
AC/AC	1	2.5	$IRI = 3.12622*PI_{2.5\text{-mm}} + 708.56$	1,854	230	0.87
AC/AC	1	5	$IRI = 4.25316*PI_{5\text{-mm}} + 957.80$	1,824	288.2	0.79
AC/AC	2	0	$IRI = 2.68169*PI_{0.0} + 274.67$	1,494	184.6	0.81
AC/AC	2	2.5	$IRI = 3.33564*PI_{2.5\text{-mm}} + 655.67$	1,494	246.6	0.66
AC/AC	2	5	$IRI = 4.39478*PI_{5\text{-mm}} + 883.20$	1,345	308.2	0.45
AC/AC	***3,4***	***0***	***$IRI = 2.42295*PI_{0.0} + 301.90$***	***5,126***	***178.8***	***0.84***
AC/AC	3,4	2.5	$IRI = 2.68324*PI_{2.5\text{-mm}} + 660.34$	5,126	217	0.76
AC/AC	3,4	5	$IRI = 3.42671*PI_{5\text{-mm}} + 876.80$	4,906	265.9	0.63
AC/PCC	***1,2,3,4***	***0***	***$IRI = 2.40300*PI_{0.0} + 292.93$***	***4,156***	***205.6***	***0.79***
AC/PCC	1,2,3,4	2.5	$IRI = 2.78217*PI_{2.5\text{-mm}} + 716.87$	4,156	229.7	0.73
AC/PCC	1,2,3,4	5	$IRI = 3.94665*PI_{5\text{-mm}} + 939.22$	4,052	259.6	0.65

Source: FHWA-RD-02-057

[a] Climatic zones: 1=DF, 2=DNF, 3=WF, 4=WNF.

DF Dry-Freeze
DNF Dry-Nonfreeze
WF Wet-Freeze
WNF Wet-Nonfreeze

Table C2. PI to IRI for Portland Cement Concrete

PI to IRI for Portland Cement Concrete						
Pavement Type	**Climate[a]**	**Blanking Band (mm)**	**Correlation Equation (IRI = mm/km, PI = mm/km)**	**N**	**SEE**	**R^2**
PCC	***1,3***	***0***	***$IRI = 2.12173*PI_{0.0} + 439.76$***	***12,039***	***259.6***	***0.8***
PCC	1,3	2.5	$IRI = 2.15316*PI_{2.5\text{-mm}} + 947.05$	12,039	278.7	0.8
PCC	1,3	5	$IRI = 2.62558*PI_{5\text{-mm}} + 1205.73$	11,946	306	0.8
PCC	2	0	$IRI = 2.58454*PI_{0.0} + 423.09$	1,448	176.5	0.9
PCC	2	2.5	$IRI = 2.5921*PI_{2.5\text{-mm}} + 1024.73$	1,448	226.5	0.8
PCC	2	5	$IRI = 3.51673*PI_{5\text{-mm}} + 1226.35$	1,364	268.7	0.7
PCC	4	0	$IRI = 2.3582*PI_{0.0} + 317.19$	2,888	236.5	0.8
PCC	4	2.5	$IRI = 2.40731*PI_{2.5\text{-mm}} + 888.10$	2,888	264.5	0.8
PCC	4	5	$IRI = 2.87407*PI_{5\text{-mm}} + 1229.63$	2,885	297.4	0.7

Source: FHWA-RD-02-057

[a] Climatic zones: 1=DF, 2=DNF, 3=WF, 4=WNF.

DF Dry-Freeze
DNF Dry-Nonfreeze
WF Wet-Freeze
WNF Wet-Nonfreeze

Table C3. PI to PI for Asphaltic Concrete

PI to PI for Asphaltic Concrete						
Type	Climate[a]	From/To	Correlation Equation (PI = mm/km)	N	SEE	R^2
AC	1,3	PI2.5-mm to PI0.0-mm	$PI_{0.0} = 1.08722*PI_{2.5\text{-mm}} + 174.42$	5,744	47.73	0.96
AC	1,3	PI5-mm to PI0.0-mm	$PI_{0.0} = 1.35776*PI_{5\text{-mm}} + 275.48$	5,684	83.58	0.88
AC	1,3	PI5-mm to PI2.5-mm	$PI_{2.5\text{-mm}} = 1.28213*PI_{5\text{-mm}} + 87.79$	5,684	46.62	0.95
AC	2,4	PI2.5-mm to PI0.0-mm	$PI_{0.0} = 1.12338*PI_{2.5\text{-mm}} + 152.84$	8,418	45.23	0.95
AC	2,4	PI5-mm to PI0.0-mm	$PI_{0.0} = 1.46417*PI_{5\text{-mm}} + 240.09$	8,093	71.73	0.86
AC	2,4	PI5-mm to PI2.5-mm	$PI_{2.5\text{-mm}} = 1.34055*PI_{5\text{-mm}} + 73.13$	8,093	38.64	0.95
AC/AC	1	PI2.5-mm to PI0.0-mm	$PI_{0.0} = 1.14153*PI_{2.5\text{-mm}} + 160.70$	1,856	43.41	0.96
AC/AC	1	PI5-mm to PI0.0-mm	$PI_{0.0} = 1.56038*PI_{5\text{-mm}} + 250.89$	1,826	73.74	0.88
AC/AC	1	PI5-mm to PI2.5-mm	$PI_{2.5\text{-mm}} = 1.39462*PI_{5\text{-mm}} + 75.55$	1,826	40.47	0.95
AC/AC	2	PI2.5-mm to PI0.0-mm	$PI_{0.0} = 1.28067*PI_{2.5\text{-mm}} + 138.15$	1,496	52.26	0.86
AC/AC	2	PI5-mm to PI0.0-mm	$PI_{0.0} = 1.75837*PI_{5\text{-mm}} + 222.84$	1,347	79.32	0.66
AC/AC	2	PI5-mm to PI2.5-mm	$PI_{2.5\text{-mm}} = 1.52523*PI_{5\text{-mm}} + 56.60$	1,347	34.14	0.89
AC/AC	3,4	PI2.5-mm to PI0.0-mm	$PI_{0.0} = 1.11926*PI_{2.5\text{-mm}} + 145.85$	5,128	44.86	0.93
AC/AC	3,4	PI5-mm to PI0.0-mm	$PI_{0.0} = 1.45876*PI_{5\text{-mm}} + 233.59$	4,908	71.53	0.81
AC/AC	3,4	PI5-mm to PI2.5-mm	$PI_{2.5\text{-mm}} = 1.36739*PI_{5\text{-mm}} + 71.17$	4,908	38.12	0.93
AC/PCC	1,2,3,4	PI2.5-mm to PI0.0-mm	$PI_{0.0} = 1.15412*PI_{2.5\text{-mm}} + 177.08$	4,158	44.46	0.93
AC/PCC	1,2,3,4	PI5-mm to PI0.0-mm	$PI_{0.0} = 1.61123*PI_{5\text{-mm}} + 271.11$	4,054	71.07	0.81
AC/PCC	1,2,3,4	PI5-mm to PI2.5-mm	$PI_{2.5\text{-mm}} = 1.44895*PI_{5\text{-mm}} + 76.83$	4,054	36.99	0.93

Source: FHWA-RD-02-057

[a] Climatic zones: 1=DF, 2=DNF, 3=WF, 4=WNF.

DF Dry-Freeze
DNF Dry-Nonfreeze
WF Wet-Freeze
WNF Wet-Nonfreeze

Table C4. PI to PI for Portland Cement Concrete

PI to PI for Portland Cement Concrete						
Type	Climate[a]	From/To	Correlation Equation (PI = mm/km)	N	SEE	R^2
PCC	1	PI2.5-mm to PI0.0-mm	$PI_{0.0} = 1.04364*PI_{2.5\text{-}mm} + 238.13$	2,237	46.9	0.95
PCC	1	PI5-mm to PI0.0-mm	$PI_{0.0} = 1.39512*PI_{5\text{-}mm} + 343.08$	2,182	71.2	0.87
PCC	1	PI5-mm to PI2.5-mm	$PI_{2.5\text{-}mm} = 1.36458*PI_{5\text{-}mm} + 96.46$	2,180	43.3	0.95
PCC	2	PI2.5-mm to PI0.0-mm	$PI_{0.0} = 1.02028*PI_{2.5\text{-}mm} + 229.78$	1,448	44.3	0.94
PCC	2	PI5-mm to PI0.0-mm	$PI_{0.0} = 1.36715*PI_{5\text{-}mm} + 313.25$	1,366	66.4	0.86
PCC	2	PI5-mm to PI2.5-mm	$PI_{2.5\text{-}mm} = 1.38376*PI_{5\text{-}mm} + 74.90$	1,364	39.8	0.95
PCC	3	PI2.5-mm to PI0.0-mm	$PI_{0.0} = 1.01255*PI_{2.5\text{-}mm} + 238.65$	9,800	50.0	0.97
PCC	3	PI5-mm to PI0.0-mm	$PI_{0.0} = 1.20723*PI_{5\text{-}mm} + 367.91$	9,764	86.7	0.91
PCC	3	PI5-mm to PI2.5-mm	$PI_{2.5\text{-}mm} = 1.20990*PI_{5\text{-}mm} + 123.95$	9,764	53.6	0.96
PCC	4	PI2.5-mm to PI0.0-mm	$PI_{0.0} = 1.01320*PI_{2.5\text{-}mm} + 244.81$	2,888	56.9	0.94
PCC	4	PI5-mm to PI0.0-mm	$PI_{0.0} = 1.19909*PI_{5\text{-}mm} + 390.49$	2,885	85.2	0.85
PCC	4	PI5-mm to PI2.5-mm	$PI_{2.5\text{-}mm} = 1.212677*PI_{5\text{-}mm} + 138.43$	2,885	43.0	0.96

Source: FHWA-RD-02-057

[a] Climatic zones: 1=DF, 2=DNF, 3=WF, 4=WNF.

DF Dry-Freeze
DNF Dry-Nonfreeze
WF Wet-Freeze
WNF Wet-Nonfreeze

The figures on the following pages present the previous four tables or equations as a series of graphs

The PI to PI charts are for informational purposes only to indicate how the index varies with the different blanking bands applied. PI indices are difficult to compare from state to state as different blanking bands give different results. IRIs derived from inertial profilers are more comparable from state to state and thus are more useful in research studies. The AASHTO specifications listed in the Conclusion section were establish to make the IRI a consistent measurement.

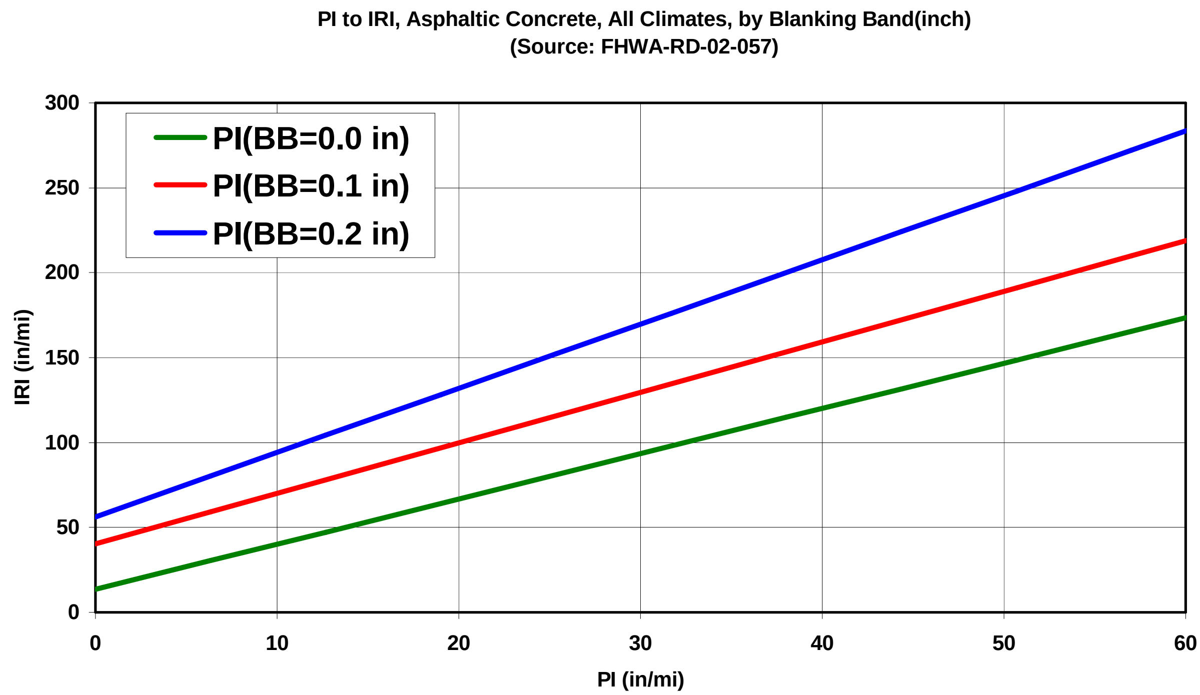


Figure C1. PI to IRI for concrete, all climates and blanking bands.
(Green line {lower one] applicable to Missouri)

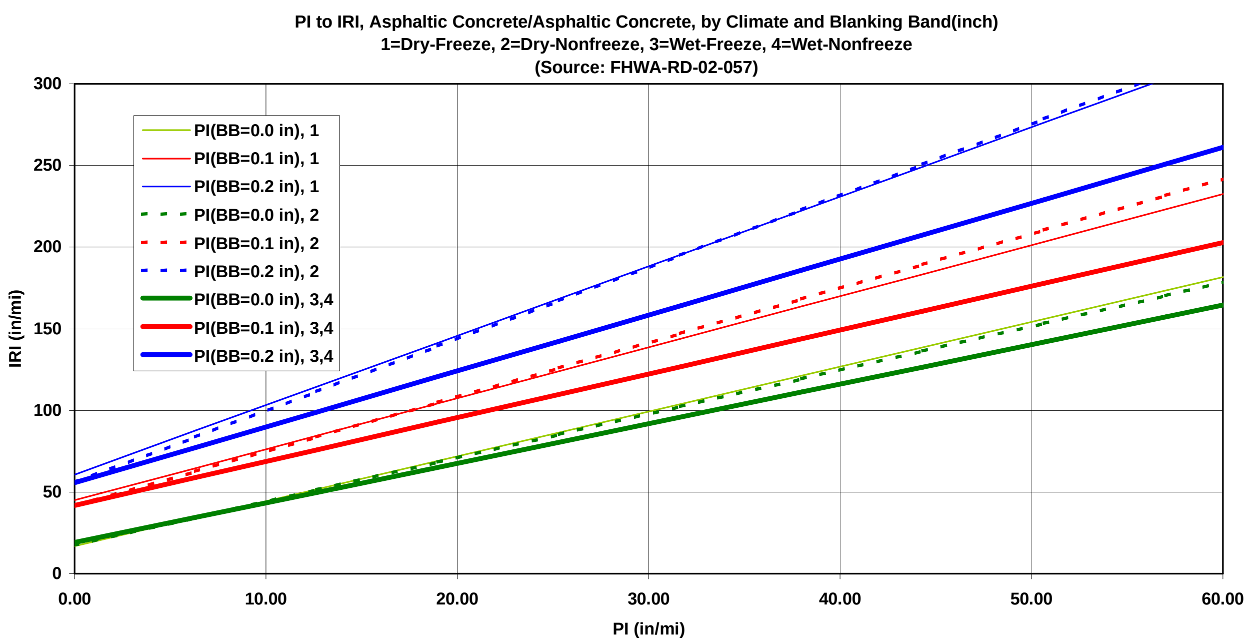


Figure C2. PI to IRI, Asphaltic Concrete/Asphaltic Concrete, all climates, all blanking bands. (Thick, solid, green line [lowest one] applicable to Missouri.)

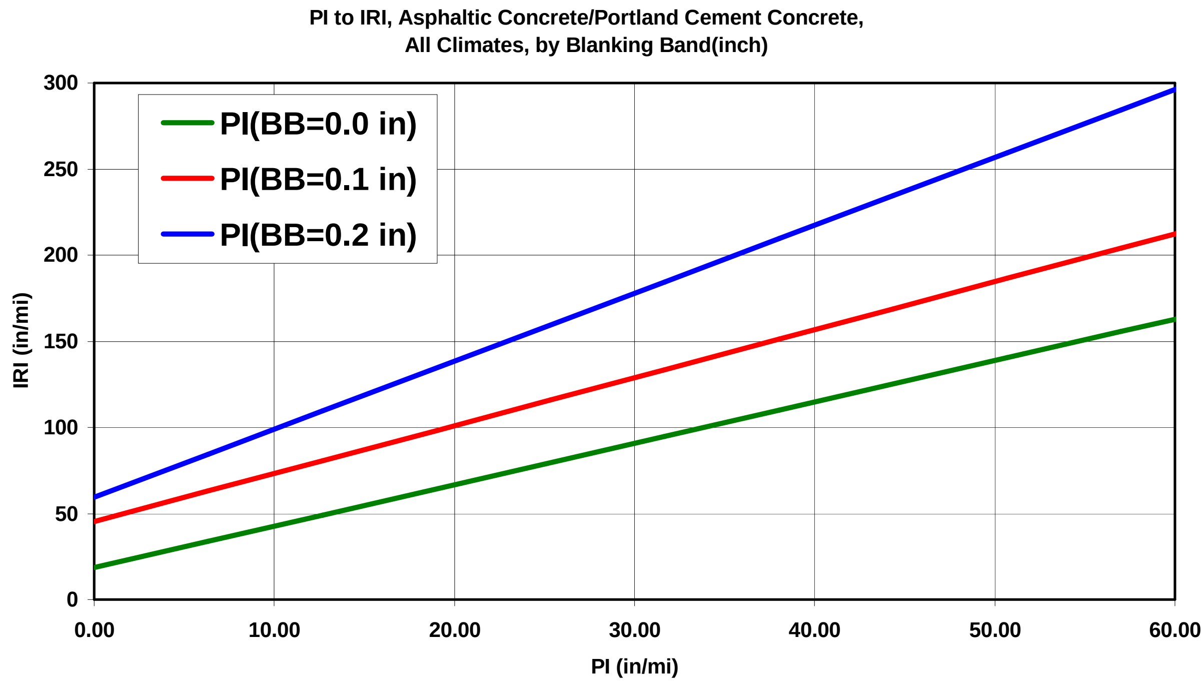


Figure C3. PI to IRI, Asphaltic Concrete/Portland Cement Concrete, all climates, all blanking bands. **(Green line [lowest one] applicable to Missouri)**

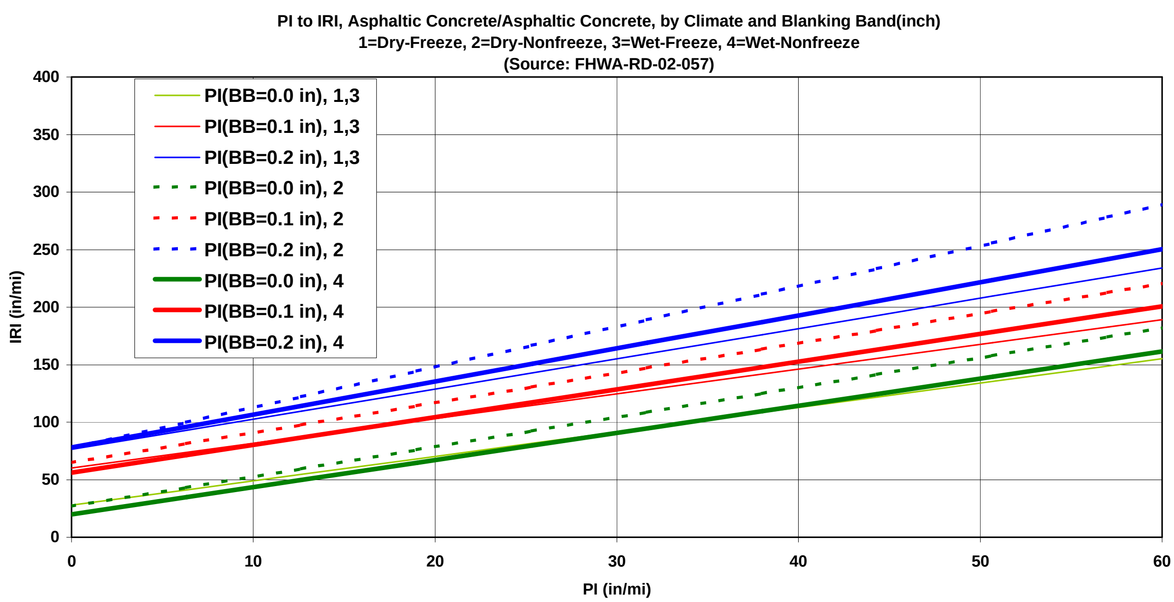


Figure C4. PI to IRI for Portland Cement Concrete, all climates, all blanking bands. **(Thin, solid, green line [lowest one] applicable to Missouri)**

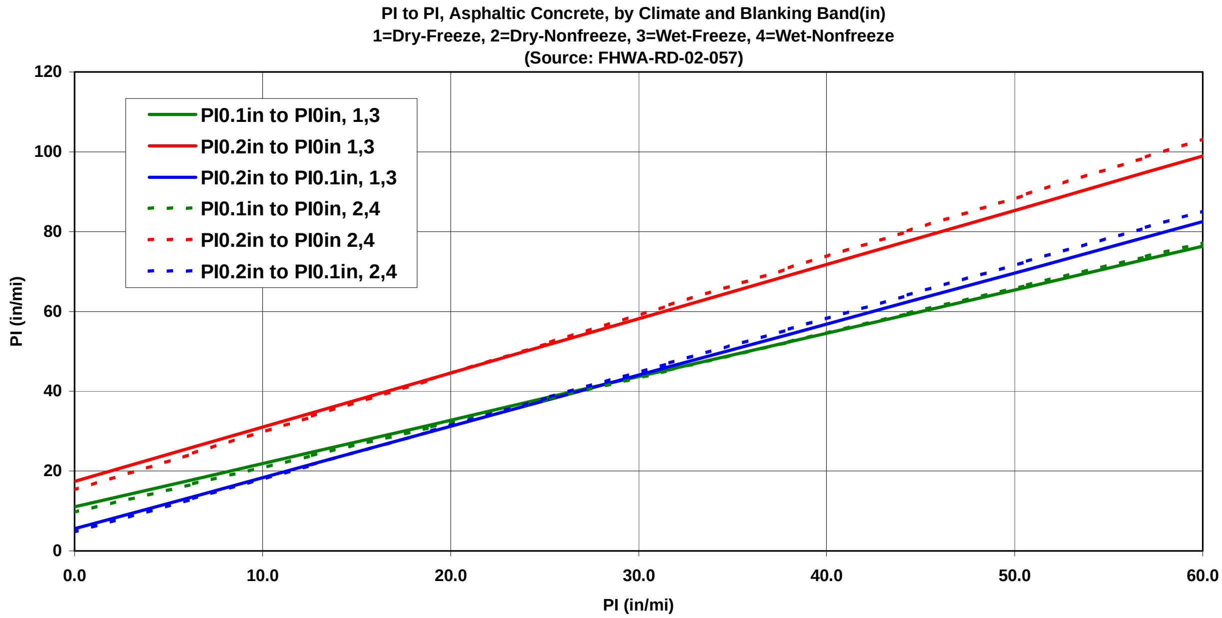


Figure C5. PI to PI for Asphaltic Concrete.

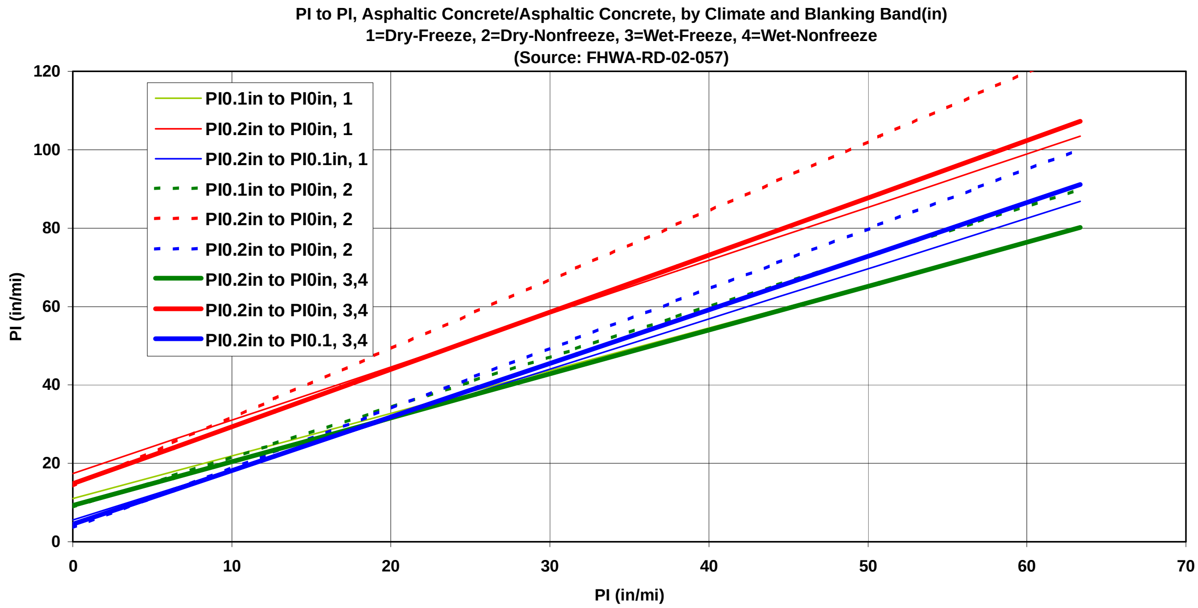


Figure C6. PI to PI for Asphaltic Concrete / Asphaltic Concrete, all climates, all blanking bands.

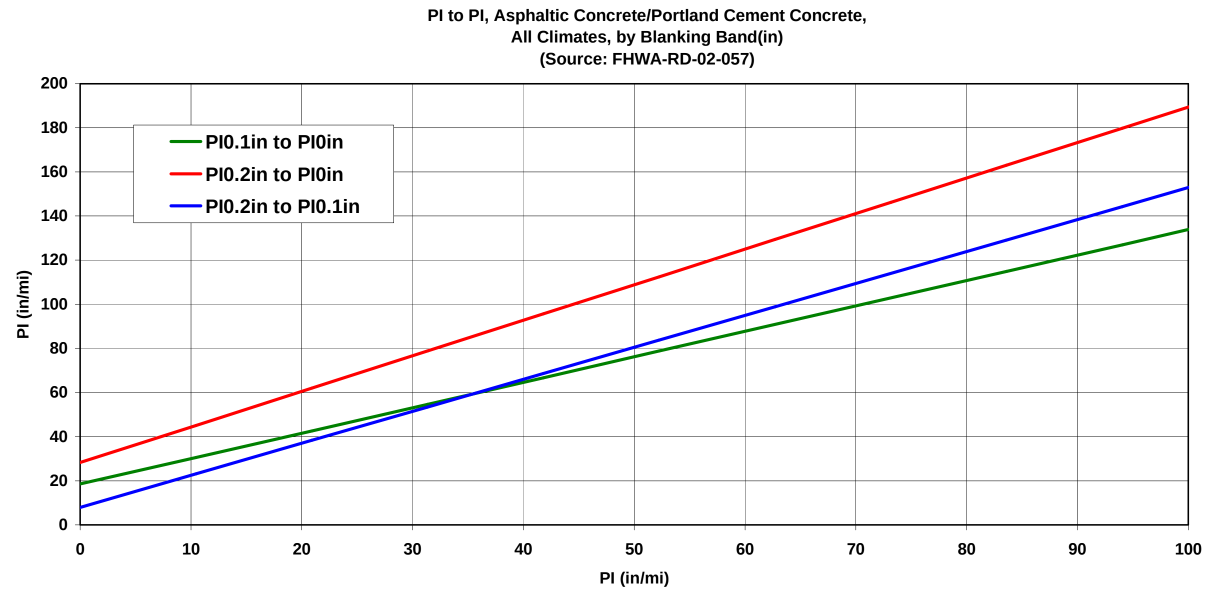


Figure C7. PI to PI forAsphaltic Concrete / Portland Cement Concrete, all climates, all blanking bands.

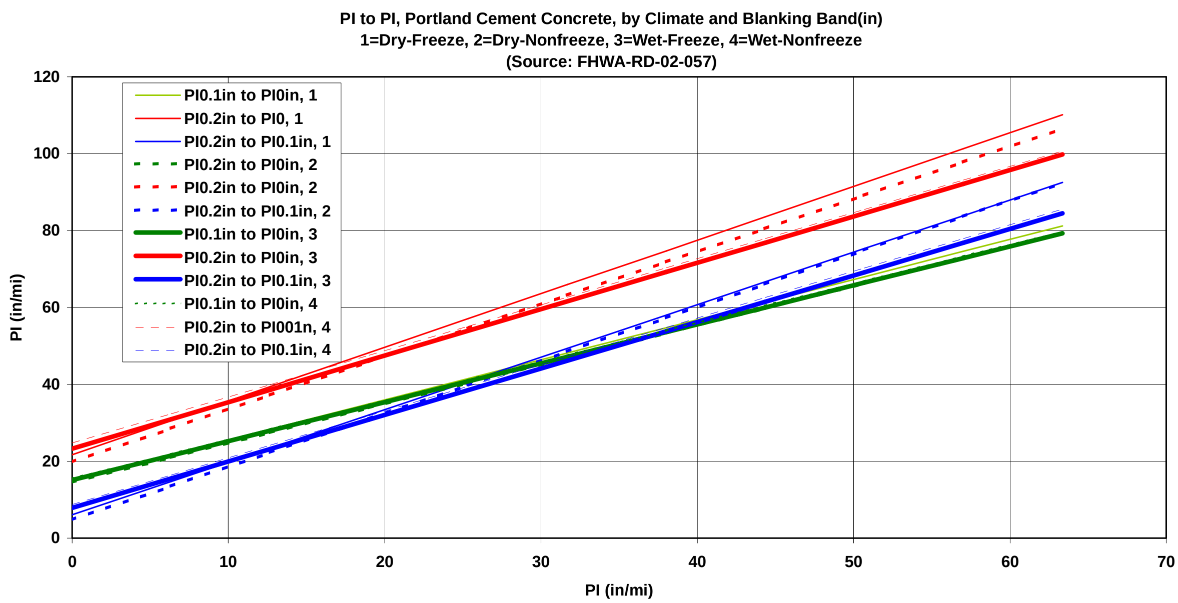


Figure C8. PI to PI, Portland Cement Concrete, all climates, all blanking bands.

Appendix D: Pavement Smoothness Pay Factor, Incentive/Disincentive Specifications

In FHWA Report FHWA-RD-02-057, “Pavement Smoothness Index Relationships, Final Report”, two tables present a summary of Smoothness indices, and Incentive/Disincentive threshold limits for Asphaltic and Portland Cement Concrete. All figures and tables in this appendix are based on information taken from this FHWA report except for updates made for the states of Connecticut, Ohio, and Minnesota which specifications are presented in Appendices E, F, and G.

Figure D1 presents the specification types and distribution for the states that provided information for the FHWA report.

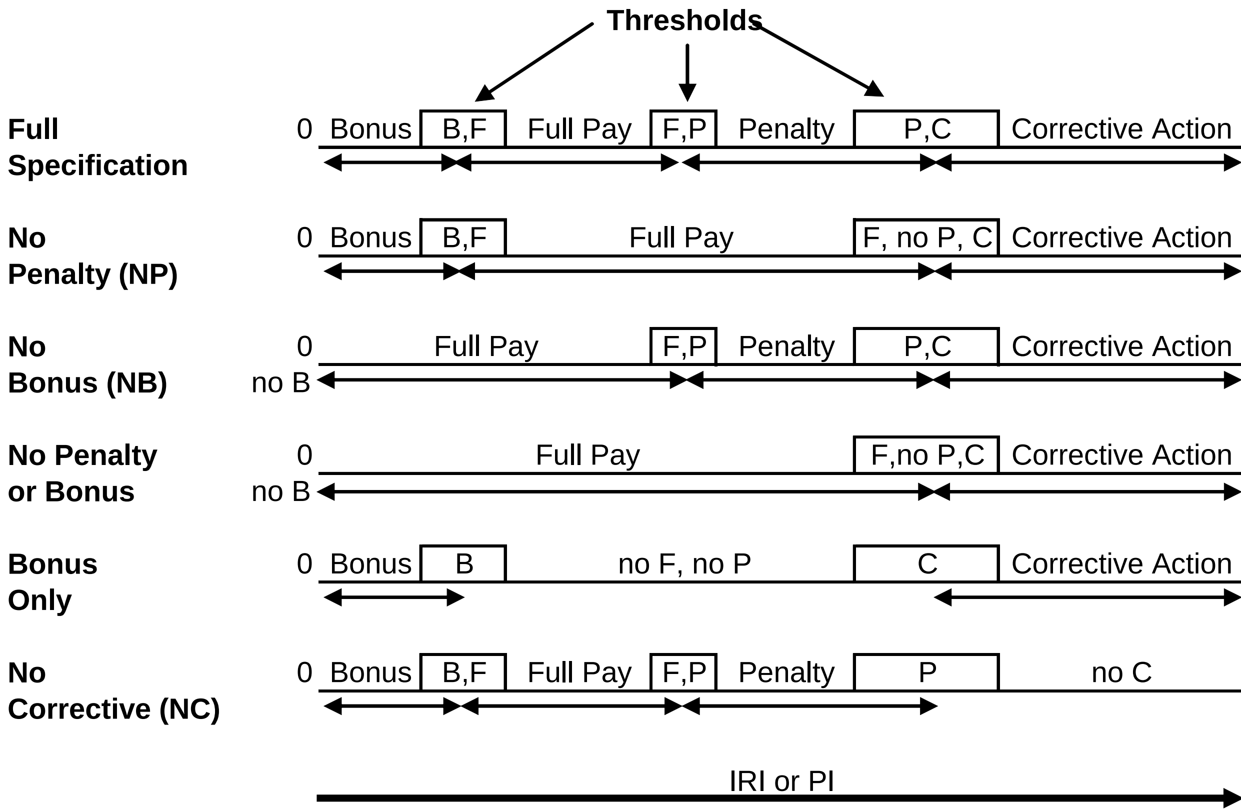
There are six specification models depending on the presence or absence of bonus pay, penalties, and corrective action. The full specification with both bonus pay and penalties included is the most common specification for both Asphaltic concrete and Portland Cement concrete pavements.

For the No Bonus and No Penalty specifications, two sets of frequencies and percentages are provided. For the No Bonus specification, the upper numbers are for No Bonus pay (with penalties) occurrences. The lower number is the combined No Bonus pay (with penalties) and the No Bonus pay (with no penalties). For the No Penalty specification, the upper numbers are for No Penalties (with bonus pay) occurrences. The lower number is the combined No Penalty (with bonus pay) and the No Penalty (with no bonus pay).

Figures D2 and D3 present the pavement smoothness indices and incentive/disincentive specification break down by state for Asphaltic and Portland Cement concrete for the information provided by the states for the FHWA report. Summary statistics are also provided.

The series of figures, D4 through D10, show the state by state specifications and thresholds for the payment ranges for Asphaltic and Portland Cement concrete by smoothness index used by the individual states. These figures include the updates made for the states of Connecticut, Ohio, and Minnesota. For asphaltic pavements, these three states use the IRI index and the full incentive/disincentive specification. For Minnesota, the IRI information is not shown in Figure D2, for Asphaltic concrete, as Minnesota has three sets of specification (equations) depending on pavement design. A separate figure D11 is provided later to show the three specification equations. For concrete pavements, only the updated Connecticut data applies.

Pay Factor Specification Types and Distribution



Distribution

Specification type	Asphalt	Con-crete	Asphalt %	Con-crete %
Full Specification	28	24	73.7%	54.5%
No Penalty (NP)	4	9	10.5%	20.5%
	9	15	23.7%	34.1%
No Bonus (NB)	1	3	2.6%	6.8%
	6	9	15.8%	20.5%
No Penalty or Bonus	5	6	13.2%	13.6%
Bonus Only	0	1	0.0%	2.3%
No Corrective (NC)	0	1	0.0%	2.3%

Italic, Underline: all NP and all NB

B = Bonus Threshold
F = Full Pay Threshold
P = Penalty Threshold
C = Corrective Threshold

Figure D1. Pay Factor, Incentive/Disincentive Specifications types and distribution.

Asphalt Pavement Smoothness Index by Specification and State

Index	Spec	State
IRI	FS	CT
IRI	FS	ME
IRI	FS	OH
IRI	FS	SD
IRI	FS	VA
IRI	FS	VT
IRI	FS	WA
IRI	NB, NP	GA
MRN	FS	AZ
MRN	FS	SC
MRN	FS	TN
MRN	NP	WV
PI0mm	FS	KS
PI0mm	FS	MO
PI0mm	FS	PA
PI0mm	FS	TX
PI2.5mm	FS	CA
PI5mm	FS	AL
PI5mm	FS	AR
PI5mm	FS	IA
PI5mm	FS	IL
PI5mm	FS	MD
PI5mm	FS	MN
PI5mm	FS	MS
PI5mm	FS	NE
PI5mm	FS	NM
PI5mm	FS	OH
PI5mm	FS	OK
PI5mm	FS	OR
PI5mm	NB	WI
PI5mm	NB, NP	CA
PI5mm	NB, NP	ID
PI5mm	NB, NP	NV
PI5mm	NB, NP	UT
PI5mm	NP	IN
PI5mm	NP	LA
PI5mm	NP	PR
RI	FS	KY

Asphalt Pavement Specification Distribution

Spec	Spec #	Spec %
FS	28	73.7%
NB	1	2.6%
NB, NP	5	13.2%
NP	4	10.5%
NB'	6	15.8%
NP'	9	23.7%

Asphalt Pavement Index Distribution

Index	Index #	Index %
IRI	8	21.1%
MRN	4	10.5%
PI0mm	4	10.5%
PI2.5mm	1	2.6%
PI5mm	20	52.6%
RI	1	2.6%

Notes:
FS = Full Specification
NB= No Bonus
NB, NP = No Bonus or Penalty
NP = No Penealty

Figure D2. Asphalt pavement smoothness index and specification breakdown by state.

Concrete Pavement Smoothness Index by Specification and State

Index	Spec	State
IRI	FS	OH
IRI	FS	VA
MRN	NP	WV
PI0mm	BO	PA
PI0mm	FS	KS
PI0mm	FS	MO
PI0mm	FS	SD
PI0mm	FS	TX
PI2.5mm	FS	CO
PI2.5mm	FS	KY
PI2.5mm	FS	WI
PI2.5mm	NB	TN
PI2.5mm	NB, NP	GA
PI5mm	FS	AL
PI5mm	FS	CT
PI5mm	FS	FL
PI5mm	FS	IA
PI5mm	FS	IL
PI5mm	FS	LA
PI5mm	FS	MD
PI5mm	FS	MN
PI5mm	FS	MT
PI5mm	FS	ND
PI5mm	FS	NE
PI5mm	FS	NM
PI5mm	FS	OH
PI5mm	FS	OK
PI5mm	FS	UT
PI5mm	NB	HI
PI5mm	NB	MS
PI5mm	NB, NP	CA
PI5mm	NB, NP	ID
PI5mm	NB, NP	NC
PI5mm	NB, NP	NV
PI5mm	NB, NP	SC
PI5mm	NP	AR
PI5mm	NP	AZ
PI5mm	NP	DE
PI5mm	NP	IN
PI5mm	NP	MI
PI5mm	NP	NY
PI5mm	NP	OR
PI5mm	NP	PR
PI7.5mm	NC	WA

Concrete Pavement Specification Distribution

Spec	Spec #	Spec %
FS	24	63.2%
BO	1	2.6%
NB	3	7.9%
NB, NP	6	15.8%
NP	9	23.7%
NC	1	2.6%
All NB	9	23.7%
All NP	15	39.5%
States	44	

Concrete Pavement Index Distribution

Index	Index #	Index %
IRI	2	4.4%
MRN	1	2.2%
PI0mm	5	11.1%
PI2.5mm	5	11.1%
PI5mm	30	66.7%
RI	1	2.2%
States	44	

Notes:
FS = Full Specification
BO = Bonus Only
NB= No Bonus
NB, NP = No Bonus or Penalty
NP = No Penealty
NC = No Corrective

Figure D3. Concrete pavement smoothness index and specification breakdown by state.

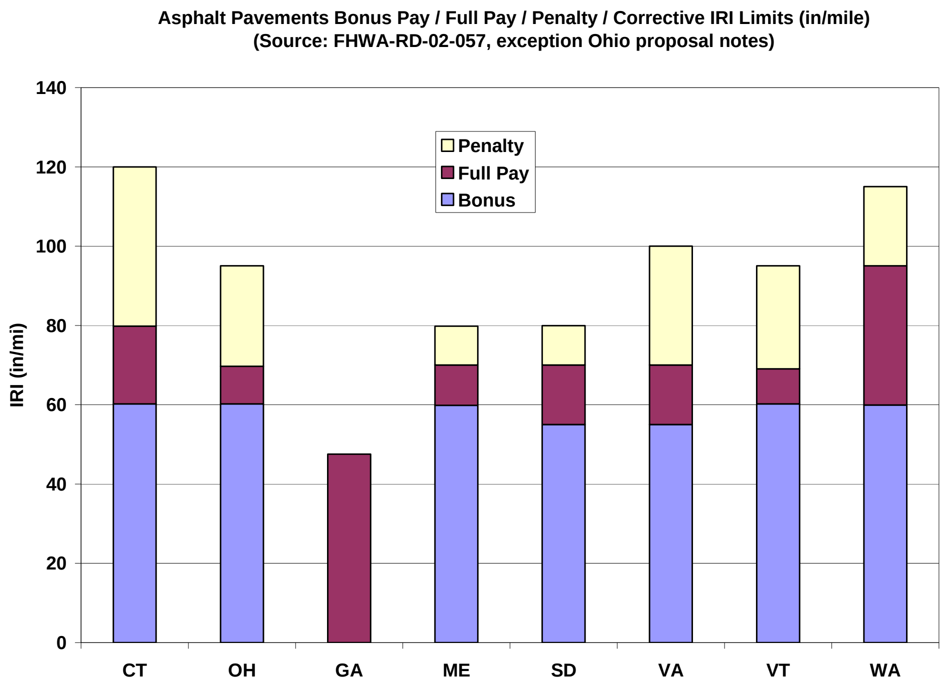


Figure D4. Asphalt pavement bonus pay / full pay/ penalty / corrective IRI limits by state.

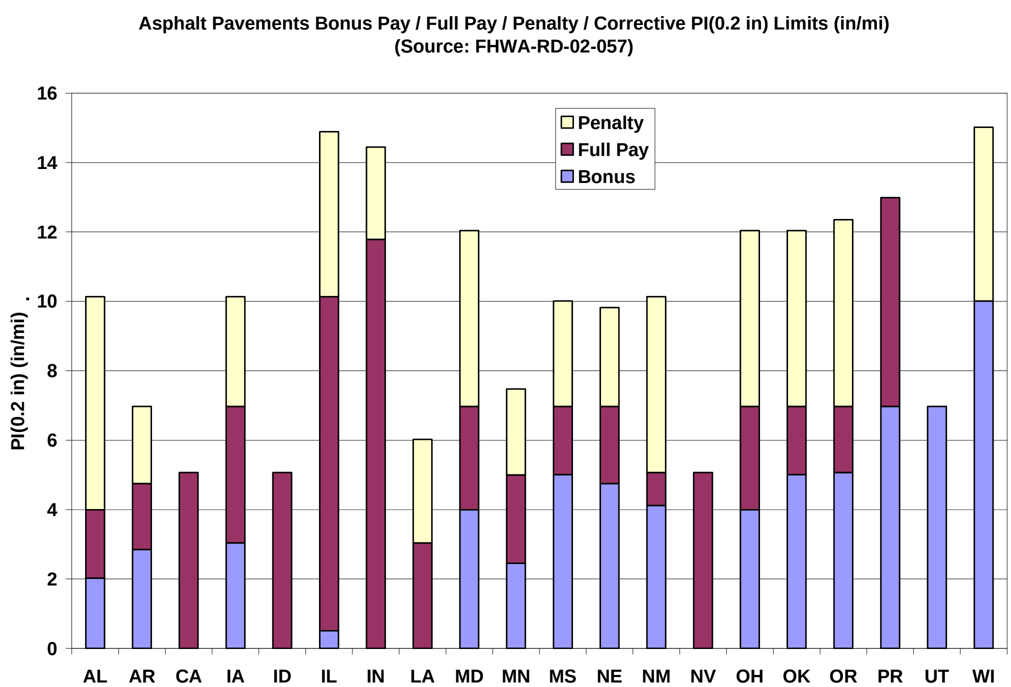


Figure D5. Asphalt pavement bonus pay / full pay/ penalty / corrective PI(0.2 in) limits by state.

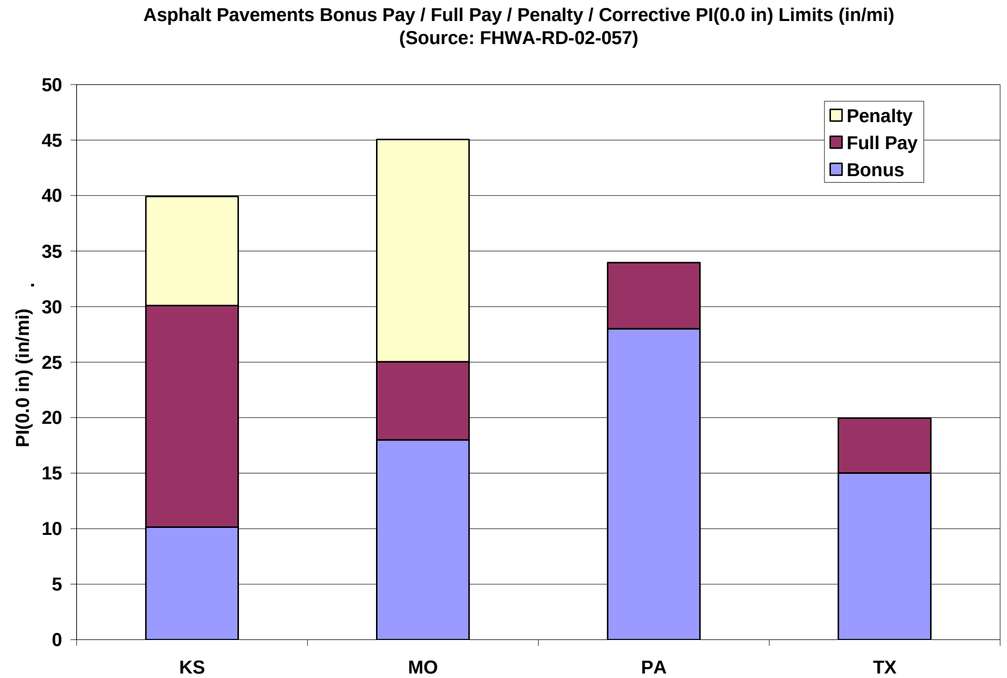


Figure D6. Asphalt pavement bonus pay / full pay/ penalty / corrective PI(0.1 in) limits by state.

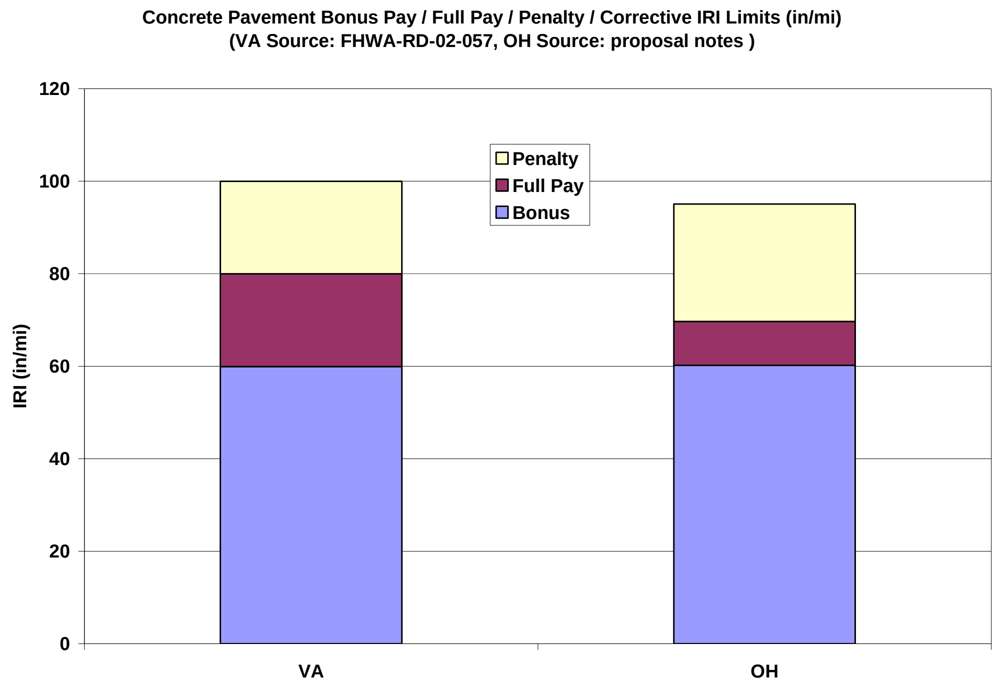


Figure D7. Concrete pavement bonus pay / full pay/ penalty / corrective IRI limits by state.

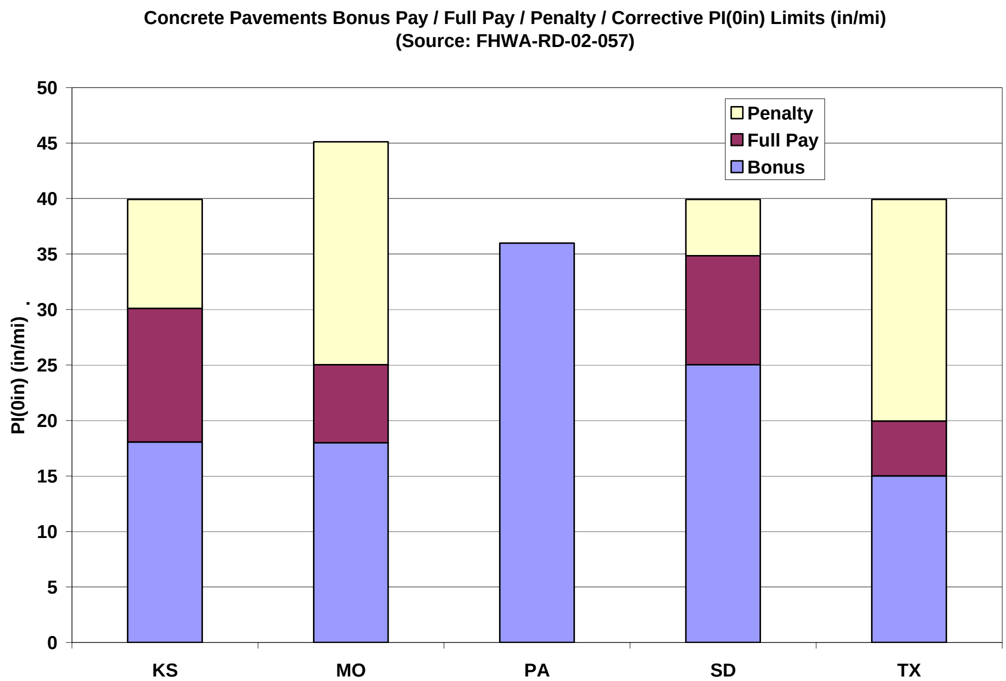


Figure D8. Concrete pavement bonus pay / full pay/ penalty / corrective PI(0 in) limits by state.

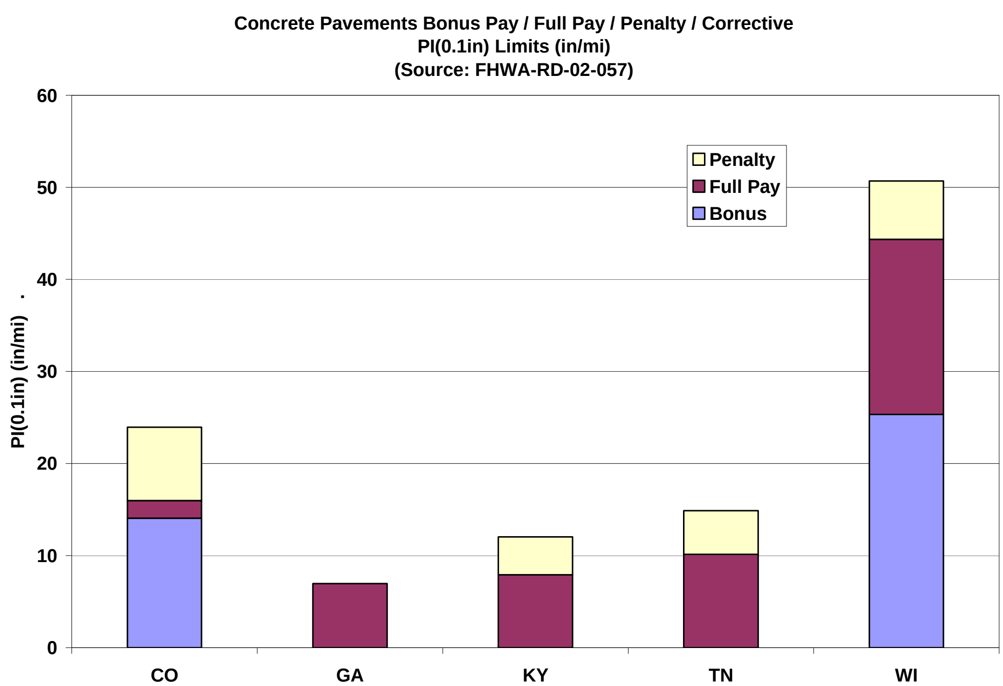


Figure D9. Concrete pavement bonus pay / full pay/ penalty / corrective PI(0.1 in) limits by state.

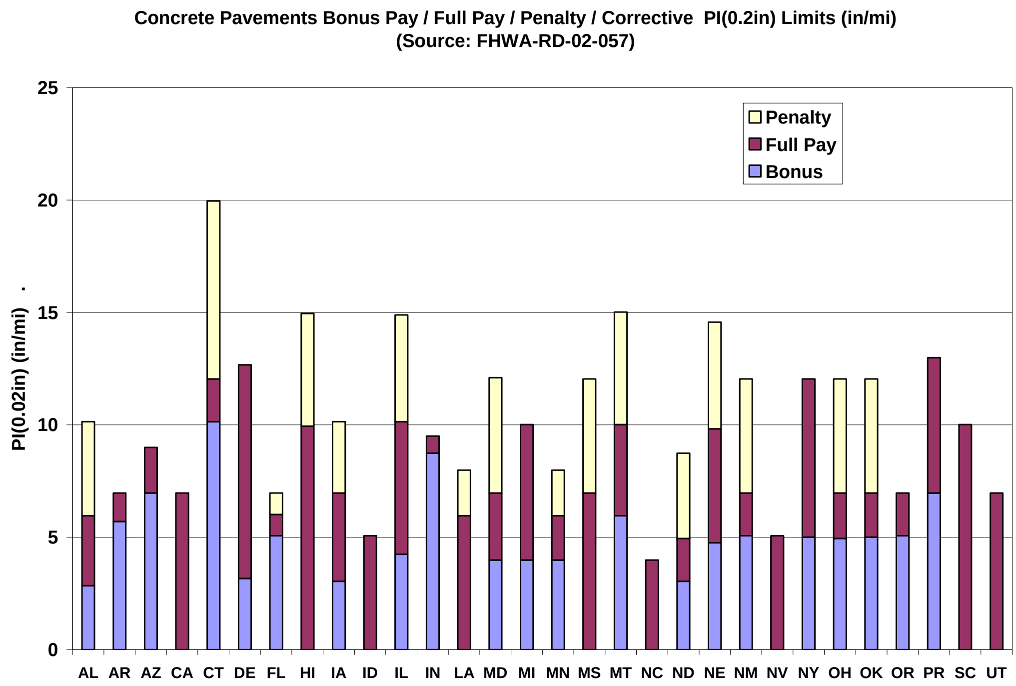


Figure D10. Concrete pavement bonus pay / full pay/ penalty / corrective PI(0.2 in) limits by state.

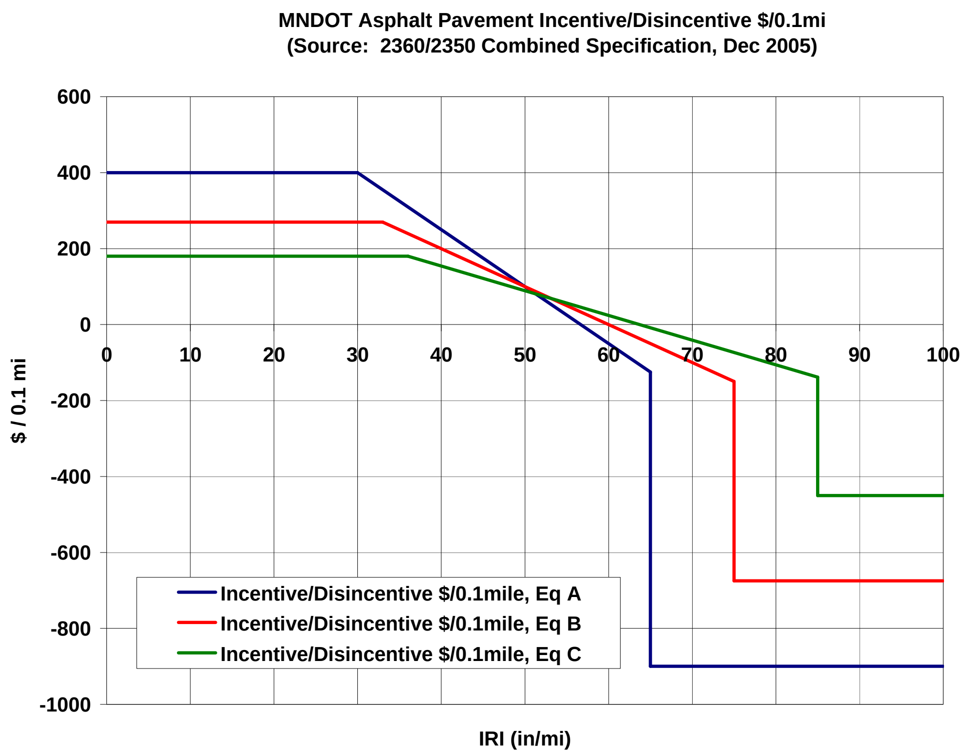


Figure D11. Minnesota DOT asphalt pavement incentive/disincentive equations.

Appendix E: Example Specifications from Connecticut DOT

Connecticut DOT Special Provision for Pavement Smoothness

SECTION 4.06 - BITUMINOUS CONCRETE

Article 4.06.03 - Construction Methods, Subarticle 10 - Surface Test of Pavement, is amended as follows: After the last paragraph of the Subarticle add the following:

(a) Pavement Smoothness (Rideability): The Engineer shall evaluate the final pavement surface for smoothness by testing in accordance with Section 4.06 and as stated herein. This provision will apply to projects requiring a minimum of two (2) courses of Hot Mix Asphalt (HMA) in which the compacted depth of each is 1.5 inches (40 mm) or greater.

Prior to the placement of the final course of pavement, the Engineer will furnish the Contractor with an International Roughness Index (IRI) value that results from the Engineer's evaluation of the material placed to date. The actual time of this "trial" evaluation will be coordinated between the Engineer and the Contractor. This evaluation will be limited to one (1) test in each direction of travel. The IRI value will serve as a guide to the Contractor in evaluating his current level of conformance with the smoothness specification.

The IRI value for the final course of pavement will be the basis for determining any payment adjustment(s) in accordance with Table 1, Schedule of Adjusted Payment of Section, 4.06.04 - Method of Measurement, Subarticle 4.06.04 - 7 "Adjustment for Rideability."

Evaluation Method - The final pavement surface shall be evaluated for smoothness using an "Automated Road Analyzer" vehicle or ARAN. Computers aboard the ARAN contain software that simulates the traversing of a so-called "quarter car" over the adjusted profile, and calculates an average IRI value as defined by the World Bank, for each lane of travel over the project. This ARAN is a Class II device as defined by the World Bank. The IRI represents the vertical (upward and downward) displacement that a passenger would experience traveling at 48 MPH (77 km/hr) in a standard vehicle over the profile established by the device. A zero IRI value would indicate a perfectly smooth pavement surface, while increasing IRI values would correspond to an increasingly rough pavement surface. The ARAN has the capability to measure longitudinal profile in each wheelpath simultaneously. IRI values shall be calculated in inches (meters) of vertical displacement every 0.01 mile (16 meters) and normalized over one (1) mile in inches/mile, or 1.6 km in m/km. For example, a 0.01-mile section yielding an actual vertical displacement of one (1) inch would be normalized to an IRI value of 100 inches/mile.

The final pavement surface will be divided into 0.10 mile (160 meter) segments representing the total lane miles of the project. The total lane miles are equal to the miles of resurfacing multiplied by the number of lanes being evaluated. The final segment will include any remaining portion of a segment not equaling 0.10 miles (160 meters) [Example: 1.52 miles of pavement would have 15 segments with the last one measuring 0.12 miles]. The IRI calculated from each wheelpath for each 0.10 mile (160 meter) segment will be averaged to determine the IRI value for that segment.

GENERAL

The evaluation shall be subject to the following:

l. Only mainline travel lanes will be evaluated. This shall include climbing lanes, operational lanes, and turning roadways that are 0.4 miles (644 meters) or greater in length.

2. Smoothness data will not be computed for the following project sections:

- Climbing and operational lanes and turning roadways less than 0.4 miles (644 meters) in length
- Acceleration and deceleration lanes
- Shoulders and gore areas
- Pavement on horizontal curves which have a 900 foot (274.32 meters) or less centerline radius of curvature, and pavement within the superelevation transition of these curves.

3. Bridge decks shall be included only if paved as part of the project. If the bridge decks are not included in the project, profile testing will be suspended two hundredths of a mile (0.02) [32 meters] prior to the first expansion joint and after the last expansion joint on the bridge decks.

4. Ramps are specifically excluded from the requirements of this Section.

5. Measurement will start two-hundredths of a mile (0.02) [32 meters] prior to and after the transverse joints at the project limits.

6. Data will be collected within 30 days of completion of the entire final course of pavement, or within 30 days of completion of any corrective work on the pavement. If the entire final course of pavement can not be completed prior to December I (winter shutdown), then data will be collected for any portion of the roadway in which the final course of pavement has been placed. These data will be saved and stored by the Department. Once the remainder of the final course has been placed, the data will be collected and combined with the data taken previously.

If the Engineer determines that any pavement corrective work is required, the Contractor will be notified in writing within five (5) working days after the completion of the final course of pavement. The Contractor shall have thirty (30) days following such notification to make any repairs to the pavement before smoothness measurements are taken.

7. No testing shall be conducted during rain or under other conditions deemed inclement by the Engineer. During testing, the roadway must be free of moisture and other deleterious materials which might affect the evaluation. Any work associated with preparing the roadway for the evaluation, such as but not limited to sweeping, will not be measured for payment.

GENERAL

Article 4.06.04 - Method of Measurernent:

Add the following Subarticle:

7. Adjustment for Rideability: Payment to the Contractor shall be based on the IRI, according to the following table. The percent adjustment will be applied to payment(s) for the total quantity of HMA surface course, excluding ramps, complete-in-place, and shall conform to the requirements of Section 4.06 and this provision.

TABLE 1 SCHEDULE FOR PAYMENT

IRI (inches per mile)	IRI (meters per kilometer)	PERCENT ADJUSTMENT
<50	<0.79	+10
51 – 60	0.80-0.95	+05
61 – 80	0.96- 1.26	0
81-100	1.27-1.58	-OS
101-110	1.59-1.74	- 10
111 – 120	1.75 - 1.89	- 25
> 120	> 1.89	- 50

NOTE: All values in the English system will be rounded to the nearest whole number. (Example: 75.5 shall be rounded to 76.)

All values in the metric system will be rounded to the nearest hundredth. (Example: 0.826 shall be rounded to 0.83.)

Article 4.06.05 - Basis of Payment is amended as follows:

Add the following at the end of the first sentence:

...except as noted herein. An adjustment in payment shall apply to the quantity of HMA for the surface course, excluding ramps, furnished and placed in accordance with Section 4.06.

Positive adjustments for rideability shall not be made for those areas reviewed and determined by the Engineer to be defective as stipulated in Subarticles 1.05.11 and 1.06.04.

GENERAL

Appendix F: Example Specifications from Ohio DOT

PROPOSAL NOTE 420 - 4/21/2006 - SURFACE SMOOTHNESS REQUIREMENTS FOR PAVEMENTS

DESCRIPTION: The surface tolerance specification requirements are modified as follows for all mainline lanes and collector-distributor road pavements of constant width. Surface tolerance requirements for other areas such as ramps, acceleration and deceleration lanes, side roads, shoulders, crossovers, approach slabs, bridge decks, etc., are not a part of this specification and are subject to the requirements of the original item(s) specified.

If the final surface course is Item 803, this specification applies to the pavement course placed just below the final surface course.

MATERIALS AND EQUIPMENT: Provide smoothness measuring equipment conforming to Supplement 1058. Furnish the Department's approval letter of the profiler to the Engineer. The Engineer will verify the smoothness measuring equipment conforms to Supplement 1058.04. After March 1, 2007 the Engineer will also verify the profile operator's certification. Furnish equipment meeting the requirements of 257.02 for corrective diamond grinding.

SMOOTHNESS MEASUREMENT: Measure the pavement surface smoothness in both wheel paths. Wheelpaths are located parallel to the centerline of the pavement and approximately 3.0 feet (1.0 m) inside all lane edges, measured transversely. Ensure the path of the profiler is parallel to the lane edges at all times. Measure the entire length of pavement, starting and stopping the profile runs when the profile sensor(s) is within 1.0 foot (0.3 m) of any existing pavement, pressure relief joint, approach slab, or other non pavement features (i.e. manholes, valveboxes). Remove any objects such as dirt, debris, curing covers, etc., prior to performing the surface smoothness measurements. Replace any curing covers after the measurements are taken. Repair any membrane curing damaged during the measurements.

Do not perform any surface smoothness measurements until the pavement has cured sufficiently to allow measuring without damaging the pavement. For the first three days, run the profile of each day's paving the next working day and give to the Engineer. When the pavement will not support the profiler on the next working day, notify the Engineer and inform the Engineer when the profile will be run. Notify the Engineer each day prior to performing any measurements.

Develop a Profile Index (PI) according to California Test 526, 1978, on file in the Office of Contracts, and an International Roughness Index (IRI) according to ASTM E 1926 for each 0.1-mile (0.16 km) section. Submit one (1) copy of both indices, two copies of the summary report and two electronic copies of all longitudinal pavement profiles in ERD format (University of Michigan Transportation Research Institute's Engineering Research Division [ERD] format) to the Engineer. The Engineer will submit one copy of the summary report and one electronic copy of the ERD information to the Office of Pavement Engineering.

Provide necessary traffic control and survey stationing for all surface smoothness measurements.

MANDATORY CORRECTIVE WORK: Perform corrective work for the applicable surface type. Corrective work must be performed on any 0.1-mile (0.16 km) section if the IRI exceeds 95 inches per mile (1.50 m/km) regardless of the PI.

Asphalt Concrete Surface: Correct all areas having deviations, high or low points, in excess of 0.30 inches (7.6 mm) in 25 feet (7.6 m)or less. Correct any 0.1-mile (0.16 km) sections having an IRI greater than 95 inches per mile (1.50 m/km). Perform corrective work by removing and replacing to the depth necessary to correct the deviations or by diamond grinding. Use asphalt concrete meeting the contract requirements for the replacement work. Apply Item 407 Tack Coat prior to placing the surface course. Limit the length of any one diamond grinding location to no more than 30 feet (10 m), measured longitudinally. The amount of diamond grinding per 0.1-mile (0.16 km) section is limited to no more than 10% of the section length, otherwise, remove and replace is required. The total amount of grinding is limited to no more than 5% of the lane-miles (lane-km) eligible for a pay adjustment.

Re-measure each 0.1-mile (0.16 km) section where corrective work was performed to ensure the IRI is less than 95 inches per mile (1.50 m/km) and there are no deviations greater than 0.30 inches (7.6 mm) in 25 feet (7.6 m) or less. Perform additional corrective work until the IRI is less than 95 inches per mile (1.50 m/km) and no deviations greater than 0.30 inches (7.6 mm) in 25 feet (7.6 m) or less exist.

If the final surface course is Item 803, seal any diamond ground areas with material meeting the requirements of 702.04 prior to placing the item 803.

Portland Cement Concrete Surface: Correct all areas having deviations, high or low points, in excess of 0.30 inches (7.6 mm) in 25 feet (7.6 m) or less. Correct any 0.1-mile (0.16 km) section having an IRI greater than 95 inches per mile (1.50 m/km). Perform corrective work by diamond grinding or removing and replacing. Use Portland cement concrete meeting the contract requirements for the replacement work.

Re-measure each 0.1-mile (0.16 km) section where corrective work was performed to ensure the IRI is less than 95 inches per mile (1.50 m/km) and there are no deviations greater than 0.30 inches (7.6 mm) in 25 feet (7.6 m) or less. Perform additional corrective work until the IRI is less than 95 inches per mile (1.50 m/km) and no deviations greater than 0.30 inches (7.6 mm) in 25 feet (7.6 m) or less exist. Complete all corrective work prior to determination of pavement thickness.

If corrective work is required the surface texture after diamond grinding is acceptable and no additional texturing is required.

EXEMPTED CORRECTIONS: Required corrective work resulting from contract requirements for maintaining traffic are considered exempted corrections. Exempted corrections occur primarily at ramps or other access points where paving must be suspended in order to maintain traffic. Required corrective work due to paving suspensions at the end of a work period, material availability, weather, or any reason other than maintaining traffic are not considered exempted corrections. No exempted corrections exist on projects where the maintenance of traffic plan does not interfere with paving operations. Perform exempted corrections according to the requirements for mandatory corrective work.

METHOD OF MEASUREMENT: Determine the PI and IRI for each lane for each 0.1-mile (0.16 km) section of paving. The PI for a 0.1-mile (0.16 km) section is the average of the PI of the two wheel paths. The IRI for a 0.1-mile (0.16 km) section is the average of the IRI of the two wheel paths.

PAY ADJUSTMENTS: A lump sum pay adjustment will be made according to the following schedule for each lane for each 0.1-mile (0.16 km) section, regardless of lane width. For all smoothness measurements made before March 1, 2008, the index, either PI or IRI, which results in greater pay (larger incentive or smaller disincentive) will be used for each 0.1-mile (0.16 km) section. Pay adjustments are based on pavement thickness. Pavement thickness is the total thickness of asphalt concrete, Portland cement concrete, or both placed as part of the contract and does not include any free draining base, aggregate base, stabilized subgrade, etc.

PAY SCHEDULE			
PI	**IRI**	**PAY ADJUSTMENT**	
Inches per mile per 0.1 mile section (mm/km per 0.16 km section)	**Inches per mile per 0.1 mile section (m/km per 0.16 km section)**	**Pavement Thickness less than 8 inches (200 mm)**	**Pavement Thickness 8 inches (200 mm) and greater**
1 (16) or less	45 (0.71) or less	$375.00	$875.00
Over 1 to 2 (16 to 32)	Over 45 to 50 (0.71 to 0.79)	$225.00	$525.00
Over 2 to 3 (32 to 47)	Over 50 to 55 (0.79 to 0.87)	$150.00	$350.00
Over 3 to 4 (47 to 63)	Over 55 to 60 (0.87 to 0.95)	$75.00	$175.00
Over 4 to 7 (63 to 110)	Over 60 to 70 (0.95 to 1.10)	$0.00	$0.00
Over 7 to 8 (110 to 126)	Over 70 to 75 (1.10 to 1.18)	-$150.00	-$350.00
Over 8 to 9 (126 to 142)	Over 75 to 80 (1.18 to 1.26)	-$300.00	-$700.00
Over 9 to 10 (142 to 158)	Over 80 to 85 (1.26 to 1.34)	-$450.00	-$1050.00
Over 10 to 11 (158 to 174)	Over 85 to 90 (1.34 to 1.42)	-$600.00	-$1400.00
Over 11 (174)	Over 90 to 95 (1.42 to 1.50)	-$750.00	-$1750.00
	Over 95 (1.50)	(1)	(1)

(1) Corrective work required

Pay adjustments for incentive will be based only on the measured PI or IRI prior to any mandatory corrective work. No incentive will be paid for any 0.1-mile (0.16 km) section where mandatory corrective work was performed regardless of the resulting PI or IRI.

Negative pay adjustments apply to sections with mandatory corrective work and exempted corrections. One-tenth mile (0.16 km) sections with exempted corrections only are eligible for incentive pay based on PI or IRI measurements taken after completior the exempted corrections.

At the contractors option, corrective work may be performed on any section with a profile index greater than 7 inches per mile (110 mm/km) or IRI greater than 70 inche per mile (1.10 m/km) to reduce or eliminate the negative pay adjustment, however, nc incentive will be paid regardless of the resulting profile index or IRI. As an option perform corrective work in the form of diamond grinding or Item 254 pavement plani to improve the profile on any course prior to the surface course. If the final course is Item 803 do not perform corrective work on the Item 803. Only diamond grinding ma performed on the course immediately below Item 803.

No payment will be made for any 0.1-mile (0.16 km) section with an IRI greater than inches per mile (1.50 m/km), regardless of the profile index, until corrective work has been completed and the IRI has been reduced to less than 95 inches per mile (1.50 m/km).

All smoothness measurements made after March 1, 2008, will be based on the IRI inc only and all pay adjustments, either incentive or dis-incentive will be based on IRI portion of the pay schedule table.

BASIS OF PAYMENT: Include the cost of all labor, equipment, and materials necessary to meet this specification in the contract unit or lump sum price for the applicable pavement items.

The Department will pay for exempted corrections conforming to 109.04

Designer's Note: This note should be used on all paving projects when:

1. The project is at least 1 centerline mile (1.6 km) long (both divided and undivided highways);
2. The design speed is 50 miles per hour (80 km/h) or greater; and one of the following applies:
   (a). The total new pavement thickness is equal to or greater than 2.25 inches (57 mm) without planing the existing surface and at least two courses are specified or.
   (b). The total new pavement thickness is equal to or greater than 2.25 inches (57 mm) with planing, at least two courses are specified AND at least the top course of asphalt concrete extends to the shoulder edge regardless if shoulders are planed or not.
3. This note should not be used for 2 lane projects that are totally in corporation limits.

Appendix G: Example Specification from Minnesota DOT

C Pavement Smoothness Specification – IRI (International Roughness Index)

C1 General

Pavement smoothness will be evaluated on the final mainline pavement surface using an Inertial Profiler (IP) and the International Roughness Index (IRI). Unless otherwise authorized by the Engineer, all smoothness testing shall be performed in the presence of the Engineer. The Engineer and the Contractor shall mutually agree upon scheduling of smoothness testing so that testing can be observed. Any testing performed without the Engineer's presence, unless otherwise authorized, may be ordered retested at the Contractor's expense.The following Table 2360.7-A (IRI) shows pavement surfaces that are excluded from smoothness testing but subject to 2360.7B surface requirements.

Table 2360.7 – A (IRI) Testing Exclusions

50 feet either side of obstructions such as manholes, water supply castings, etc.*
Ramps, Loops, Climbing lanes
Side Streets, Side Connections
Turn Lanes, Storage Lanes, Crossovers, Bypass Lanes
Shoulders
Intersections constructed under traffic – Begin and end the exclusion 30.5m [**100 feet**] from the intersection radius
Sections less than 15.24m **[50 ft]** in length
Acceleration, Deceleration Lanes
Projects less than 300m [**1000 feet**] in length
Mainline paving where the normally posted regulatory speed is less than or equal to 70 km/hr [**45 miles per hour**]
Begin the exclusion at the sign
Single lift overlays over concrete

*Mainline shall be included in profiling if obstructions are located in auxiliary or parking lanes

C1A Smoothness Requirements

Pavement smoothness requirements will be evaluated by the International Roughness Index (IRI) Equation A, Equation B, or Equation C. The pavement smoothness Equation will be identified in the Special Provisions of the proposal. Location of bumps and/or dips and magnitude will be based on California Test Method 526.

C2 Measurement

Smoothness will be measured with an IP, which produces both an IRI value and a profilogram (profile trace of the surface tested). The IP shall conform to the Class 1 requirements of ASTM E950-94 and must be certified according to the most recent procedure on file in the Bituminous Office. For pavement evaluation, one pass will be made in each lane, 2.74 m [**9 feet**] from centerline. The IP shall be run in the direction the traffic will be moving. Each lane will be tested and evaluated separately. The Engineer will determine the length in kilometers [**miles**] for each mainline traffic lane. The IP shall be operated at the optimum speed as defined by the manufacturer.

C3 Smoothness testing

The Contractor shall furnish a properly calibrated, documented, and MnDOT certified IP. The IP shall be equipped with automatic data reduction capabilities. Computer programs used to calculate the IRI statistic from a longitudinal roadway profile shall follow the procedure developed by the World Bank for a quarter-car simulation as described in NCHRP report 228. Mn/DOT certification documentation shall be provided to the Engineer on the first day the IP is used on the project. IP settings are on file in the Bituminous Office. The Contractor shall furnish a competent operator, trained in the operation of the IP and evaluation of both California Test Method 526 and the International Roughness Index.

The Contractor shall remove all objects and foreign material on the pavement surface prior to surface evaluation by power brooming. The pavement surface will be divided into sections which represent continuous placement. A section will terminate 15.24m **[50 ft]** before a bridge approach panel, bridge surface, manhole or similar interruption. In the final pavement evaluation, a day's work joint will be included in the trace with no special consideration. A section will be separated into segments of 0.1 km **[0.1 mi]**. A segment will be in one traffic lane only.

An IRI value shall be computed for each segment of 15.24m **[50 ft]** or more. The IRI value will include the 15.24 m **[50 ft]** at the ends of the section only when the Contractor is responsible for the adjoining surface.
End of run areas not included in the IRI value and any sections of pavement less than 15.24m **[50 ft]** in length shall be checked longitudinally with a 3.028 m **[10 ft]** straight edge and the surface shall not deviate from a straight line by more than 6 mm in 3.028 m **[1/4 inch in 10 ft]**. Transverse joints shall be evaluated by centering the straightedge longitudinally across the transverse joint.
The Contractor shall submit the graphical trace, a summary of the bump(s)/dip(s) locations, the magnitude of the bump(s)/dip(s) and each segment IRI value on the same day as the profiling was conducted. The Contractor shall submit a final spreadsheet summary of the smoothness data to the Engineer within five calendar days after all mainline pavement placement. The summary shall be signed by the Contractor. The spreadsheet summary shall be in tabular form, with each 0.1 km **[0.1 mile]** segment occupying a row. Each row shall include the beginning and ending station for the segment, the length of the segment, the final IRI value for the segment, the IRI based incentive/disincentive in dollars for the segment, and the deductions for bump(s)/dip(s) in dollars for the segment. Each continuous run will occupy a separate table and each table will have a header that includes the following: the project number, the roadway number or designation, a lane designation, the mix type of the final lift, the PG binder of the final lift, the date of the final smoothness runs, and the beginning and ending station of the continuous run. The following information shall be included at the bottom of each summary: a subtotal for the IRI based incentive/disincentive, a subtotal for the bump deductions, and a total for incentive/disincentive for both IRI values and bumps. Software to summarize the data is available from the Mn/DOT Bituminous Office at www.mrr.dot.state.mn.us/pavement/bituminous/bituminous.asp.
The Contractor will be responsible for all traffic control associated with the smoothness testing and any corrective action (when applicable) that is required of the final pavement surface.

C3A Retesting

The Engineer may require any portion or the total project to be retested if the results are questioned. This includes both IRI values and bump/dip locations. The Engineer will decide whether Mn/DOT, an independent testing firm (ITF), or the Contractor will retest the roadway surface.
If the retested IRI values differ by more than 10% from the original IRI values, the retested values will be used as the basis for acceptance and any incentive/disincentive payments. In addition, bump/dip locations as shown by the retest will replace the original results.
If the Engineer directs the Contractor or an independent testing firm to perform retesting and the original results are found to be accurate, the Department will pay the Contractor or the independent testing firm $62.14 per lane km [$100 per lane mile] that is retested, with a minimum charge of $500.00. The Contractor will be responsible for any costs associated with retesting if the original values differ by more than 10% from the retested values.

C4 IRI Values

The IP shall be equipped with automatic data reduction capabilities for determining the IRI values.
An IRI value shall be calculated for each segment of the final pavement surface. The IRI values shall be determined by following NCHRP report 228. The IRI values shall be reported in units of m per km **[inches per mile]**.
Both m per km and inches per mile shall be reported with two digits right of the decimal. Follow Mn/DOT rounding procedures per the Bituminous Manual section 5-693.730.
When there is a segment equal to or less than 76.2 m **[250 ft]** in length at the end of a lane of

paving, the IRI value for that segment shall be mathematically weighted and added to and included in the evaluation of the adjacent segment. Segments greater than 76.2 m **[250 ft]** in length will be evaluated individually.

C4a Bumps and Dips – IRI Equation A and IRI Equation B

Bump/dip location will be determined in accordance with California Method 526. Bumps and dips equal to or exceeding 10.2 mm in a 7.62 m **[0.4 inch in a 25 ft]** span shall be identified separately. When the profile trace shows a successive, uninterrupted bump, dip; or dip, bump combination (up to a maximum of 3 alternating trace deviations that relate to one bump or dip on the roadway), identify and evaluate these occurrences as one event.
The Contractor shall correct, by diamond grinding, all areas represented by bumps or dips of 10.2 mm **[0.4 inch]** or more as measured by California Test Method 526. However, the Engineer may allow bumps or dips of 10.2 mm to 15.2 mm **[0.4 inches to 0.6 inches]** in a 7.62 m **[25 foot]** span to be left uncorrected, and in such case, the contractor will be assessed a price deduct as specified in section C6 ("Payment") of this special provision.
Corrected dips or bumps will be considered satisfactory when the profilogram shows the deviations are less than 10.2 mm in a 7.62 m **[0.4 inch in a 25 foot]** span.

C4b Bumps and Dips – IRI Equation C

Bump/dip location will be determined in accordance with California Method 526. Bumps and dips equal to or exceeding 12.7 mm in a 7.62 m **[0.5 inch in a 25 ft]** span shall be identified separately. When the profile trace shows a successive, uninterrupted bump, dip; or dip, bump combination (up to a maximum of 3 alternating trace deviations that relate to one bump or dip on the roadway), identify and evaluate these occurrences as one event.
The Contractor shall correct, by diamond grinding, all areas represented by bumps or dips of 12.7 mm **[0.5 inch]** or more as measured by California Test Method 526. However, the Engineer may allow bumps or dips of 12.7 mm to 17.8 mm **[0.5 inches to 0.7 inches]** in a 7.62 m **[25 foot]** span to be left uncorrected, and in such case, the contractor will be assessed a price deduct as specified in section C6 ("Payment") of this special provision.
Corrected dips or bumps will be considered satisfactory when the profilogram shows the deviations are less than 12.7 mm in a 7.62 m **[0.5 inch in a 25 foot]** span.

C5 Surface Correction

Unless otherwise approved by the Engineer, corrective work shall be by diamond grinding. Other methods may include; overlaying the area, or replacing the area by milling and inlaying. The Engineer shall approve of the Contractor's method of correcting segment(s) prior to the Contractor starting corrective work. Any corrective actions by milling and inlay or overlay shall meet the specifications for ride quality over the entire length of the correction, including the first and last 15 m [**50 feet**]. Bumps or dips in excess of 10.2 mm [**0.4 inches]** where evaluation is by Equation A or B or bumps or dips in excess of 12.7 mm **[0.5 inch]** where evaluation is by Equation C that are located at transverse joints at areas of corrective actions utilizing overlay or milling and inlay, shall be removed by diamond grinding. The Contractor shall notify the Engineer prior to commencement of the corrective action. If the surface is corrected by overlay, inlay or replacement, the surface correction shall begin and end with a transverse saw cut. Surface corrections shall be made prior to placing permanent pavement markings. In the event that permanent pavement marking are damaged or destroyed during surface correction activities, they will be replaced at no cost to the Agency.
When pavement smoothness evaluation by Equation A is specified the Engineer may require that the Contractor, at no expense to the Department, correct segments with an IRI greater than 1.03 m per km **[65 inches/mile] or the** Engineer may assess a $560 per 0.1 km **[$900 per 0.1 mile]** penalty in lieu of requiring corrective work.
When pavement smoothness evaluation by Equation B is specified the Engineer may require that

the Contractor, at no expense to the Department, correct segments with an IRI greater than 1.18 m per km **[75 inches/mile] or the** Engineer may assess a $420 per 0.1 km **[$675 per 0.1 mile]** penalty in lieu of requiring corrective work.
When pavement smoothness evaluation by Equation C is specified the Engineer may require that the Contractor, at no expense to the Department, correct segments with an IRI greater than 1.34 m per km **[85 inches/mile] or the** Engineer may assess a $280 per 0.1 km **[$280 per 0.1 mile]** penalty in lieu of requiring corrective work.
Bump, dip, and smoothness correction work shall be for the entire traffic lane width. Pavement cross slope shall be maintained through corrective areas.
All corrective work shall be subject to the approval of the Engineer. After all required corrective work is completed a final segment(s) IRI value and bump/dip tabulation shall be determined and submitted to the Engineer. Corrective work and re-evaluation shall be at the Contractor's expense.
Segments requiring grinding will be re-profiled within two working days of completion of grinding. Individual bumps/dips and segments requiring grinding shall be completed with 15 working days of notification.

C6 Payment

The cost of traffic control for certified smoothness testing and/or any corrective work is incidental to the cost of the Wear course mixture.
The Contractor may receive an incentive payment or be assessed a penalty based on the number of segments and the IRI value. The total ride incentive shall not exceed 10% of the total mix price for pavement smoothness evaluated under IRI Equation A, 5% of the total mix price for pavement smoothness evaluated under Equation B, or 5% of the total mix price for pavement smoothness evaluated under Equation C. Total mix shall be defined as **all** mixture placed on the project. Pay adjustments for incentives will only be based on the segment IRI value before any corrective work has been performed. Any segment that contains corrective action for IRI value or bumps is not eligible for incentive pay.
The Contractor will not receive a net incentive payment for ride if more than 25% of all density lots for the project fail to meet minimum density requirements.
For pavement smoothness evaluated under Equation A uncorrected bumps or dips greater than or equal to 10.2 mm **[0.4 inches]** in a 7.62 m **[25 foot]** span will be assessed a price deduction of $900 per event.
For pavement smoothness evaluated under Equation B uncorrected bumps or dips greater than or equal to 10.2 mm **[0.4 inches]** in a 7.62 m **[25 foot]** span will be assessed a price deduction of $675 per event.
For pavement smoothness evaluated under Equation C uncorrected deviations (bumps or dips) greater than or equal to 12.7 mm **[0.5 inches]** in a 7.62 m **[25 foot]** span will be assessed a price deduction of $450 per event.
Combinations of bumps and dips which arise from the same single bump or dip are considered to be one event, and shall be counted only once for the purposes of calculating price deductions.
Typically, bump-dipbump
combinations, or dip-bump-dip combinations, that are confined to a 30 feet longitudinal segment are considered to be one event.
Bumps or dips resulting from a construction joint will be assessed a $900 penalty, regardless of the IRI Equation used for evaluation or pavement smoothness.
Incentive/disincentive payments will be based on the IRI determined for each segment and will be based on the following equations and criteria.

C6a IRI Equation A*

IRI m/km **[inches/mile]**	Incentive/Disincentive $/0.1km **[$/0.1mile]**
< 0.47 m/km **[< 30 inches/mile]**	$249 **[$400]**
0.47 m/km to 1.03 m/km **[30 inches/mile to 65 inches/mile]**	$523 – (IRI x 584) **[$850 – (IRI x 15)]**
1.03 m/km **[> 65 inches/mile]**	-$560 **[-$900]**

* Typically, 3-lift minimum construction

C6b IRI Equation B*

IRI m/km **[inches/mile]**	Incentive/Disincentive $/0.1km **[$/0.1mile]**
< 0.52 m/km **[< 33 inches/mile]**	$168 **[$270]**
0.52 m/km to 1.18 m/km **[33 inches/mile to 75 inches/mile]**	$373 – (IRI x 395) **[$600 – (IRI x 10)]**
1.18 m/km **[> 75 inches/mile]**	-$420 **[-$675]**

* Typically, 2-lift construction

C6c IRI Equation C*

IRI m/km **[inches/mile]**	Incentive/Disincentive $/0.1km **[$/0.1mile]**
< 0.57 m/km **[< 36 inches/mile]**	$112 **[$180]**
0.57 m/km to 1.34 m/km **[36 inches/mile to 85 inches/mile]**	$258 – (IRI x 257) **[$414 – (IRI x 6.5)]**
1.34 m/km **[> 85 inches/mile]**	-$280 **[-$450]**

* Typically, single lift construction

The current bituminous specification, 2360 Combined 2360/2350 (Gyratory/Marshall Design), requires pavement smoothness be measured by IRI (International Roughness Index). However, the specification does not contain guidance for selecting the appropriate "IRI equation" for pavement smoothness evaluation. Therefore, the following guideline should be used to determine which equation is appropriate. Also included in this memo are guidelines for selecting Percent Ride Improvement on 1-lift overlays. The designer should use their judgement or consult the Bituminous Office for other construction types not covered in this memo.

For the following construction types, use **IRI Equation A:**

• New construction with a minimum of 3 lifts
• Overlay with a minimum of 3 lifts, lift thicknesses of at least 40 mm (1.5")
• Construction with a minimum of 3 lifts, with curb and gutter and at least 8 feet separating the traffic lane from the curb and gutter (shoulder at least 8' wide)

For the following construction types, use **IRI Equation B:**

• New construction with 2 lifts
• Construction with curb and gutter adjacent to at least one driving lane, and three lifts
• Two- lift overlays, 40mm (1.5") minimum lift thickness
• Winter carry-over - wearing course on two lifts
• Reclaim with 2 lifts
• Cold inplace recycled with 2 lifts
• Two lifts over concrete

For single lift overlay construction on bituminous the Designer can choose either **IRI Equation C** or **Percent Ride Improvement.** See Note 1 below for single lift overlay on concrete.

The Percent Ride Improvement provision compares the IRI of the roadway before any construction activities have taken place to the IRI of the roadway after construction activities are finished. Incentive/disincentive is determined by the percent ride improvement. Percent ride improvement is intended to be used in situations where the existing roadway is in poor condition. Data from pilot projects show that the rougher the road segment to begin with the greater the relative improvement possible. For instance, a road segment with a starting IRI of 150 in/mile is more likely to be reduced to an IRI of 75 in/mile than a road segment starting at 75 in/mile is to be reduced to an IRI of 37.5 in/mile. Contact the Special Provisions Unit to insert the Percent Ride Improvement in a Contract.

For the following construction types, use **Percent Ride Improvement** (1):

• Single lift bituminous over bituminous (BOB) overlays on a roadway surface with an overall PSR < 2.8 (IRI greater than 120 in/mi)*.

For the following construction types, use **IRI Equation C** (1):

• Single lift bituminous over bituminous (BOB) overlays on a roadway surface with an overall PSR > 2.8 (IRI 120 in/mi or less)*.

* This information is available in the District's Pavement Management Condition Rating Reports

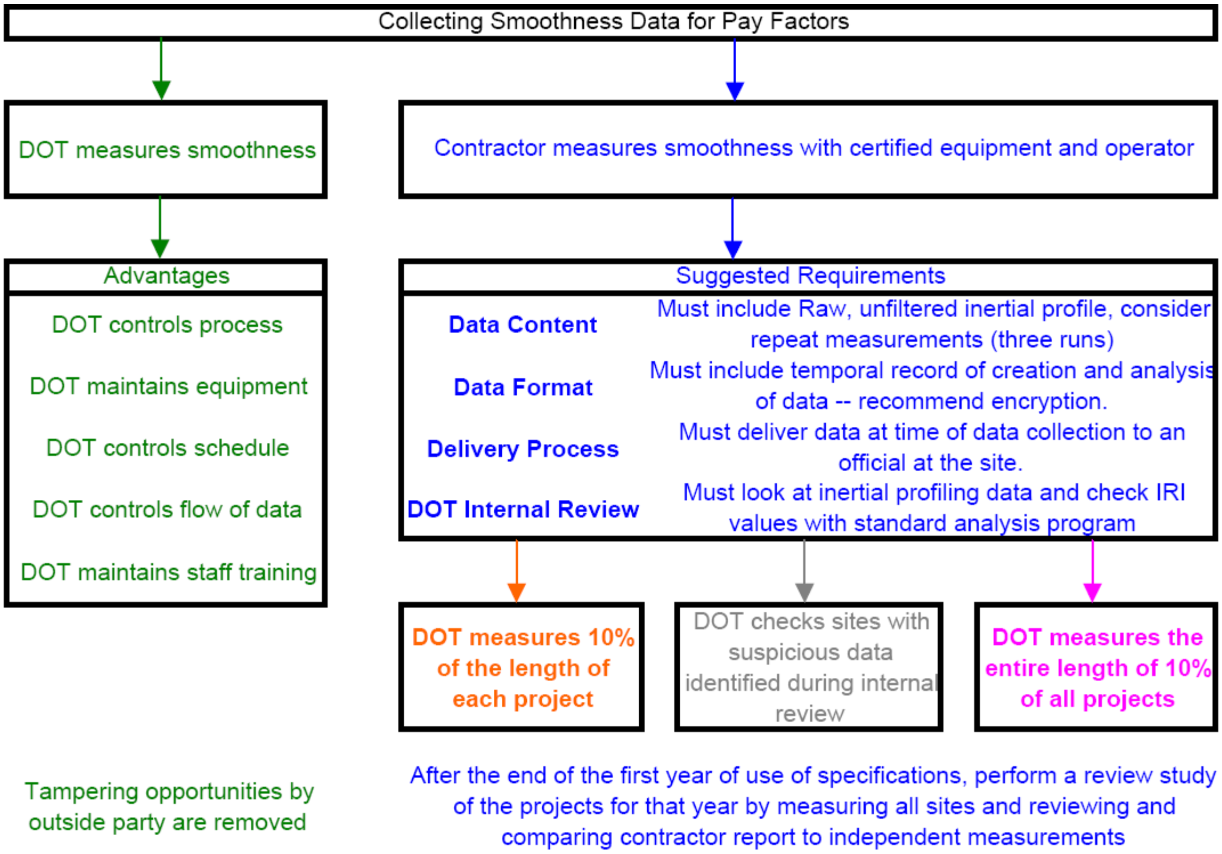
Note 1: The 2360 specification (Table 2360.7 – A) excludes IRI testing of single lift overlays on concrete. However, there may be unique situations on single lift BOC construction where a smoothness evaluation requirement is appropriate. The designer should consult the Bituminous Office for guidance in those considerations.

Because IRI is a new index for pavement smoothness measurement in the bituminous specification the following "typical" IRI values and the equivalent PSR are given so that you have a perspective of various pavement smoothness numbers:

IRI			PSR
New pavement (3-lifts)	–	37 in/mile	4.1
New pavement (2-lifts)	–	47 in/mile	3.9
New pavement (1-lift)	–	60 in/mile	3.6
Aged pavement (10 yrs)	–	110 in/mile	2.9
Aged pavement (20 yrs)	–	150 in/mile	2.5

Table 2360.7 – A, lists pavement surfaces that are excluded from smoothness testing but subject to 2360.7B (Surface Requirements). There may be other instances where you feel the ride specification is not appropriate on a Project. In those instances make note in the Special Provisions that ride will be verified by 2360.7B.

Appendix H: Collecting Smoothness Data for Pay Factors Flowchart



Note: The option to measure 10% of the length of each project is the least logical for the DOT as a crew is required to travel to each site. This option is not very different from DOT measuring smoothness. Still, this option was presented because it is likely that different contractors will measure profiles on most of the sites. To prevent one tampering incident from any one of the contractors, it may be necessary to do all of these initially, until all security initiatives are adopted. An independent review of the practices and results of the DOT are recommended at the end of the first year.