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Mn/DOT Combined Smoothness Specification

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This report presents the development of a combined smoothness specification for asphalt and concrete pavements and associated training for the certification of profiler operators by highway agencies. The report discusses the analyses conducted to develop appropriate levels of incentives and disincentives approximately equivalent to previous specifications, as a baseline. A brief survey of current practices by other states is also included. Appendices include the draft specification developed for this project, and the training materials that were presented in several workshops as part of the project.

Features of the combined smoothness specification include the use of the International Roughness Index for smoothness assurance on all pavements, certification of profiler operators, uniform electronic data filenames, profile measurement in both wheel paths, the use of the ProVAL software (developed by FHWA), and areas of localized roughness calculated by ProVAL.

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Final Report

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EXECUTIVE SUMMARY

This report describes the work completed by Minnesota State University, Mankato, on an implementation project for the Minnesota Department of Transportation to develop a combined smoothness specification for bituminous and concrete pavements. Another component of this project was the development of an associated certification training course to ensure that pavement profiler operators have adequate training and knowledge to conduct pavement profile measurements, to perform the duties required in the specification, and to prepare and submit the submittals required by the specification.

This report consists of four major components.

1. Review of past and current practices of Mn/DOT and other states regarding pavement smoothness specifications.
2. Development of the combined smoothness specification, and the associated analyses and evaluations that were conducted in its development.
3. Development and presentation of the certification / training workshops.
4. Recommendations for further implementation and development of the combined smoothness specification.

The newly developed specification includes the following changes to those previously used for bituminous and concrete smoothness.

- Combination of bituminous and concrete smoothness specifications.
- Certification requirement for profiler operators, in addition to profiling equipment.
- Profile measurement in both wheel paths, rather than only the right wheel path.
- Requirement for common electronic data filenames.
- Introduction of Areas of Localized Roughness as a replacement for the Bump and Dip specification.
- Pay adjustments are computed after any corrective work, and corrected segments are included in the pay adjustment calculation.

The training workshops consisted of a pilot workshop attended by Mn/DOT personnel, and two full workshops attended by contractors and other pavement profiler operators. This was followed by an industry forum after the 2009 construction season to elicit comments and concerns from those who used the draft specifications on actual paving projects.

It is recommended that the combined specification be fully implemented by the 2011 construction season. In addition, it is important that further review of the levels of incentives/disincentives and the cutoff points for areas of localized roughness be conducted to establish more firmly the appropriate values of these specification elements. An online method of workshop delivery is encouraged. Continual assessment of changes in technology and in the paving industry is recommended in order to react to new methods of work and new technologies, and to more accurately represent the pavement smoothness for the driving public.

Chapter 1. INTRODUCTION

This report describes the development of a combined smoothness specification for pavement construction. The new specification applies to bituminous and concrete pavement construction, including overlays. Associated with this new, combined specification is some background research and analysis to establish the incentive and disincentive levels, and the development of training materials and a certification course for those who will be using the specification on a regular basis. This chapter describes the background and the need for the combined specification, and the overall objectives of the project. It also describes the format and content of this report.

Background

The pavement contractor charged with building a high-quality, high-performance, smooth road within the economic realities of the low-bid system is faced with competing objectives. The pavement must be smooth for the driving public, but also cost-effective, strong and must meet many other specifications required by the owner of the road, the state highway agency, and ultimately the drivers who use the road. As an incentive to encourage contractors to optimize these competing objectives, states began offering bonuses to contractors who could resolve the technical problems associated with the task and still achieve a smooth surface on which to drive. As a necessary complement to the incentives, states also instituted penalties for rough pavements. Most states, including Minnesota, have recognized the benefit of offering incentives for smoother pavements. Although it may be that unit prices for pavements increase initially when such a specification is initiated, studies have shown that eventually the costs return to about the same level as before, but with an increase in quality as contractors learn to produce better-quality pavement surfaces [1].

Prior to the specification development described in this report, Mn/DOT had incentive-disincentive smoothness specifications for both bituminous and concrete pavement construction. Since these specifications were separate, and were contained within the overall bituminous pavement and concrete pavement specification items, many differences and potential discrepancies evolved over time in the two sets of requirements. The Pavement Section of Mn/DOT decided that it would be advantageous to develop a single, unified, specification for pavement smoothness that would apply to all pavement construction.

The analysis of pavement profiles is another area where improvement was needed. Previously, the smoothness characteristics (International Roughness Index and the bump/dip requirement) were calculated by the on-board computer of the equipment conducting the profile measurements. The results were then typed into a Microsoft Excel spreadsheet to summarize the smoothness and to compute the bonus or penalty for each applicable tenth-mile section.

To improve on the accuracy, reliability, and ease of the computations and reporting, Mn/DOT desired to implement the FHWA software tool called Profile Viewer and Analyzer (ProVAL). This was developed by the FHWA with the intent that it will become a new standard for pavement profile analysis. The software has the capability of importing pavement profiles from many different profiling machines.

Another area of improvement is the certification of profiler operators, both from the contractor and the DOT. Currently, only the equipment must be certified, and contractors are required to bring testing equipment to Mn/DOT prior to the construction season for verification. At times, the equipment manufacturer brings in testing equipment for verification, and Mn/DOT has no guarantee that the contractor's operators are properly trained in the use of the equipment, and especially its use with the ProVAL software. The work conducted under this project developed a new certification program for contractor and DOT representatives. Certification of the equipment and the operators will greatly improve data collection and analysis, and quality control and assurance on Mn/DOT pavement construction projects.

Objectives

There were three major objectives of this project, described as follows.

1. Combine the bituminous and concrete pavement specifications, as closely as possible, into one unified specification governing all pavements constructed by the state.
2. Develop a certification program for profiler operators. This certification program will initially be classroom-based instruction with certification by examination.
3. Provide specific, actionable recommendations for full implementation of the newly developed specification and for the certification training.

Content of the Report

This report is organized as primarily to chronicle the development of the combined smoothness specification and the associated certification training program. It includes the following sections.

- Review of current and historical practice regarding pavement smoothness in Minnesota and other states.
- Development of the combined smoothness specification.
- Development and presentation of the certification training workshops.
- Recommendations for full implementation of the specification and the certification program.

Chapter 2. REVIEW OF PRACTICE

This chapter provides a summary of past and current Mn/DOT pavement smoothness practices and current practices of other states.

Past Practices – Minnesota

Highway agencies have been measuring profiles and computing ride statistics for many years. These have included the Profile Index (0.2- and 0.0-inch blanking bands), International Roughness Index, Half-Car Roughness Index, Ride Number, and many others. As new interpretation methods and ride indices have been developed, states have adopted the new technologies with varying degrees of enthusiasm. Minnesota has often been at the forefront of the adoption of new technologies, construction practices, and specifications. This has been the case in pavement smoothness indices as well. This section provides a chronology of pavement smoothness and ride index use in Minnesota over the past decade.

2001

By the year 2001, Mn/DOT had been using the California Profilograph and the Profile Index for many years. An Ames Lightweight Profiler and a Walking Profiler from ARRB were purchased to conduct research and evaluations of the newer technologies in order to evaluate the possibilities of improving on the disadvantages of using the Profile Index. At about the same time, the Federal Highway Administration was promoting the use of lightweight profilers for smoothness measurements and profiler certification.

One of the major disadvantages of the PI method of pavement smoothness measurements and acceptance was that the equipment certification was not reliable using the 0.2-inch blanking band. Repeated measurements differed by as much as 25 percent in some cases. Thus, Mn/DOT used the 0.0-inch blanking band for certification, and the 0.2-inch blanking band for contract administration and incentive payments. This caused some problems with repeatable measurements and an imbalance in the way smoothness incentives were being paid.

Mn/DOT began performing random quality assurance testing with the lightweight profiler on projects where the ride incentive had been determined using the 0.2-inch blanking band Profile Index. It was determined that more research and field evaluations were needed, and that the certification program should be improved in order to be consistent among all contractors and pavement smoothness testing equipment.

2002

In the spring of 2002, Mn/DOT initiated the Profile Index Smoothness Measuring Device Program, using two test sections at MnROAD (one concrete, one bituminous). The contractors' California Profilograph results (0.0-inch blanking band PI) were compared against those generated with the ARRB Walking Profiler (a non-inertial profiler that produced a very accurate description of the pavement profile).

During quality assurance testing on some job sites, some problems were again experienced problems repeating the contractors' 0.2-inch blanking band PI values with the lightweight profiler.

2002 – 2003

Mn/DOT began a more thorough analysis of certification and construction data, and found a very weak correlation among PI results between the 0.0- and 0.2-inch blanking bands. The benefits of using the IRI compared to the PI measures of pavement smoothness were evaluated as well. Some of the advantages of using IRI instead of PI include the following.

- While both IRI and PI amplify some wavelengths and attenuate others, the IRI is fairly constant in its amplification/attenuation in the wavelength range that affects the driver most.
- IRI is much more repeatable than either PI blanking band levels. This is especially true with modern laser devices (triple laser and line laser).
- The Profilograph (and thus the Profile Index) does not actually see a pavement the same way a vehicle sees it. It does not always directly correlate with the ride quality of a pavement [2]. The IRI does better at correlating the pavement to the ride quality.
- Due to the short length of the profilograph, the trace (pavement profile) may show roadway features that are not actually present in the roadway.

2004

In the 2004 paving season, Mn/DOT let three bituminous construction projects with IRI as a pilot specification. In addition, the annual smoothness equipment certification program was expanded to include IRI and devices that measure pavement profile.

2005

In 2005, an additional 13 bituminous projects were let with IRI pilot specifications.

2006

By the 2006 construction season, all bituminous projects were using IRI exclusively. In the same year, Mn/DOT let three concrete projects with IRI pilot specifications. Concurrently, a research project was underway to evaluate the change from PI to IRI on concrete pavements [3]. The report of this effort was published in 2007.

In the same year, Mn/DOT began using a Pathways High Speed Profiler for quality assurance on pavement smoothness specifications. The equipment certification program was also improved with the incorporation of the cross-correlation evaluation method.

2007

By the year 2007, Mn/DOT had converted to exclusive use of IRI for all bituminous and concrete paving projects.

Also in 2007, Mn/DOT discontinued certification for California Profilographs for use on new contracts in Minnesota. Certification continued for multi-year projects where PI had been specified, and as a service to other states.

2008

In 2008, Mn/DOT began using an International Cybernetics Corporation (ICC) SurPro Reference Profiler. This device enabled Mn/DOT to collect data on its certification test sections using a

sample interval that more closely matched those used by the inertial profilers under evaluation. In addition, the SurPro's increased speed of data collection allowed Mn/DOT to collect multiple runs throughout each day of certification to control for changes in pavement surface characteristics caused by temperature variation.

2009

In 2009, Mn/DOT completely eliminated its PI certification program. An Ames High Speed Profiler was purchased with dual RoLine lasers for quality control and quality assurance measurements. One major use of this new equipment is to address the question of texture in concrete pavements.

Another event in 2009 was the inclusion of the new combined smoothness specification, described in detail in this report, as a "ghost specification" on several paving projects – both bituminous and concrete. This new specification was also presented in several workshops, training sessions, industry association conferences, and other Mn/DOT and County Engineer conferences.

Current Practice – Minnesota

As mentioned in the previous section, by the year 2009, Minnesota had begun using the new combined ride specification as a "ghost spec" on several bituminous and concrete pavement projects throughout the state. In the 2010 season, Mn/DOT will move to the next step, which is to implement the new specification, with various modifications, on "pilot projects" where the new specification will be the primary requirement with full incentives and reduced disincentives. By the 2011 construction season, Mn/DOT plans to require the combined specification on all bituminous and concrete paving projects.

As described elsewhere in this report, the new combined specification has the following characteristics.

- International Roughness Index for both bituminous and concrete pavements.
- Profile measured in both wheel paths.
- Equipment and operator certification.
- Smoothness (IRI) calculated every 0.1-mile segment.
- Areas of Localized Roughness calculated on a continuous basis with an analysis interval of 25 feet.
- Use of FHWA ProVAL software for computation and reporting.
- Corrected segments included in incentive calculation.

Current Practice – Other States

This section summarizes the practices of other states in most of the areas listed above. The information in this section was taken from various sources, including the following web sites.

- www.smoothpavements.com (both bituminous and concrete pavements)
- www.pavement.com (concrete pavement only)

The information on these sites may be as much as two years old. In addition, it should be recognized that while the smoothpavements.com site had data directly from state specifications, it seems that the pavement.com data is from a voluntary survey, to which not all states responded.

Use of IRI for Smoothness Index

At least 30 states use IRI for bituminous pavements. Only about 11 states use IRI for smoothness evaluation on concrete pavements.

Measured in Both Wheel Paths

Of all states with smoothness specifications for concrete pavements, and which responded to the survey, 27 states require profile measurement in both wheel paths, while 4 requirement measurements in the center of the lane, and 2 in the right lane.

Equipment and Operator Certification

Based on a review of smoothness specifications for states that use IRI and PI, only about eight states require profiler operators to be certified and to present their certification to the field engineer on site prior to conducting smoothness measurements.

A thorough search was not conducted of all state specifications, but it is likely that all states with a smoothness specification (48 states with bituminous and 44 states with concrete specifications) have equipment certification or calibration requirements.

Segment Length for Smoothness Computation

Segment length for smoothness computation varies among states with concrete smoothness specifications, although the most common interval is 0.1 mile. Four states have intervals less than 0.1 mile (0.01 mile, 0.1 km, 328 ft, and 250 ft) and three states specify intervals greater than 0.1 mile (0.25 mile, and 600 ft).

Incentives/Disincentives

Most states incorporate an incentive / disincentive into the pavement smoothness specifications. Some states only allow for incentive / must correct, and some require the "must correct" but do not allow incentive payments.

Bituminous Pavement

A total of 39 states provide for incentives and disincentives, while 4 states provide incentives, but do not allow for disincentives – only a "must correct." These states generally have a minimum incentive payment and a range where the pavement is acceptable without incentive, and then include a cutoff point where the smoothness of the pavement must be corrected. Five states do not allow for incentives at all, but still have a "must correct" provision.

Concrete Pavement

More information was readily available for concrete pavements. A total of 26 states provide for both incentive and disincentive. Nine states have incentives and "must correct" provisions, and

eight states have "must correct" as the only option. One state includes a disincentive prior to the "must correct" requirements.

Information is also available for the IRI value at maximum incentive and the value of the maximum incentive for concrete pavements. The IRI value where the maximum incentive is paid varies from 60 in/mi down to 30 in/mi, with the majority at about 45 in/mi. The maximum incentive payment available is $1,500 per 0.1-mile segment, at 45 in/mi. Another state offers a maximum incentive payment of $0.50 per square yard, which equates to $352 per 0.1-mile segment at 12 feet wide.

Use of ALR

According to the smoothpavements.com web site, about six states (not including Minnesota) have incorporated the Areas of Localized Roughness specification to replace the bump/dip provision. A total of 41 states (bituminous) and 42 states (concrete) have some type of localized roughness provision (primarily a version of the bump/dip requirement).

Use of ProVAL

Also according to smoothpavements.com, 6 states (not including Minnesota) and the FHWA Western Federal Lands Division require the use of the FHWA software ProVAL.

Chapter 3. DEVELOPMENT OF COMBINED SMOOTHNESS SPECIFICATION

This chapter discusses the development efforts and the plan for implementation of the new combined ride specification for pavement construction in Minnesota. Some of the issues to be clarified included the following.

- Combination of bituminous and concrete ride specifications.
- Requirement for operator certification.
- Requirement for measuring profile in both wheel paths.
- Requirement for common data filename.
- Establishment of incentive and disincentive levels (or verification of existing levels).
- Establishment of IRI limits for areas of localized roughness.
- Allowance for pay adjustments to be computed after corrective work.
- Solicitation of external review comments.

These items and their eventual outcomes are discussed in this chapter.

Iterative Development of Combined Specification

Just as with the development of any specification or similar document, the combined ride specification underwent many revisions in an iterative development process. Approximately 28 versions were circulated among the technical advisory panel. Comments and questions were discussed at approximately nine panel meetings over the course of 18 months. During the specification development, external review was solicited from Mn/DOT construction personnel, industry associations, contractors, and profiler operators.

Combination of Bituminous and Concrete Ride Specifications

The combination of the bituminous and concrete ride specifications was a natural progression in the development of pavement smoothness in Minnesota. Since the driving public is primarily concerned with the smoothness of the pavement surface rather than the type of pavement, the surface material is irrelevant. As discussed in the previous chapter, only recently had the concrete pavement ride specification changed to use the International Roughness Index rather than the Profile Index. With both pavement types using the same index, the next logical step was to combine the two specifications into one. The advantages of combining the specifications include the following.

- Future changes are reflected in requirements for both specifications automatically. It will not be necessary to establish changes in two different specifications and ensure that all unintended consequences of a change have been considered in both.
- Equipment and operator requirements are common, and contractors who construct both types of pavements do not need to conform to two different sets of requirements.
- Many other aspects of the specifications are similar, and thus benefit from the combination.
- The revision and combination of the specifications provide Mn/DOT with an opportunity to modify other areas of the specifications to reflect current practice and the capabilities of newer technologies, such as operator certification, the new ProVAL analysis software and the areas of localized roughness analysis method.

The primary drawback of the combined specification, which is not significant, is that contractors and Mn/DOT personnel must determine the appropriate equation for the material type and other characteristics of the pavement. In the new combined specification there are 13 different pay adjustment equations, for bituminous, concrete, and percent improvement projects. Within each of these categories, there are different equations depending on the level of the IRI value.

Operator Certification

The proper training and certification of pavement profiler operators is important to ensure that the data produced is appropriate for the analysis and that variability due to the operator is minimized. It is important that all operators – both contractor and agency personnel – are trained and certified, to legitimize the results.

The operator training course does not focus on the actual operation of individual profiling machines, but on the primary sources of potential error in the measured profile and the practices that operators can conduct to minimize those potential errors. Another focus of the training course is to familiarize operators with the combined smoothness specification and the ProVAL software. Operators should be familiar with the contractor's duties and actions they can expect to be performed by the agency. The must recognize the requirements of the specification relating to submission of data (electronic and paper) and corrective work plans.

Measurement in Both Wheel Paths

Previously, all pavement profiles were conducted in the right wheel path. While this provides adequate information for one side of the lane, common practice among other states is to require measurements in both wheel paths. The additional data provide a more complete representation of the smoothness of the pavement surface.

A benefit to contractors resulting from this decision is that the left wheel path often exhibits lower IRI values than the right wheel path, which would provide for greater incentive pay adjustments than the right wheel path alone. It is unclear how significant this difference is, or if it affects concrete pavements as much as bituminous pavements.

Common Data Filenames

The obvious benefit of having a common method for naming data files is that the agency can quickly refer to specific roadways, and locations within a roadway to find rough features in a pavement surface at a later date. Previously, each contractor had its own naming practice which did not coincide with any naming or numbering utilized by the agency. The required naming format for the electronic data files, with the extension "ERD" is shown below.

YYMMDD-T-N-D-L-W-S.ERD

Where:

YY = Two-digit year
MM = Month (include leading zeros)
DD = Day of month (include leading zeros)
T = Route type (I, MN, US, CSAH, etc.)

N = Route number (no leading zeros) and auxiliary ID (if applicable, for example E, W, etc.)
D = Primary route direction (I or D)
L = Lane number (1 for driving lane, increasing by one for each lane to the left)
W = Wheel path (L, R, or B, indicating Left, Right, or Both)
S = Beginning station

For example: "080721-I-35W-I-2-L-5+21.ERD" would indicate a beginning station of 5+21, in the left wheel path of the second lane (one lane left of the driving lane), in the increasing (northbound) direction of I-35W, tested on 21 July 2008.

Incentive and Disincentive Levels

The levels of pay adjustment for the 0.1-mile segment smoothness were not changed from the previous specifications. These were simply combined into the new specification in three distinct tables. Some discussions were conducted about the lower limit at which the maximum pay incentive would be met, and whether decreasing this limit and raising the maximum possible incentive would encourage contractors to build even smoother pavements. Ultimately, it was decided that this question would wait until a future revision of the specification.

Areas of Localized Roughness Levels

Since an entirely new analysis method for evaluating local roughness (bumps and dips) was introduced in this combined specification, a thorough analysis was conducted to evaluate the appropriate IRI levels for identifying disincentives and "must correct" segments. This new method is termed *Areas of Localized Roughness* (ALR) or *Smoothness Assurance*. This analysis was conducted in order to set IRI cutoff level for ALR which would provide for similar required levels of grinding as in the bump/dip specification.

Although the methods of analysis for the two specifications (bump/dip and ALR) are very different, they both identify localized areas that need corrective work. Based on discussions with contractors and grinder operators, and using the grinding simulation in ProVAL, an average of 100 longitudinal feet of grinding is normal for an average bump. It was assumed that since a dip often is represented by two adjacent bumps, a distance of about 175 feet of grinding is needed to remove the average dip. This longitudinal grinding distance, of course, is dependent on the magnitude of the bump or dip. These values are simply average distances in the judgment of experienced operators. For the economic analysis described later in this section, an average grinding cost of about $10 per linear foot of grinding, 12 feet wide, was used, which is equivalent to $7.50 per square yard.

The first portion of the analysis is essentially a summary of the segment length, recommended grinding length, and the percent of the project length that is "out of spec" before and after the simulation of grinding by the FHWA ProVAL software. These statistics were generated for several roadways constructed in the 2008 season, and for ALR cutoff IRI values of 95.0, 120.0, 140.0 and 160.0 in/mi. For the same roadways, a standard 25-foot straightedge analysis was conducted by ProVAL and the number of bump and dip occurrences were counted (greater than 0.4 inch and 0.5 inch in a 25-foot span for bumps and dips, respectively). This definition of

maximum bump and dip was taken from the previous specifications for pavement smoothness used by Mn/DOT for bituminous and concrete pavement construction.

Table 1 provides basic information regarding the individual roadway, the direction and wheel path that was measured, the number of lifts, and the overall segment length, in feet of the bituminous profiles included in this analysis. Table 2 includes similar information for the concrete profiles. Table 3 presents the results of the bump and dip analysis. The number of occurrences was determined by counting the actual number of times the 25-straightedge trace exceeded the maximum allowable value, and the Possible Grind Length was estimated by the assumptions of grind length per occurrence, as defined above.

Table 1. Highway Identification and Properties – Bituminous.

Hwy ID	Direction	Wheel Path	Number of Lifts	Segment Length (feet)
TH223-EB-R	EB	Right	1	39,155
TH223-EB-L	EB	Left	1	39,155
TH223-WB-R	WB	Right	1	39,176
TH223-WB-L	WB	Left	1	39,176
CSAH61-NB-R	NB	Right	2	83,044
CSAH61-SB-R	SB	Right	2	83,398
TH210-EB-R	EB	Right	3	109,972
TH210-EB-L	EB	Left	3	109,972
TH210-WB-R	WB	Right	3	110,042
TH210-WB-L	WB	Left	3	110,042
TH65-NB-R	NB	Right	3	46,500
TH65-SB-R	SB	Right	3	48,716

Table 2. Highway Identification and Properties – Concrete.

Hwy ID	Direction	Segment Length (feet)
261+25 SB lane 11.ERD	SB	3,829
NB 12981.ERD	NB	3,613
NB 1298+25 lane 1.ERD	NB	1,636
NB 1298+25 lane 2.ERD	NB	1,636
10606016	NB	9,976
1070262A	SB	10,504
10702636	EB	10,445
10702637	EB	10,445

In Table 3, for example, it can be seen that in the TH 223 project, the eastbound direction, (averaging the right and left lanes) about 5.5% of the entire project length would need to be corrected for bumps and dips. This is due to an average of about 9 bumps and 7 dips in each of the two lanes, over the 39,155-foot project.

Table 3. Bump and Dip Analysis and Estimated Required Grinding.

Bituminous

Hwy ID	Bumps/Dips			
	Number of Occurrences		Possible Grind Length, ft	
	Bumps	Dips	(assuming 100 ft/bump, 175 ft/dip)	% of Project
TH223-EB-R	11	8	2500	6.4%
TH223-EB-L	7	6	1750	4.5%
TH223-WB-R	1	3	625	1.6%
TH223-WB-L	2	3	725	1.9%
CSAH61-NB-R	6	7	1825	2.2%
CSAH61-SB-R	6	5	1475	1.8%
TH210-EB-R	0	0	0	0.0%
TH210-EB-L	2	1	375	0.3%
TH210-WB-R	1	1	275	0.2%
TH210-WB-L	1	0	100	0.1%
TH65-NB-R	0	0	0	0.0%
TH65-SB-R	1	0	100	0.2%

Concrete

Hwy ID	Bumps/Dips			
	Number of Occurrences		Possible Grind Length, ft	
	Bumps > 0.4"	Dips > 0.5"	(assuming 100 ft/bump, 175 ft/dip)	% of Project
261+25 SB lane 11.ERD	0	0	0	0.0%
NB 12981.ERD	0	0	0	0.0%
NB 1298+25 lane 1.ERD	0	0	0	0.0%
NB 1298+25 lane 2.ERD	0	0	0	0.0%
10606016	0	0	0	0.0%
1070262A	0	0	0	0.0%
10702636	0	0	0	0.0%
10702637	0	0	0	0.0%

The "Before" and "After" columns in Table 4 through Table 7 refer to the percent of the project length that is out of specification prior to and following the grinding simulation conducted by ProVAL. The information in Table 8 is a summary of the estimated grinding as a percentage of total project length for the four analyses conducted. These tables represent the results of the ALR to Bump/Dip comparison.

Items of note in comparing the Bump/Dip and ALR analyses in Table 3 through Table 8 include:

- As the IRI cutoff for ALR increases, the percentage of length of a project that requires grinding decreases.
- For pavements with higher required grinding at the 95.0 in/mi cutoff, the required grinding decreases more quickly as the cutoff level increases.
- The estimated grinding for correction in the bump/dip specification is generally similar to that required for the ALR specification, with some exceptions.
- For bituminous pavements, there seems to be a more gradual decrease in grinding as the ALR cutoff increases than for concrete pavements. The concrete pavements analyzed

had a much larger drop in required grinding between 95.0 and 120.0 in/mi than did the bituminous pavements, with two exceptions.

Table 4. ALR Analysis with 95.0 in/mi Cutoff and ProVAL-Predicted Required Grinding.

	ALR Cutoff = 95.0 in/mi			
	Grinding		% Out of Tolerance	
Hwy ID	Length (ft)	% Project Length	Before	After
TH223-EB-R	7,843	20.0%	7.0%	3.3%
TH223-EB-L	6,594	16.8%	5.1%	2.1%
TH223-WB-R	4,864	12.4%	3.7%	1.4%
TH223-WB-L	5,359	13.7%	4.4%	1.8%
CSAH61-NB-R	23,260	28.0%	7.9%	1.8%
CSAH61-SB-R	15,281	18.3%	4.4%	1.2%
TH210-EB-R	4,838	4.4%	1.0%	0.4%
TH210-EB-L	3,456	3.1%	0.9%	0.4%
TH210-WB-R	5,480	5.0%	1.2%	0.3%
TH210-WB-L	3,486	3.2%	0.6%	0.2%
TH65-NB-R	2,777	6.0%	1.2%	0.3%
TH65-SB-R	3,583	7.4%	1.3%	0.4%

Concrete

	ALR Cutoff = 95.0 in/mi			
	Grinding		% Out of Tolerance	
Hwy ID	Length (ft)	% Project Length	Before	After
261+25 SB lane 11.ERD	596	15.6%	2.8%	0.6%
NB 12981.ERD	747	20.7%	3.4%	0.0%
NB 1298+25 lane 1.ERD	879	53.7%	46.8%	17.9%
NB 1298+25 lane 2.ERD	770	47.1%	72.7%	27.2%
10606016	1,230	12.3%	2.2%	51.0%
1070262A	1,170	11.1%	3.1%	0.8%
10702636	2,282	21.8%	8.7%	0.8%
10702637	998	9.6%	4.0%	0.7%

Table 5. ALR Analysis with 120.0 in/mi Cutoff and ProVAL-Predicted Required Grinding.

Bituminous

Hwy ID	ALR Cutoff = 120.0 in/mi			
	Grinding		% Out of Tolerance	
	Length (ft)	% Project Length	Before	After
TH223-EB-R	4,709	12.0%	3.9%	2.0%
TH223-EB-L	3,006	7.7%	2.4%	0.9%
TH223-WB-R	2,406	6.1%	1.4%	0.5%
TH223-WB-L	2,743	7.0%	2.2%	0.8%
CSAH61-NB-R	10,555	12.7%	2.8%	0.9%
CSAH61-SB-R	6,231	7.5%	1.6%	0.6%
TH210-EB-R	1,658	1.5%	0.4%	0.2%
TH210-EB-L	1,025	0.9%	0.4%	0.2%
TH210-WB-R	1,840	1.7%	0.4%	0.1%
TH210-WB-L	889	0.8%	0.3%	0.1%
TH65-NB-R	794	1.7%	0.4%	0.1%
TH65-SB-R	1,614	3.3%	0.5%	0.2%

Concrete

Hwy ID	ALR Cutoff = 120.0 in/mi			
	Grinding		% Out of Tolerance	
	Length (ft)	% Project Length	Before	After
261+25 SB lane 11.ERD	0	0.0%	0.0%	0.0%
NB 12981.ERD	121	3.3%	0.4%	0.0%
NB 1298+25 lane 1.ERD	755	46.1%	17.8%	6.5%
NB 1298+25 lane 2.ERD	770	47.1%	38.2%	10.1%
10606016	359	3.6%	0.7%	0.2%
1070262A	400	3.8%	1.2%	0.1%
10702636	668	6.4%	1.7%	0.3%
10702637	582	5.6%	1.7%	0.2%

Table 6. ALR Analysis with 140.0 in/mi Cutoff and ProVAL-Predicted Required Grinding.

Bituminous

	ALR Cutoff = 140.0 in/mi			
	Grinding		% Out of Tolerance	
Hwy ID	Length (ft)	% Project Length	Before	After
TH223-EB-R	2,865	7.3%	2.4%	1.3%
TH223-EB-L	1,882	4.8%	1.5%	0.6%
TH223-WB-R	1,220	3.1%	0.9%	0.2%
TH223-WB-L	1,712	4.4%	1.1%	0.4%
CSAH61-NB-R	4,654	5.6%	1.5%	0.7%
CSAH61-SB-R	2,474	3.0%	1.0%	0.4%
TH210-EB-R	589	0.5%	0.3%	0.2%
TH210-EB-L	277	0.3%	0.2%	0.2%
TH210-WB-R	602	0.5%	0.2%	0.1%
TH210-WB-L	252	0.2%	0.2%	0.1%
TH65-NB-R	452	1.0%	0.3%	0.1%
TH65-SB-R	703	1.4%	0.2%	0.1%

Concrete

	ALR Cutoff = 140.0 in/mi			
	Grinding		% Out of Tolerance	
Hwy ID	Length (ft)	% Project Length	Before	After
261+25 SB lane 11.ERD	0	0.0%	0.0%	0.0%
NB 12981.ERD	0	0.0%	0.0%	0.0%
NB 1298+25 lane 1.ERD	437	26.7%	8.9%	1.3%
NB 1298+25 lane 2.ERD	661	40.4%	23.5%	5.2%
10606016	197	2.0%	0.3%	0.1%
1070262A	182	1.7%	0.2%	0.0%
10702636	397	3.8%	1.3%	0.2%
10702637	447	4.3%	0.9%	0.1%

Table 7. ALR Analysis with 160.0 in/mi Cutoff and ProVAL-Predicted Required Grinding.

Bituminous

Hwy ID	ALR Cutoff = 160.0 in/mi			
	Grinding		% Out of Tolerance	
	Length (ft)	% Project Length	Before	After
TH223-EB-R	2,141	5.5%	1.8%	0.9%
TH223-EB-L	1,037	2.6%	1.0%	0.4%
TH223-WB-R	778	2.0%	0.5%	0.1%
TH223-WB-L	1,181	3.0%	0.7%	0.2%
CSAH61-NB-R	2,256	2.7%	1.0%	0.4%
CSAH61-SB-R	1,471	1.8%	0.7%	0.3%
TH210-EB-R	146	0.1%	0.2%	0.2%
TH210-EB-L	179	0.2%	0.2%	0.2%
TH210-WB-R	238	0.2%	0.2%	0.1%
TH210-WB-L	159	0.1%	0.1%	0.1%
TH65-NB-R	269	0.6%	0.2%	0.0%
TH65-SB-R	377	0.8%	0.1%	0.0%

Concrete

Hwy ID	ALR Cutoff = 160.0 in/mi			
	Grinding		% Out of Tolerance	
	Length (ft)	% Project Length	Before	After
261+25 SB lane 11.ERD	0	0.0%	0.0%	0.0%
NB 12981.ERD	0	0.0%	0.0%	0.0%
NB 1298+25 lane 1.ERD	350	21.4%	4.8%	0.0%
NB 1298+25 lane 2.ERD	562	34.4%	11.1%	1.9%
10606016	94	0.9%	0.1%	0.0%
1070262A	85	0.8%	0.1%	0.0%
10702636	358	3.4%	1.0%	0.2%
10702637	261	2.5%	0.4%	0.0%

In Table 8 specifically, some observations of the results include the following.

- For most bituminous pavements, the "equivalent" level of ALR cutoff that requires a similar amount of grinding as the Bump/Dip specification is between 140.0 and 160.0 in/mi.
- For the concrete pavements evaluated as part of this analysis, none would have required grinding under the Bump/Dip specification, but almost all would have required some grinding under any of the ALR cutoff levels. One in particular is the "NB 1298+25" lanes 1 and 2, which show required grinding of 4.8 and 11.1 percent of their length, respectively, even with the 160.0 in/mi ALR cutoff, and none with Bump/Dip specification.
- The decrease in required grinding follows a similar pattern, even though the magnitude varies. The pattern is different, however, for concrete and bituminous pavements. This is illustrated in Figure 1 and Figure 2. In each of these figures, the grinding requirements at 95.0 in/mi ALR cutoff are primarily between 5 and 20 percent. However, at the 120.0 in/mi cutoff, the required grinding for concrete has dropped to about 7 percent, compared to a range of 5 to 13 percent for bituminous pavements. In addition, at the 140.0 and

160.0 in/mi cutoff levels, the concrete pavements have dropped slightly, to below 5 percent (and to 0 percent in some cases) while the bituminous pavements have dropped more significantly, but none have decreased to 0 percent.

While there are many possible reasons for these differences, it seems that over several contractors and projects across the state, the trends are similar.

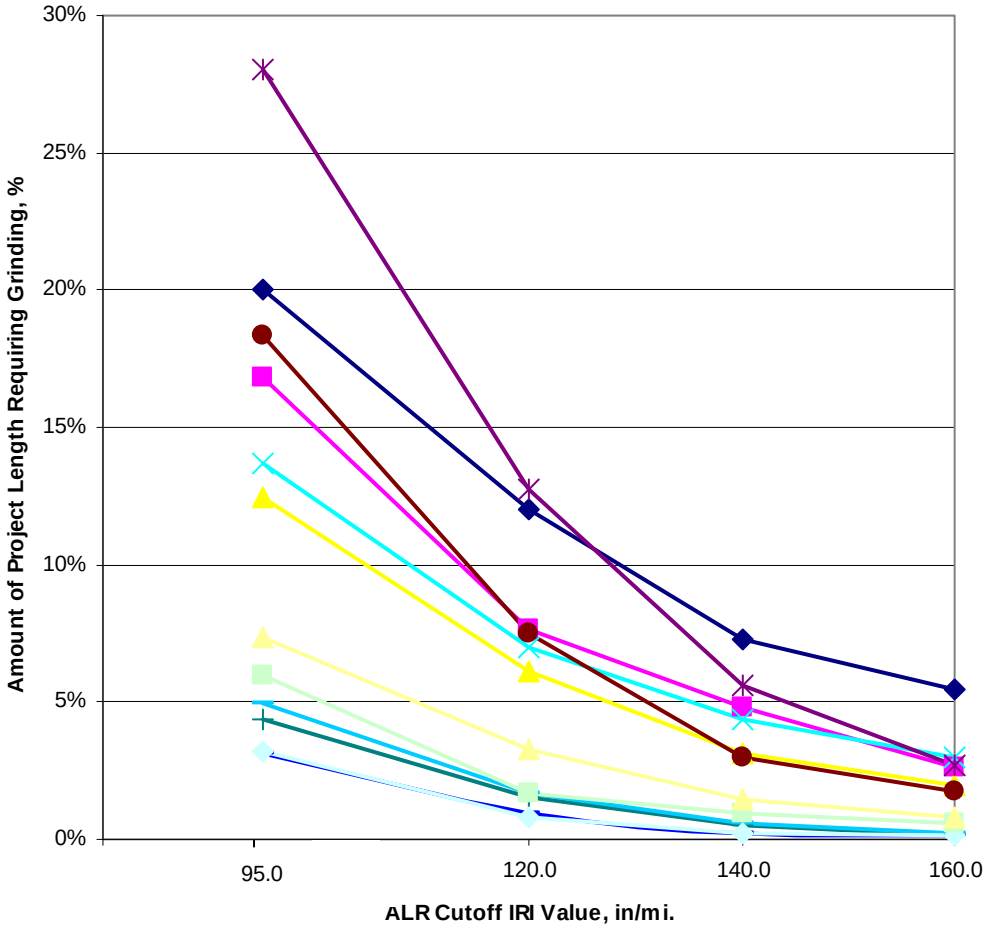

Figure 1. Change in Grinding Requirements vs. ALR Cutoff Value, Bituminous Pavements.

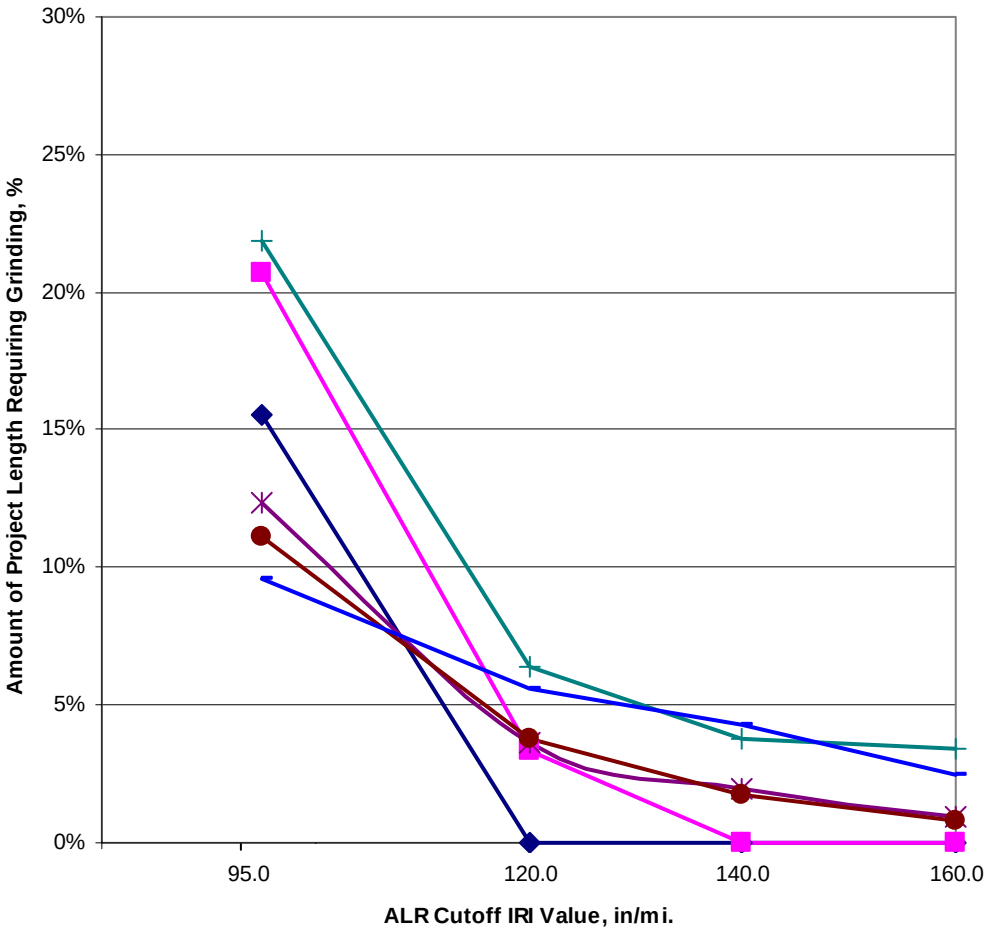

Figure 2. Change in Grinding Requirements vs. ALR Cutoff Value, Concrete Pavements.

Table 8. Summary of Percent Grinding by ALR Cutoff and Bump/Dip Analysis.

Bituminous

Hwy ID	Grinding, % of Project Length				
	95.0 in/mi Cutoff	120.0 in/mi Cutoff	140.0 in/mi Cutoff	160.0 in/mi Cutoff	Bump/Dip
TH223-EB-R	20.0%	12.0%	7.3%	5.5%	6.4%
TH223-EB-L	16.8%	7.7%	4.8%	2.6%	4.5%
TH223-WB-R	12.4%	6.1%	3.1%	2.0%	1.6%
TH223-WB-L	13.7%	7.0%	4.4%	3.0%	1.9%
CSAH61-NB-R	28.0%	12.7%	5.6%	2.7%	2.2%
CSAH61-SB-R	18.3%	7.5%	3.0%	1.8%	1.8%
TH210-EB-R	4.4%	1.5%	0.5%	0.1%	0.0%
TH210-EB-L	3.1%	0.9%	0.3%	0.2%	0.3%
TH210-WB-R	5.0%	1.7%	0.5%	0.2%	0.2%
TH210-WB-L	3.2%	0.8%	0.2%	0.1%	0.1%
TH65-NB-R	6.0%	1.7%	1.0%	0.6%	0.0%
TH65-SB-R	7.4%	3.3%	1.4%	0.8%	0.2%

Concrete

Hwy ID	Grinding, % of Project Length				
	95.0 in/mi Cutoff	120.0 in/mi Cutoff	140.0 in/mi Cutoff	160.0 in/mi Cutoff	Bump/Dip
261+25 SB lane 11.ERD	15.6%	0.0%	0.0%	0.0%	0.0%
NB 12981.ERD	20.7%	3.3%	0.0%	0.0%	0.0%
NB 1298+25 lane 1.ERD	53.7%	46.1%	26.7%	21.4%	0.0%
NB 1298+25 lane 2.ERD	47.1%	47.1%	40.4%	34.4%	0.0%
10606016	12.3%	3.6%	2.0%	0.9%	0.0%
1070262A	11.1%	3.8%	1.7%	0.8%	0.0%
10702636	21.8%	6.4%	3.8%	3.4%	0.0%
10702637	9.6%	5.6%	4.3%	2.5%	0.0%

Table 9 shows the number of segments requiring grinding before corrective work is undertaken, and the number of segments that still do not meet the associated ALR cutoff level after the ProVAL grinding algorithm is applied. The "Before" column represents segments where the IRI exceeds the maximum level in the "Pay Adjustment" section of the specification. This is based on a 0.1-mi segment length. In the ALR cutoff columns, the "# Segments Requiring Grinding" indicates the number of 0.1-mi segments that include a violation of the associated ALR values for IRI on a 25-ft "Continuous Short Interval" and that are included in the grinding analysis by ProVAL. The columns labeled "# Corrective Work Segments Remaining" indicate the number of 0.1-mi segments that still do not meet the "Pay Adjustment" maximum IRI values after grinding, and for which the specification allows for a lump-sum deduction per segment. The lump-sum penalties are not included in the analysis, however.

Table 9. Number of Segments Exceeding ALR Limits, Before and After Grinding (ALR).

		After							
	Before	95 in/mi Cutoff		120 in/mi Cutoff		140 in/mi Cutoff		160 in/mi Cutoff	
Highway ID	# Corrective Work Segments	# Segments Requiring Grinding	# Corrective Work Segments Remaining	# Segments Requiring Grinding	# Corrective Work Segments Remaining	# Segments Requiring Grinding	# Corrective Work Segments Remaining	# Segments Requiring Grinding	# Corrective Work Segments Remaining
Bituminous									
CSAH61-NB-R	11	138	3	94	3	43	4	22	6
CSAH61-SB-R	3	105	2	55	2	24	2	15	2
TH65-SB-R	1	31	0	17	1	8	1	5	1
TH223-WB-R	4	45	1	31	1	19	2	11	3
Concrete									
261+25 SB Lane 11	0	5	0	0	0	0	0	0	0
10702636	0	16	0	10	0	4	0	4	0
NB 1298+25 Lane1	3	4	1	4	1	4	1	3	1

As can be seen in Table 9, as the ALR cutoff is increased, the number of 0.1-mile segments requiring some level of grinding decreases, as would be expected. Additionally, as the requirement for ALR is eased (increased), and fewer 0.1-mi segments receive some level of grinding, the number of 0.1-mi segments remaining listed as "Corrective Work" increases in many cases. This occurs since the grinding required for ALR correction also improves the overall IRI of the 0.1-mi segment, and therefore the overall smoothness of the pavement.

Table 10 indicates the estimated pay adjustments for each roadway in the analysis, both with the bump/dip and the ALR specifications. These values indicate the amount of pay adjustment for the smoothness analysis for the entire 0.1-mile segment. The decreasing incentive value as the cutoff limit increases occurs due to the fact that the pay adjustment for the segments is computed after the correction has taken place, and with a higher cutoff, fewer segments would be corrected. The pay adjustment for the 160.0-in/mi cutoff point matches the adjustment with the previous specification more closely than the others.

Table 10. Pay Adjustments, Before and After Grinding (Bump/Dip vs. ALR).

		Areas of Localized Roughness			
Highway ID	Bump/Dip	95 in/mi Cutoff	120 in/mi Cutoff	140 in/mi Cutoff	160 in/mi Cutoff
Bituminous					
CSAH61-NB-R	$ 165	$ 24,988	$ 16,784	$ 12,577	$ 10,856
CSAH61-SB-R	$ 17,880	$ 29,653	$ 24,408	$ 21,887	$ 21,325
TH65-SB-R	$ 20,749	$ 31,127	$ 29,587	$ 28,922	$ 28,615
TH223-WB-R	$ 7,594	$ 13,765	$ 11,401	$ 10,468	$ 10,184
Concrete					
261+25 SB Lane 11	$ 2,263	$ 5,111	$ 2,663	$ 2,663	$ 2,663
10702636	$ 2,290	$ 14,688	$ 6,033	$ 4,438	$ 4,319
NB 1298+25 Lane1	$ (615)	$ 636	$ 472	$ (930)	$ (1,221)

The information in Table 11 includes the estimated cost of grinding each project, comparing what may be required of the contractor with the bump/dip specification to that with the ALR specification. These numbers were generated based on grinding a full 12-ft lane width. As mentioned above, the estimated amount of grinding was based on grinding longitudinally 100 feet for bumps and 175 feet for dips. The estimated grinding amount for ALR was provided by the ProVAL analysis. A unit cost of $7.50 per square yard was estimated for all grinding costs.

Table 11. Cost of Grinding (at $7.50 per yd^2), Bump/Dip vs. ALR.

		Areas of Localized Roughness			
Highway ID	Bump/Dip	95 in/mi Cutoff	120 in/mi Cutoff	140 in/mi Cutoff	160 in/mi Cutoff
Bituminous					
CSAH61-NB-R	$ 18,520	$ 232,600	$ 105,550	$ 46,540	$ 22,560
CSAH61-SB-R	$ 14,750	$ 152,810	$ 62,310	$ 24,740	$ 14,710
TH65-SB-R	$ 1,000	$ 35,380	$ 16,140	$ 7,030	$ 3,770
TH223-WB-R	$ 6,250	$ 48,640	$ 24,060	$ 12,200	$ 7,780
Concrete					
261+25 SB Lane 11	$ -	$ 5,960	$ -	$ -	$ -
10702636	$ -	$ 22,820	$ 6,680	$ 3,970	$ 3,580
NB 1298+25 Lane1	$ -	$ 8,790	$ 7,550	$ 4,370	$ 3,500

Table 12 shows the net pay adjustment including the estimate cost of grinding, with the pay adjustment factors from each of the specifications (Bump/Dip and ALR). In most of the roadways analyzed with ALR, the net adjustment increases (in favor of the contractor) as the ALR cutoff increases. In the concrete pavements, as the ALR cutoff increases, the net adjustment decreases in some cases. It seems that this is the case due to the rapid drop-off of required grinding of concrete pavements when the ALR increases from 95.0 in/mi to 120.0 in/mi. This leaves fewer segments requiring grinding, and the grinding on those segments that need it is limited to small areas. Thus, the pay adjustment is affected by segments that are rough, but not so rough as to require corrective action on their own. The benefit in terms of "grinding to incentive" is not as prevalent, and the net adjustment decreases.

Based on the results of the net adjustment, including estimated grinding, it is apparent that an ALR cutoff value for IRI, producing an equivalent net adjustment in cost with the bump/dip specification, would be between 140.0 and 160.0 in/mi. As stated above, this is based on the pay adjustments from each specification, using the appropriate equation for 1, 2, and 3 lifts, a unit cost for grinding of $7.50 per square yard, and required grinding length for bumps and dips at 100 ft and 175 ft, respectively.

Table 12. Net Adjustment, Including Grinding Cost (Bump/Dip vs. ALR).

		Areas of Localized Roughness			
Highway ID	Bump/Dip	95 in/mi Cutoff	120 in/mi Cutoff	140 in/mi Cutoff	160 in/mi Cutoff
Bituminous					
CSAH61-NB-R	$ 18,355	$ 207,612	$ 88,766	$ 33,963	$ 11,704
CSAH61-SB-R	$ (3,130)	$ 123,157	$ 37,902	$ 2,853	$ (6,615)
TH65-SB-R	$ (19,749)	$ 4,254	$ (13,447)	$ (21,892)	$ (24,845)
TH223-WB-R	$ (1,344)	$ 34,876	$ 12,660	$ 1,732	$ (2,404)
	$ -	$ -	$ -	$ -	$ -
Concrete	$ -	$ -	$ -	$ -	$ -
261+25 SB Lane 11	$ (2,263)	$ 849	$ (2,663)	$ (2,663)	$ (2,663)
10702636	$ (2,290)	$ 8,132	$ 647	$ (468)	$ (739)
NB 1298+25 Lane1	$ 615	$ 8,154	$ 7,078	$ 5,300	$ 4,721

The TAP initially decided to set the cutoff for ALR at 120.0 in/mi, using the 25-foot short interval, and to require corrective action for all areas of localized roughness where the short interval IRI exceeded this limit. After the experience of the ghost specifications and deliberation

with the TAP and the contractors involved with the ghost specs, the panel decided to modify the cutoff limit and to allow more engineering judgment into the corrective work decisions. The final cutoff levels of short-interval IRI will be as follows.

- Below 125.0 in/mi, the area will be considered acceptable and allowed to remain without any corrective work.
- Between 125.0 and 149.9 in/mi, the area will be considered an area of localized roughness, and must either be corrected by the contractor or, if approved by the resident engineer, remain in place with a penalty of $5 per linear foot (one lane wide).
- Between 150.0 and 249.9 in/mi, the area will be considered an area of localized roughness, and must either be corrected by the contractor or, if approved by the resident engineer, remain in place with a penalty of $10 per linear foot (one lane wide).
- At 250.0 in/mi or greater, the area of localized roughness must be corrected.

In addition, the initial combined specification which was used in the ghost spec projects (in 2009) had no provision for engineer's judgment for the need to correct an area of localized roughness exceeding 120.0 in/mi. In the revised version, however, this provision is reinserted. As mentioned above, below 125.0 in/mi, no designation of "area of localized roughness" is given. At 250.0 in/mi or greater is the range for "must correct." Between 125.0 and 249.9 in/mi, however, the engineer can decide, based on visual observation and driving the segment, if the area must be corrected, or if it can remain in place with a penalty assessed to the contractor, at the levels described above.

Pay Adjustments after Corrective Work

Another important feature of the combined specification is the inclusion of corrected segments in the computation of pay adjustments. It is recognized that the cost of corrective work is most often greater than the additional incentive that can be earned with a lower IRI value, and that only incremental improvements can be expected on segments without significant "bumps." For this reason, it is not expected that a contractor will correct the pavement surface any more than necessary, or "grind into incentive."

External Review

The project panel solicited external review of the new specification, both before and after the workshops and the ghost spec projects. The primary mode of review was the industry forum held in November 2009, after the ghost spec projects. At this meeting, several contractors and industry representatives participated with the project staff and the technical advisory panel. This section describes the primary responses and suggestions received during this industry forum meeting.

Comments received at this meeting include the following. Some of these were addressed in the specification, and others were taken as information only.

- The testing would be easier with two lasers (to profile both wheel paths at the same time).
- With ALR – make the engineer ride the section before requiring grinding. If engineer can't pick it out, then don't require it.

- Regarding engineering judgment – some engineers want some control, but others want the specification to decide everything.
- Regarding the straightedge length for excluded segments:
    - 10-ft straightedge is too short
    - Use a 25-ft minimum
    - Some participants said 50 ft is appropriate
- Costs of grinding
    - $650-700 / hr for a grinder and operator, + mob/demob
    - 1 bump usually takes 30-45 minutes.
- Percent improvement specification – contractor must collect data before construction in order to get paid the incentive.

Other comments and questions received after the meeting, in private conversations, include the following.

- Would like to see implementation of the line laser in the combined ride specification.
- The 50-foot exclusion at headers is acceptable, as long as it is still measured for ride in some way.
- Recommendation adjustment for ALR penalties, to be more reasonably matched with the actual costs of grinding.
    - $5/lin ft for ALR 125.0-150.0 in/mi (or 125.0-175.0 in/mi)
    - $10/lin ft for ALR 150.0-250.0 in/mi (or 175.0-250.0 in/mi)
- Would Mn/DOT accept ALR computed with software other than ProVAL? Could the specification read "ProVAL or an approved equivalent"?
- When a contractor is required to match existing curb and gutter, he should not be responsible for the ride.
- The average of left and right wheel paths should be used for ALR calculations as well as for smoothness.

Chapter 4. DEVELOPMENT AND PRESENTATION OF WORKSHOPS

As part of the development of the combined ride specification, a training and workshop for certification of profiler operators was developed. The objectives of the workshop are to help participants:

- Understand pavement roughness and its causes,
- Understand the new Mn/DOT combined ride specification,
- Understand the basic operation of the FHWA ProVAL software, and
- Pass a written examination for profiler operator certification.

The modules presented in the workshop include the following.

1. Introduction to Pavement Smoothness
2. Presentation of the Combined Ride Specification
3. General Profiler Operation Principles
4. Introduction to ProVAL and Hands-On Practice Sessions
5. Review and Conclusion

At the end of the workshop, a written, practical examination was administered. This examination consisted of several basic questions regarding the specification and the operation of ProVAL, and general principles related to the cause of potential errors in profile data. The final portion of the examination called for the production of all profile-related submittals required by the specification, using a complete set of data from an actual paving project.

This section describes the development and delivery of certification training, and summaries of the pilot and final workshops conducted.

Content Development

The complete set of slides used in the workshop is presented in Appendix B. The complete set of content developed for the workshop includes the following. Each of these is included in electronic format on the CD accompanying this report.

- **PowerPoint slides**
  - Module 1 – Introduction to Pavement Roughness and Smoothness Measurements
  - Module 2 – Combined Smoothness Specification
  - Module 3 – General Profiler Operation Principles
  - Module 4 – Introduction to FHWA's ProVAL Software
  - Module 5 – Review and Conclusion
- **Participant Notebook**
  - Workshop Agenda
  - Contact Information
  - Workshop Outline
  - Workshop Materials (copies of slides with space for notes – three per page)
  - Hands-on Exercises (step-by-step instructions using ProVAL)
  - Draft Combined Ride Specification

    - Mn/DOT Pavement Surface Smoothness Worksheets (hard copy)
- **Presenter's Notebook**
    - Same information as in the Participant Notebook, except that the workshop materials (slides) are only one slide per page, and include additional notes for the presenter associated with each slide.
- **Final Draft Combined Ride Specification**
- **Other Documents**
    - Sample agenda
    - Sample attendance roster
    - Sample participant and presenter notebook cover pages
    - Sample hands-on training examples
    - Sample certification examination
    - Mn/DOT Pavement Surface Smoothness Worksheets (electronic)
- **Sample Data Files**
    - Sample ERD files used in the hands-on exercises

Pilot Workshop

The pilot workshop was presented to Mn/DOT construction personnel from across the state at the training facility in Arden Hills on 5 March 2009. Based on the comments received at this pilot workshop, several changes were made to the content and presentation of the material. Some of the major changes included:

- Elimination of much of the detailed information about profiles and their effect on drivers,
- Enhancement of the hand-on training and step-by-step examples, and
- Shortening of the review section in the final module.

The workshop materials were revised and reviewed again by the TAP members prior to the certification workshops with contractors and profiler operators.

Certification Workshops

The two certification workshops were conducted on 23 April 2009 and 15 June 2009, at Minnesota State University campuses in Mankato and Edina, respectively. The content presented included the revised materials based on comments received at the pilot workshop.

The two workshops were attended by a total of 16 non-Mn/DOT participants representing contractors and profiling service companies. The participants were generally representatives from contractors who had been asked and agreed to participate in the ghost specification projects in the 2009 construction season.

General comments from the participants indicated that it was informative, and that they felt that they could conduct the profiling and data analysis requirements in the field, but that it would take some time to become familiar with the specification and the data analysis and submittal requirements.

Industry Follow-Up

After the ghost specification projects had been completed, an industry forum was conducted at the Minnesota State University campus at 7700 France Avenue in Edina. A review of the specification was presented and a general discussion regarding the experiences of the profiler operators and contractors involved in the ghost specification was conducted. The comments received were detailed in the previous chapter.

Chapter 5. RECOMMENDATIONS FOR FUTURE IMPLEMENTATION

Based on the development of the combined ride specification and the certification program described in the previous chapters, this chapter presents specific recommendations for further development and implementation.

1. Further implementation of the combined specification through pilot projects and as a primary smoothness specification in the 2010 and 2011 construction seasons, respectively.
2. Continuous review of the specification during its initial years of implementation, and periodic review thereafter. This could include several analyses, including:
    a. Changes in the level of incentives and/or disincentives applied per unit length.
    b. Changes in the amount of optional and required correction on a unit length basis.
    c. Change in unit bid prices for pavement items due to the implementation of the new specification, if possible.
    d. Assessment of the ALR levels (125.0, 150.0, and 250.0 in/mi) and the associated consequences at each level.
3. Development of an online method of workshop delivery and certification examination.
4. Assessment of changes in the pavement profiling industry. The continuous development and improvement of technology will require Mn/DOT to evaluate the benefits of new profiling devices and analysis methods.

REFERENCES

1. R. Boeger and R.J. Crowe, "It's the Ride That Count$," *Public Roads*, vol. 65, no. 4, (Jan/Feb 2002).
2. T. Gerardi and M. Freeman, "Current Smoothness Assessment Methods and Vehicle Response," Presentation, Presented at Pavement Evaluation 2002, Conference of the FWD and Road Profile User's Groups, Roanoke, VA, (2002).
3. W.J. Wilde, *Implementation of an International Roughness Index for Mn/DOT Pavement Construction and Rehabilitation*, Minnesota Local Road Research Board, Report 2007-09, Minneapolis, MN, (2007).

APPENDIX A. FINAL DRAFT COMBINED RIDE SPECIFICATION

2XXX
Pavement Surface Smoothness

2XXX.1 Description

The final mainline and all other pavement surfaces where the posted vehicle speed is 30 mph [48 km/hr] or greater shall be measured using an Inertial Profiler (IP) and the International Roughness Index (IRI), except those specifically excluded by Table 2XXX.5-2. Pavement smoothness for each lane will be computed by obtaining the IRI for the left and right wheel paths in an individual lane and then averaging the results. The averaged results will be used to determine pay adjustments. Each lane shall be tested and evaluated separately.

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 rerun at the Contractor's expense.

The term "smoothness" will mean the composite IRI value per 0.1 mile [0.1609 km] segment on which pay adjustments are made. The term "areas of localized roughness" will mean those areas exceeding the limiting criteria for a continuous IRI calculation with a 25-ft [7.62-m] interval, as computed using the most recent version of the FHWA's Profile Viewing and Analysis (ProVAL) software.

All costs relative to the Contractor providing the IP, appropriate test results, and associated traffic control shall be incidental to the unit bid price for Wearing Course Mixture for bituminous pavements, for Concrete Pavement for concrete pavements, or for Concrete Grinding.

2XXX.2 Equipment

The Contractor shall furnish a properly calibrated, documented, and Mn/DOT-certified IP. The IP shall export raw profile data in an unfiltered ERD file format, and shall produce a profilogram (profile trace of the surface tested). The IP shall conform to the Class 1 requirements of the most recent revision of ASTM E950 and must be certified according to the most recent procedure on file in the Pavement Engineering Section. Mn/DOT certification documentation shall be submitted to the Engineer prior to the IP being used on the project. Settings for individual certified profilers are on file in the Mn/DOT Pavement Engineering Section, and are accessible at www.dot.state.mn.us/materials/smoothness.html.

Profile analysis for determination of IRI and areas of localized roughness will be conducted using the most recent version of the ProVAL Software. IRI values shall be reported in units of in/mi [m/km]. Units of m/km shall be reported to two digits right of the decimal, and units of in/mi shall be reported to one digit right of the decimal, following the rounding procedures found in AASHTO R11.

2XXX.3 Operator Certification

The Contractor shall furnish an operator, trained in the operation of the particular IP furnished under section 2XXX.2, and knowledgeable in the use of the most recent version of the ProVAL software. All profiler operators shall pass a proficiency test and possess a current certification issued by the Department. Documentation of operator certification shall be presented to the Engineer upon request.

2XXX.4 Pavement Surface Testing

The Contractor shall remove all objects and foreign material on the pavement surface prior to surface evaluation. The Contractor will be responsible for all traffic control associated with testing and any corrective work (when applicable) that is required of the final pavement surface.

The IP shall be run in the direction the traffic will be moving. Profiles shall be measured in the left and right wheel paths of each lane.

Each lane will be separated into segments 0.1 mi [0.1609 km] in length. Final segments in a lane that are less than 0.1 mi [0.1609 km] shall be evaluated as an independent segment, and pay adjustments will be prorated

for length. Segments 10 ft [3.05 m] long or less, and the first and last 10 ft [3.05 m] of projects that do not connect to an existing segment for which the Contractor is responsible, shall be evaluated by the Engineer using a 10-ft [3.05-m] straightedge. Surface deviations using the straightedge that deviate from a straight line by more than 1/4 inch in 10 ft [6 mm in 3.05 m] shall be subject to corrective work. Transverse joints shall be evaluated by centering the straightedge longitudinally across the transverse joint.

Each pass shall be made continuously, regardless of length, but shall terminate prior to items in the list of exclusions in Table 2XXX.5-2. The subsequent pass shall begin approximately 50 ft [15.24 m] prior to, and shall include, construction headers and end-of-day work joints. In concrete pavements, terminal headers that tie into existing portland cement concrete pavement shall be evaluated, and smoothness measurements shall begin approximately 50 ft [15.24 m] before and end approximately 50 ft [15.24 m] after terminal headers. Bridge approach panels and bridge surfaces are exempt from these requirements; however, paving start-up areas are not exempt.

For percent improvement projects, the smoothness shall be measured prior to the start of construction (initial IRI) and after the completion of construction (final IRI). Stationing used for the final smoothness measurement shall be the same as that used for the initial smoothness measurement, to allow for a direct comparison when calculating the percent improvement. Both the initial IRI and the final IRI will be measured with the same IP.

A Smoothness

The IRI for the left and right wheel paths in an individual lane will be computed and then averaged when determining pay adjustments. Each lane shall be tested and evaluated separately. The Engineer shall determine the length in miles [kilometers] for each mainline traffic lane. The IP shall be operated at the optimum speed as defined by the manufacturer. For percent improvement projects, the initial IRI and final IRI will be used to calculate the percent ride improvement.

B Areas of Localized Roughness

Areas of localized roughness will be identified using the ProVAL "Smoothness Assurance" analysis, calculating IRI with a continuous short interval of 25 ft [7.62 m] and the 250-mm filter applied. Only the right wheel path will be used to determine areas of localized roughness. The longitudinal limits of the corrective work shall be taken from the ProVAL "Grinding" section within the "Smoothness Assurance" analysis, using the "Default Grinding Strategy" option.

2XXX.5 Exclusions

Table 2XXX.5-1 indicates areas that are excluded from smoothness evaluation, but must still be measured with the IP, and are still subject to evaluation for Areas of Localized Roughness and the 10-ft [3.05-m] straightedge. Table 2XXX.5-2 indicates areas that are excluded from surface testing with the IP, but are subject to evaluation with the 10-ft [3.05-m] straightedge.

Table 2XXX.5-1. Areas Excluded from Smoothness Evaluation

For All Pavements
Paving where the posted vehicle speed is less than 45 mph [73 km/hr]
Ramps, loops, acceleration and deceleration lanes less than 500 ft [152.5 m] in length
Projects less than 1000 ft [305 m] in length
For Bituminous Pavements
Single lift overlays over concrete

Table 2XXX.5-2. Areas Excluded from Smoothness and Areas of Localized Roughness Evaluation

For All Pavements
Turn lanes, crossovers
10 ft [3.05 m] on either side of obstructions such as manholes, water supply castings, etc., in lane in which obstruction is located

Intersections constructed under traffic – begin and end exclusion 100 ft [30.5 m] from the intersection radius
Paved shoulders, side streets, side connections
For Concrete Pavements
Bridge decks and approach panels (The occurrence of bridges shall not interrupt the continuity determination)
Undoweled shoulders less than 10 ft [3.05 m] wide
Headers adjacent to colored concrete

Areas that are excluded from surface testing with the IP but subject to evaluation with the 10-ft [3.05-m] straightedge as shown in Table 2XXX.5-2 above, and that show no variation greater than 1/4 inch in 10 ft [6 mm in 3.05 m] over the span of the straightedge in the longitudinal or transverse direction, may remain in place without correction or penalty if, in the judgment of the Engineer, the smoothness is satisfactory.

Corrected variations will be considered satisfactory when the 10-ft [3.05-m] straightedge shows the deviations are less than or equal to 1/4 inch in a 10 ft [6 mm in a 3.05 m] span in any direction.

2XXX.6 Submittals

This section describes the submittals required throughout the project with respect to pavement surface testing.

A Prior to Profiling

The IP operator shall present to the Engineer current, valid documentation, issued by the Department, indicating the inertial profiling equipment certification and the operator's certification, as described in sections 2XXX.2 and 2XXX.3, respectively.

B Day of Profiling

The Contractor shall submit the printed profilogram (graphical trace), indicating each segment's IRI value, and the signature of the Operator to the Engineer on the same day the profiling is conducted.

The Contractor shall also submit electronic files in ERD format that represent the raw data from each pass. The electronic ERD filenames shall follow the standardized format shown below. Electronic ERD files that do not follow this standardized naming convention will not be accepted.

YYMMDD-T-N-D-L-W-S.ERD

Where:

YY	=	Two-digit year
MM	=	Month (include leading zeros)
DD	=	Day of month (include leading zeros)
T	=	Route type (I, MN, US, CSAH, etc.)
N	=	Route number (no leading zeros) and auxiliary ID (if applicable, for example E, W, etc.)
D	=	Primary route direction (I or D)
L	=	Lane number (1 for driving lane, increasing by one for each lane to the left)
W	=	Wheel path (L, R, or B, indicating Left, Right, or Both)
S	=	Beginning station

For example: "080721-I-35W-I-2-L-5+21.ERD" would indicate a beginning station of 5+21, in the left wheel path of the second lane (one lane left of the driving lane), in the increasing (northbound) direction of I-35W, tested on 21 July 2008.

If the actual data is not submitted by the Contractor to the Engineer on the same day as the profiling was conducted, the Department will not pay incentives for those segments but any disincentives will still apply.

C Upon Completion of Pavement Placement

Within five calendar days after all pavement placement, and prior to the commencement of any corrective work, the Contractor shall submit a paper ProVAL summary report for each lane, indicating the results of the "Ride Statistics at Intervals" and the "Smoothness Assurance" analyses. The Contractor shall follow the naming convention specified in section 2XXX.6.B when creating ProVAL summary reports. If no corrective work is required, the Contractor shall submit the final spreadsheet summary as described in section 2XXX.6.E.

D Prior to Corrective Work

If corrective work is required, the Contractor shall submit a written corrective work plan to the Engineer according to the requirements in section 2XXX.8. The Engineer shall approve of the Contractor's plan prior to the Contract starting corrective work. In addition, the corrective work plan shall include the locations (begin and end points) that will be corrected.

E After Corrective Work

Within five calendar days after all required corrective work is completed, the corrected areas shall be reprofiled with a certified IP according to section 2XXX.4. Updated ProVAL reports as described in section 2XXX.6.C and a spreadsheet summary shall be submitted to the Engineer. The spreadsheet summary shall be in tabular form, with each 0.1-mi [0.1609-km] segment occupying a row. An acceptable spreadsheet summary template in electronic form is available on the Mn/DOT Smoothness web page, which can be accessed at www.dot.state.mn.us/materials/smoothness.html.

2XXX.7 Pay Adjustment

Smoothness requirements will be evaluated by the IRI equations for bituminous pavements, concrete pavements, or percent improvement projects, as applicable. Equations HMA-A, HMA-B, and HMA-C are for use with bituminous pavements. Equations PCC-A and PCC-B are for use with concrete pavements. Equation PI-A is for use with percent improvement projects.

Pay adjustments will be based on the IRI determined for each segment, and will be based on the equations and criteria in Table 2XXX.7-1 (bituminous), Table 2XXX.7-2 (concrete) or Table 2XXX.7-3 (percent improvement) as applicable.

Pay adjustments will only be based on the segment IRI value (or percent improvement value, for percent improvement projects) measured prior to any corrective work, except that segments where corrective work is required shall be reprofiled after corrective work has been performed and included in the pay adjustment calculations. The segment IRI value is the average of the IRI values computed with the left and the right wheel path passes, individually.

For bituminous and bituminous percent improvement projects, the Contractor will not receive a net incentive payment for smoothness if more than 25.0% of all density lots for the project fail to meet minimum density requirements.

A Bituminous Pavements

The total smoothness incentive shall not exceed 10.0% of the total mix price for pavement smoothness evaluated under IRI Equation HMA-A, or 5.0% of the total mix price for pavement smoothness evaluated under Equation HMA-B, or HMA-C. Total mix shall be defined as all mixture placed on the project.

Typically, equation HMA-A will be used for 3-lift minimum construction; equation HMA-B will be used for 2-lift construction; and equation HMA-C will be used for single lift construction.

Table 2XXX.7-1. Pay Adjustments for Bituminous Pavements

Equation	English		Metric	
	IRI in/mi	Pay Adjustment $/0.1-mi	IRI m/km	Pay Adjustment $/0.1609 km
HMA-A	< 30.0	400.00	< 0.47	400.00
	30.0 to 65.0	850.00 – 15.000 x IRI	0.47 to 1.03	850.00 – 957.450 x IRI
	> 65.0	Corrective Work to 56.7 in/mi or lower	> 1.03	Corrective Work to 0.89 m/km or lower
HMA-B	< 33.0	270.00	< 0.52	270.00
	33.0 to 75.0	600.00 – 10.000 x IRI	0.52 to 1.18	600.00 – 638.950 x IRI
	> 75.0	Corrective Work to 60.0 in/mi or lower	> 1.18	Corrective Work to 0.94 m/km or lower
HMA-C	< 36.0	180.00	< 0.57	180.00
	36.0 to 85.0	414.00 – 6.500 x IRI	0.57 to 1.34	414.00 – 410.500 x IRI
	> 85.0	Corrective Work to 63.7 in/mi or lower	> 1.34	Corrective Work to 1.01 m/km or lower

B Concrete Pavements

For concrete pavements, equation PCC-A will be used for projects where the posted speed will be 45 mph [73 km/hr] or greater. For concrete pavement rehabilitation projects, equation PCC-B will be used when the Contract specifies pay adjustments for concrete grinding.

Table 2XXX.7-2. Pay Adjustments for Concrete Pavements

Equation	English		Metric	
	IRI in/mi	Pay Adjustment $/0.1-mi	IRI m/km	Pay Adjustment $/0.1609 km
PCC-A	< 50.0	890.00	< 0.79	890.00
	50.0 to 90.0	2940.00 – 41.000 x IRI	0.79 to 1.42	2940.00 – 2597.800 x IRI
	> 90.0	Corrective Work to 71.7 in/mi or lower	> 1.42	Corrective Work to 1.13 m/km or lower
PCC-B	< 50.0	450.00	< 0.79	450.00
	50.0 to 71.2	1511.30 – 21.226 x IRI	0.79 to 1.12	1511.30 – 1344.900 x IRI
	71.3 to 90.0	0.00	1.13 to 1.42	0.00
	> 90.0	Corrective Work to 90.0 in/mi or lower	> 1.42	Corrective Work to 1.42 m/km or lower

C Percent Improvement Projects

Pay adjustments will be based on the number of segments and the percent improvement values. The total pay adjustment for smoothness shall not exceed 5.0% of the total mix price. Total mix shall be defined as all mixture placed on the project. No corrective work will be required and no negative pay adjustment will be assessed if the initial segment IRI value is less than 60.0 in/mi [0.95 m/km] and the percent improvement is greater than zero. Percent improvement (%I) will be calculated as follows:

$$(\%I) = \frac{(\text{Initial Segment IRI} - \text{Final Segment IRI}) \times 100}{\text{Initial Segment IRI}}$$

where Initial Segment IRI is the IRI determined by the Contractor prior to any patching or other repair, and Final Segment IRI is the IRI determined by the Contractor after paving is completed.

For pay adjustments to be computed, the Initial Segment IRI must be measured prior to construction according to Section 4.A of this specification.

Table 2XXX.7-3. Pay Adjustments for Percent Improvement Projects

Equation	Percent Improvement (%I)	Pay Adjustment, per $/0.1-mi [$/0.1609-km] segment
PI-A	> 64.0	180.00
	15.0 to 64.0	-236.00 + 6.500 x (%I)
	< 15.0	Corrective Work to 36.3%I or higher

2XXX.8 Corrective Work

The Contractor shall notify the Engineer at least 24 hours prior to commencement of the corrective work. The Contractor shall not commence corrective work until the methods and procedures have been approved in writing by the Engineer.

All smoothness corrective work for areas of localized roughness shall be for the entire lane width. Pavement cross slope shall be maintained through corrective areas.

Localized areas for which the IRI value is less than 125.0 in/mi [1.97 m/km] shall be considered acceptable. Localized area for which the IRI value is 125.0 in/mi [1.97 m/km] or greater, or less than 250.0 in/mi [3.94 m/km] may be accepted if the ride is satisfactory in the judgment of the engineer. The engineer may require that such sections either be corrected by the contractor or assessed deductions as indicated in Table 2XXX.8-1. Any localized area for which the IRI value is 250.0 in/mi [3.94 m/km] or greater must be corrected.

Prior to commencing corrective work by grinding, the ProVAL Grinding Simulation, with an 18-foot [5.5-m] wheelbase grinder and a maximum grinder depth of 0.3 in [7.62 mm], must indicate a predicted improvement to the 25-ft IRI value for sections proposed to be ground. If the grinding simulation does not predict improvement for a section, that section must be corrected by a method other than grinding or the appropriate deduction in Table 2XXX.8-1 will apply.

Table 2XXX.8-1. Deductions and Corrective Work Requirements.

ALR (25-ft IRI)	Deduction, per linear 1.0 ft [0.3048 m]
< 125.0 in/mi [1.97 m/km]	Acceptable
≥ 125.0 [1.97 m/km] and < 150.0 [2.36 m/km]	$5
≥ 150.0 [2.36 m/km] and < 250.0 [3.94 m/km]	$10
≥ 250.0 [3.94 m/km]	Must grind or repair

Areas of localized roughness will be considered acceptable when the retested segment indicates no areas of localized roughness. If, after retesting, any areas of localized roughness remain, these will be assessed as indicated in Table 2XXX.8-1.

For concrete pavement rehabilitation projects, the Contractor shall correct all areas of localized roughness for which the IRI value is greater than 90.0 in/mi [1.42 m/km], based on the locations recommended by the ProVAL "Smoothness Assurance" analysis.

Corrective work by diamond grinding may result in thin pavements. The Engineer shall determine if this condition needs to be verified by coring. Additional coring for thickness verification shall be at no cost to the Department. Thin pavement sections after diamond grinding may result in thickness price deductions.

Surface corrections shall be made prior to placing permanent pavement markings. In the event that permanent pavement marking are damaged or destroyed during corrective work, they will be replaced at no cost to the Department.

Residue and excess water resulting from this grinding shall be handled in accordance with Mn/DOT Specification 1717.

A Bituminous Pavements

Unless otherwise approved by the Engineer, corrective work shall be by an approved surface diamond grinding device consisting of multiple diamond blades. Other methods may include overlaying the area, or replacing the area by milling and inlaying. Any corrective work by milling and inlay or by overlay shall meet the specifications for smoothness over the entire length of the correction. If the surface is corrected by milling and inlay or by overlay, the surface correction shall begin and end with a transverse saw cut. The Engineer may require diamond ground bituminous surfaces to be fog-sealed by the Contractor at the Contractor's expense.

B Concrete Pavements

Unless otherwise approved by the Engineer, corrective work shall be by an approved surface diamond grinding device consisting of multiple diamond blades. Joint sealant that has been damaged by diamond grinding on concrete pavement as determined by the Engineer shall be repaired and replaced at no expense to the Department.

C Percent Improvement Projects

The Engineer may require that the Contractor, at no expense to the Department, correct segments with a percentage improvement of less than 15.0%.

2XXX.9 Retesting

The Engineer may require any portion or the total project to be retested if the results are questioned. The Engineer will decide whether Mn/DOT, an independent testing firm, or the Contractor will retest the roadway surface.

If the retested IRI values differ by more than 10.0% from the original IRI values, the retested values will be used as the basis for acceptance and any pay adjustments. If the retested data is within 10.0% of the original IRI values, the original data will be used. The Contractor will be responsible for any costs associated with retesting if the retested values differ by more than 10.0% from the original values.

If the Engineer directs the Contractor or an independent testing firm to perform retesting (besides that required after corrective work) and the original results are found to be accurate, the Department will pay the Contractor or the independent testing firm $100.00 per lane mile [$62.14 per lane km] that is retested, with a minimum charge of $500.00.

APPENDIX B. TRAINING MATERIALS – PARTICIPANT WORKBOOK

Pavement Smoothness Workshop

Participant Workbook

Mn/DOT Pavement Smoothness Specifications

FHWA ProVAL Software Ver. 2.7

Minnesota State University, Mankato
23 April 2009

Minnesota State University, 7700 France Ave.
15 June 2009

Contents

Workshop Agenda

Objectives of this Workshop

- Understand pavement roughness and what causes it.
- Understand the new Mn/DOT pavement smoothness specification.
- Understand the basic operation of the FHWA ProVAL software.
- Be prepared to pass a written examination for profiler operator certification.

Agenda

8:30 am	Registration
9:00 am	Welcome
9:10 am	Session 1 – Introduction to Pavement Roughness and Smoothness Measurements
9:50 am	Session 2 – New Smoothness Specification
10:50 am	Break
11:00 am	Session 3 – General Profiler Operation
12:00 am	Lunch (on your own)
1:00 pm	Session 4 – Introduction to ProVAL (part 1)
2:15 pm	Break
2:30 pm	Session 4 – Introduction to ProVAL (part 2)
3:00 pm	Session 5 – Conclusion and Workshop Evaluations
3:30 pm	Certification Testing
4:00 pm	Adjourn

Contact Information

If you would like more information about the topics covered in this workshop, or if you have specific comments or questions about the workshop or the material presented, please contact the presenters or the Mn/DOT Pavement Unit staff. Their contact information is below.

Thank you for your participation in the Mn/DOT Pavement Smoothness Specifications Workshop.

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Workshop Outline

Session 1: Introduction to Pavement Roughness

- Introduction of presenters and participants
- Workshop Overview and Objectives
- What is Pavement Roughness?
- What Causes Pavement Roughness?
- Benefits of Smooth Pavements
- Review of Smoothness Measurements
- Smoothness Indices

Session 2: Mn/DOT's New Smoothness Specification

- Overview of the Combined Specification
- What's New in the Combined Specification?
- Surface Testing
- Submittals
- Corrective Work
- Pay Adjustments
- Retesting
- Certification

Session 3: General Profiler Operation

- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation and Submittal

Session 4: Introduction to ProVAL

- General Features
- Smoothness Analyses
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Report Preparation and Submittal

Session 5: Conclusion

- Workshop Review
- Review of Smoothness Specification
- Other States' Specifications

Hands-on Exercises

List of Sample Files

Example1-ImportingAndViewing.erd

Example2-5-RideStatistics.erd

Example6-ProVAL-Reports.erd

SampleProfile-Right.erd

SampleProfile-Left.erd

SampleProfile-Right-AfterGrinding.erd

SampleBituminousProfile.erd

SampleConcreteProfile.erd

List of Examples

☐ 1. Importing and viewing profiles in ProVAL

☐ 2. Analyzing ride statistics at intervals

☐ 3. Analyzing smoothness assurance

☐ 4. Conducting grinding simulation

☐ 5. Generating ProVAL reports

☐ 6. Pay Adjustment Worksheets

☐ 7. Overall step-by-step process

Minnesota Department of Transportation
Pavement Smoothness Specifications
Workshop

Module 1
Pavement Roughness and
Smoothness Measurements

Workshop Overview

Roughness Intro
- Workshop Overview
- Workshop Objectives
- Module Introduction
- What is Pavement Roughness?
- What causes it?
- Benefits of smooth pavements
- Smoothness Measurements
- Smoothness Indices

- Introduction to Pavement Roughness
- Measures of Smoothness
- New Mn/DOT Smoothness Specification
- General Profiler Operation
- Introduction to ProVAL
- Conclusion

Workshop Objectives

Roughness Intro
- Workshop Overview
- Workshop Objectives
- Module Introduction
- What is Pavement Roughness?
- What causes it?
- Benefits of smooth pavements
- Smoothness Measurements
- Smoothness Indices

- Understand
  - pavement roughness and its causes
  - the new Mn/DOT pavement smoothness specification
  - basic operation of ProVAL
- Pass a written examination for operator certification

Module Introduction

Roughness Intro
Workshop Overview
Workshop Objectives
Module Introduction
What is Pavement Roughness?
What causes it?
Benefits of smooth pavements
Smoothness Measurements
Smoothness Indices

- What is pavement roughness?
- What causes it?
- Benefits of smooth pavements.
- Smoothness Measurements
- Smoothness Indices

What is Pavement Roughness?

What is Pavement Roughness?

Roughness Intro
Workshop Overview
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What is Pavement Roughness?
What causes it?
Benefits of smooth pavements
Smoothness Measurements
Smoothness Indices

Pavement Roughness

Deviations of a surface from a true planar surface with characteristic dimensions that affect ride quality.[1]

Pavement Smoothness

Lack of roughness. Free of bumps and dips that cause discomfort to the traveling public. [2]

[1]ASTM International; [2]NHI

What is Pavement Roughness?

Roughness Intro
- Workshop Overview
- Workshop Objectives
- Module Introduction
- What is Pavement Roughness?
- What causes it?
- Benefits of smooth pavements
- Smoothness Measurements
- Smoothness Indices

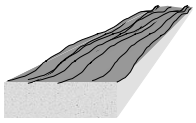
Public's Definition

"I may not be able to define pavement roughness, but I know it when I feel it!"

What is Pavement Roughness?

Roughness Intro
- Workshop Overview
- Workshop Objectives
- Module Introduction
- What is Pavement Roughness?
- What causes it?
- Benefits of smooth pavements
- Smoothness Measurements
- Smoothness Indices

A slice of the road surface on an imaginary line



What is Pavement Roughness?

Roughness Intro
- Workshop Overview
- Workshop Objectives
- Module Introduction
- What is Pavement Roughness?
- What causes it?
- Benefits of smooth pavements
- Smoothness Measurements
- Smoothness Indices

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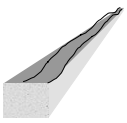
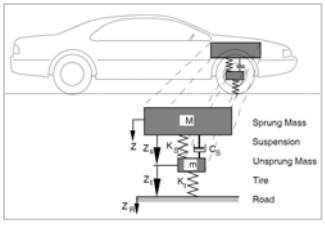


What is Pavement Roughness?

A slice of the road surface on an imaginary line

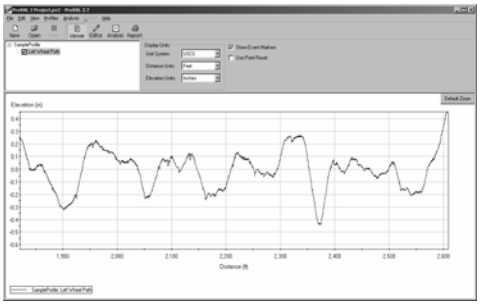
What is Pavement Roughness?



The traditional Quarter-Car Model

Gillespie, 1992

What is Pavement Roughness?



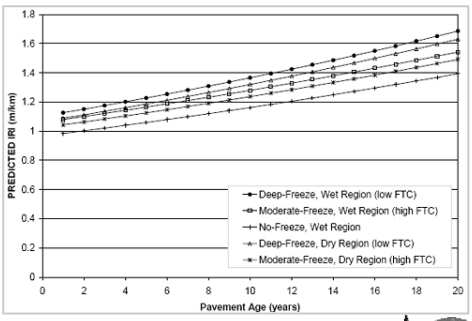
What Causes Pavement Roughness?

What Causes Pavement Roughness?

- Traffic
- Climate
- Construction
- Materials

Traffic-Related Roughness

Climate-Related Roughness



Construction-Related Roughness

- "…initially smoother pavements perform longer with fewer needed maintenance activities than initially rougher pavements."

ASTM, 2001

Materials-Related Roughness

- Mix-related
  - Bituminous: tender mixes
  - Concrete: ravel-susceptible surfaces
- Subsurface
  - Moisture susceptibility
  - Permanent deformation

Benefits of Smooth Pavements

Benefits of Pavement Smoothness

- Last longer
- Improved Safety
- Satisfied public
- Save money
  - Fuel
  - Vehicle maintenance

Benefits of Pavement Smoothness

Last longer

- "a pavement with a higher initial [smoothness] will last longer than an otherwise equivalent, but initially rougher, pavement"
- "smoothness specifications… have been shown to be an effective means of achieving higher levels of initial smoothness"

NCHRP 1-31

Benefits of Pavement Smoothness

Reduction in Initial Roughness	Average % Increase in Service Life	
	Asphalt	Concrete
10%	5	7
25%	13	18
50%	27	36

SME

Benefits of Pavement Smoothness

Safer

– "bumps, dips, and other changes in the surface profile … in extreme cases may represent a potential safety hazard."

NCHRP 1-31

Benefits of Pavement Smoothness

Satisfied public

– "smoothness is the public's measure of quality workmanship"
– "smoothness is the most significant measure motorists use to judge the quality of our Nation's roads"

NQI Survey

Benefits of Pavement Smoothness

Roughness Intro
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Save money

- "for a 10% decrease in IRI, fuel economy increased by 4.5%"[1]
- "driving on too-rough roads costs our Nation's motorists $23 billion per year in extra vehicle operating costs"[2]

[1]FHWA; [2]USDOT

Review of Smoothness Measurements

Smoothness

Smoothness
Workshop Overview
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Smoothness Indices

- Measurement Methods
  - Rolling Straightedge
  - Profilometer
  - Inertial Profiler

Measuring the Profile

- We have no idea what the true profile looks like between two data points

Measuring the Profile

- We have no idea what the true profile looks like between two data points

Measuring the Profile

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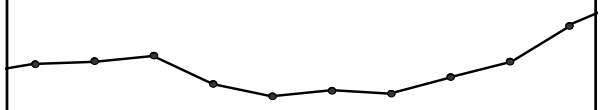

Measuring the Profile

- Profilers do not measure the “true” profile
- They capture a sample of the true profile
- A profiler is valid if it produces the same ride statistics that would be obtained from the true profile

Rolling Straightedge

Geotest

Rolling Straightedge

Smoothness

- Workshop Overview
- Workshop Objectives
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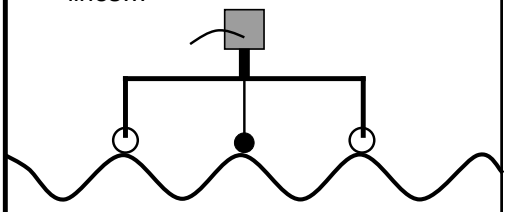
- The Straightedge makes some wavelengths look like straight lines…



- There is no vertical deviation of the recording wheel

Rolling Straightedge

Smoothness

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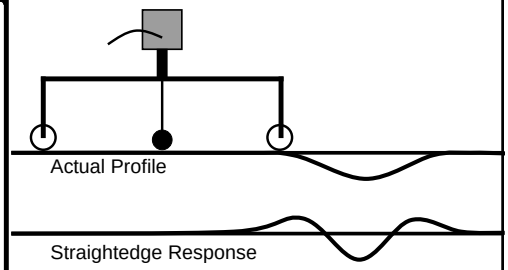

Rolling Straightedge

Smoothness

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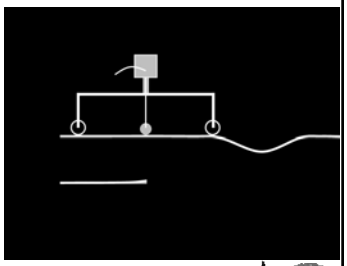
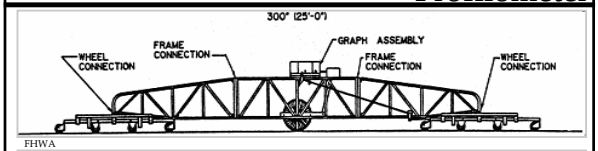
Actual Profile

Straightedge Response



Profilometer



FHWA


SSI, Inc.

Profilometer

Smoothness

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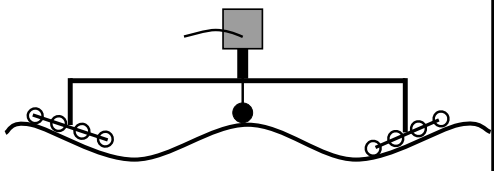

Inertial Profiler

Inertial Profiler

Smoothness

- Workshop Overview
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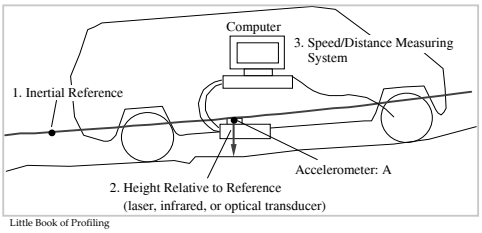

Little Book of Profiling

Smoothness Indices

Smoothness Indices

Smoothness

- Workshop Overview
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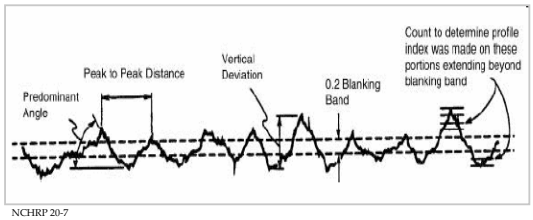
- Profile Index
- International Roughness Index

Profile Index

- Measurements recorded by a profilograph are used to obtain the PI of the pavement
- The PI is one measure of the smoothness of the roadway

Profilograph Trace



NCHRP 20-7

Profile Index

- Some states use a 0.2-inch “blanking band” that masks much of the minor roughness.
- Many have gone to a 0.0-inch blanking band.

International Roughness Index

Smoothness

Workshop Overview
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Benefits of smooth pavements
Smoothness Measurements
Smoothness Indices

- In 1982, the World Bank conducted an experiment in Brazil to establish an international standard for roughness measurements
- Initially, this was to provide a standard way of allocating funding for pavement construction and maintenance in third world countries.

International Roughness Index

Smoothness

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- Resulted in the IRI
- Widespread use in the US since 1990

International Roughness Index

Smoothness

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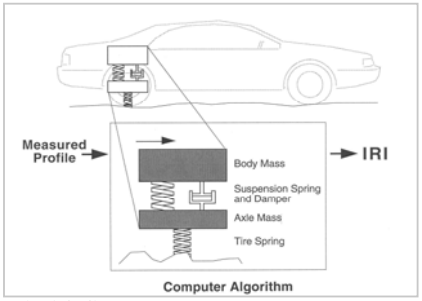

Little Book of Profiling

International Roughness Index

- The “quarter-car” models
  - Tire
  - Mass of the axle
  - Suspension spring and damper
  - Mass of the body
- Computation of IRI is standardized in ASTM E 1926

Advantages of the IRI

- Reproducible, portable and stable with time
- Describes vehicle vibrations caused by roughness

Advantages of the IRI

- IRI is more representative of how the road feels by the “seat of the pants”.
- PI measures vertical deviations of the profile only, not frequencies and amplitudes.

Testimonial!

Smoothness

- Workshop Overview
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"One of my associates who does pavement analysis for us likens [IRI] to air temperature versus wind chill factor."

"Air temperature is really what the road profile is…"

Gomaco World Magazine, 2002

Testimonial!

Smoothness

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"The wind chill factor is what you feel and IRI is really what you feel, in this case, in the seat of your pants as a response to the road profile."

Gomaco World Magazine, 2002

Coming Up Next…

Smoothness

- Workshop Overview
- Workshop Objectives
- Module Introduction
- What is Pavement Roughness?
- What causes it?
- Benefits of smooth pavements
- Smoothness Measurements
- Smoothness Indices

New Mn/DOT Combined Specification

Minnesota Department of Transportation
Pavement Smoothness Specifications
Workshop

Module 2
New Smoothness Specification

Module Introduction

New Specification
- Module Introduction
- Module Objectives
- Combined Specification
- What's New?
- Surface Testing
- Submittals
- Corrective Work
- Pay Adjustments
- Retesting
- Certification

- Objectives
- Combined Specification
- What's New?
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- Certification

Module Objectives

New Specification
- Module Introduction
- Module Objectives
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- What's New?
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- Certification

- Understand the new Mn/DOT smoothness specification
- Become prepared to pass the "specification" portion of the written certification examination.

Combined Specification

Combined Smoothness Specification

New Specification

Module Introduction
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Combined Specification
What's New?
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Certification

1. Description
2. Equipment
3. Operator Certification
4. Pavement Surface Testing
5. Exclusions
6. Submittals
7. Pay Adjustment
8. Corrective Work
9. Retesting

What's New?

What's New?

New Specification
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Certification

- Operator Certification
- Areas of Localized Roughness
- FHWA ProVAL Software

Operator Certification

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- Operators must be
  - "trained in the operation of the particular IP" used on the project
  - Knowledgeable in the use of ProVAL
- Operators must pass a proficiency test and possess current certification.

Areas of Localized Roughness

New Specification
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Module Objectives
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Certification

- Identified by ProVAL software
- Replaces "Bump and Dip" specification
- More about ALR to come…

ProVAL Software

New Specification
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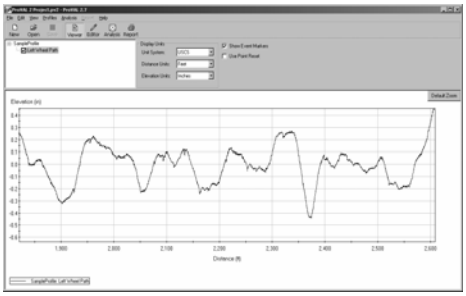

ProVAL Software

New Specification
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Certification

- Developed by FHWA
- Specified by at least 6 states, AASHTO, and FHWA Western Federal Lands Division

ProVAL Software

New Specification
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Certification

- Calculates pavement smoothness statistics
- Determines areas of localized roughness
- Determines best grinding strategies
- Simulates results of grinding
- Introduction to ProVAL – Module 4

Surface Testing

Pavement Surface Testing

- Two statistics:
  - Smoothness
  - Areas of localized roughness (ALR)

Pavement Surface Testing

General

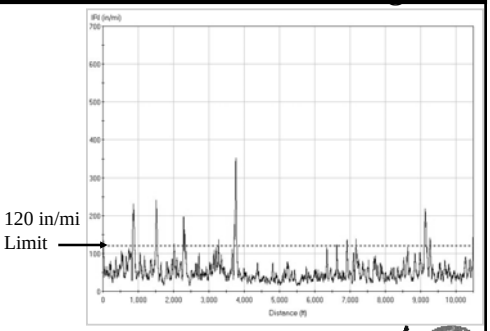
- 0.1-mi segments
- Short segments tested by 10-ft straightedge
  - If vertical deviation > ¼ inch, corrective work
- Continuous passes, divided into segments by ProVAL

Smoothness

Basic Procedure

1. Measure profile in *both* left and right wheel paths
2. Determine IRI using ProVAL for each wheel path, for each segment
3. Average left and right wheel path IRI values for a segment to determine pay adjustments

Areas of Localized Roughness



Areas of Localized Roughness

- Right wheel path only
- Apply 250-mm filter (on ProVAL "Smoothness" tab)
- Recommended corrective work determined on "Grinding" tab

Areas of Localized Roughness

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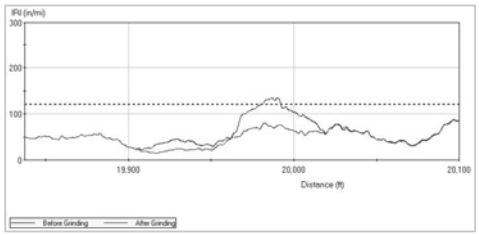
ProVAL "Grinding Results"



Exclusions

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- Two tables of excluded areas
- Table 5-1: Areas excluded from Smoothness Evaluation (still subject to ALR)
- Table 5-2: Areas excluded from Smoothness and ALR

Exclusions

New Specification
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- Table 1

Table 2XXX.5-1. Areas Excluded from Smoothness Evaluation

For All Pavements
Paving where the posted vehicle speed is less than 73 km/hr [45 mph]
Ramps, loops, acceleration and deceleration lanes
Projects less than 305 m [1000 ft] in length
For Bituminous Pavements
Single lift overlays over concrete

Exclusions

- Table 2

Table 2XXX.5-2. Areas Excluded from Smoothness and Areas of Localized Roughness Evaluation

For All Pavements
Turn lanes, crossovers
3.05 m [10 ft] on either side of obstructions such as manholes, water supply castings, etc., in lane in which obstruction is located
Intersections constructed under traffic – begin and end exclusion 30.5 m [100 ft] from the intersection radius
Paved shoulders, side streets, side connections
For Concrete Pavements
Bridge decks and approach panels (The occurrence of bridges shall not interrupt the continuity determination)
Undoweled shoulders less than 3.05 m [10 ft] wide
Headers adjacent to colored concrete

Exclusions

- All Table 2 excluded areas still subject to 10-ft straightedge
  - ¼-inch vertical deviation in 10 ft

Submittals

Submittals

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- Prior to Profiling
- Day of Profiling
- Completion of Pavement Placement
- Prior to Corrective Work
- After Corrective Work

Prior to Profiling

New Specification
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- Present current, valid documentation
  - Inertial Profiling Equipment
  - Operator

Day of Profiling

New Specification
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- Printed Profilogram (graphical trace)
  - Each segment's IRI value
  - Signature of operator
- Electronic data files in ERD format
  - Standardized filenames

Day of Profiling

New Specification
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If the printed trace with IRI data is not submitted by the Contractor to the Engineer on the same day as the profiling was conducted, the Department will not pay incentives for those segments but any disincentives will still apply.

ERD Filenames

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- YYMMDD-T-N-D-L-W-S.ERD
  - YY = two-digit year
  - MM = month (with leading zeroes)
  - DD = day of month (with leading zeroes)
  - T = route type (I, MN, US, CSAH, etc.)
  - N = route number and auxiliary ID (E, W, etc.)

ERD Filenames

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- YYMMDD-T-N-D-L-W-S.ERD
  - D = primary route direction (I or D)
  - L = lane number (1=driving lane, increased by one for each lane to the left)
  - W = wheel path ('L'eft, 'R'ight, or 'B'oth)
  - S = Beginning station

ERD Filenames

For example:

090721-I-035W-I-2-L-5+21.ERD

Left wheel path, second lane (one lane left of driving lane), increasing (northbound) direction, beginning at station 5+21, I-35W, tested on 21 July 2009.

Completion of Pavement Placement

- Paper ProVAL summary report for each lane
  - Indicate results of "Ride Statistics at Intervals" and "Smoothness Assurance" analyses.
  - Use ERD naming method in ProVAL.

Prior to Corrective Work

- Written corrective work plan (see Corrective Work section)
  - Include locations (begin and end points) to be corrected
  - Obtain Engineer's approval prior to beginning corrective work

After Corrective Work

New Specification
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- Spreadsheet summary and updated ProVAL reports
  - Within 5 calendar days after all corrective work is completed

IRI Before and After Corrective Work

New Specification
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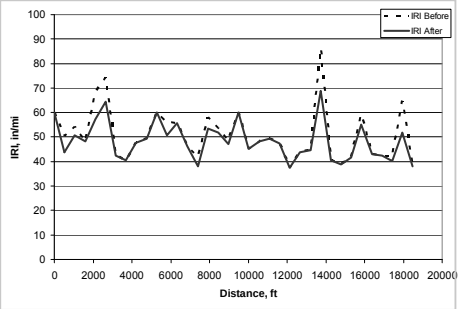

Completion of Pavement Placement

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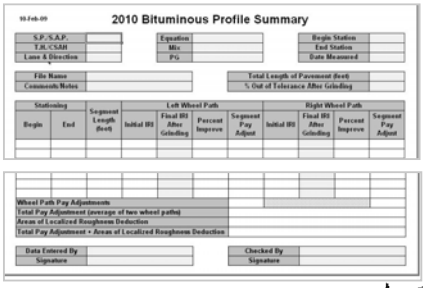
Bituminous


2010 Bituminous Profile Summary

Completion of Pavement Placement

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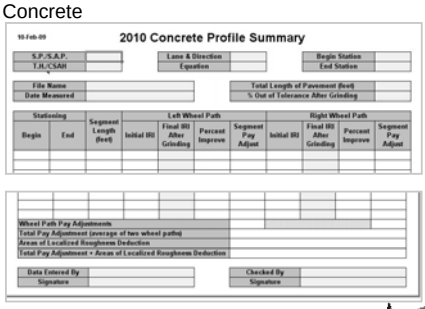
Concrete



10-Feb-09

2010 Concrete Profile Summary

S.P./S.A.P.		Lane & Direction		Begin Station	
T.H./CSAH		Equation		End Station	
File Name			Total Length of Pavement (feet)		
Date Measured			% Out of Tolerance After Grinding		

Stationing			Left Wheel Path				Right Wheel Path			
Begin	End	Segment Length (feet)	Initial IRI	Final IRI After Grinding	Percent Improve	Segment Pay Adjust	Initial IRI	Final IRI After Grinding	Percent Improve	Segment Pay Adjust

Wheel Path Pay Adjustments	
Total Pay Adjustment (average of two wheel paths)	
Areas of Localized Roughness Deduction	
Total Pay Adjustment + Areas of Localized Roughness Deduction	

Data Entered By Signature		Checked By Signature	

Corrective Work

Corrective Work

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Certification

- Notify Engineer at least 24 hours prior to commencement of corrective work
- Corrective work for full lane width
- Maintain pavement cross slope

Corrective Work

New Specification
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Certification

- ALR locations defined by ProVAL "Smoothness Assurance" analysis
- ALR is any area where the localized IRI is greater than 120.0 in/mi
- Initial corrective work in areas specified by ProVAL is required.

Corrective Work

New Specification
Module Introduction
Module Objectives
Combined Specification
What's New?
Surface Testing
Submittals
Corrective Work
Pay Adjustments
Retesting
Certification

- After corrective work, any area remaining > 120.0 in/mi is assessed deduction of $2.00 per linear foot.

Corrective Work

New Specification
Module Introduction
Module Objectives
Combined Specification
What's New?
Surface Testing
Submittals
Corrective Work
Pay Adjustments
Retesting
Certification

- When grinding is excessive, Engineer may request additional thickness cores.
- Thickness pay adjustments determined *after* smoothness corrective work.

Corrective Work

New Specification
Module Introduction
Module Objectives
Combined Specification
What's New?
Surface Testing
Submittals
Corrective Work
Pay Adjustments
Retesting
Certification

- For concrete rehabilitation projects, correct ALR where IRI > 90.0 in/mi

Corrective Work – Bituminous

New Specification
Module Introduction
Module Objectives
Combined Specification
What's New?
Surface Testing
Submittals
Corrective Work
Pay Adjustments
Retesting
Certification

- Acceptable Methods
  - Diamond grinding (preferred)
  - Overlay
  - Mill and inlay
- After grinding, fog seal may be required

Corrective Work – Concrete

New Specification
Module Introduction
Module Objectives
Combined Specification
What's New?
Surface Testing
Submittals
Corrective Work
Pay Adjustments
Retesting
Certification

- Diamond grinding (unless otherwise approved)
- After grinding, repair any joint sealant damage

Corrective Work – Percent Improvement

New Specification
Module Introduction
Module Objectives
Combined Specification
What's New?
Surface Testing
Submittals
Corrective Work
Pay Adjustments
Retesting
Certification

- Engineer may require correction where percent improvement is less than 15.0%.

Pay Adjustments

Pay Adjustments

New Specification
Module Introduction
Module Objectives
Combined Specification
What's New?
Surface Testing
Submittals
Corrective Work
Pay Adjustments
Retesting
Certification

- Select appropriate Table
  - Table 10-1: Bituminous
  - Table 10-2: Concrete
  - Table 10-3: Percent Improvement

Pay Adjustments

New Specification
Module Introduction
Module Objectives
Combined Specification
What's New?
Surface Testing
Submittals
Corrective Work
Pay Adjustments
Retesting
Certification

- Bituminous Equations
  - HMA-A (3-lift construction)
  - HMA-B (2-lift construction)
  - HMA-C (1-lift construction)
- Concrete Equations
  - PCC-A (≥ 45 mph posted speed)
  - PCC-B (diamond grinding for rehabilitation)

Pay Adjustments

New Specification
Module Introduction
Module Objectives
Combined Specification
What's New?
Surface Testing
Submittals
Corrective Work
Pay Adjustments
Retesting
Certification

- Percent Improvement Equations
  - PI-A

Pay Adjustments

New Specification
Module Introduction
Module Objectives
Combined Specification
What's New?
Surface Testing
Submittals
Corrective Work
Pay Adjustments
Retesting
Certification

- Based on segment IRI value (average of left and right wheel path IRI values)
- After corrective work is complete
- For bituminous and percent improvement projects, no net incentive if > 25% of density tests failed.

Bituminous Pay Adjustments

- Max adjustment of 10% of total mix price for HMA-A, or 5% of total mix price for HMA-B or HMA-C.
- In general:
  - HMA-A: 3-lift construction
  - HMA-B: 2-lift construction
  - HMA-C: single lift construction

Bituminous Pay Adjustments

HMA-A (3-lift)	IRI, in/mi	Pay Adjustment, per segment
	< 30.0	$400
	30.0 to 65.0	$(850 – 15·IRI)
	> 65.0	Corrective Work to ≤ 56.7 in/mi

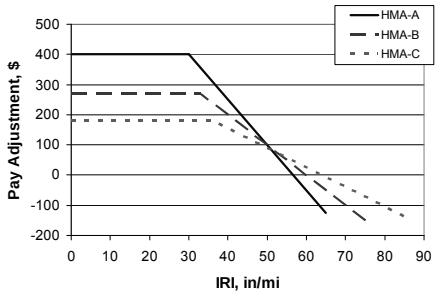
Bituminous Pay Adjustments

HMA-B (2-lift)	IRI, in/mi	Pay Adjustment, per segment
	< 33.0	$270
	33.0 to 75.0	$(600 – 10·IRI)
	> 75.0	Corrective Work to ≤ 60.0 in/mi

Bituminous Pay Adjustments

HMA-C (1-lift)	IRI, in/mi	Pay Adjustment, per segment
	< 36.0	$180
	36.0 to 85.0	$(414 – 6.5·IRI)
	> 85.0	Corrective Work to ≤ 63.7 in/mi

Bituminous Pay Adjustments



Concrete Pay Adjustments

- In general:
  - PCC-A: For posted speeds ≥ 45 mph
  - PCC-B: When contract specified diamond grinding for rehabilitation

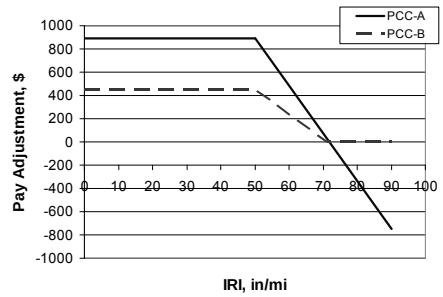
Concrete Pay Adjustments

PCC-A	IRI, in/mi	Pay Adjustment, per segment
	< 50.0	$890
	50.0 to 90.0	$(2940 – 41·IRI)
	> 90.0	Corrective Work to ≤ 71.7 in/mi

Concrete Pay Adjustments

PCC-B	IRI, in/mi	Pay Adjustment, per segment
	< 50.0	$450
	50.0 to 71.2	$(1511.30 – 21.226·IRI)
	71.3 to 90.0	$0
	> 90.0	Corrective Work to ≤ 90.0 in/mi

Concrete Pay Adjustments



Percent Improvement Pay Adjustments

$$\%I = \frac{(Initial\ \ Segment\ \ IRI - Final\ \ Segment\ \ IRI)}{Initial\ \ Segment\ \ IRI} \times 100$$

- Max adjustment of 5% of total mix price
- No corrective work required if Initial IRI is < 60.0 in/mi and %I > 0.

Percent Improvement Pay Adjustments

PI-A	Percent Improvement, (%I)	Pay Adjustment, per segment
	> 64.0	$180
	15.0 to 64.0	$(6.5·%I - 236)
	< 15.0	Corrective Work to ≥ 36.0 %I

Retesting

Retesting

- If results are questioned, Engineer may require retesting of an area or entire project.
- If retested results differ by more than 10% of original IRI values, use retested values. Otherwise, use original values.

Retesting

- If retested results differ by more than 10% of original IRI values, Contractor is responsible for retesting costs.

Retesting

- Retesting is not the same as Reprofiling!
  - Retesting is done when the agency's results are more than 10% different than the contractor's results
  - Reprofiling is done after corrective work, for computation of pay adjustments.

Certification

Certification

New Specification

- Module Introduction
- Module Objectives
- Combined Specification
- What's New?
- Surface Testing
- Submittals
- Corrective Work
- Pay Adjustments
- Retesting
- Certification

- Equipment certified annually at MnROAD

Equipment Certification

New Specification

- Module Introduction
- Module Objectives
- Combined Specification
- What's New?
- Surface Testing
- Submittals
- Corrective Work
- Pay Adjustments
- Retesting
- Certification

Equipment Certification

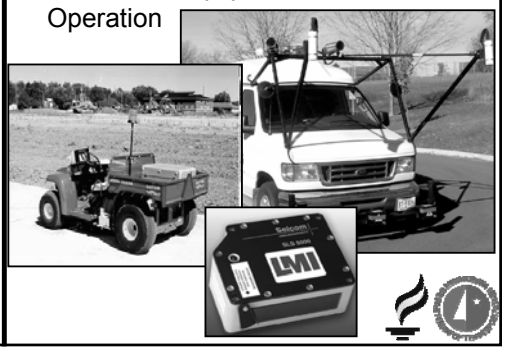
- 2009 Equipment Certification at MnROAD facility:
  - May 4-7, 2009
  - May 11-14, 2009

Operator Certification

- Operators certified every two years at MnROAD or online
  - Initially, full training course
  - Re-certification by short refresher course
  - Must pass written exam on course content

Coming Up Next…

Smoothness Equipment and Operation



Minnesota Department of Transportation
Pavement Smoothness Specifications
Workshop

Module 3
General Profiler Operation

Module Introduction

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation and Submittal

Module Objectives

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Understand need for certification and calibration
- Understand the potential factors that may affect the measured profiles
- Understand the general testing principles of the new specification
- Become prepared to learn data processing using ProVAL

Profiling Equipment

Profiling Equipment

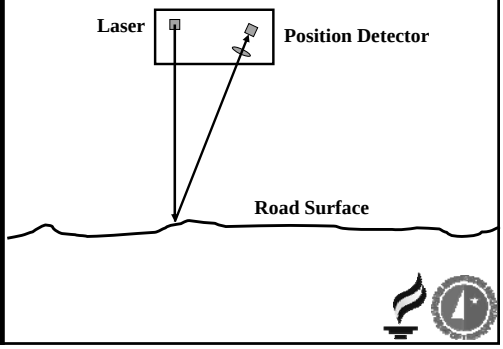
- Height Sensor
- Accelerometer
- Distance Measuring Instrument

Height Sensor

- Measures distance from vehicle to pavement surface
- Must be corrected to subtract vehicle "bounce"

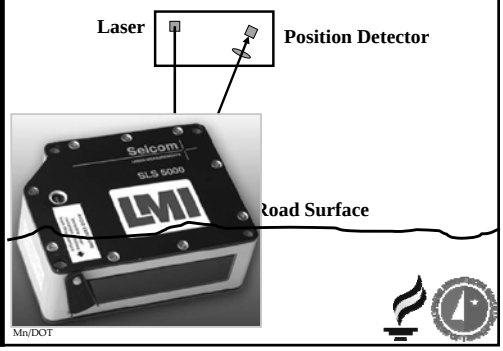
Height Sensor

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation



Height Sensor

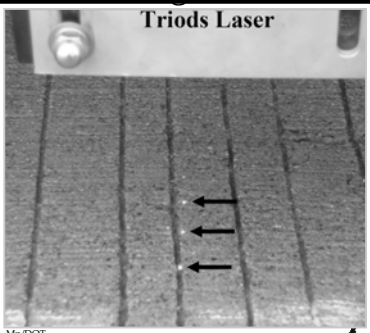
General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation



Mn/DOT

Height Sensor – Laser

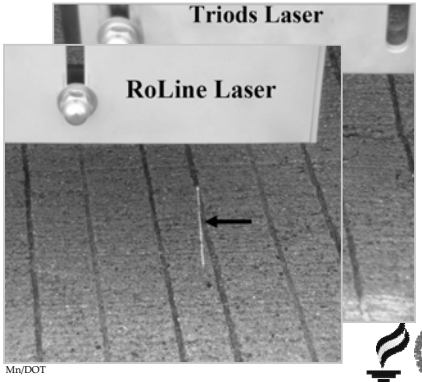
General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation



Mn/DOT

Height Sensor – Laser

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation



Mn/DOT

Accelerometer

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Measures vertical acceleration – vehicle bounce
- Acceleration is integrated twice to obtain displacement
- Measures vehicle's up and down movement

Accelerometer

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation


PCB Piezotronics

Distance Measuring Instrument

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- DMI Measures distance traveled by profiler
- Sometimes attached to wheel – counts wheel rotations
- Can be affected by rolling radius of tire

Profile Measurement

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Combined output of height sensor, accelerometer, and distance measurement

Factors Affecting Profiles

External Factors Affecting Measurement

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Pavement
- Environment

Pavement-Related Factors

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Vertical alignment
- Lateral location of testing
- Surface texture
- Pavement markings
- Daily variations (concrete slabs)

Vertical and Horizontal Alignment

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Accelerometer can be affected when grades greater than 6%

Lateral Location

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Test in locations required by specification
- Repeat measurements require testing in same path

Surface Texture

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Should not be a factor for laper profilometers
- Newer line lasers or footprint lasers average over texture, similar to a tire

Pavement Markings

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Avoid profiling over reflective pavement markings

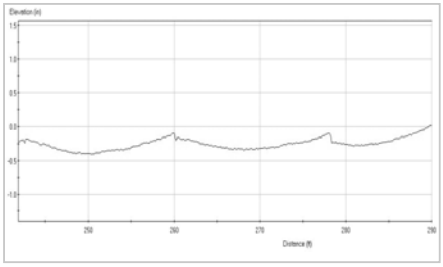
Daily Variations – Concrete

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Concrete slab edges curl upward when cool on top
- As slab warms, it becomes flatter
- Usually more pronounced in early morning

Daily Variations – Concrete

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation



Environment-Related Factors

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Wind
- Temperature
- Humidity
- Surface Moisture

Always follow manufacturer's recommendations

Wind

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Not a significant factor
- May impede consistent tracking ability

Temperature

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Some lasers require proper operating temperature
- Normally between 0 and 40 C (32 and 104 °F)

Humidity

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Normal operating conditions should be less than 90% humidity
- Avoid conditions where condensation occurs

Surface Moisture

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Profiling dry pavements is best
- Damp pavement is acceptable
- Do not profile with standing water present
- Avoid profiling when passing vehicles cause water spray

General Operation Principles

Profiler Operation

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Pre-operations checks
- Operating Procedures
- Post-operations checks
- Frequent Verification

Pre-Operations Checks

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Tire pressure
  - To ensure DMI accuracy
- Sensors
  - Clean sensor glass
  - Check for damage

Pre-Operations Checks

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Static Height Test
  - Place calibration block below sensor
  - Obtain reading from sensor
  - Should be within 1% of actual height
- Bounce Test
  - Physically bounce profiler while stationary
  - Bouncing motion should not appear on profile

Operating Procedure

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Operating Speed
- Lead-in
- Lateral Position
- Longitudinal Position

Operating Speed

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

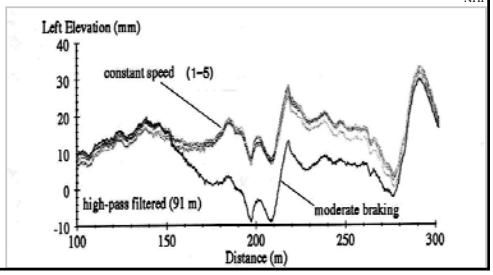
- Accelerometers cannot measure vertical acceleration at low speeds
- High speed profilers generally require 15 – 65 mph
- Maximum speed for lightweight profilers is about 20 mph

Operating Speed

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Maintain constant speed
- Data can be corrupted when accelerating or decelerating

NHI



Operating Speed

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Do not stop and restart during a run
- If required to stop, restart at beginning point
- Use vehicle's cruise control, if available

Lead-In

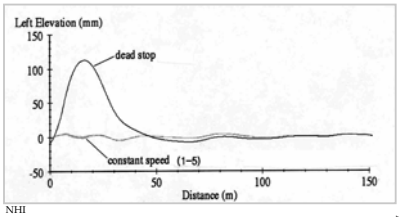
General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Lead-in distance used for accelerating and initializing data
- Follow manufacturer's recommendation for lead-in distance
- Improper lead-in distance will distort profile data

Lead-In

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

Effect of omitting lead-in distance



NHI

Lateral Position

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Operate profiler in a straight line, maintaining sensors inside wheel path

Lateral Position

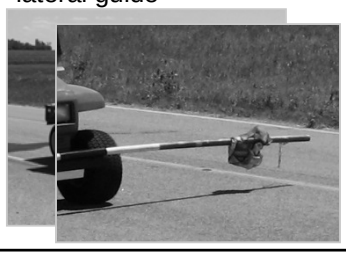
General Operation
Module Introduction
Module Objectives
Profiling Equipment
Factors Affecting Profiles
General Operation Principles
Potential Sources of Error
Report Generation

- Use centerline, pavement edge, longitudinal joint, etc., as a guide
- Lightweight profilers may use a lateral guide

Lateral Position

General Operation
Module Introduction
Module Objectives
Profiling Equipment
Factors Affecting Profiles
General Operation Principles
Potential Sources of Error
Report Generation

- Use centerline, pavement edge, longitudinal joint, etc., as a guide
- Lightweight profilers may use a lateral guide

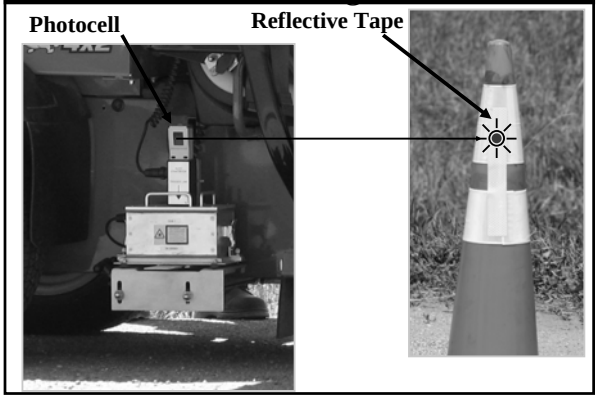


Longitudinal Position

General Operation
Module Introduction
Module Objectives
Profiling Equipment
Factors Affecting Profiles
General Operation Principles
Potential Sources of Error
Report Generation

- Set up start and stop location
- Use manual key press to begin data collection
- May also use an automatic trigger
  - Photocell and reflective tape

Longitudinal Position



Longitudinal Position

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Automatic Trigger
  - Start and stop data collection at exact locations
  - Improved repeatability
  - Ability to identify specific features in profile by distance

During Testing

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Check reading in real-time, if possible, for reasonable output

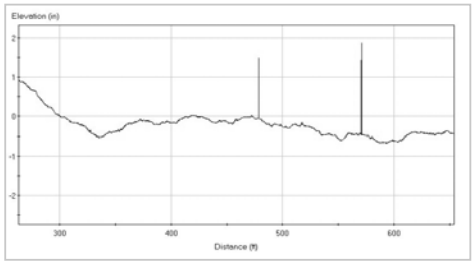
Post-Operations Checks

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Make sure profile is reasonable
- Make sure IRI values are reasonable
- Compare multiple runs (of same location) for repeatability
- Check for spikes in profile

Check for Spikes in Profile

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation



Potential Sources of Error

Potential Sources of Error

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Equipment
- Environment
- Operator

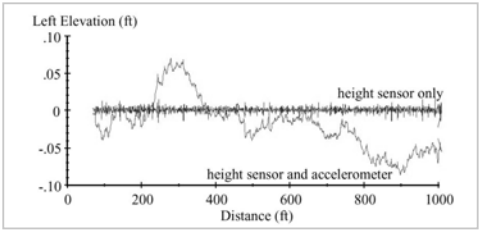
Potential Equipment Errors

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Height sensor
- Accelerometer
- DMI
- Computer
- Other electronics

Accelerometer Malfunction

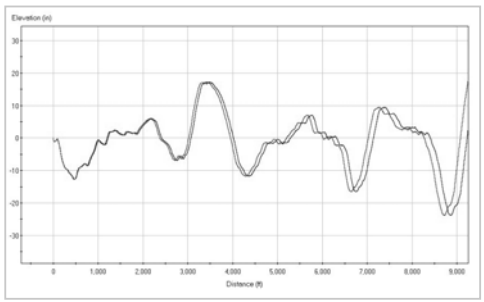
General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation



Little Book of Profiling

Inaccurate DMI

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation



Potential Equipment Errors

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Make sure equipment is connected properly
- Conduct pre-operational checks
- Make sure equipment is calibrated

Potential Environmental Errors

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Wet pavement
- Debris on surface

Potential Operator Errors

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Inconsistent speed
- Acceleration or braking
- Stopping
- Inadequate lead-in
- Improper lateral position
  - Very Important

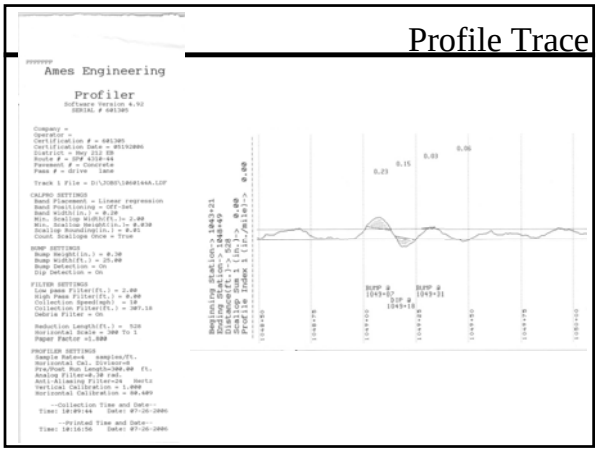
Report Generation

Report Generation

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Profilogram trace after each profile run

Profile Trace



Report Generation

- Profilogram trace after each profile run
- Electronic data files (ERD format)

Electronic Files

ERD Filenames

090721-I-035W-I-2-L-5+21.ERD

Left wheel path, second lane (one lane left of driving lane), increasing (northbound) direction, beginning at station 5+21, I-35W, tested on 21 July 2009.

Report Generation

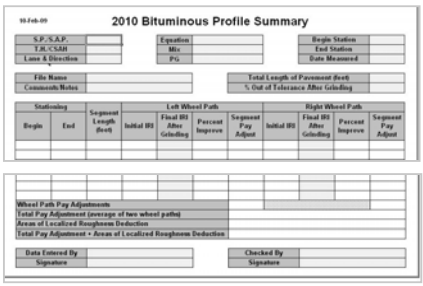
- Profilogram trace after each profile run
- Electronic data files (ERD format)
- Spreadsheet summary

Completion of Pavement Placement

- Signed spreadsheet summary of smoothness
  - within 5 days after completion of pavement placement
  - Prior to commencement of corrective work
  - Spreadsheet template available at: www.dot.state.mn.us/materials/smoothness.html

Completion of Pavement Placement

General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation



Completion of Pavement Placement

General Operation
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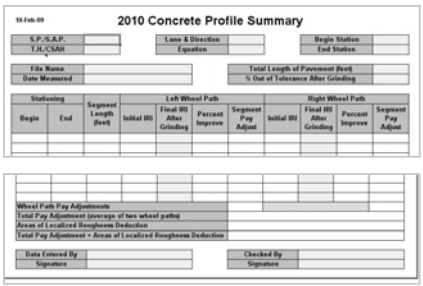


Report Generation

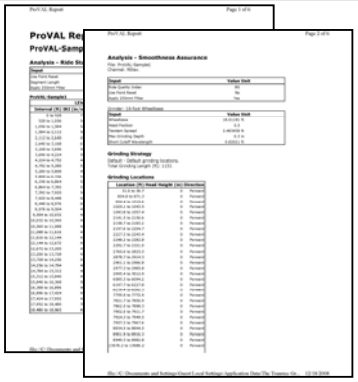
General Operation
- Module Introduction
- Module Objectives
- Profiling Equipment
- Factors Affecting Profiles
- General Operation Principles
- Potential Sources of Error
- Report Generation

- Profilogram trace after each profile run
- Electronic data files (ERD format)
- Spreadsheet summary
- Final ProVAL summary report

Completion of Pavement Placement

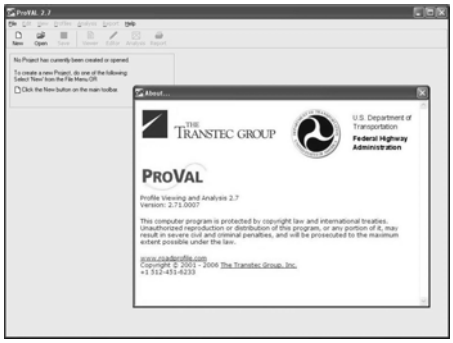
- Paper ProVAL summary report for each lane
  - Indicate results of “Ride Statistics at Intervals” and “Smoothness Assurance” analyses
  - Use ERD naming method in ProVAL report

ProVAL Report



Coming Up Next…

ProVAL Demonstration



Minnesota Department of Transportation
Pavement Smoothness Specifications
Workshop

Module 4
Introduction to ProVAL

PROVAL
Pavement Profile Viewing & Analysis

Module Introduction

- Objectives
- General Features
- Smoothness Analyses
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Report Preparation and Submittal

Module Objectives

- Understand basic operation of ProVAL software
- Be able to produce Smoothness and Areas of Localized Roughness reports
- Be able to prepare and submit required reports

General Features

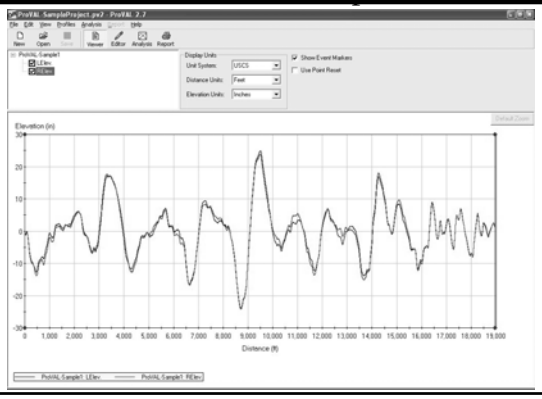
ProVAL General Features

- Import ERD files
- View profiles

Import ERD files

1. Find file in Windows Explorer or other means
2. Check the “Channel” box for the elevation (LElev., RElev. or both)

Import ERD files



Import ERD files

ProVAL Intro.

- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

1. Find file in Windows Explorer or other means
2. Check the “Channel” box for the elevation (LElev., RElev. or both)
3. Select “File/Save As…”
4. Enter project name.
5. Click “Save”

Viewing Profiles

ProVAL Intro.

- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- “Display Units” come from the original file, and should not be changed.
- Try the zoom feature.
- Click “Default Zoom” to return

Examples

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Import ERD files
- Viewing profiles

PROVAL
Pavement Profile Viewing & Analysis

Smoothness Analyses

Smoothness Analyses

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Ride Statistics at Intervals
- Smoothness Assurance

Ride Statistics at Intervals

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Select “Analysis” menu item
- Select “Ride Statistics at Intervals”
- Select both Left and Right elevation checkboxes
- Make sure “Input Set” is set to “Original” and “Apply 250-mm Filter” is checked

Why the 250-mm Filter?

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- “A digital filter is a calculation procedure that transforms a series of numbers (a signal) into a new series of numbers.”

  - Little Book of Profiling

Why the 250-mm Filter?

ProVAL Intro.
- Module Introduction
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- General Features
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- ProVAL Reports
- Summary Worksheet
- Required Submittals

- If the sample interval is less than 6.6 inches, then the 250-mm filter must be applied.
- This prepares the data for the IRI analysis.

Why the 250-mm Filter?

ProVAL Intro.

Module Introduction
Module Objectives
General Features
Smoothness Analysis
Areas of Localized Roughness
ProVAL Reports
Summary Worksheet
Required Submittals

- Some systems apply this filter automatically.
- For example, K.J. Law systems apply a similar filter prior to storing the data.
- In these cases, make sure the "Apply 250-mm Filter" option is NOT checked

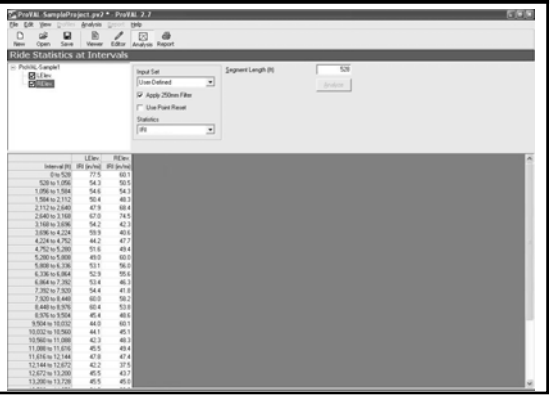
Ride Statistics at Intervals

ProVAL Intro.

Module Introduction
Module Objectives
General Features
Smoothness Analysis
Areas of Localized Roughness
ProVAL Reports
Summary Worksheet
Required Submittals

- Make sure "Segment Length" is set to 528 ft or 160.9344 m
- Select "IRI" in "Statistics" pull-down box
- Click "Analyze"

Ride Statistics at Intervals



Ride Statistics at Intervals

ProVAL Intro.
- Module Introduction
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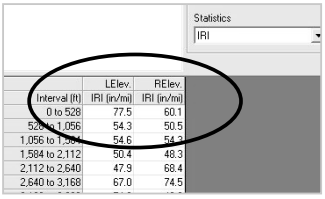
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Average the IRI values from the left and right wheel paths



Ride Statistics at Intervals

ProVAL Intro.
- Module Introduction
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- ProVAL Reports
- Summary Worksheet
- Required Submittals

- The Pay Adjustment equations in the specification use this average IRI output from ProVAL

Ride Statistics at Intervals

ProVAL Intro.
- Module Introduction
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- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

Remember bituminous Table HMA-A

HMA-A	IRI, in/mi	Pay Adjustment, per segment
	< 30.0	$400
	30.0 to 65.0	$(850 – 15·IRI)
	> 65.0	Corrective Work to ≤ 65.0 in/mi

Examples

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Ride Statistics at Intervals (or "Smoothness Analysis")

Areas of Localized Roughness

Smoothness Assurance

ProVAL Intro.
- Module Introduction
- Module Objectives
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- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- The Smoothness Assurance analysis determines Areas of Localized Roughness (ALR)

Smoothness Assurance

ProVAL Intro.
Module Introduction
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Smoothness Analysis
Areas of Localized Roughness
ProVAL Reports
Summary Worksheet
Required Submittals

- Select “Analysis/Smoothness Assurance”

Smoothness Assurance

ProVAL Intro.
Module Introduction
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Areas of Localized Roughness
ProVAL Reports
Summary Worksheet
Required Submittals

- In the “Inputs” tab, “Smoothness Specifications” frame:
  - “Ride Quality Index” = “IRI”
  - “Ride Quality Threshold” = “120”
  - “Continuous Short Interval” = “25”
  - Choose “Fixed Interval Report” and enter “528”

Smoothness Assurance

ProVAL Intro.
Module Introduction
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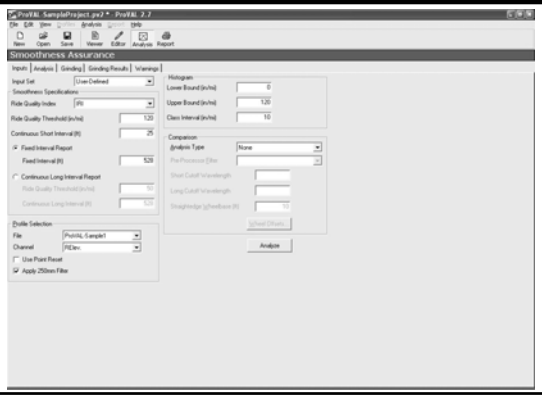
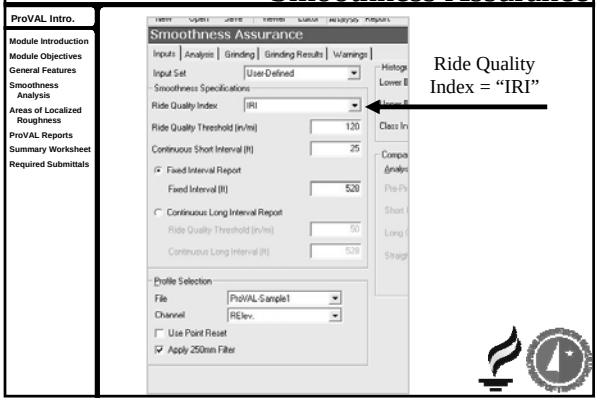
Areas of Localized Roughness
ProVAL Reports
Summary Worksheet
Required Submittals

- In the “Inputs” tab, “Profile Selection” frame:
  - Select the file name
  - Select the right wheel path “Channel”
  - Check the “Apply 250-mm Filter” if necessary

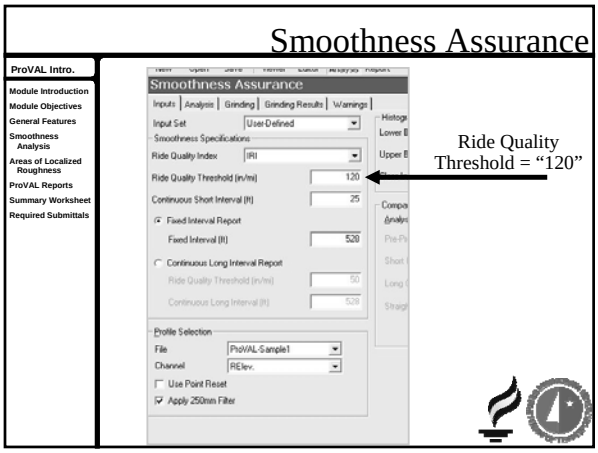
Smoothness Assurance



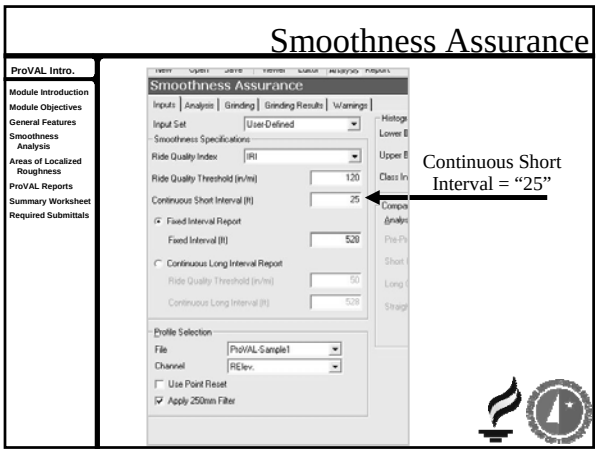
Smoothness Assurance



Smoothness Assurance

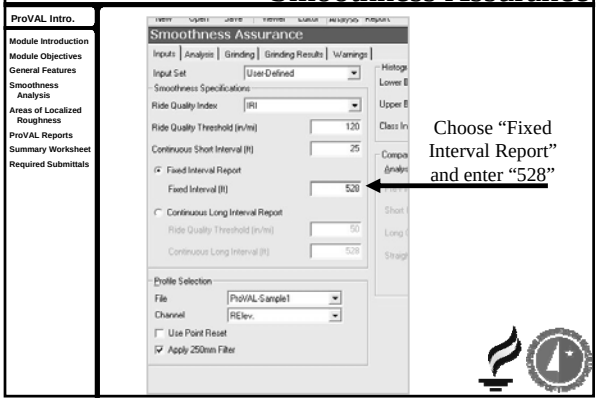


Smoothness Assurance



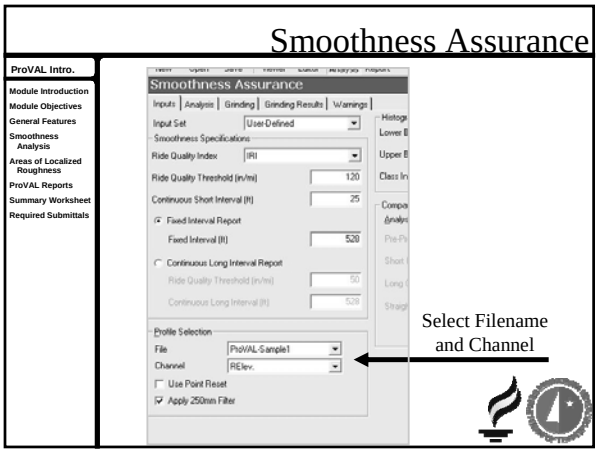
Continuous Short Interval = "25"

Smoothness Assurance



Choose "Fixed Interval Report" and enter "528"

Smoothness Assurance



Select Filename and Channel

Smoothness Assurance

ProVAL Intro.
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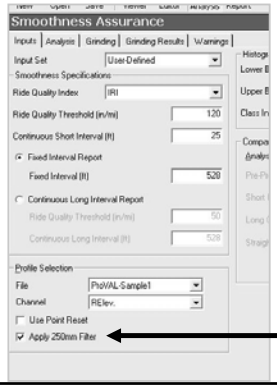

Check "Apply 250mm Filter"

Smoothness Assurance

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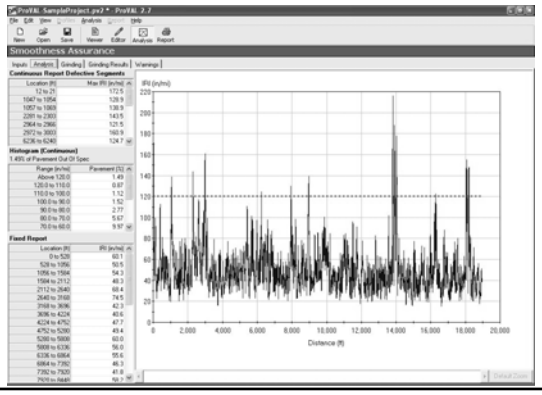
- In the "Inputs" tab, the "Histogram" and "Comparison" frames may be ignored.
- Press "Analyze"
- After the "Performing Analysis" message box disappears, click the "Analysis" tab.

Smoothness Assurance



Smoothness Assurance

ProVAL Intro.
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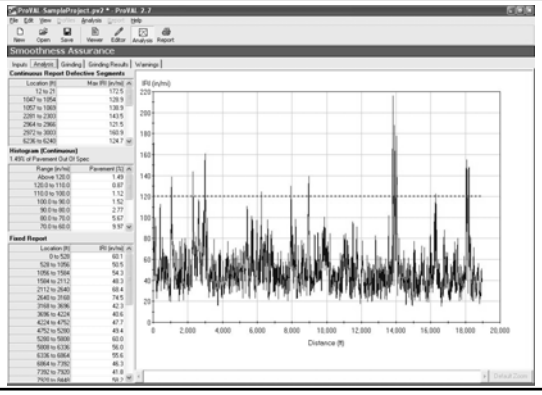
- Summary Worksheet
- Required Submittals

- Note the following sections:
  - Continuous Report Defective Segments
  - Histogram (Continuous)
  - Fixed Report
  - Plot of continuous results

Smoothness Assurance



Smoothness Assurance

ProVAL Intro.
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- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
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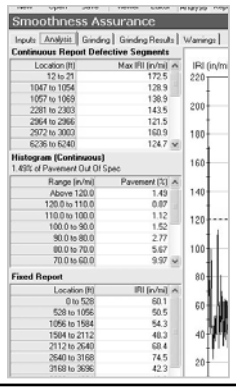

- Data of importance:
  - Continuous Report Defective Segments
  - % of Pavement Out Of Spec

Continuous Report Defective Segments

ProVAL Intro.
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- Required Submittals

- This table shows portions of the run where the 25-foot IRI analysis exceeded 120 in/mi.

% of Pavement out of Spec

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- This number shows the percentage of the run, on a longitudinal distance basis, that exceeds the ALR limits of 120 in/mi.
- In this example, 1.49% of 18,965 feet, or 283 feet, is above this limit.

Examples

ProVAL Intro.
- Module Introduction
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- Smoothness Analysis
- Areas of Localized Roughness
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- Smoothness Assurance (or “Areas of Localized Roughness”)

PROVAL
Pavement Profile Viewing & Analysis

Grinding Simulation

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

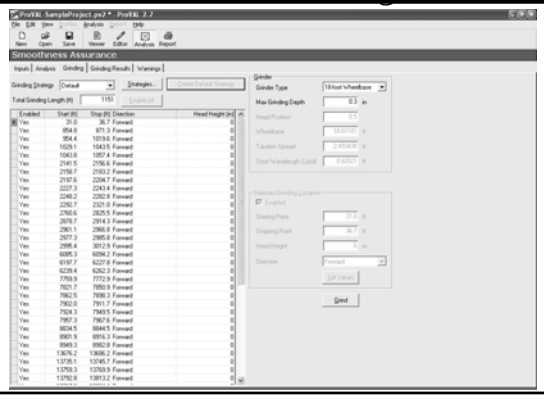
- Click on the “Grinding” tab
- Select the default grinding strategy
- In the “Grinder” frame, the defaults are:
  - “Grinder Type” = “18-foot Wheelbase”
  - “Max Grinding Depth” = “0.3” in

Grinding Simulation

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

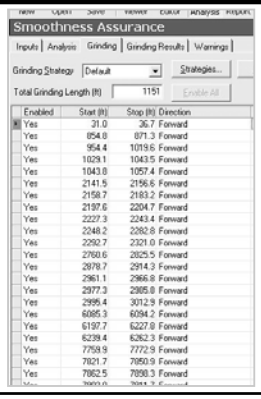
- Click “Create Default Grinding Strategy”
- The analysis may take some time. In this example, the 3.6-mile profile takes 30-60 seconds, depending on the computer.

Grinding Simulation



Grinding Simulation

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals



- Data of importance:
  - Total Grinding Length
  - Start and stop points for each ALR

Grinding Simulation

ProVAL Intro.
- Module Introduction
- Module Objectives
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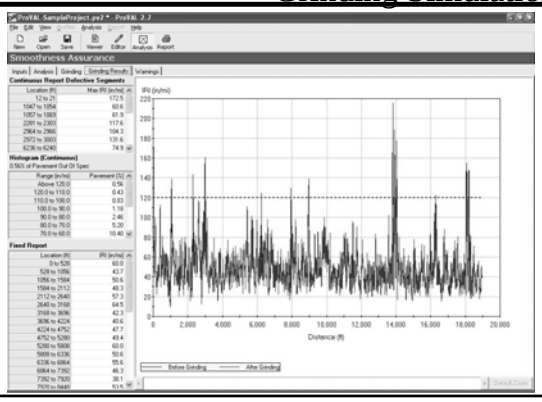
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Click the “Grind” button
- Then click the “Grinding Results” tab for a before and after plot.

Grinding Simulation



Grinding Simulation

ProVAL Intro.
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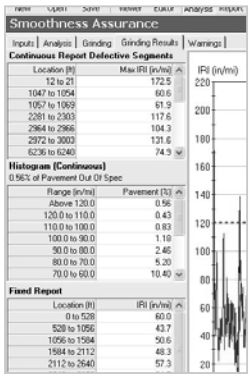
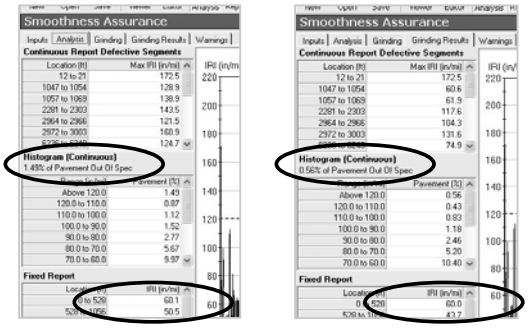
Required Submittals



- Data of importance:
  - Continuous Report Defective Segments
  - % of Pavement Out Of Spec

Grinding Simulation

Before Grinding **After Grinding**



Areas of Localized Roughness

ProVAL Intro.
Module Introduction
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Areas of Localized Roughness
ProVAL Reports
Summary Worksheet
Required Submittals

- In this example, 0.56% of 18,965 feet, or 106 feet, remains above the limit after grinding.
- The “after grinding” ALR values are estimated by ProVAL, but the actual values must be obtained by reprofiling.

Examples

ProVAL Intro.
- Module Introduction
- Module Objectives
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- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Grinding simulation

PROVAL
Pavement Profile Viewing & Analysis

ProVAL Reports

ProVAL Reports

ProVAL Intro.
- Module Introduction
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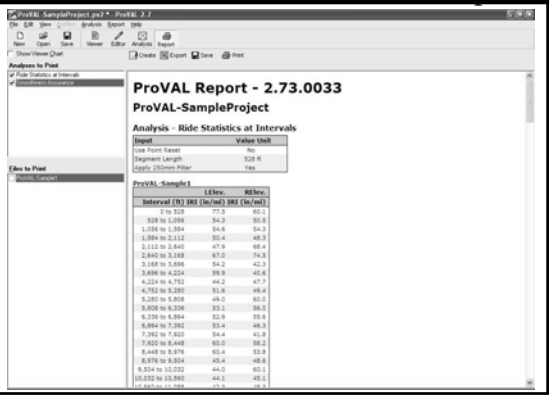
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Click “Report” button
- Select reports desired in the “Analyses to Print” area
- Click “Create” button

ProVAL Reports



ProVAL Reports

ProVAL Intro.

- Module Introduction
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- ProVAL Reports
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- Required Submittals

- In this example report, there are two analyses
  - Ride Statistics at Intervals
  - Smoothness Assurance

ProVAL Reports – Ride Statistics

ProVAL Intro.

- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Look for these areas of the report:
  - Analysis – Ride Statistics at Intervals
  - Interval, IRI for left and/or right wheel paths

ProVAL Reports – Ride Statistics

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

Analysis - Ride Statistics at Intervals

Input	Value Unit
Use Point Reset	No
Segment Length	528 ft
Apply 250mm Filter	Yes

ProVAL-Sample1

Interval (ft)	LElev. IRI (in/mi)	RElev. IRI (in/mi)
0 to 528	77.5	60.1
528 to 1,056	54.3	50.5
1,056 to 1,584	54.6	54.3
1,584 to 2,112	50.4	48.3
2,112 to 2,640	47.9	68.4
2,640 to 3,168	67.0	74.5
3,168 to 3,696	54.2	42.3
3,696 to 4,224	59.9	40.6

ProVAL Reports – Smoothness

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Look for these areas of the report:
  - Total Grinding Length
  - Grinding Locations
  - Defective Segments
  - Percent of Pavement out of Spec Before and After Grinding

ProVAL Reports – Smoothness

ProVAL Intro.
- Module Introduction
- Module Objectives
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- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

Grinding Strategy

Default - Default grinding locations.
Total Grinding Length (ft): 1151

Grinding Locations

Location (ft)	Head Height (in)	Direction
31.0 to 36.7	0	Forward
854.8 to 871.3	0	Forward
954.4 to 1019.6	0	Forward
1029.1 to 1043.5	0	Forward
1043.8 to 1057.4	0	Forward
2141.5 to 2156.6	0	Forward
2158.7 to 2183.2	0	Forward

ProVAL Reports – Smoothness

ProVAL Intro.
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Histogram

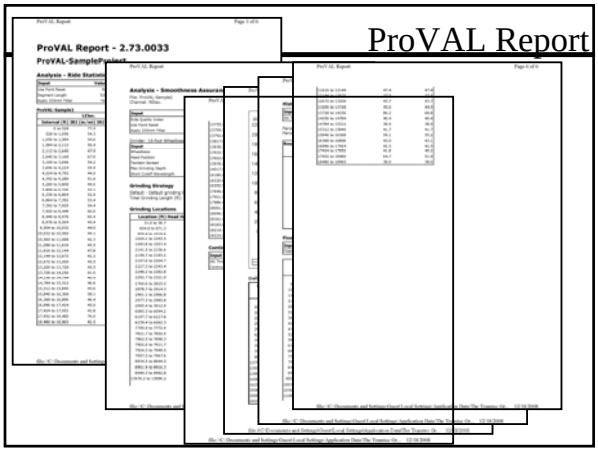
Input	Value Unit
IRI Threshold	120 in/mi

Percent of Pavement Out Of Spec Before Grinding: 1.49 %
Percent of Pavement Out Of Spec After Grinding: 0.56 %

Roughness Range (In/mi)	Percent of Pavement Before Grinding (%)	Percent of Pavement After Grinding (%)
Above 120.0	1.49	0.56
120.0 to 110.0	0.85	0.42
110.0 to 100.0	1.12	0.83

These values do not go into the summary spreadsheet. The lane must be reprofiled after corrective work.

ProVAL Report



Examples

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- ProVAL reports

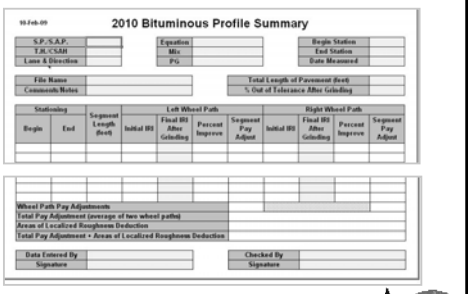
PROVAL
Pavement Profile Viewing & Analysis

Summary Worksheet

Summary Worksheet

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

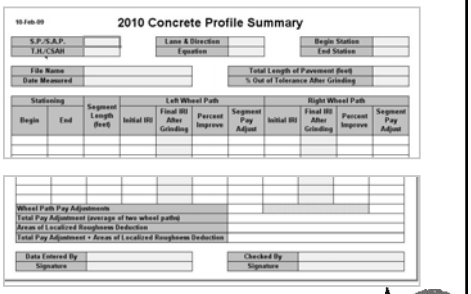
www.dot.state.mn.us/materials/smoothness.html



Summary Worksheet

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

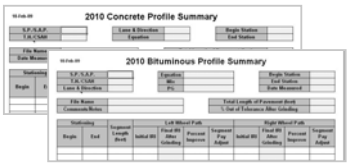
www.dot.state.mn.us/materials/smoothness.html



Examples

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Summary Worksheet



Required Submittals

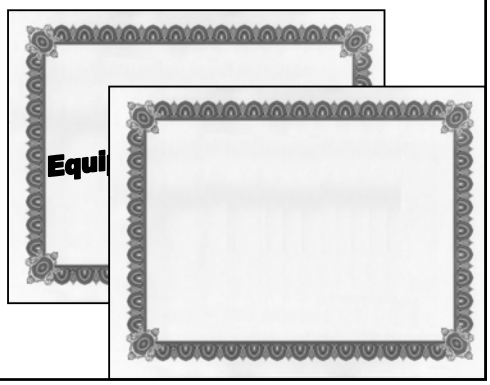
Required Submittals

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Prior to Profiling
  - Equipment Certification
  - Operator Certification

Prior to Profiling

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

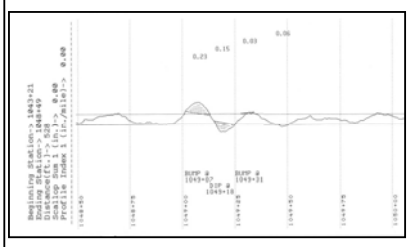


Required Submittals

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Day of Profiling
  - Printed graphical trace
  - Electronic ERD files
    - Follow file naming convention

Profile Trace



Electronic Files

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

ERD Filenames

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

For example:

090331-MN-212-I-2-R-5+21.ERD

Right wheel path, second lane (one lane left of driving lane), increasing (northbound) direction, beginning at station 5+21, MN 212, tested on 31 March 2009.

Required Submittals

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Completion of Paving
  - Printed ProVAL report

Examples

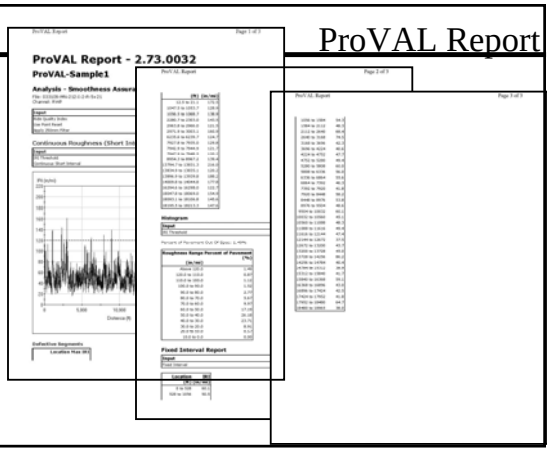
ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

Overview of entire process

- Printed ProVAL report
  - Within 5 days of paving completion
  - Prior to corrective work

PROVAL
Pavement Profile Viewing & Analysis

ProVAL Report



Required Submittals

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Prior to Corrective Work
  - Written corrective work plan
    - Printed ProVAL grinding simulation

Required Submittals

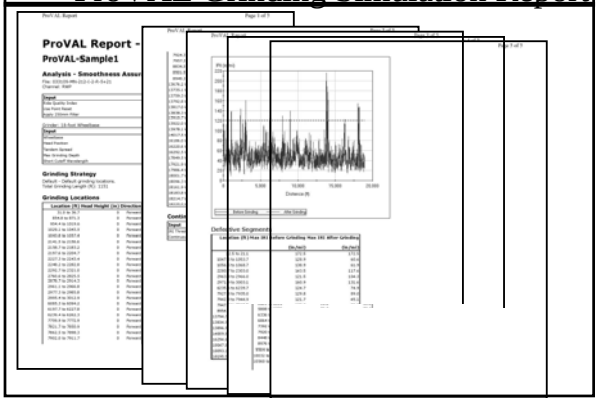
- After Corrective Work
  - Updated ProVAL reports
  - Spreadsheet summary

Examples

- Printed ProVAL grinding simulation

PROVAL
Pavement Profile Viewing & Analysis

ProVAL Grinding Simulation Report



Updated ProVAL Report

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Profile Left and Right wheel paths
- Conduct analyses
  - Ride Statistics at Intervals
  - Smoothness Assurance

Examples

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Initial ALR analysis
  - Smoothness Assurance on right wheel path

PROVAL Pavement Profile Viewing & Analysis

Examples

ProVAL Intro.
- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

- Prior to Corrective work
  - Corrective work plan (may be ProVAL grinding analysis)

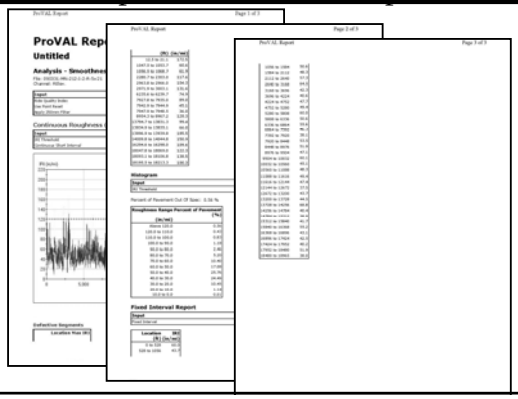
PROVAL Pavement Profile Viewing & Analysis

Examples

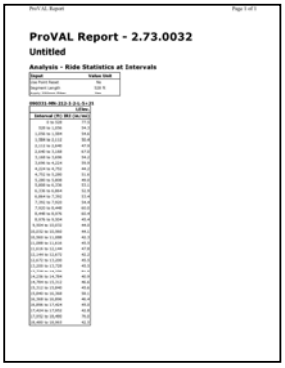
- After Corrective Work
  - Reprofile and submit updated ProVAL report
  - Submit summary spreadsheet

PROVAL
Pavement Profile Viewing & Analysis

Updated ProVAL Report – RWP



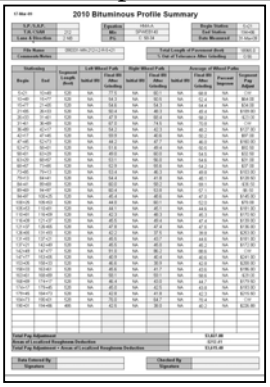
Updated ProVAL Report – LWP


ProVAL Report - 2.73.0032
Untitled
Analysis - Ride Statistics at Intervals

Spreadsheet Summary

ProVAL Intro.

- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals



Coming Up Next…

ProVAL Intro.

- Module Introduction
- Module Objectives
- General Features
- Smoothness Analysis
- Areas of Localized Roughness
- ProVAL Reports
- Summary Worksheet
- Required Submittals

Conclusion – The Final Session

Minnesota Department of Transportation
Pavement Smoothness Specifications
Workshop

Module 5
Review and Conclusion

Module Introduction

- Workshop Review
- Review Smoothness Specification
- Other States' Specifications

Module Objectives

- Ensure understanding of important concepts
- Prepare to take and pass written examination for certification

Workshop Review

Pavement Roughness

- International Roughness Index
- Measurement Methods

Smoothness Measurements

- IRI
  - More representative of how the road "feels"

Combined Smoothness Specification

- Operator certification
- Two smoothness statistics
  - Ride Statistics
  - Areas of Localized Roughness using ProVAL Smoothness Assurance

General Profiler Operation

- Factors affecting profilers
- Pre- and Post-operations checks
- Follow manufacturer's operating procedures

General Profiler Operation

- Operating speed
- Lead-in
- Lateral position
- Longitudinal position

General Profiler Operation

- Calibrate equipment
- Remove debris from surface
- Test at consistent speed

ProVAL Software

- Smoothness analyses
- Areas of localized roughness
- Reports
- Summary worksheet
- Submittals

Review Smoothness Specification

Certification

Conclusion
Module Introduction
Workshop Review
Review Smoothness Specification
Other States' Specifications

- "trained in the operation of the particular IP" they will be using on the project
- Must pass a proficiency test and possess current certification.

Testing

Conclusion
Module Introduction
Workshop Review
Review Smoothness Specification
Other States' Specifications

- Surface testing
  - Profiling in left and right wheel paths
  - Compute IRI for each wheel path and then average the results for each 0.1-mile segment
  - Run ProVAL Smoothness Assurance Module for areas of localized roughness

Submittals

Conclusion
Module Introduction
Workshop Review
Review Smoothness Specification
Other States' Specifications

- Prior to profiling
  - Operator and equipment certifications
- Day of profiling
  - Printed profilogram
  - ERD files

Submittals

- Completion of placement (within 5 days after completion)
  - Printed ProVAL reports
- Prior to corrective work
  - Corrective work plan

Submittals

- After corrective work
  - Summary spreadsheet
  - Updated ProVAL reports

Corrective Work

- Reprofile after corrective work is complete

Pay Adjustments

- Computed after corrective work is complete

New Smoothness Specification

- New specification to be used in 2009 construction season as "ghost" specification
- Widespread use in 2010

Other States' Experiences

Other States' Experiences

- Who is using ProVAL?
- Who is using IRI?
- Who is requiring operator certification?

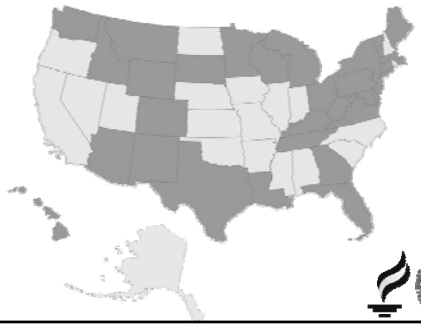
Who is Using ProVAL?

As of 2007:

- Colorado
- Ohio
- Louisiana
- Pennsylvania
- Michigan
- FHWA Western Federal Lands

Who is Using IRI?

As of 2007:



Who Requires Operator Certification?

A partial list:

- Georgia
- Wyoming
- Texas
- Kansas
- Florida
- New Mexico
- Missouri

For More Information

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Associate Professor
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Hands-on Exercises

List of Sample Files

Example1-ImportingAndViewing.erd

Example2-5-RideStatistics.erd

Example6-ProVAL-Reports.erd

SampleProfile-Right.erd

SampleProfile-Left.erd

SampleProfile-Right-AfterGrinding.erd

SampleBituminousProfile.erd

SampleConcreteProfile.erd

List of Examples

☐ 1. Importing and viewing profiles in ProVAL

☐ 2. Analyzing ride statistics at intervals

☐ 3. Analyzing smoothness assurance

☐ 4. Conducting grinding simulation

☐ 5. Generating ProVAL reports

☐ 6. Pay Adjustment Worksheets

☐ 7. Overall step-by-step process

Example #1 – Importing profiles into ProVAL

Instructions

1. Use ProVAL to import an ERD file for viewing, analysis, and saving as a ProVAL project file.

a. Start the ProVAL software
b. Click the menu "File/Open"
c. Browse to the location of the ERD file.
d. Select "**Example1-ImportingAndViewing.erd**" and Click "Open".

2. You may also start the software by browsing to the desired file using "My Computer" or other file management program and double-clicking the ERD file you intend to import.

3. ProVAL will open the selected file in the "Viewer" pane and will begin a new PV2 project.

4. Press "Save" and ProVAL will ask for a project file name and location. By saving a ProVAL project, ProVAL will also convert the ERD file to a "ppf" file.

5. After importing an ERD file into ProVAL, select the channel you wish to view (in this case "Elev." in the upper left window, below the toolbar.

6. Zoom in closer on the data by dragging a box in the profile window. Dragging successive boxes zooms in closer. Return to the full view by Clicking "Default Zoom" in the upper right of the profile window.

7. Become familiar with the program layout and structure. Try out different unit systems, and different distance and elevation units. Turn the "Event Markers' off and on again.

Notes

Example #2 – Analyzing ride statistics at intervals

Instructions

1. This example will demonstrate how to conduct Ride Statistics analyses with pavement profiles.

2. Beginning with **Example2-5-RideStatistics.erd**, Click the "Analysis" tool button.

3. If the analysis title is not "Ride Statistics at Intervals" Select the menu item "Analysis/Ride Statistics at Intervals".

4. Select the profile you wish to analyze by checking the box in the profile list (the upper left window, below the title of the analysis method. Normally, there is only one profile in an ERD file. Sometimes there are two (one for each wheel path).

5. Select and enter the appropriate inputs.

6. Press the "Analyze" button. Read the results in the columns below. The IRI for each 0.1-mile segment is displayed. This data can be extracted and placed in the Excel smoothness spreadsheets. This will be demonstrated in a later example.

Notes

Example #3 – Analyzing smoothness assurance

Instructions

1. This example will demonstrate how to conduct Smoothness Assurance analyses with ProVAL.

2. Beginning with the results of the "Ride Statistics at Intervals" exercise, Select the menu item "Analysis/Smoothness Assurance".

3. In the "Input" tab, select and enter the appropriate inputs.

Important: Make sure the "Ride Quality Threshold" value is set to 120 in/mi.

4. Click the "Analyze" button.

5. View the results of the smoothness analysis by Clicking the "Analysis" tab. Any point on the profile where the "continuous" IRI exceeds 120 in/mi can be seen above the dashed red line.

6. Notice the "Histogram" window. This shows the percent of the total project length that it "Out of Spec" (the 120 in/mi threshold).

7. Just as in the profile viewer window, the smoothness assurance results can be zoomed. Zoom in on the first segment to exceed 120 in/mi. This shows a location between 5789 and 5794 feet from the beginning that is out of spec. This segment is recorded in the first line of the "Continuous Report Defective Segments" window.

8. The zoomed window can be scrolled up and down the segment length, and the entire segment can be viewed by pressing the "Default Zoom" button.

Notes

Example #4 – Conducting grinding simulation

Instructions

1. In this example, the grinding simulation will be demonstrated. Begin with the results of the Smoothness Assurance analysis.

2. While in the "Analysis" window, Click on the "Grinding" tab.

3. Notice the "Grinder" properties frame. This allows the user to select the type of grinder, the maximum grinding depth, and other properties. Click on the "Create Default Strategy" button.

4. The grinding analysis may take several minutes, depending on the speed of the computer, the length of the profile, and the amount of grinding needed.

5. The results of the grinding analysis include the "Total Grinding Length" and individual locations where grinding will be conducted, using the grinder properties to the right of the window.

6. Now Click the "Grind" button. This executes the grinding strategy. When the "Progress" bar disappears, Click on the "Grinding Results" tab.

7. The "Grinding Results" tab shows a plot of continuous IRI before and after the grinding simulation. Not all areas can be corrected with a single pass of the grinder. The "Fixed Report" now shows the results of the 0.1-mile segment IRI after grinding. These results are used in the Pay Adjustment determination.

8. Notice that the "Continuous Report Defective Segments" now shows the maximum IRI of the segments that were ground. Most of these are now within the IRI threshold. Some remain above.

9. Notice that the "Histogram" window now shows a smaller "% Pavement Out Of Spec" than before grinding.

Notes

Example #4 – Conducting grinding simulation – Page 2

Instructions

10. Remember that this analysis is conducted on the right wheel path only.

11. Using the results grinding simulation, 0.56% of the total length of the profile remains out of specification. Scroll the "Fixed Report" table to the bottom to see the total length of the profile, and calculate the length remaining "Out Of Spec".

12. This length will be used in the "Areas of Localized Roughness" deduction calculation. A deduction of $2.00 per lineal foot will be applied to the overall Pay Adjustment.

Notes

Example #5 – Generating ProVAL reports

Instructions

1. In this example, the ProVAL report generator will be demonstrated.

2. In the ProVAL too bar, Click the “Report” button.

3. The “Analyses to Print” window should show the analyses already conducted, and they should be “checked”.

4. Click the “Create” button.

5. The report can now be printed for submittal. The data in the “Ride Statistics at Intervals” section can also be copied and pasted into MS Excel. The pasted data can then be formatted and copied into the Mn/DOT Smoothness Worksheets.

Notes

Example #6 – Pay Adjustment Worksheets

Instructions

1. This example will demonstrate the use of the pay adjustment worksheets. The results of the "Ride Statistics at Intervals" analysis are entered in these worksheets. For pay adjustments, only the "Ride Statistics at Intervals" from reprofiled (after actual grinding takes place) is accepted.

2. After the profile is measured again (after corrective work is completed), perform the "Ride Statistics at Intervals" on the new profile. For this example, open the file "**Example6-ProVAL-Reports.erd**".

3. Perform the "Ride Statistics at Intervals" and "Smoothness Assurance" analyses on this "after corrective work" profile.

4. Create the report in ProVAL.

5. Choose the appropriate worksheet, based on the type of pavement and the equation used (HMA-A, -B, -C, or PCC-A, -B or the percent improvement worksheets).

6. Copy the results from the "Analysis – Ride Statistics at Intervals" section, "IRI" column, of each wheel path report. Paste the results into a blank spreadsheet.

7. Copy the IRI data (the right-most column), 40 lines at a time, from each wheel path, into the "Profile Summary" worksheet. In Excel, Select the "Edit/Paste Special…" option and in the window that appears, select the "Values" option and then Click "OK". You may also enter the IRI values manually.

8. Enter the other required information into the worksheet from the ProVAL report.

Notes

Example #6 – Pay Adjustment Worksheets – Page 2

Instructions

9. Notice the total Pay Adjustments for each wheel path, and the average of the two wheel paths. Also at the bottom of the worksheet is the total adjustment for Areas of Localized Roughness. The sum of these is the Total Pay Adjustment.

10. This worksheet should be created for every 4 miles (40 segments) of profile, per lane. For multiple worksheets for the same profile, only include the ALR information in the first worksheet. On subsequent worksheets for the same profile, enter "0" for these cells.

11. The operator must sign the worksheet and submit it to the Mn/DOT resident engineer or representative.

Notes

Example #7 – Overall step-by-step process

Instructions

This example will take us from the beginning of profiling on a jobsite through the final submittal after paving and corrective action are complete.

1. **Prior to profiling**
   Submit equipment and operator certification to resident engineer.

2. **Day of profiling**
   Printed profilogram (graphical trace) with operator signature.
   ERD files with proper file names.

3. **Completion of pavement placement**
   Printed ProVAL summary

4. **Prior to corrective work**
   Written corrective work plan (may be in the form of a Printed ProVAL grinding strategy).

5. **After corrective work**
   Spreadsheet summary and updated ProVAL reports

Notes

Example #7 – Overall step-by-step process – Page 2

Instructions	Notes

Completion of pavement placement

Conduct "Smoothness Assurance"
- Open "**SampleProfile-Right.erd**"
- Right-click "RElev." and select "Rename"
- Enter name of profile according to convention
- Select "Analysis/Smoothness Assurance"
- Set RQ Threshold = 120 in/mi
- Select file and channel
- Click "Analyze"

- Click "Report"
- Click "Create"
- Print the report

Submit printed ProVAL summary report.

Prior to corrective work

Repeat smoothness assurance analysis conducted above (to the Click "Analyze" step), or continue after printing the previous analysis.
Click the "Grinding" tab.
Click "Create Default Strategy"
Click "Grind"

Click "Report"
Click "Create"
Print the report

Submit written corrective work plan.

Example #7 – Overall step-by-step process – Page 3

Instructions

After corrective work

Reprofile
Conduct "Ride Statistics at Intervals" analysis (RWP)
Open "**SampleProfile-Right-AfterGrinding.erd**"
Rename "RElev." as before, with current date
Select "Analysis/Ride Statistics at Intervals"
Select the profile
Click "Analyze"
Conduct "Smoothness Assurance" analysis as previously described (to the Click "Analyze" step)

Click "Report"
Click "Create"
Print the report (for the right wheel path)

Conduct "Ride Statistics at Intervals" analysis (LWP)
Open "**SampleProfile-Left.erd**"
Rename "LElev." as before, with current date
Select "Analysis/Ride Statistics at Intervals"
Select the profile
Click "Analyze"
Click "Report"
Click "Create"
Print the report (for the left wheel path)

Submit the updated ProVAL report

Complete Summary Spreadsheet
Input data into summary spreadsheet
Enter begin and end station
End = begin + profile length
Enter "% Out of Tolerance After Grinding"
This number comes from RWP analysis after reprofiling.
Type in (or copy and paste) LWP and RWP IRI values into the "Final IRI After Grinding" columns.
Print the summary spreadsheet

Submit summary spreadsheet

Notes

2XXX
Pavement Surface Smoothness

2XXX.1 DESCRIPTION

The final mainline and all other pavement surfaces where the posted vehicle speed is 48 km/hr [30 mph] or greater shall be measured using an Inertial Profiler (IP) and the International Roughness Index (IRI), except those specifically excluded by Table 2XXX.5-2. Pavement smoothness for each lane will be computed by obtaining the IRI for the left and right wheel paths in an individual lane and then averaging the results. The averaged results will be used to determine pay adjustments. Each lane shall be tested and evaluated separately.

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 rerun at the Contractor's expense.

The term "smoothness" will mean the composite IRI value per 0.1609 km [0.1 mile] segment on which pay adjustments are made. The term "areas of localized roughness" will mean those areas exceeding the limiting criteria for a continuous IRI calculation with a 7.62-m [25-ft] interval, as computed using the most recent version of the FHWA's Profile Viewing and Analysis (ProVAL) software.

All costs relative to the Contractor providing the IP, appropriate test results, and associated traffic control shall be incidental to the unit bid price for Wearing Course Mixture for bituminous pavements, for Concrete Pavement for concrete pavements, or for Diamond Grinding.

2XXX.2 EQUIPMENT

The Contractor shall furnish a properly calibrated, documented, and Mn/DOT-certified IP. The IP shall export raw profile data in an unfiltered ERD file format, and shall produce a profilogram (profile trace of the surface tested). The IP shall conform to the Class 1 requirements of the most recent revision of ASTM E950 and must be certified according to the most recent procedure on file in the Pavement Engineering Section. Mn/DOT certification documentation shall be submitted to the Engineer prior to the IP being used on the project. Settings for individual certified profilers are on file in the Mn/DOT Pavement Engineering Section, and are accessible at www.dot.state.mn.us/materials/smoothness.html.

Profile analysis for determination of IRI and areas of localized roughness will be conducted using the most recent version of the ProVAL Software. IRI values shall be reported in units of m/km [in/mi]. Units of m/km shall be reported to two digits right of the decimal, and units of in/mi shall be reported to one digit right of the decimal, following the rounding procedures found in AASHTO R11.

2XXX.3 OPERATOR CERTIFICATION

The Contractor shall furnish an operator, trained in the operation of the particular IP furnished under section 2XXX.2, and knowledgeable in the

use of the most recent version of the ProVAL software. All profiler operators shall pass a proficiency test and possess a current certification issued by the Department. Documentation of operator certification shall be presented to the Engineer upon request.

2XXX.4 PAVEMENT SURFACE TESTING

The Contractor shall remove all objects and foreign material on the pavement surface prior to surface evaluation. The Contractor will be responsible for all traffic control associated with testing and any corrective work (when applicable) that is required of the final pavement surface.

The IP shall be run in the direction the traffic will be moving. One pass shall be made in the left and the right wheel paths of each lane.

Each lane will be separated into segments 0.1609 km [0.1 mi] in length. Final segments in a lane that are less than 0.1609 km [0.1 mi] but longer than 3.05 m [10 ft] shall be evaluated as an independent segment, and pay adjustments will be prorated for length. Segments 3.05 m [10 ft] long or less, and the first and last 3.05 m [10 ft] of projects that do not connect to an existing segment for which the Contractor is responsible, shall be evaluated by the Engineer using a 3.05-m [10-ft] straightedge. Surface deviations using the straightedge that deviate from a straight line by more than 6 mm in 3.05 m [1/4 inch in 10 ft] shall be subject to corrective work. Transverse joints shall be evaluated by centering the straightedge longitudinally across the transverse joint.

Each pass shall be made continuously, regardless of length, but shall terminate approximately 3.05 m [10 ft] prior to construction headers, end-of-day work joints, or items in the list of exclusions in Table 2XXX.5-2. The subsequent pass shall begin approximately 3.05 m [10 ft] prior to, and shall include, construction headers and end-of-day work joints. In concrete pavements, terminal headers that tie into existing portland cement concrete pavement shall be evaluated, and smoothness measurements shall begin approximately 3.05 m [10 ft] before and end approximately 3.05 m [10 ft] after terminal headers. Bridge approach panels and bridge surfaces are exempt from these requirements; however, paving start-up areas are not exempt.

For percent improvement projects, the smoothness shall be measured prior to the start of construction (initial IRI) and after the completion of construction (final IRI). Stationing used for the final smoothness measurement shall be the same as that used for the initial smoothness measurement, to allow for a direct comparison when calculating the percent improvement. Both the initial IRI and the final IRI will be measured with the same IP.

A. Smoothness

The IRI for the left and right wheel paths in an individual lane will be computed and then averaged when determining pay adjustments. Each lane shall be tested and evaluated separately. The Engineer shall 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. For percent improvement projects, the initial IRI and final IRI will be used to calculate the percent ride improvement.

B. Areas of Localized Roughness

Areas of localized roughness will be identified using the ProVAL "Smoothness Assurance" analysis, with a 5.5-m [18-foot] wheelbase grinder and a maximum grinder depth of 7.62 mm [0.3 in], calculating IRI with a continuous short interval of 7.62 m [25 ft] and the 250-mm filter applied. Only the right wheel path will be used to determine areas of localized roughness. The longitudinal limits of the corrective work shall be taken from the ProVAL "Grinding" section within the "Smoothness Assurance" analysis, using the "Default Grinding Strategy" option.

2XXX.5 EXCLUSIONS

Table 2XXX.5-1 indicates areas that are excluded from smoothness evaluation, but must still be measured with the IP, and are still subject to evaluation for Areas of Localized Roughness and the 3.05-m [10-ft] straightedge. Table 2XXX.5-2 indicates areas that are excluded from surface testing with the IP, but are subject to evaluation with the 3.05-m [10-ft] straightedge.

Table 2XXX.5-1. Areas Excluded from Smoothness Evaluation

For All Pavements Paving where the posted vehicle speed is less than 73 km/hr [45 mph]
Ramps, loops, acceleration and deceleration lanes less than 152.5 m [500 ft] in length
Projects less than 305 m [1000 ft] in length
For Bituminous Pavements Single lift overlays over concrete

Table 2XXX.5-2. Areas Excluded from Smoothness and Areas of Localized Roughness Evaluation

For All Pavements Turn lanes, crossovers
3.05 m [10 ft] on either side of obstructions such as manholes, water supply castings, etc., in lane in which obstruction is located
Intersections constructed under traffic – begin and end exclusion 30.5 m [100 ft] from the intersection radius
Paved shoulders, side streets, side connections
For Concrete Pavements Bridge decks and approach panels (The occurrence of bridges shall not interrupt the continuity determination)
Undoweled shoulders less than 3.05 m [10 ft] wide
Headers adjacent to colored concrete

Areas that are excluded from surface testing with the IP but subject to evaluation with the 3.05-m [10-ft] straightedge as shown in Table 2XXX.5-2 above, and that show no variation greater than 6 mm in 3.05 m [1/4 inch in 10 ft] over the span of the straightedge in the longitudinal or transverse direction, may remain in place without correction or penalty if, in the judgment of the Engineer, the smoothness is satisfactory.

Corrected variations will be considered satisfactory when the 3.05-m [10-ft] straightedge shows the deviations are less than or equal to 6 mm in a 3.05 m [1/4 inch in a 10 ft] span in any direction.

2XXX.6 SUBMITTALS

This section describes the submittals required throughout the project with respect to pavement surface testing.

A. Prior to Profiling

The IP operator shall present to the Engineer current, valid documentation, issued by the Department, indicating the inertial profiling equipment certification and the operator's certification, as described in sections 2XXX.2 and 2XXX.3, respectively.

B. Day of Profiling

The Contractor shall submit the printed profilogram (graphical trace), indicating each segment's IRI value, and the signature of the Operator to the Engineer on the same day the profiling is conducted.

The Contractor shall also submit electronic files in ERD format that represent the raw data from each pass. The electronic ERD filenames shall follow the standardized format shown below. Electronic ERD files that do not follow this standardized naming convention will not be accepted.

YYMMDD-T-N-D-L-W-S.ERD

Where:

YY	=	Two-digit year
MM	=	Month (include leading zeros)
DD	=	Day of month (include leading zeros)
T	=	Route type (I, MN, US, CSAH, etc.)
N	=	Route number (no leading zeros) and auxiliary ID (if applicable, for example E, W, etc.)
D	=	Primary route direction (I or D)
L	=	Lane number (1 for driving lane, increasing by one for each lane to the left)
W	=	Wheel path (L, R, or B, indicating Left, Right, or Both)
S	=	Beginning station

For example: "080721-I-35W-I-2-L-5+21.ERD" would indicate a beginning station of 5+21, in the left wheel path of the second lane (one lane left of the driving lane), in the increasing (northbound) direction of I-35W, tested on 21 July 2008.

If the actual data is not submitted by the Contractor to the Engineer on the same day as the profiling was conducted, the Department will not pay incentives for those segments but any disincentives will still apply.

C. Upon Completion of Pavement Placement

Within five calendar days after all pavement placement, and prior to the commencement of any corrective work, the Contractor shall submit a paper ProVAL summary report for each lane, indicating the results of the "Ride Statistics at Intervals" and the "Smoothness Assurance" analyses. The

Contractor shall follow the naming convention specified in section 2XXX.6.B when creating ProVAL summary reports.

D. Prior to Corrective Work

If corrective work is required, the Contractor shall submit a written corrective work plan to the Engineer according to the requirements in section 2XXX.8. The Engineer shall approve of the Contractor's plan prior to the Contract starting corrective work. In addition, the corrective work plan shall include the locations (begin and end points) that will be corrected.

E. After Corrective Work

Within five calendar days after all required corrective work is completed, the corrected areas shall be reprofiled with a certified IP according to section 2XXX.4. Updated ProVAL reports as described in section 2XXX.6.C and a spreadsheet summary shall be submitted to the Engineer. The spreadsheet summary shall be in tabular form, with each 0.1609 km [0.1 mile] segment occupying a row. An acceptable spreadsheet summary template in electronic form is available on the Mn/DOT Smoothness web page, which can be accessed at www.dot.state.mn.us/materials/smoothness.html.

2XXX.7 PAY ADJUSTMENT

Smoothness requirements will be evaluated by the IRI equations for bituminous pavements, concrete pavements, or percent improvement projects, as applicable. Equations HMA-A, HMA-B, and HMA-C are for use with bituminous pavements. Equations PCC-A and PCC-B are for use with concrete pavements. Equation PI-A is for use with percent improvement projects.

Pay adjustments will be based on the IRI determined for each segment, and will be based on the equations and criteria in Table 2XXX.10-1 (bituminous), Table 2XXX.10-2 (concrete) or Table 2XXX.10-3 (percent improvement) as applicable.

Pay adjustments will only be based on the segment IRI value (or percent improvement value, for percent improvement projects) after any corrective work has been performed. The segment IRI value is the average of the IRI values computed with the left and the right wheel path passes, individually.

For bituminous and bituminous percent improvement projects, the Contractor will not receive a net incentive payment for smoothness if more than 25.0% of all density lots for the project fail to meet minimum density requirements.

A. Bituminous Pavements

The total smoothness incentive shall not exceed 10.0% of the total mix price for pavement smoothness evaluated under IRI Equation HMA-A, or 5.0% of the total mix price for pavement smoothness evaluated under Equation HMA-B, or HMA-C. Total mix shall be defined as all mixture placed on the project.

Typically, equation HMA-A will be used for 3-lift minimum construction, equation HMA-B will be used for 2-lift construction, and equation HMA-C will be used for single lift construction.

Table 2XXX.10-1. Pay Adjustments for Bituminous Pavements

Equation	Metric		English	
	IRI m/km	Pay Adjustment $/0.1609 km	IRI in/mi	Pay Adjustment $/0.1-mi
HMA-A	< 0.47	400.00	< 30.0	400.00
	0.47 to 1.03	850.00 – 957.450 x IRI	30.0 to 65.0	850.00 – 15.000 x IRI
	> 1.03	Corrective Work to 0.89 m/km or lower	> 65.0	Corrective Work to 56.7 in/mi or lower
HMA-B	< 0.52	270.00	< 33.0	270.00
	0.52 to 1.18	600.00 – 638.950 x IRI	33.0 to 75.0	600.00 – 10.000 x IRI
	> 1.18	Corrective Work to 0.94 m/km or lower	> 75.0	Corrective Work to 60.0 in/mi or lower
HMA-C	< 0.57	180.00	< 36.0	180.00
	0.57 to 1.34	414.00 – 410.500 x IRI	36.0 to 85.0	414.00 – 6.500 x IRI
	> 1.34	Corrective Work to 1.01 m/km or lower	> 85.0	Corrective Work to 63.7 in/mi or lower

B Concrete Pavements

For concrete pavements, equation PCC-A will be used for projects where the posted speed will be 73 km/hr [45 mph] or greater. For concrete pavement rehabilitation projects, equation PCC-B will be used when the Contract specifies pay adjustments for diamond grinding.

Table 2XXX.10-2. Pay Adjustments for Concrete Pavements

Equation	Metric		English	
	IRI m/km	Pay Adjustment $/0.1609 km	IRI In/mi	Pay Adjustment $/0.1-mi
PCC-A	< 0.79	890.00	< 50.0	890.00
	0.79 to 1.42	2940.00 – 2597.800 x IRI	50.0 to 90.0	2940.00 – 41.000 x IRI
	> 1.42	Corrective Work to 1.13 m/km or lower	> 90.0	Corrective Work to 71.7 in/mi or lower
PCC-B	< 0.79	450.00	< 50.0	450.00
	0.79 to 1.12	1511.30 – 1344.900 x IRI	50.0 to 71.2	1511.30 – 21.226 x IRI
	1.13 to 1.42	0.00	71.3 to 90.0	0.00
	> 1.42	Corrective Work to 1.42 m/km or lower	> 90.0	Corrective Work to 90.0 in/mi or lower

C Percent Improvement Projects

Pay adjustments will be based on the number of segments and the percent improvement values. The total pay adjustment for smoothness shall not exceed 5.0% of the total mix price. Total mix shall be defined as all mixture placed on the project. No corrective work will be required and no negative pay adjustment will be assessed if the initial segment IRI value is less than 0.95

m/km [60.0 in/mi] and the percent improvement is greater than zero. Percent improvement (%I) will be calculated as follows:

$$(\%I) = \frac{\text{(Initial Segment IRI – Final Segment IRI)}}{\text{Initial Segment IRI}} \times 100$$

Table 2XXX.10-3. Pay Adjustments for Percent Improvement Projects

Equation	Percent Improvement (%I)	Pay Adjustment, per $/0.1609-km [$/0.1-mi] segment
PI-A	> 64.0	180.00
	15.0 to 64.0	-236.00 + 6.500 x (%I)
	< 15.0	Corrective Work to 36.3%I or higher

2XXX.8 CORRECTIVE WORK

The Contractor shall notify the Engineer within 24 hours before commencement of the corrective work. The Contractor shall not commence corrective work until the methods and procedures have been approved in writing by the Engineer.

All smoothness corrective work for areas of localized roughness shall be for the entire lane width. Pavement cross slope shall be maintained through corrective areas.

Any localized area for which the IRI value is less than 1.89 m/km [120.0 in/mi] shall be considered acceptable. Localized areas where the IRI value is greater than 1.89 m/km [120.0 in/mi] shall be considered defective and subject to corrective work. Areas of localized roughness will be considered acceptable when the retested segment indicates no areas of localized roughness. If, after retesting, any areas of localized roughness remain, these will be assessed a deduction in the amount of $2.00 per linear 0.3048 m [1.0 ft].

For concrete pavement rehabilitation projects, the Contractor shall correct all areas of localized roughness for which the IRI value is greater than 1.42 m/km [90.0 in/mi], based on the locations recommended by the ProVAL "Smoothness Assurance" analysis.

Corrective work by diamond grinding may result in thin pavements. The Engineer shall determine if this condition needs to be verified by coring. Additional coring for thickness verification shall be at no cost to the Department. Thin pavement sections after diamond grinding may result in thickness price deductions.

Surface corrections shall be made prior to placing permanent pavement markings. In the event that permanent pavement marking are damaged or destroyed during corrective work, they will be replaced at no cost to the Department.

Residue and excess water resulting from this grinding shall be removed from the roadway by vacuuming or other method as approved by the Engineer. Residue and water shall not be permitted either to flow across lanes occupied by traffic or to flow into gutters or other drainage facilities. All materials will be disposed of outside of the right of way unless otherwise directed by the Engineer.

A Bituminous Pavements

Unless otherwise approved by the Engineer, corrective work shall be by an approved surface diamond grinding device consisting of multiple diamond blades. Other methods may include overlaying the area, or replacing the area by milling and inlaying. Any corrective work by milling and inlay or by overlay shall meet the specifications for smoothness over the entire length of the correction. If the surface is corrected by milling and inlay or by overlay, the surface correction shall begin and end with a transverse saw cut. The Engineer may require diamond ground bituminous surfaces to be fog-sealed by the Contractor at the Contractor's expense.

B Concrete Pavements

Unless otherwise approved by the Engineer, corrective work shall be by an approved surface diamond grinding device consisting of multiple diamond blades. Joint sealant that has been damaged by diamond grinding on concrete pavement as determined by the Engineer shall be repaired and replaced at no expense to the Department.

C Percent Improvement Projects

The Engineer may require that the Contractor, at no expense to the Department, correct segments with a percentage improvement of less than 15.0%.

2XXX.9 RETESTING

The Engineer may require any portion or the total project to be retested if the results are questioned. The Engineer will decide whether Mn/DOT, an independent testing firm, or the Contractor will retest the roadway surface.

If the retested IRI values differ by more than 10.0% from the original IRI values, the retested values will be used as the basis for acceptance and any pay adjustments. If the retested data is within 10.0% of the original IRI values, the original data will be used. The Contractor will be responsible for any costs associated with retesting if the retested values differ by more than 10.0% from the original values.

If the Engineer directs the Contractor or an independent testing firm to perform retesting (besides that required after corrective work) 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 [$100.00 per lane mile] that is retested, with a minimum charge of $500.00.

17-Mar-09

2010 Bituminous Profile Summary

S.P./S.A.P.	
T.H./CSAH	
Lane & Direction	

Equation	
Mix	
PG	

Begin Station	
End Station	
Date Measured	

File Name	
Comments/Notes	

Total Length of Pavement (feet)	
% Out of Tolerance After Grinding	

Stationing		Segment Length (feet)	Left Wheel Path		Right Wheel Path		Average of Wheel Paths			
Begin	End		Initial IRI	Final IRI After Grinding	Initial IRI	Final IRI After Grinding	Initial IRI	Final IRI After Grinding	Percent Improve	Segment Pay Adjust
Total Pay Adjustment										
Areas of Localized Roughness Deduction										
Total Pay Adjustment + Areas of Localized Roughness Deduction										

Data Entered By	
Signature	

Checked By	
Signature	

17-Mar-09

2010 Concrete Profile Summary

S.P./S.A.P.		Lane & Direction		Begin Station	
T.H./CSAH		Equation		End Station	

File Name		Total Length of Pavement (feet)	
Date Measured		% Out of Tolerance After Grinding	

Stationing		Segment Length (feet)	Left Wheel Path		Right Wheel Path		Average of Wheel Paths			
Begin	End		Initial IRI	Final IRI After Grinding	Initial IRI	Final IRI After Grinding	Initial IRI	Final IRI After Grinding	Percent Improve	Segment Pay Adjust
Total Pay Adjustment										
Areas of Localized Roughness Deduction										
Total Pay Adjustment + Areas of Localized Roughness Deduction										

Data Entered By		Checked By	
Signature		Signature	

17-Mar-09

2010 Bituminous % Improvement Profile Summary

S.P./S.A.P.	
T.H./CSAH	
Lane & Direction	

Equation	
Mix	
PG	

Begin Station	
End Station	
Date Measured	

File Name	
Comments/Notes	

Total Length of Pavement (feet)	
% Out of Tolerance After Grinding	

Stationing		Segment Length (feet)	Left Wheel Path		Right Wheel Path		Average of Wheel Paths			
Begin	End		Initial IRI	Final IRI After Grinding	Initial IRI	Final IRI After Grinding	Initial IRI	Final IRI After Grinding	Percent Improve	Segment Pay Adjust
Total Pay Adjustment										
Areas of Localized Roughness Deduction										
Total Pay Adjustment + Areas of Localized Roughness Deduction										

Data Entered By	
Signature	

Checked By	
Signature	

17-Mar-09

2010 Concrete % Improvement Profile Summary

S.P./S.A.P.		**Lane & Direction**		**Begin Station**	
T.H./CSAH		**Equation**		**End Station**	

File Name		**Total Length of Pavement (feet)**	
Date Measured		**% Out of Tolerance After Grinding**	

Stationing		Segment Length (feet)	Left Wheel Path		Right Wheel Path		Average of Wheel Paths			
Begin	End		Initial IRI	Final IRI After Grinding	Initial IRI	Final IRI After Grinding	Initial IRI	Final IRI After Grinding	Percent Improve	Segment Pay Adjust
Total Pay Adjustment										
Areas of Localized Roughness Deduction										
Total Pay Adjustment + Areas of Localized Roughness Deduction										

Data Entered By		**Checked By**	
Signature		**Signature**	