

PROFILOGRAPH SPECIFICATION STUDY

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16. Abstract <p>Pavement smoothness is probably the single most important indicator of pavement performance according to the traveling public. Rough or uneven pavements adversely affect driver safety, ride quality, fuel efficiency, and vehicle wear and tear. Rough pavements also lead to decreased pavement durability as rough pavements are proven to deteriorate faster than smooth pavements. Under the current specification the Mississippi Department of Transportation uses the Profile Index for highway pavement smoothness acceptance.</p> <p>This report covers the activities that were performed to enhance the current Mississippi Department of Transportation (MDOT) ride specification for pavements. The project team reviewed the MDOT ride specification for flexible and PCC pavements and compared it with current literature and state of practice. This report provides information on the review of MDOT current ride specification, literature review, and recommendations for improvements.</p> <p>The recommendations cover the proposed improvements to the current ride specification, tolerances, project classification levels, analysis tools and indices, and methods of acceptance.</p>			
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LIST OF SYMBOLS/TERMS

AASHTO	American Association State Highway and Transportation Officials
ASTM	The American Society of Testing and Materials
DMI	Distance Measuring Instrument
FHWA	Federal Highway Administration
IRI	International Roughness Index
MDR	Mobile Data Recorder
MDOT	Mississippi Department of Transportation
MRI	Mean Roughness Index
NHI	National Highway Institute
PI	Profile Index
PMS	Pavement Management System
PRI	Profilograph Roughness Index
SI	International System of Units

INTRODUCTION

1.0 General

State highway agencies and DOTs are tasked with building roads that benefit and please their customers, the traveling public. Pavement smoothness is probably the single most important indicator of pavement performance according to the traveling public. Initial pavement smoothness at the time of construction is also a key factor in the performance and economics of a pavement facility over its life cycle. Rough or uneven pavements adversely affect driver safety, ride quality, fuel efficiency, and vehicle wear and tear. Rough pavements also lead to decreased pavement durability as rough pavements are proven to deteriorate faster than smooth pavements.

Following are some benefits of smooth pavements:

- Satisfied travelers
- Decreased fuel consumption
- Decreased vehicle maintenance costs and tire wear
- Longer pavement service life
- Decreased dynamic loading
- Decreased road maintenance costs

This study will examine MDOT's current pavement smoothness acceptance measurement and specification, investigate the Mean Roughness Index (MRI) method, and outline a new draft specification.

1.1 Objective

The objective of this study is to investigate MDOT's transition from using Profile Index (PI) values to using Mean Roughness Index (MRI) values for highway pavement smoothness acceptance. The reasons for the transition from PI to MRI are listed below:

- A push or pull type California profilograph does not necessarily record the true profile of the road. Further, its turning radius is limited, and it is time-consuming to use.
- The profilograph necessitates lane closure and puts personnel on the road. If a high-speed profiler is used (as opposed to a lightweight) to collect IRI, collection is done at highway speed without lane closure, and personnel are kept off the road.
- A profile index (PI) reading does not indicate vehicle responses or ride quality. In some instances pavements are accepted by PI specifications even though they may have rough final ride quality.
- International Roughness Index (IRI) is the industry standard for roughness measurement. Variations of IRI include HRI (half-car roughness index) and MRI (mean roughness index). MRI is the average of the IRI collected in the right and left wheel paths. MRI is used by MDOT in its network-level pavement condition survey done every two years.
- MRI is used for annual pavement monitoring as required by FHWA for the Highway Performance Monitoring System (HPMS). HPMS is an annual report submitted to FHWA by all states, and part of HPMS concerns pavement condition. When PI is used for acceptance and MRI is used for long term pavement monitoring, it is not possible to relate the roughness of the pavement at any point in time with its as-constructed smoothness measurement.

1.2 Scope of Work

The research team developed a detailed work plan that entails the scope of activities necessary to successfully complete the project objectives. This report covers the activities that were performed during this project. The following specific activities included:

- Review of the current MDOT ride specification
- Review of the literature
- Data analysis of new ride specification
- Recommendations, and
- Implementation of new specification plan.

BACKGROUND

2.0 Pavement Roughness

High-speed road profiling is a technology that began in the 1960s at the General Motors Research Laboratory. Inertial profilers collect pavement profile data at highway speeds and generate the true profile of a roadway. The American Society of Testing and Materials (ASTM) Standard E 867 defines traveled surface roughness as the deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics and ride quality. Causes of roughness include but are not limited to:

- Construction irregularities such as poor materials and construction practices
- Repetitive traffic loading
- Non-uniform initial compaction
- Frost heave and volume changes such as subgrade shrinking and swelling

2.1 Flexible Pavement Roughness

Defects contributing to roughness in a pavement that occur in the asphalt mixture during or soon after placement and compaction are referred to as mat problems. The structural performance of a pavement is affected if the roughness is severe enough to increase the dynamic or impact loading. Defects can be caused by equipment related problems and/or mixture related problems as described below:

2.1.1 Equipment-Related Defects

Improper operation of the vibratory roller can lead to roughness or a wash boarding effect. Wash boarding is roughness that is built into the pavement during compaction and it worsens if the roller is operated at high speeds when the frequency is less than 2400 vibrations per minute. The vibrator frequency should be set at as high as possible, and the amplitude should coincide with the layer thickness. Thick lifts usually require higher amplitude settings, while thinner lifts require lower amplitude settings. Another smoothness issue that arises during compaction is shoving, which is defined as displacement of the mix in the longitudinal direction. When the floating beam bounces or the truck driver holds the brakes while the truck is being pushed, short waves occur. When the string line used for grade referencing sags between support posts, long waves can occur. The haul truck bumping into the paver during laydown and the condition of the underlying surface creates long waves. In pavements more than 4 inches thick, long waves are created at the points where the compactor reverses direction.

2.1.2 Mix-Related Defects

Any factors that cause changes in the volume, stiffness, temperature or composition can cause short and long waves. A mix design that varies in stiffness as a result of changes in the mix temperature or composition can cause short waves. Long waves, however, can result from changes in temperature or

segregation of the mix from one truckload to the next. If the maximum aggregate size used in the mix is too large compared to the depth of the lift, the screed can drag, causing screed marks. Mix temperature variations cause the screed to become unresponsive to changes in the angle of attack because the mix stiffness changes (3).

Deficiencies in the mix include (a) too much asphalt cement and/or moisture in the mix, (b) too much midsize sand material and too little fine sand material, and (c) a lack of room in the aggregate gradation for the asphalt cement (low VMA). Heat checking occurs because of temperature differentials within the layers of the mix or if the mix is too hot.

2.2 Portland Cement Concrete Pavement Roughness

The structural performance of a Portland Cement Concrete (PCC) pavement is affected if the roughness is severe enough to increase the dynamic or impact loading. Defects can be caused by equipment related problems and/or mixture related problems as described below.

2.2.1 Mix Design Related Defects

Non-doweled pavements constructed in freezing regions have shown a higher roughness than those constructed in warmer climates. The freezing index, coefficient of thermal expansion, and PCC elastic modulus are factors associated with slab curling distress. Some non-doweled pavements have shown increased upward slab curvature over time and the pavements have high

amounts of faulting. Upward slab curvature in freezing areas and faulting can be lessened by using dowels. The mean annual temperature, annual precipitation, number of wet days per year and the slab thickness affect lower curvature.

2.2.2 Material Related Defects

Pavements with high elastic modulus values or pavements having a high ratio between elastic modulus of concrete and split tensile strength appear to have increased roughness. Pavements with higher ratios for coarse to fine aggregate maintain smoothness longer. Using PCC with higher tensile strength in doweled and non-doweled pavements is beneficial to smoothness.

2.3 Literature Review

The purposes of the literature review were to obtain background information, to research different smoothness measurement techniques, and to investigate common practices in other state DOTs. The literature review included technical reports from previous research, journals, articles, research reports, industry journals, books on methodology and statistical analysis, internet sources, and periodicals. Similarly, it included compilations from all areas of government, including Federal Highway Administration (FHWA), the American Association of State Highway Transportation Officials (AASHTO), and other DOTs. Some of these publications have been referenced in this report.

In 1986 the International Roughness Index (IRI) was originally developed for the World Bank as part of the continued research effort from the National Cooperative

Highway Research Program (NCHRP) Project and has since been adopted by the FHWA and other countries (Karamihas 1998). The IRI is a roughness measure that has been demonstrated to be consistent with a wide variety of equipment, including single and two-track profiling systems, rod and level, and response-type road roughness measuring systems. The FHWA has also adopted IRI to evaluate the smoothness performance of Long-Term Pavement Performance (LTPP) pavement test sections.

IRI is defined as an index resulting from a mathematical simulation of vehicular response to the longitudinal profile of a pavement using a 'quarter-car' simulation model and a traveling speed of typically 50 mph. The roughness scale is stable, transportable, relevant, and readily measurable by pavement engineers. It ranges from 0 to 1000 in/mi (0 to 16 m/km), with 0 in/mi being a perfectly smooth road and 1000 in/mi a road that is in impassable condition. Since the establishment of the guidelines for acquiring IRI by the World Bank in 1986, the IRI has become the most widely used consistent indicator of road roughness (Sayers et al, 1986). Mean Roughness Index (MRI) is the average of the IRIs of the left and right wheel paths and is used for HPMS reporting and network-level condition surveys.

Based on the information published online by the Transtec Group concerning the pavement smoothness specification in the United States, 33 (65%) DOTs currently use IRI, compared to 14 (28%) that use profile index (PI) specification for measuring roughness index. Additionally, eight DOTs (24%) use the mean average roughness Index (MRI), and three (10%) use half-car roughness Index (HRI), specifications. MDOT is considering use of the MRI specifications.

Another road profile measurement is the Profile Index (PI). It was originally obtained from a trace collected by a mechanical profilograph (Scofield 1992). It is widely used to measure and control the initial smoothness by evaluating a profile traces to identify extreme bumps and to establish overall measure of smoothness method (FHWA 2002). This trace was reduced by a rater, and analyzing the trace could be subjective, slow, and labor-intensive. Computer software was developed that would scan a trace and then compute PI. These programs eliminated a lot of the subjectivity that occurs with a rater. However, in the last decades, the PI accuracy concerns have grown significantly, and despite efforts to enhance the accuracy of PI computations, it is clear from the literature that IRI and its variations such as MRI are becoming the standard option in future smoothness specifications.

PAVEMENT SMOOTHNESS CURRENT PRACTICES

3.0 Overview

For reasons discussed in the previous sections, MDOT desires to change its construction specifications to the use of Mean Roughness Index (MRI) from the current practice of using Profile Index (PI). Below is a review of current MDOT PI specifications.

3.1 Review of MDOT Specification

Measurement of pavement smoothness is commonly used to determine the initial quality of construction as perceived by the driving public. MDOT currently uses a hand-operated California-style profilograph and the resulting PI to evaluate ride quality of new wearing surfaces before opening the project to traffic. There are advantages, such as staff training, data analysis simplicity, and low capital investment using the PI. There are also disadvantages, such as equipment mobility, on-site calibration check and reassembly, traffic control, data biasing due to the fixed span distance between the wheels, and critical pumps for ride quality incentives using the PI.

MDOT currently utilizes the walking profilograph to determine the roughness of each applicable lift of asphalt or concrete, although many contractors are now utilizing lightweight profilers that are equipped with computer software packages. A computerized or standard profilograph produces a trace of the pavement called a profilogram that is corrected to a PI. Paving material and type of construction determine the maximum allowable PI measured in inches/mile. The total PI for the

0.10-mile analysis section must not exceed a value as determined by the specifications (MDOT 2004) as shown in Table 1.

Table 1: MDOT Smoothness Specification

Paving Material	Number Lifts	PI Required (in/mi)
Asphalt	Lower Intermediate Lift	<= 60
	Surface Lift	<=30
Asphalt	Leveling Lift Surface Lift	<=60
Asphalt	Existing Surface Surface Lift	TBD by Contractor Greater of 60% of Existing Surface PI or 60 (60 is the maximum allowable)
Milled Project	One Lift	<=45
Milled Project	First Lift	<=45
	Second Lift	<=30
Concrete		<=30

Bumps and dips above and below the tracing blanking band are summed, then converted to inches per mile to determine the total PI and not to exceed the values set forth by MDOT specifications as shown in Table 2.

Table 2: MDOT PI Specification

Profile Index	Leveling Course	Bottom Binder Course	Top Binder Course	Surface Course
in/mi	25	17	10	7

MDOT requires the contractors to measure the roughness of the surface lift used on traffic lanes, climbing lanes, auxiliary lanes and two-way turn lanes. Paved sections of pavement are divided into 0.10-mile (528 feet) segments. Measuring surface segments for mainline concrete pavement surfaces includes all pavements other than shoulders, parking lanes, ramps, tapers, acceleration and deceleration lanes, bridge decks, and bridge approach slabs. Measurements are made in the outside wheel path

(three feet from the edge of pavement of longitudinal joint) of exterior lanes and either wheel path of interior lanes. Measuring surface segments for asphalt paving surfaces include traffic lanes, auxiliary lanes, climbing lanes and two-way turn lanes. The outside wheel path of the exterior lane and either wheel path of interior lanes are measured.

Bumps and dips above and below the tracing blanking band are summed then converted to inches per mile to determine the total PI, and bumps and dips that exceed the blanking band allowance are then counted. Individual bumps and dips for asphalt and Portland Cement Concrete (PCC) pavements cannot exceed four tenths of an inch per 25 feet and three tenths of an inch per 25 feet respectively. Any individual bump or dip equal to or greater than these numbers must be corrected at the contractor's expense. Sometimes it is difficult to determine the locations of the bumps and dips on the project using the current PI methods. Thus, corrective action that is required according to the results is often not accounted for.

Transverse screed marks can create a bump in the pavement if they are not smoothed out by the compaction operations. Mechanical condition or improper setup of the paver screed can also cause the markings. Poor transverse joints create a bump at the joint and/or a dip in the pavement several feet beyond the joint. Improperly constructed joints, inadequate compaction at the joint, improper start-up procedures after a stoppage, or improper construction and removal of tapers are causes for joint problems.

Short transverse cracks are referred to as checks. Tender mixes tend to check during compaction due to deficiencies in the mix such as:

- Too much asphalt cement and/or moisture in the mix
- Too much midsize sand material and too little fine sand material
- Lack of room in the aggregate gradation for the asphalt cement (low VMA).

3.2 Operator and Profiler Certification

MDOT profiler certification requirements will be updated to follow AASHTO PP 49-08, which is the Standard Practice for Certification of Inertial Profiling Systems. The certification process will be conducted annually, and that certification will be valid for 12 months as opposed to the current 6-month format. The most significant change to the certification process will be implementing certification of both the inertial profiling equipment as well as its operator. Approval will not eliminate project verification of the equipment if this is deemed necessary by the project engineer. A list of approved equipment and operators will be maintained by MDOT's Research Division.

3.2.1 Operator Certification

Operators must be certified by MDOT for approved operation of contactor inertial profilers. Operators must complete both written and field proficiency tests covering MDOT ride smoothness specifications, operation of an inertial profiler, collection of profile data, and data evaluation. The operator must know how to perform all calibrations, tests, and/or checks on their profiling equipment. Operator certification will be valid for 12 months, and only MDOT-approved operators will be allowed to collect smoothness acceptance data on

projects. A list of approved contractor operators will be maintained by MDOT's Research Division.

3.2.2 Equipment Certification

Prior to certification and prior to data collection, the inertial profiling equipment and operating system should be verified and/or calibrated. All static and dynamic tests or calibrations should be conducted in accordance with the manufacturer's specifications. Calibration ensures that quality and accurate data is collected. Tests and calibrations include a vertical height sensor check (block test), a stability check (bounce test), and a distance measuring instrument (DMI) calibration.

Once the profiler is calibrated, the contractor will perform ten repeat runs on an MDOT identified test section. The results of these ten runs will be compared to MDOT's reference profile by means of cross correlation. Cross correlation will evaluate the profilers in terms of both equipment repeatability and equipment accuracy. For equipment repeatability, each of the ten profiles will be cross correlated to each of the remaining nine. The repeatability score for each trace is the average of all the values, and a score of 0.92 or greater is required on all traces. For equipment accuracy, each of the ten profiles is cross correlated to the reference profile. The accuracy score is the average of the ten individual cross correlation values, and a score of 0.90 or greater is required for all traces.

3.3 Pay Adjustments

MDOT current specifications require the use of the PI to determine the amount of incentives for good to superior riding surfaces. If the PI for the measured segment exceeds 30 in/mi for new asphalt or concrete construction, the contractor must make corrections at his expense as shown in Table 3.3.

Table 3: Pay Adjustments

Profile Index (in/mi/segment)	Contract Price Adjustment (Percent of HMA Unit Bid)
Less than 10.0	108
10.0 to 14.0	106
14.1 to 18.0	104
18.1 to 22.0	102
22.1 to 30.0	100
Over 30.0	Corrective Action

Additionally, the PI specification for the overlay and the milling/overlay operations is shown in table 4.

Table 4: Overlay and Mill/Overlay PI values

Overlay Requirement	Profile Index (in/mi/segment)
1 Intermediate Lift + 1 Surface Lift	<= 60.0 <=30.0
Leveling Lift + 1 Surface Lift	<=60.0
1 Surface Lift	Greater of 60% (existing surface) OR 60.0
Milling +1 Lift	<=45.0
Milling + Leveling Lift + Surface Lift	<=30.0
Milling + Lower Lift + Surface Lift	<=45.0 <=30.0

DATA COLLECTION AND ANALYSIS

4.0 Methodology

MDOT's California profilograph, ICC lightweight inertial profiler, ICC high-speed inertial profiler, and Pathway high-speed inertial profiler were used to collect data from new construction projects and overlay projects. Projects consisted of new construction and overlays; some projects were milled before the overlay, and some were not. Tested projects included:

- New construction
- Non-milled + one lift
- Milled + one lift
- Milled + leveling lift + surface
- Milled + two lifts
- Non-milled + one lift
- Non-milled + two lifts
- Non-milled + leveling + surface

Inertial profilers are utility vehicles equipped with a profiling system. The profiling system consists of a height sensor, accelerometer, distance measuring instrument (DMI), and software for computing the profile. The non-contact laser height sensor measures the distance from the pavement to the vehicle. The accelerometer, which is located on top of the height sensor, records the vertical acceleration of the vehicle which is then converted to vertical movement. The surface profile is computed by combining the output of the height sensor, accelerometer, and DMI.

4.1 Analysis Results and Discussion

This section will present a descriptive analysis and discussion of the MRI data on 9 selected projects by the MDOT Research Division. The projects were divided into three categories: Category A, Category B, and Category C.

- **Category A** represents new construction, 3 or more lifts, or milling plus 2 lifts.
- **Category B** represents milling and a single lift or 2 lifts.
- **Category C** represents a single lift overlay.

Data collection of long and short interval segments is used in this analysis. The long interval segment uses a 0.1-mile (528 feet) distance and the short interval uses a 0.004-mile (25 feet) distance. The Maximum MRI value was set to 60 (in/mi) for category A, 70 (in/mi) for category B, and 80 (in/mi) or 50% improvement for category C. The 25-foot short interval MRI value was set to 130, 140, and 150 (in/mi) for Categories A, B, and C respectively.

The following is a descriptive analysis of the Collins bypass project. It was 1.9 mile long and was divided into 19 segments. Each segment represents 0.1 mile.

Table 5 shows the Category A summary of the MRI for lanes 1 and 4 of Collins bypass, US Highway 84 in Covington County. The 0.1-mile (528 feet) long interval segment was used.

Table 5: Category A MRI Summary for Lanes 1 and 4 of the Collins Bypass

	MRI (in/mi)	
	Lane 1	Lane 4
Mean	57	49
Median	54	49
Standard Deviation	12	9
Minimum	44	31
Maximum	87	70
Total Segments	19	19

The average MRIs for lanes 1 and 4 were 57 and 49 respectively. The maximum MRI for Lane 1 was 87, while for Lane 4 it was 70, which indicates local roughness. The road segments for Category A that show local roughness needs to be examined and corrected/removed. The minimum MRI for Lane 1 was 31, and for Lane 4 it was 44. That is below the required MRI value, which is an indication that some segments of the 1.99 mile (10,509 feet) road have achieved great smoothness.

Table 6 describes the maximum MRI and corresponding defective segments or local roughness of the Collins bypass highway 84 for Lanes 1 and 4.

Table 6: Category A Defective Segments Summary for Lanes 1 and 4 of the Collins Bypass

	MRI (in/mi)	
	Lane 1	Lane 4
Mean	156	198
Median	142	149
Standard Deviation	31	72
Minimum	130	144
Maximum	229	296
Total Segments	16	5

The lengths of the segments which need to be removed or corrected range from 5 to 60 feet long. Lane 1 has 16, and Lane 2 has only 5 areas that exceeded that maximum MRI limit for short interval segments that need to be corrected.

The following is a descriptive analysis of the MRI results describing Category B for a 0.64-mile (3,367 feet) section of milling and overlaying for Lanes 1 and 2 on SR 149 in Coahoma County. This project was divided into 7 segments, each of which is 0.1 mile long.

Table 7 shows the initial and final MRI (in/mi) for lane 1 and 2, as well as the percentage of improvements to the overall road smoothness for category B operation.

Table 7: Category B MRI and Improvement Summary for Lane 1 and 2 for SR 149 in Coahoma County

	MRI (in/mi) for Lane 1			MRI (in/mi) for Lane 2		
	Initial MRI	Final MRI	Improv %	Initial MRI	Final MRI	Improv %
Mean	223	75	66	153	59	59
Median	230	75	67	162	58	62
Standard Deviation	26	9	5	43	6	11
Minimum	185	64	59	89	52	41
Maximum	266	90	72	212	68	71
Total Segments	7	7	7	7	7	7

The data for the initial and final MRI on Lanes 1 and 2 of the SR 149 in Coahoma County were collected to identify the percentage of improvement using the MRI method. The mean MRI for Lane 1 before the paving operation was 223 in/mi compared to 75 in/mi after the operation, which is a 66% smoothness improvement. The mean

MRI was 153 in/mi, compared to 59 in/mi after the paving operation for Lane 2, which is a 59% smoothness improvement as shown in Table 7.

It is worth noting, however, that final MRI results show that Lane 2 has no local roughness, while Lane 1 shows few segments of local roughness that have exceeded the 70 in/mi MRI limit for Category B.

The following MRI data shows results for a Category B, 1.56-mile (8,258 feet) milling and overlaying operation of Lanes 1 and 4 on US 49 in Coahoma County. This project was divided into 16 segments, each of which is 0.1 mile long.

Table 8 describes the MRI data for Category B. The initial and final data were collected before and after the milling and overlaying asphalt operation.

Table 8: Category B MRI and Improvement Summary for Lanes 1 and 4 US 49 in Coahoma County

	MRI (in/mi) for Lane 1			MRI (in/mi) for Lane 2		
	Initial MRI	Final MRI	Improv %	Initial MRI	Final MRI	Improv %
Mean	91	62	31	84	69	16
Median	85	60	31	83	63	23
Standard Deviation	19	12	11	13	21	27
Minimum	71	42	12	66	47	-50
Maximum	134	84	52	107	104	47
Total Segments	16	16	16	16	16	16

The data for the initial and final MRI on Lanes 1 and 4 of the US 49 in Coahoma County were collected to show the percentage of the level of improvement using the MRI method. The average MRI for Lane 1 before the paving operation was 91 in/mi compared to 62 in/mi after the operation, which is a 31% smoothness improvement. It

was 84 in/mi, compared to 69 in/mi after the paving operation for Lane 4, which is a 16% smoothness improvement as shown in Table 4.

However, further analysis on Lane 4 identified a 0.50-mile segment (2640 feet) of the road that had heavy of local roughness that exceeded both the short and long interval MRI limit for category B as shown in Figure 1. This should initiate further investigation, and corrective action should be taken. Lane 1 had a little minor local roughness that did not affect the overall ride smoothness quality of the lane as shown in Figure 1.

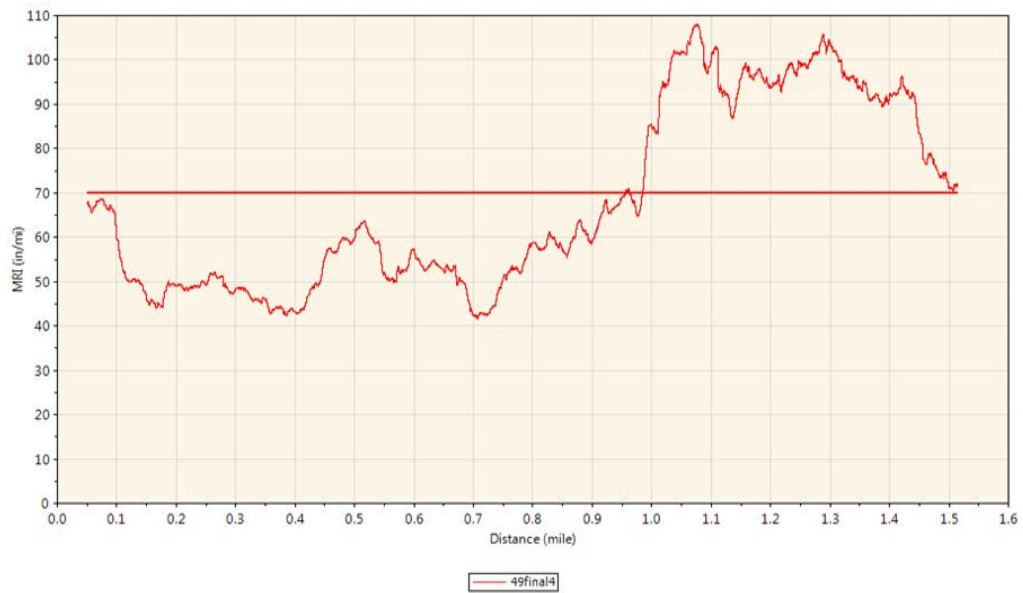


Figure 1: ProVal Data Analysis Graph of Lane 4 Local Roughness

The following MRI data results represents Category C for a 1.19-mile (6291 feet) section of a single overlay operation of Lanes 1 and 2 on SR 21 in Scott County. This project was divided into 12 segments, each of which is 0.1 mile long.

Table 9 outlines the MRI data for Category C. The initial and final data were collected before and after the single overlying asphalt operation.

Table 9: Category C MRI and Improvement Summary for Lanes 1 and 2 SR 21 in Scott County

	MRI (in/mi) for Lane 1			MRI (in/mi) for Lane 2		
	Initial MRI	Final MRI	Improv %	Initial MRI	Final MRI	Improv %
Mean	151	74	50	151	76	49
Median	152	74	52	152	78	50
Standard Deviation	15	10	8	15	12	8
Minimum	122	58	38	122	54	37
Maximum	168	93	65	168	97	68
Total Segments	12	12	12	12	12	12

The data for the initial and final MRI on Lanes 1 and 2 of SR 21 in Scott County were collected to show the percentage of improvement using the MRI method. The average MRI for Lane 1 before the paving operation was 151 in/mi, compared to 74 in/mi after the operation, which is a 50% smoothness improvement. It was 151 in/mi, compared to 76 in/mi after the paving operation for Lane 2, which is a 49% smoothness improvement as shown in Table 9. The average MRI value was below the 80 in/mi threshold for the long interval. However, the short interval shows a few local roughness segments which exceeded the 140 in/mi MRI and need to be corrected or removed.

PROPOSED NEW PAVEMENT SMOOTHNESS ACCEPTANCE SPECIFICATION

5.0 General

The following is the proposed new specification for pavement smoothness acceptance based upon the data collection and analysis. This specification is a draft and is subject to change. Please check MDOT's specifications for the most current version. MDOT plans to implement the specification in the spring of 2012.

5.1 Proposed Pavement Smoothness Requirements

The minimum surface smoothness requirements are modified as indicated for all traffic lanes, auxiliary lanes, climbing lanes and two-way turn lanes. Areas excluded from smoothness testing are acceleration and deceleration lanes, tapered sections, transition sections for width, shoulders, crossovers, ramps, parking lanes, side street returns, bridge decks, bridge approach slabs or existing pavement not constructed under the contract, etc. Profiling shall terminate 15 feet from each transverse joint separating the pavement from the bridge deck. Roadway pavement on bridge replacement projects having 1,000 feet or less of pavement on each side of the structure and pavement on horizontal curves having a radius of less than 1,000 feet at the centerline and within the superelevation transition of such curves are excluded.

This specification applies to new asphalt concrete and PCC pavements, asphalt projects consisting of one intermediate lift + one surface lift, asphalt projects that

require one leveling + one surface lift, asphalt projects with only a surface lift, and projects requiring milling + one or two lifts. The PI requirements of 30.0 inches per mile per 0.10-mile segment (zero blanking band) and 7.0 inches per mile per 0.10-mile segment (0.2 blanking band) and MRI requirement of 60 inches per mile per 0.10-mile segment pertain to the surface lifts. All other lifts, whether leveling lifts or intermediate lifts of mill and overlay or overlay only projects, shall not exceed a PI of 45.0 inches per mile per 0.10-mile segment or MRI of 70 inches per mile per 0.10-mile segment.

5.1.1 Materials and Equipment

Provide smoothness measuring equipment conforming to the Department's Equipment/Operator specification. Furnish grinding equipment conforming to Mississippi Standard Specification 501.03.19.1.1.

5.1.2 Smoothness Measurement

Remove debris and objects from pavement prior to surface measurement. Measure the pavement surface of each applicable lift. For asphalt the measurement will be taken in the outside wheel path of exterior lanes and either wheel path of interior lanes. The wheel path is designated as being located three feet from the edge of pavement or longitudinal joint. For PCC pavements, both wheel paths shall be tested. The testing will be limited to one pass for each lift of a lane. Additional testing is required on surface corrected pavements.

For asphalt pavements perform surface smoothness measurements within 72 hours after each day's production unless authorized otherwise by the Engineer. Each course will be accepted on a segment to segment basis. A segment consists of 0.10 mile. When a segment less than 0.10 mile occurs at the end of a section, the remaining portion of a day's lift will not be tested until the lift is continued and for this reason may be included in the subsequent segment. If a segment less than 0.10 mile is at the end of the project, incentive pay will not be provided. Notify the Engineer each day prior to performing measurements.

For PCC pavements, perform surface smoothness measurements, either when starting up or after a long shutdown period, as soon as the concrete has cured sufficiently to allow testing. Membrane curing damaged during the testing operation shall be repaired by the Contractor at no expense to the State. Each course will be accepted on a segment-to-segment basis. For the purpose of determining pavement smoothness and contract price adjustment for rideability, each day's production will be subdivided into sections which terminate at bridges, transverse joints or other interruptions. Each section will be subdivided into segments of 0.10 mile. When a segment less than 0.10 mile occurs at the end of a section, the remaining portion of a day's lift will not be tested until the lift is continued and for this reason may be included in the subsequent segment. If a segment less than 0.10 mile is at the end of the project, incentive pay will not be provided. If a day's paving is less than 50 feet, it shall be tested using the ten-

foot straightedge. Notify the Engineer each day prior to performing measurements.

For PCC pavements other than main-line pavement, the surface will be tested using a 10-foot straightedge at locations selected by the Engineer. The variation on the surface from the testing edge of the straightedge between any two contacts, longitudinal or transverse with the surface, shall not exceed $\frac{1}{4}$ inch. Irregularities exceeding the specified tolerances shall be corrected, at no expense to the State, by the Contractor with an approved grinding device or by other means as directed by the Engineer. Following correction, the area will be retested to verify compliance with the specified tolerances.

Develop an International Roughness Index (IRI) according to ASTM E 1926 for each 0.10-mile segment. Submit an electronic copy in ERD or ProVAL-compatible format to the Project Engineer.

Scheduling will be the responsibility of the Contractor with approval of the Engineer. The Contractor will be responsible for traffic control associated with the testing operation. For hot spot locating purposes mark the beginning and ending profiling point with paint and highway pavement marking material. The distance measuring units shall be feet with the start stationing set at 0.0 feet.

5.1.3 Mandatory Corrective Work

Until the implementation date of this specification, the Contractor is allowed to select the index that he uses. Once he/she selects an index for the project, he/she must use that index for the duration of the project. Perform corrective work for the applicable surface type. Profile Index measurements exceeding 30.0 inches per mile per 0.10-mile segment (0.0 blanking band) and 7.0 inches per mile per 0.10-mile segment (0.2-inch blanking band) shall be corrected. If the individual uses the PI, individual bumps and/or dips exceeding 0.30 inch for PCC pavement and 0.40 inch for asphalt pavement, will require corrective work. If the MRI is used, localized roughness exceeding 60 inches per mile per 0.10-mile segment for the long interval and 90 inches per mile per 0.10-mile segment for the short interval (20 feet) will require correction.

5.1.3.1 Asphalt Concrete Pavements

If PI is used, correct individual bumps and/or dips that exceeds four tenths of an inch when measured from a chord length of 25 feet or less (regardless of the profile index value for the segment). Correct any 0.10-mile segment having an MRI greater than 60 inches per mile as specified in subsection 403.03.4. All such correction shall be at the Contractor's expense. Re-measure each 0.10-mile segment where corrective work was performed to ensure the MRI is less than 60 inches per mile for the long interval and 120 inches per mile for the short

interval. Perform additional corrective work until the MRI for the segment is less than 60 inches per mile for the long interval and 120 inches per miles for the short interval. Perform corrective work as specified in subsection 403.03.4. All such correction shall be at the Contractor's expense.

5.1.3.2 PCC Pavements

If the PI is used, correct individual bumps and/or dips that exceeds three tenths of an inch when measured from a chord length of 25 feet or less (regardless of the profile index value for the segment). After correcting individual deviations in excess of 0.30 inches in 25 feet, corrective action shall be made to reduce the profile index to 30 inches per mile per 0.10-mile segment or less. Of those segments where corrections were made, the pavement surface will be tested to verify that correction produced a profile index of 30 inches per mile per 0.10-mile segment or less. All such correction shall be at the Contractor's expense. Diamond grinding and equipment shall conform to sub-section 501.03.19.1 and 501.03.19.1.1.

If MRI is used, correct localized roughness in any 0.10-mile segment having an MRI greater than 60 inches per mile for the long interval and 120 inches per mile for the short interval. Re-measure each 0.10-mile segment where corrective work was performed to ensure the

MRI is less than 60 inches per mile for the long interval and 120 inches per mile for the short interval. Perform additional corrective work until the MRI for the segment is less than 60 inches per mile for the long interval and 120 inches per miles for the short interval. Perform corrective work as specified in subsection 403.03.4. All such correction shall be at the Contractor's expense.

Each area or segment of pavement removed shall be at least 10 feet in length and at least the full width of the lane involved. When it is necessary to remove and replace a section of pavement, any remaining portion of the slab adjacent to the new surface shall be textured as specified in the contract.

Where surface corrections are made, the Contractor shall reestablish the surface texture to a uniform texture equal in roughness to the surrounding uncorrected pavement. This work shall be at no additional cost to the State.

Corrective work shall be completed prior to determining pavement thickness.

5.2 Method of Measurement

Determine the PI and MRI for each 0.10-mile segment of pavement. The PI and MRI are both measured in one lane.

5.2.1 Pay Adjustments

A lump sum pay adjustment will be made according to the following schedule for each 0.10-mile segment of each lane. For all smoothness measurements made before the implementation date of this specification, the index, either PI or MRI, selected by the contractor, will be used for each 0.10-mile segment. Contract price adjustments for rideability shall only be applicable to the surface lift and furthermore to only the segment(s) or portions of the segment(s) of the surface lift that require determination of smoothness. Pay adjustments are based on pavement smoothness for pavements with a surface tolerance requirement of $PI \leq 30.0$ inches per mile per 0.10-mile segment. All other lifts, whether leveling lifts or intermediate lifts of mill and overlay or overlay only projects, shall not exceed a PI of 45.0 inches per mile per 0.10-mile segment or MRI of 80 inches per mile per 0.10-mile segment. Single lift overlays that do not require milling shall not exceed an MRI of 80 inches per mile per 0.10-mile segment or 50% improvement, whichever is greater, as shown in Table 10.

Table 10: PI and MRI Specifications for Asphalt Concrete Pavements

New Construction PI (in/mi per 0.10-mile segment 0.0 Blanking Band	PI (in/mi per 0.10-mile segment) 0.2 Blanking Band	MRI (in/mi per 0.1-mile segment)	Pay Adjustment (%)
Less than 10.0	1.0 or less	<=40.0	108
10.0 to 14.0	1.1 to 2.0	40.1 to 45.0	106
14.1 to 18.0	2.1 to 3.0	45.1 to 50.0	104
18.1 to 22.0	3.1 to 4.0	50.1 to 55.0	102
22.1 to 30.0	4.1 to 7.0	55.1 to 60.0	100
Over 30	Over 7.0	>=60.0	100 with correction to applicable PI or MRI

Table 11 shows the recommended PI, MRI specification and applicable pay adjustments for the PCC pavements.

Table 11: PI and MRI Specifications for PCC Pavements

New Construction PI (in/mi per 0.10-mile segment 0.0 Blanking Band	MRI (in/mi per 0.1-mile segment)	Pay Adjustment (%)
Less than 10.0	<=40.0	Plus \$0.26
10.0 to 14.0	40.1 to 45.0	Plus \$0.20
14.1 to 18.0	45.1 to 50.0	Plus \$0.13
18.1 to 22.0	50.1 to 55.0	Plus \$0.07
22.1 to 30.0	55.1 to 60.0	Plus \$0.00
Over 30	>=60.0	Plus \$0.00 with correction to applicable PI or MRI

Pay adjustments for incentive will be based only on the measured PI or MRI before mandatory correction work is performed. No incentive will be paid for any 0.1-mile segment where mandatory corrective work was performed.

All smoothness measurements made after the implementation date of this specification will be based on the MRI only and all pay adjustments will be based on the MRI portion of the tables.

5.3 Profiler Operator Certification

Operators shall be approved by the MDOT. Approval does not eliminate project verification of the operator. Only MDOT approved operators are allowed to collect smoothness acceptance data on projects. A list of approved contractor operators will be maintained by the State.

5.3.1 Operator Qualification

Operators must be certified to operate inertial profilers. Operators will be tested on MDOT ride smoothness specifications, operating an inertial profiler, collection of profile data and evaluating quality of data collected and the MRI value calculated. The operator must know how to perform static vertical calibration block tests, dynamic calibration tests such as DMI testing, and bounce testing. Operator certification will be valid for a minimum of 12 months.

5.4 Profiler Equipment Certification

Profilers shall be approved by the MDOT. Approval does not eliminate project verification of the equipment. Provide a copy of the certification letter to the Project Engineer before profiling the pavement. Do not alter the profiler and software settings in any manner until the next MDOT certification. Only MDOT approved operators are

allowed to collect smoothness acceptance data on projects. A list of approved contractor equipment will be maintained by the State. Equipment certification will be valid for a minimum of 12 months. Re-certification will be required after any major component repairs or replacements.

5.4.1 Equipment

This specification applies to the certification of pavement smoothness profiling equipment. It covers the minimum requirements for calibration and certification of asphalt and PCC pavement smoothness measuring equipment. The equipment minimum requirements must meet the requirements of AASHTO Designation: PP 49-031.

- The inertial profiling system must meet all requirements found in MP 11.
- The interval at which relative profile elevations are reported must be less than or equal to two inches.
- The algorithm for filtering the profile data should use a cutoff wavelength of 300 feet.
- The software must be capable of reporting in ERD format.
- The profiler software must also be able to calculate and report the MRI (in inches/mile) from the corresponding measured true profile and permit the operator to:
 - a) automatically trigger the start of data collection at the designated location;
 - b) in addition to any binary data file storage, provisions shall be made to provide the measured true profiles in electronic text files following the format prescribed by PP

50 for evaluation of profiler accuracy and repeatability;
and

- c) verify the height and distance measurements as described in the Equipment Calibration Verification section.

5.4.2 Equipment Calibration Verification

Prior to certification and prior to data collection, the inertial profiling equipment and operating system shall be verified and/or checked for operational stability.

5.4.2.1 Static Tests

Perform the following static calibration procedures and document the results. Maintain a log to provide verification of calibration history.

Vertical height sensor check tests shall be run after the profiler has reached operational stability as specified by the manufacturer. The test shall be conducted on a flat and level area. Do not lean on the profiler or cause it to move in any way during the test. Follow the steps outlined for the vertical height sensor test. As a minimum, use the base plate and the 1.00 or 2.00 blocks.

- A smooth base plate is positioned under the height sensor and ten height measurements are taken.
- A 0.25-inch block is placed under the height sensor on top of the base plate and ten height measurements are taken.
- The 0.25-inch block is removed from the base plate and replaced with a 0.50-inch block and ten height measurements are taken.

- The 0.50-inch block is removed from the base plate and replaced with a 1.00-inch block and ten height measurements are taken.
- The 1.00-inch block is removed from the base plate and replaced with a 2.00-inch block and ten height measurements are taken.

The owners of the profiler shall furnish their own base plate and gage blocks. Department personnel shall measure the thickness of the gage blocks at three different positions using a caliper, and the average thickness of each block will be determined and marked on each block. The profiler operator will take ten (10) measurements of each block. The absolute difference between each measurement taken by the equipment operator, and the average of the three measurements taken by the Department will be determined. Next average the absolute differences. The average of the absolute differences must be less than or equal to 0.01 inch for each gage block.

5.4.2.2 Dynamic Tests

Perform the following dynamic calibration procedures and document the results. Maintain a log to provide verification of calibration history. Tests shall be run after the profiler has reached operational stability as specified by the manufacturer. DMI Test: Set the distance measuring instrument to report distances in units of feet. Maintain air

pressure according to the manufacturer's recommendations. Drive the profiler three times for a known distance of 528 feet. At the end of each run, record the DMI reading. After making 3 runs, compute the absolute difference between the DMI reading and known distance of the path for each run. To pass the test, the average of the three absolute differences must be less than or equal to 0.1 percent. If the profiler's DMI does not meet this requirement, the operator shall calibrate the DMI based on the known distance. After entering the new calibration factor, the operator shall repeat the 3 runs, the absolute differences between the runs and known distance, and the average of the three absolute differences must be less than or equal to 0.1 percent. Failure to meet this requirement will require equipment repair.

5.4.2.3 Bounce Tests

This test consists of applying a vertical load in an eccentric manner to one or more corners of the equipment in an up and down motion. The value for this test should be zero IRI or a flat profile trace, however; a maximum IRI value of 6 inches/mile will be accepted.

5.5 Profiler Certification Approval Process

The contractor will arrange a date with the MDOT Research Division for testing and certification. The certification will be valid for 12 months from the date of approval.

If any changes in equipment, settings, software updates, etc occur, the profiler must be re-approved by the Research Division.

Any profiler approved until the date of implementation of this specification will meet the following requirements. Approval consists of 10 runs of the profile device on a 0.10 mile segment of pre-marked PCC pavement and/or asphalt pavement. The average of all PI runs will fall within a range of 7.0% of the average of the Department's three profilograph reference runs. For MRI, each of the ten reported run values will be within 5.0% of the average of those values for each 0.10 mile segment to demonstrate repeatability of the equipment. The average of the ten reported run values will be within whichever is greater; either 5% of the averaged referenced value produced by the Department's reference profiler or within 5 inches/mile for each segment to demonstrate reproducibility of the equipment.

Re-approval of all profilers after the date of the implementation of this specification will meet the following requirements. The contractor will be notified by the MDOT Research Division of the date for the annual MDOT profiler round-up/rodeo. The approval will be valid for one year provided no equipment, operator, or software changes are made. Any changes in equipment settings, operators, or software, etc. will require re-approval by the Department.

Test track approval will consist of ten runs of the inertial profiling device. Electronic copies of all road profiles shall be submitted to the Department in ERD or ProVAL-compatible format. Each of the ten reported run values will be within 5.0% of the average of those values for each 0.10 mile segment to demonstrate repeatability of the

equipment. The average of the ten reported run values will be within whichever is greater; either 5% of the averaged referenced value produced by the Department's reference profiler or within 5 inches/mile for each segment to demonstrate reproducibility of the equipment.

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

Pavement smoothness is probably the single most important indicator of pavement performance according to the traveling public. Rough or uneven pavements adversely affect driver safety, ride quality, fuel efficiency and vehicle wear and tear. Pavement durability is also negatively impacted by rough pavements. The Mississippi Department of Transportation is currently uses the PI method. Benefits of smooth pavements include the followings:

- Satisfied travelers
- Decreases in fuel consumption
- Decreased vehicle maintenance costs
- Longer service life
- Lower dynamic loading and
- Decreased road maintenance costs.

Concerns about PI accuracy concerns have grown significantly in recent years, and due to its more accurate depiction of actual ride quality, MRI has been adopted by many state DOTs for smoothness specifications. Because of the prevailing use of the profilograph for evaluating surface smoothness on paving projects in Mississippi, the transition to a new specification must inevitably be accomplished in stages so that agency personnel and contractors alike can develop an understanding of the proposed new criteria for evaluating surface smoothness.

A new specification was developed and would apply to new asphalt concrete and PCC pavements, asphalt projects consisting of one intermediate lift + one surface lift, asphalt projects that require one leveling + one surface lift, asphalt projects with only a surface lift, and projects requiring milling + one or two lifts. The PI requirements of 30.0 inches per mile per 0.10 mile segment (Zero blanking band) and 7.0 inches per mile per 0.10-mile segment (0.2 blanking band) and MRI requirement of 60 inches per mile per 0.10-mile segment pertain to the surface lifts. All other lifts, whether leveling lifts or intermediate lifts of mill and overlay or overlay only projects, shall not exceed a PI of 45.0 inches per mile per 0.10-mile segment or MRI of 70 inches per mile per 0.10-mile segment.

6.2 Conclusion

The objectives of this study were to investigate transitioning the Mississippi Department of Transportation (MDOT) from using Profile Index (PI) values for highway pavement smoothness acceptance to using Mean Roughness Index (MRI) values and to recommend a new MRI pavement smoothness acceptance specification for MDOT.

These objectives were achieved through literature review, comparison of field data of both profilers, and results from the pilot programs. The data support the decision to transmission from the PI to MRI, and a proposed specification was developed.

6.3 Recommendations

For the long-term implementation of a profile-based smoothness specification, states must consider the need for a test facility to evaluate surface profilers and ensure that the devices used provide accurate, repeatable, and reliable measurements of surface smoothness during construction. This evaluation may be particularly important when surface smoothness tests are to be done by the contractor. Based on the analysis of the pilot project data results the following recommendations should be considered:

- Gradual implementation of the newly developed smoothness specification for flexible pavements using live pilot project.
- Training and education for all district and project office personnel involved in the transition into the new system.
- Construction and maintenance of a central location site for equipment calibration and testing. The site should consist of 0.1 mile segments to allow the profiler to reach the required speed and other requirements.
- The full transition should require an annual State controlled profiler operator and equipment certification program.
- Conduct a new pilot program for the PCC pavement smoothness.
- Conduct further testing and evaluation for the bridge deck smoothness acceptance.

REFERENCES

1. Swan, M. and Karamihas S.M., Use of Ride Quality Index for Construction Quality Control and Acceptance Specifications. *Transportation Research Record No.1861* (2003) p 10.
2. Pavement Smoothness/Roughness. *Federal Highway Administration Report, Western Lands Highway Division.*
3. Hot-Mix Asphalt Paving Handbook 2000. *Transportation Research Board* (1991) pp.194-212.
4. Chang, George K., et al., ProVAL Viewing and Analysis User's Guide. The Transtec Group, Inc. (2005)
5. Karamihas, S.M., et al., Guidelines for Longitudinal Pavement Profile Measurement. National Cooperative Highway Research Program Report 434 (1999) pp 23-28.
6. Achieving a High Level of Smoothness in Concrete Pavements without Sacrificing Long-Term Performance. *Federal Highway Administration.* FHWA- HRT, 05-068. (2005)
7. Sayers, Michael W., Profiles of Roughness. *Transportation Research Record No. 1260* (1990) pp.106-111.
8. Ksaibati, Khaled, et al., Development of Florida Smoothness Specifications for Flexible Pavements. *Transportation Research Record No. 1654.* (1999) pp. 43-49.
9. Sayers, M.W. and Karamihas, S.M., "The Little Book of Profiling." The University of Michigan Transportation Research Institute, September 1998.
10. Smoothness Pavement online, www.smoothpavements.com
11. Scofield, Larry A., Kalevaela, Sylvester, Anderson, Mary and Hossain, Asm. "A Half Century with the California Profilograph." Arizona Department of Transportation (ADOT), February 1992.
12. Pavement Smoothness Index Relationships report, FHWA 2002.