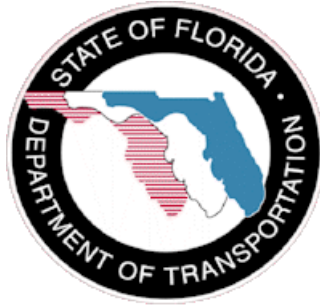


State of Florida  
**Department of Transportation**



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**Pavement Smoothness Acceptance Testing:  
Survey of Current State Practices**

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**FDOT Office**

State Materials Office

**Research Report Number**

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**Authors**

Bouزيد Choubane

Stacy Scott

Alex Mraz

John Schiffermuller

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## ***Executive Summary***

In June 2009, the Florida Department of Transportation (FDOT) conducted a survey to assess the current smoothness measurement techniques and acceptance practices implemented by the various highway agencies for both concrete and asphalt roadway surfaces. A total of 36 agencies responded to the survey including 33 State DOTs, the Federal Highway Administration (FHWA), and 2 Canadian highway agencies. This report provides a summary of the information gathered through this survey.

# 1 *Introduction*

Pavement smoothness is an important indicator of pavement condition, both in terms of performance, and as a determinant of road user costs. Therefore, attaining acceptable surface smoothness on newly constructed or rehabilitated pavements is becoming a major concern to highway agencies (1). This need to quantify pavement surface smoothness has resulted in the development of numerous measurement techniques and devices. Of greater interest to highway agencies are those that would provide for versatility, ease and speed of use (2, 3).

High-speed pavement profiling technology was initially introduced in the 1960s at the General Motors Research Laboratory (4). Since then, a considerable amount of research has been conducted to gain further understanding on the factors affecting high-speed profiling from both the analytical and experimental points of view. Comparative studies have indicated, for instance, that optical and laser-based profilers generally exhibited better performance, in terms of repeatability and accuracy. These studies have also shown that the use of ultrasonic-based profilers may not be appropriate for textured surfaces such as chip seal or open-graded pavements, while ambient light could contaminate optical sensors (5, 6, 7).

Once a longitudinal profile is measured, any profile-based roughness index may be calculated. Although a number of roughness indices exist, the International Roughness Index (IRI) and Ride Number (RN) statistics are generally used as pavement surface condition indicators. IRI is defined as a mathematical transform (a property) of a true profile describing surface roughness that causes vehicle vibration (8). The underlying IRI model is a series of differential equations that relate the motions of a simulated quarter-car to a road profile. The IRI is computed as a linear accumulation of the simulated suspension motion, normalized by the length of the profile. IRI has, therefore, units of slope and is computed from a single longitudinal wheel path profile. It has demonstrated a strong compatibility with the equipment used to develop pavement management systems. The Federal Highway Administration (FHWA) currently requires state agencies to report IRI on a portion of their network for the national Highway Performance Monitoring System (HPMS) (9). RN is obtained through a practical mathematical process of the longitudinal road surface profiles. The practice is the result of NCHRP work on the effect of

road surface roughness on ride comfort conducted in the 1980s (9). The objective of that work was to determine how road profiles were linked to the subjective opinion about the road ride quality from members of the public. Thus, RN is linked by statistical correlation to public opinion of ride quality (10).

In June 2009, the Florida Department of Transportation (FDOT) conducted a survey to assess the current smoothness measurement techniques and acceptance practices implemented by the various highway agencies for both concrete and asphalt roadway surfaces. This report provides a summary of the information collected through this survey.

## **2**      ***Smoothness-Measuring Devices***

The pavement profile-measuring devices of interest to this survey are described in the following sections.

### ***2.1 High-Speed Inertial Profilers***

High-Speed Inertial Profilers (HSIP) are devices that collect profile data at ordinary traffic speeds. A typical inertial profiler (Figure 1) consists of an instrumented vehicle with three essential transducers, namely, (1) accelerometer(s), (2) road sensing transducer(s), and (3) a distance-measuring instrument. The respective outputs from these three sensors are combined to compute a pavement surface profile. The accelerometers measure the vertical motion of the vehicle body. Data processing algorithms convert the vertical acceleration signals to the elevation path followed by the body of the host vehicle as it travels along the roadway. The distance of the road surface below the elevation path of the vehicle is measured with non-contacting sensors such as lasers, optical, or infrared transducers. When this measurement is subtracted from the elevation of the vehicle body, the road profile is obtained. The distance-measuring instrument (DMI) determines the longitudinal position along the road, and is usually recorded from the vehicle speedometer or from direct measurements of rotation of one of the vehicle wheels. The longitudinal distance measurement is needed to associate a position with each profile elevation.



**Figure 1 FDOT High-Speed Inertial Profiler**

## **2.2 Lightweight Profiler**

As illustrated in Figure 2, the lightweight profiler is a golf-cart like vehicle light enough to drive on “green” concrete pavements. It uses an infrared laser sensor and a precision accelerometer to measure pavement’s longitudinal profile. The laser and accelerometer are mounted on the front bumper of the vehicle. The data collected can be used to produce a variety of ride parameters such as IRI, RN, or simulate the output from a California profilograph. The equipment operates at speeds of up to approximately 20 mph and complies with the requirements of ASTM E950 for Class 1 profiling equipment.





**Figure 2 FDOT Lightweight Profiler**

### **2.3 California Profilograph**

Profilographs are used to measure the longitudinal profile of a concrete pavement. The mechanical models of the profilographs have been produced since 1960, while the automated version was introduced in the mid-1980s.

California profilograph (Figure 3) is relatively inexpensive, manually operated by one person at walking speed, and provides a trace of the pavement surface users can easily understand. It consists of a 25-ft aluminum frame supported on both ends by a non-uniformly spaced series of wheels. The surface-sensing wheel and recorder are located at the center of the reference platform. Support wheels have varied in number from four to twelve, with systems in many states using twelve wheels. These wheels are attached to the ends of a 25-foot long truss mounted on a multiple axle carriage that includes four wheels spaced 17 inches from the truss centerline and two wheels spaced 17 inches on the opposite side of the truss centerline. The support wheels are commonly spaced at 2.7-foot intervals and positioned near the ends of the truss, resulting in an overall profilograph span of approximately 33 feet.



**Figure 3 California Profilograph**

#### *2.4 Rainhart Profilograph*

The Rainhart profilograph operates similar to the California profilograph. The major difference is that the Rainhart profilograph uses twelve wheels arranged in four groups of three. This wheel arrangement ensures that each wheel travels a separate path. This allows measurement of twelve wheel paths instead of just three as with the California profilograph.

#### *2.5 Rolling Straightedge*

The rolling straightedge (Figure 4) is an apparatus used for quick assessment of the road surface irregularities, i.e., bumps or dips. The apparatus is approximately 15-feet long and 0.82-feet wide and has a strong aluminum frame to which wheels are attached at the bottom edge of both sides. The wheels are attached such as to create a moving straight reference line. Midway along the length of the straightedge is a wheel that moves vertically in relation to the reference line and the vertical movement is continuously measured on a dial, visible to the operator. A particular vertical measurement can be set as a reference and any pavement deviation exceeding it will give an indication of a suspect area.



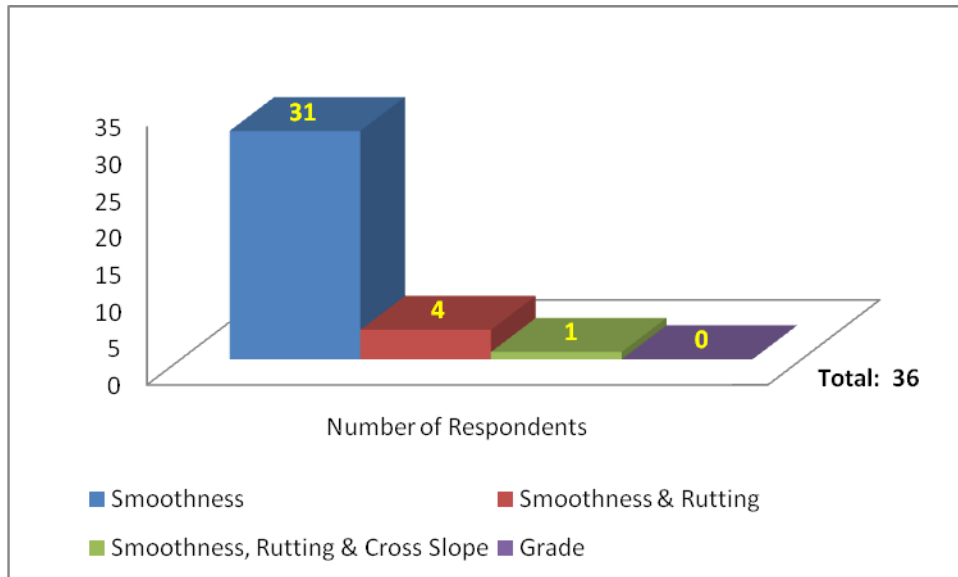
**Figure 4 A 15-foot Rolling Straightedge**

### 3 *Summary of Survey Responses*

In June 2009, the Florida Department of Transportation (FDOT) conducted a survey to assess the current smoothness, measurement techniques, and acceptance practices implemented by the various highway agencies for both concrete and asphalt roadway surfaces. A total of 36 agencies responded to the survey including 33 State DOTs, the Federal Highway Administration (FHWA), and 2 Canadian highway agencies. In this section, the survey results are summarized on a question by question basis.

**Question 1: Please select the data collected (check all that apply)**

- Smoothness
- Rutting
- Cross Slope
- Grade

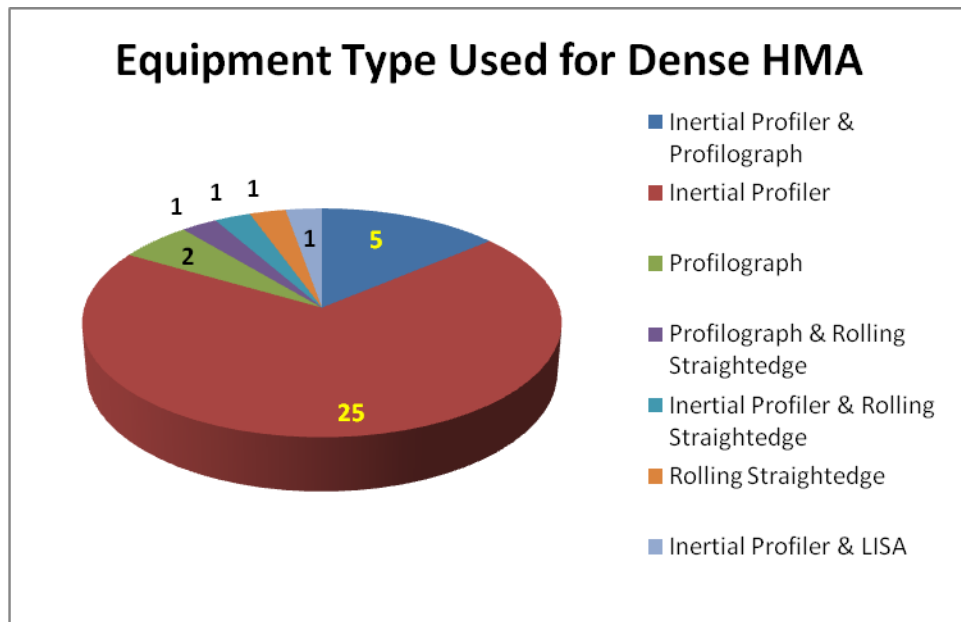


**Figure 5 Smoothness and other distress data collected by agencies**

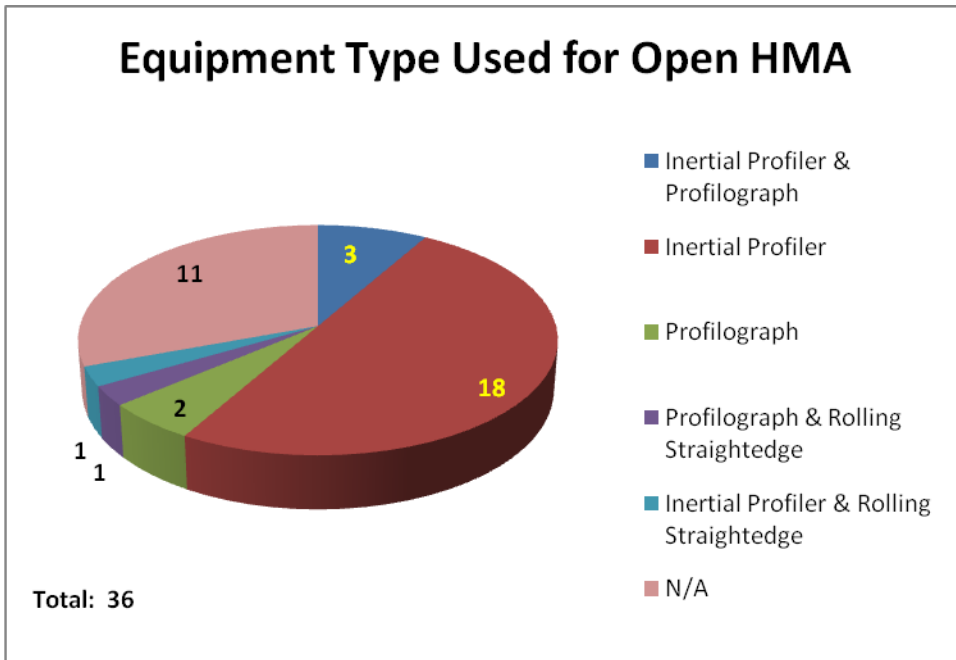
**Question 2: What type of smoothness testing device is specified for?**

- Dense-Graded Hot Mix Asphalt (HMA)
- Open-Graded Hot Mix Asphalt (HMA)
- Portland Cement Concrete (PCC)

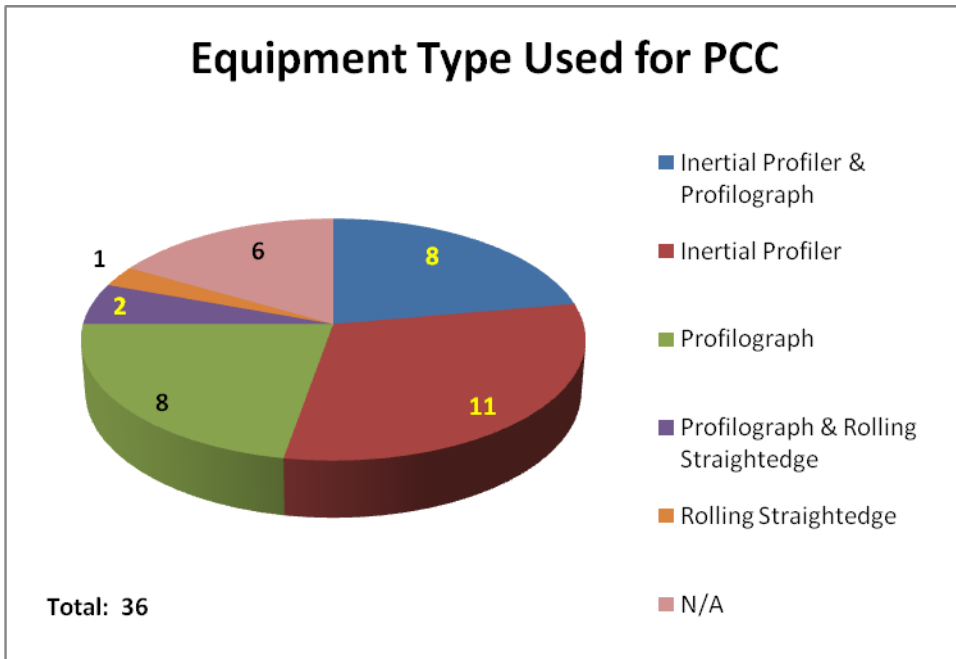
As a note, some agencies used more than one device for measurement on a particular pavement surface type. The resulting graph differentiates these agencies from those that used a single device.



**Figure 6 Profiling equipment specified for dense graded HMA**



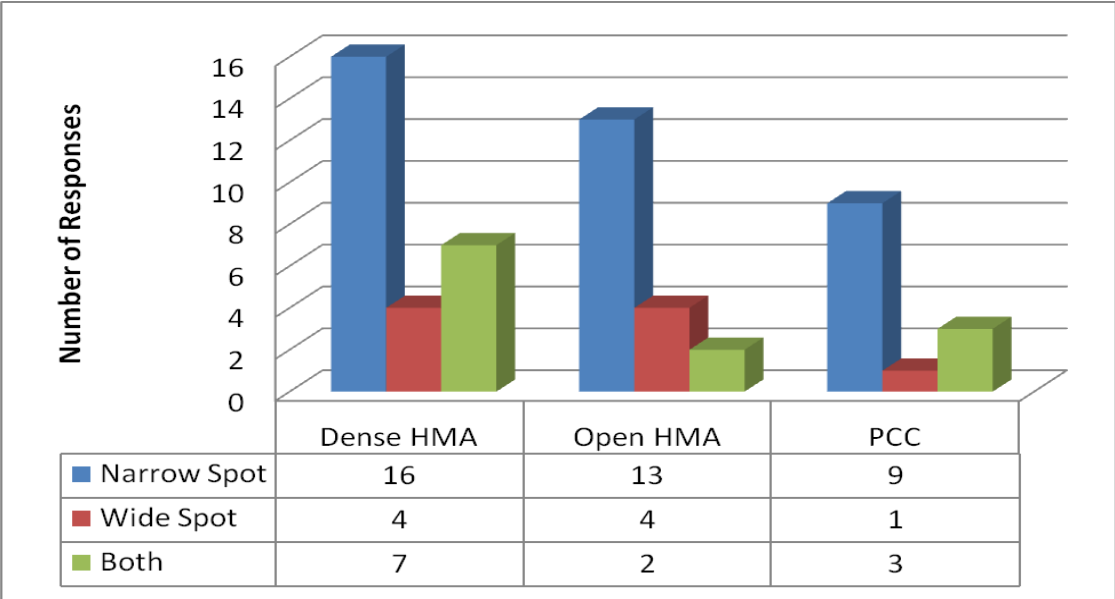
**Figure 7 Profiling equipment specified for open graded HMA**



**Figure 8 Profiling Equipment specified for PCC**

**Question 3: What type of sensor and sensor “footprint” (ex: wide-spot or narrow-spot) is used to collect smoothness data for?**

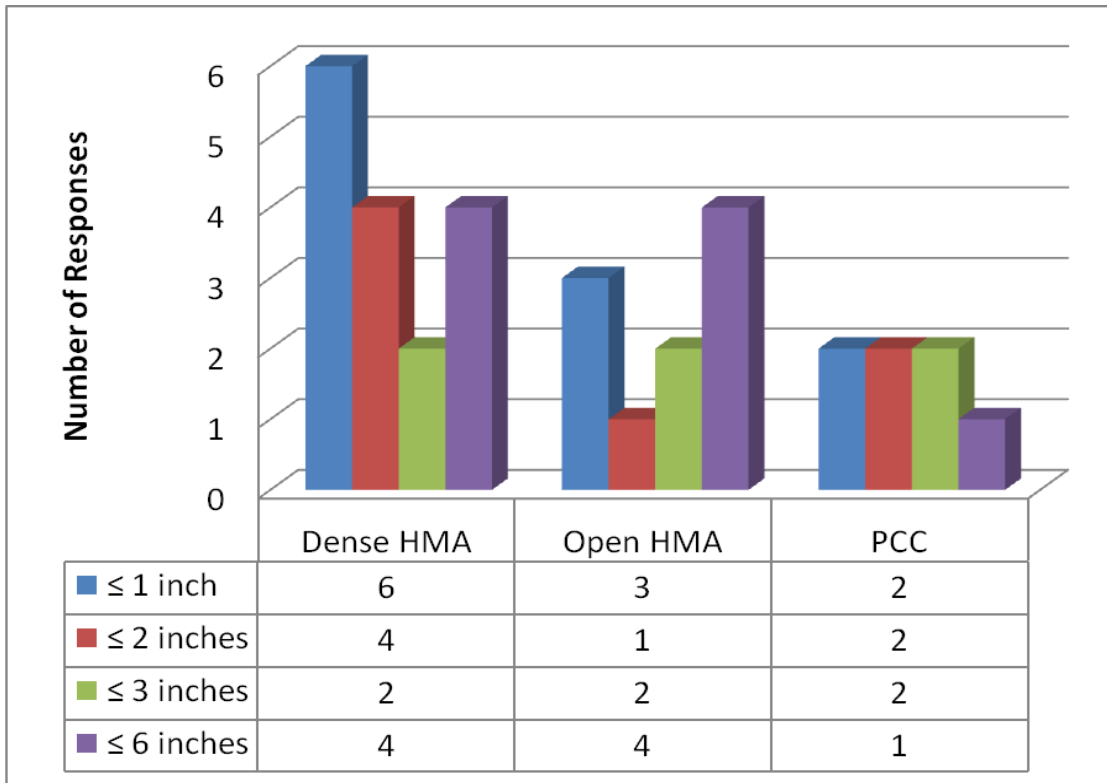
- Dense-Graded Hot Mix Asphalt
- Open-Graded Hot Mix Asphalt
- Portland Cement Concrete



**Figure 9 Inertial profiler sensor footprint**

**Question 4: What sampling interval is used for?**

- Dense-Graded Hot Mix Asphalt
- Open-Graded Hot Mix Asphalt
- Portland Cement Concrete

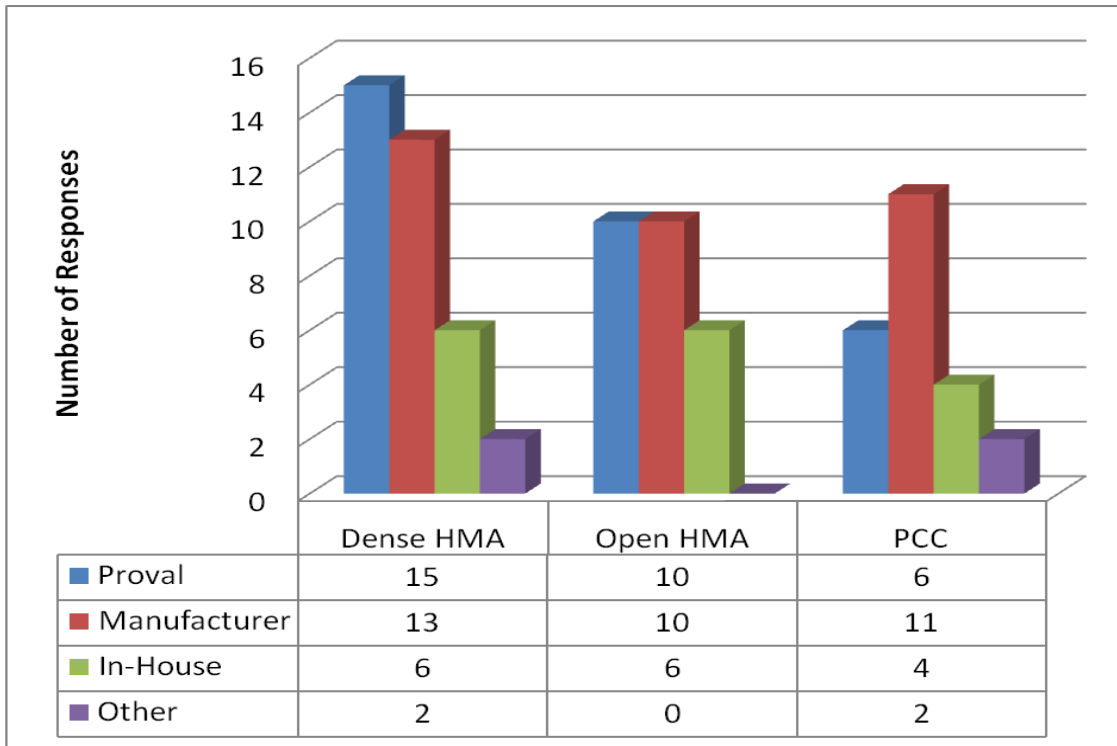


**Figure 10 Profile sampling interval**



**Question 5: What program (software) do you use to analyze the data for?**

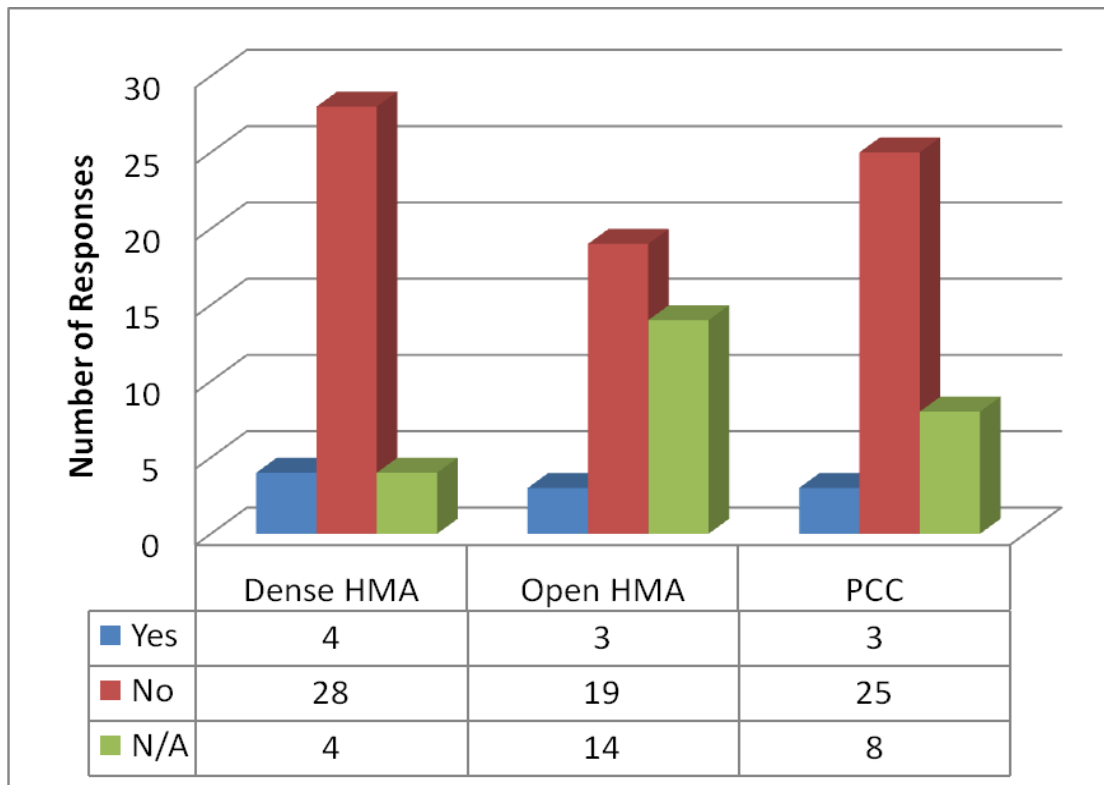
- Dense-Graded Hot Mix Asphalt
- Open-Graded Hot Mix Asphalt
- Portland Cement Concrete



**Figure 11 Agencies with profile analysis software**

**Question 6: Does your state have a warranty specification for (if so, please provide latest)?**

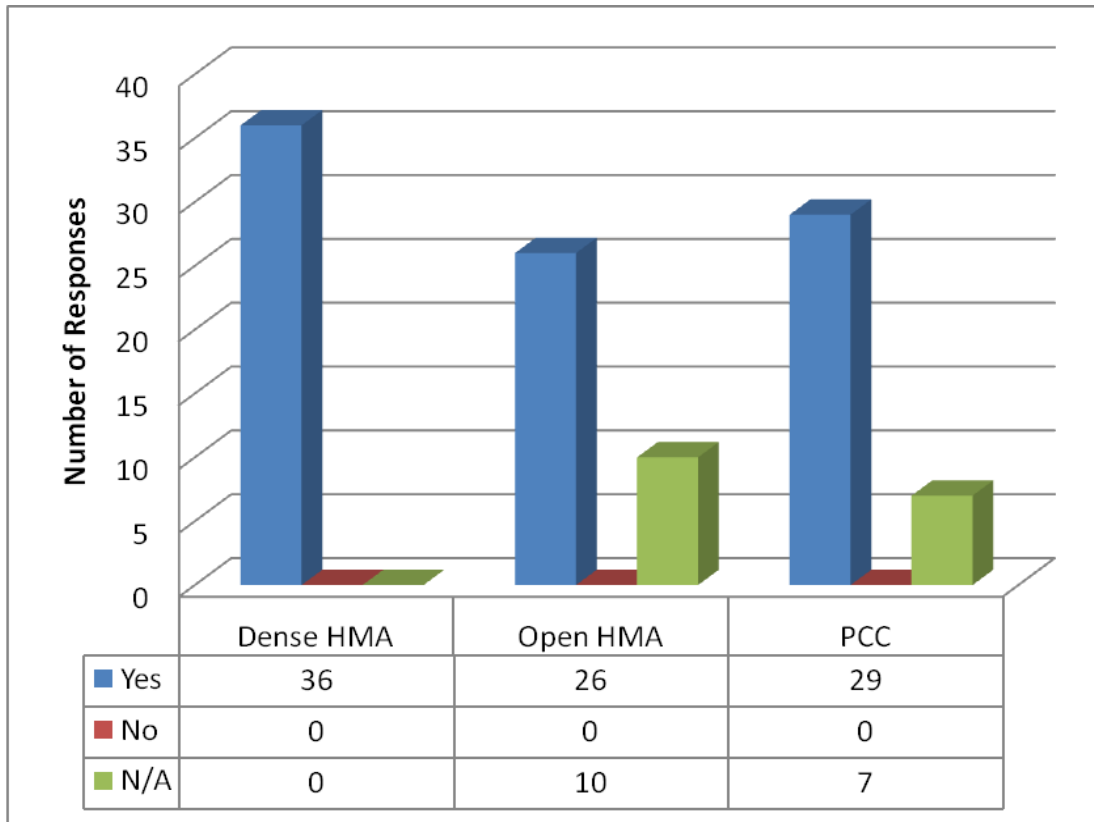
- Dense-Graded Hot Mix Asphalt
- Open-Graded Hot Mix Asphalt
- Portland Cement Concrete



**Figure 12 Agencies with warranty specification(s)**

**Question 7: Does your state have a smoothness acceptance specification for (if so, please provide latest)?**

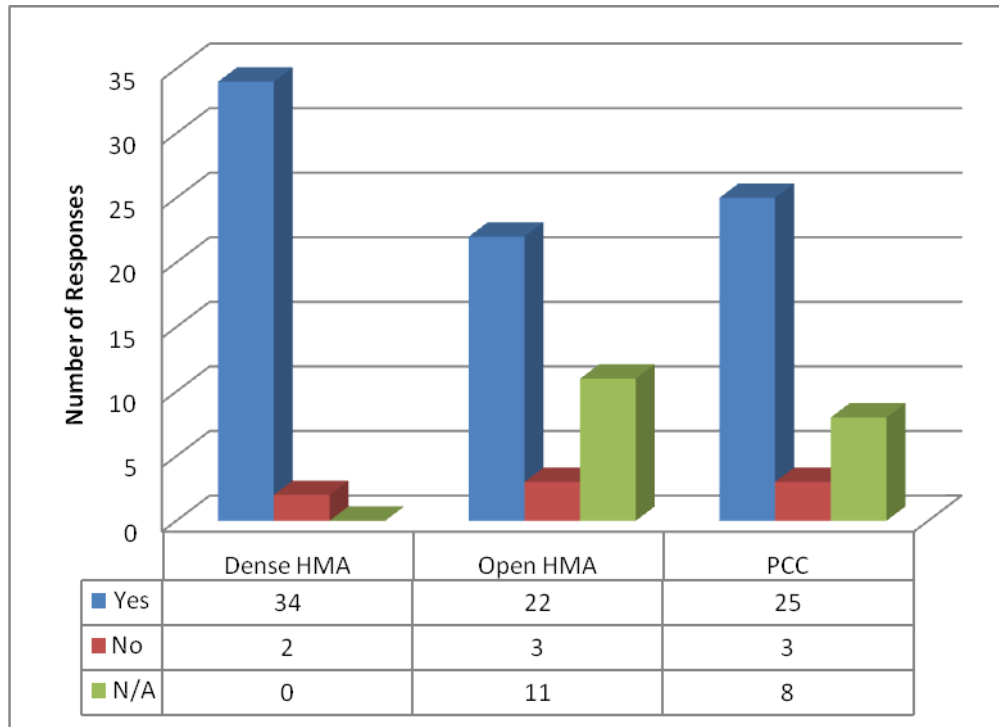
- Dense-Graded Hot Mix Asphalt
- Open-Graded Hot Mix Asphalt
- Portland Cement Concrete



**Figure 13 Agencies with smoothness acceptance specification(s)**

**Question 8: Does your specification include smoothness incentive/disincentive (or penalty) clause for?**

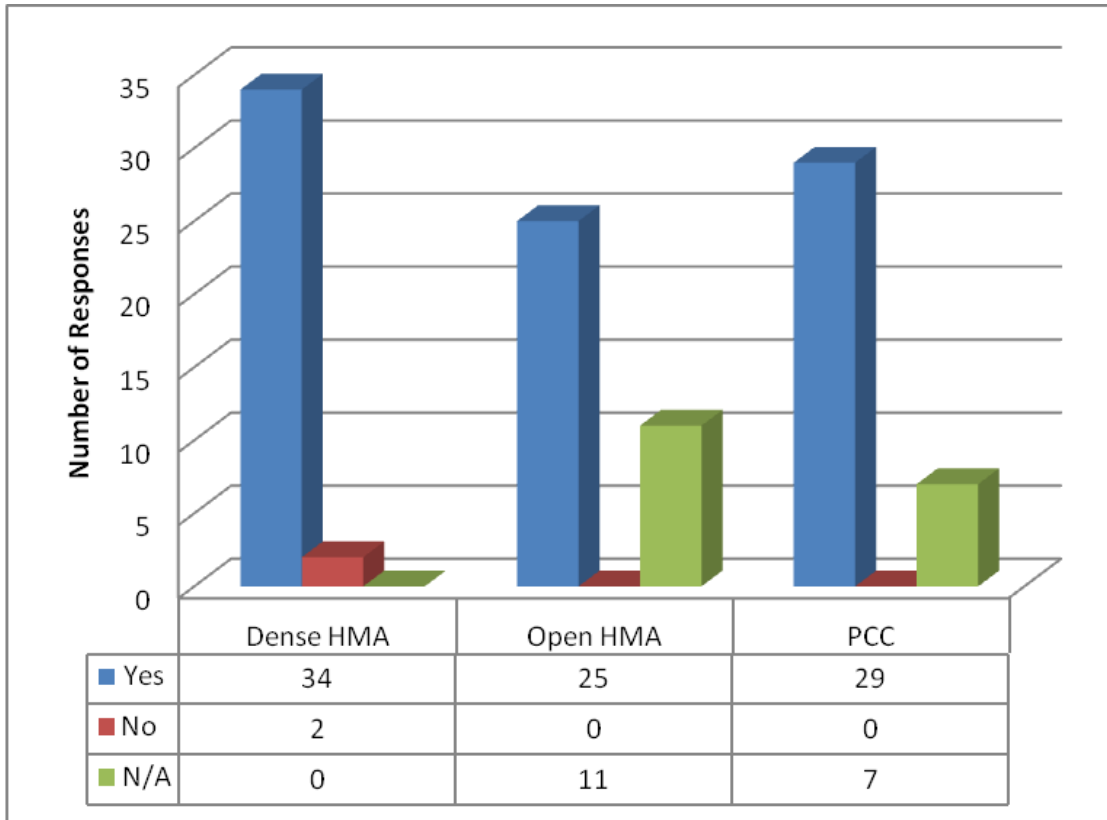
- Dense-Graded Hot Mix Asphalt
- Open-Graded Hot Mix Asphalt
- Portland Cement Concrete



**Figure 14 Agencies with smoothness incentive/penalty specification(s)**

**Question 9: Is a retest required/allowed after the contractors make any required smoothness corrections?**

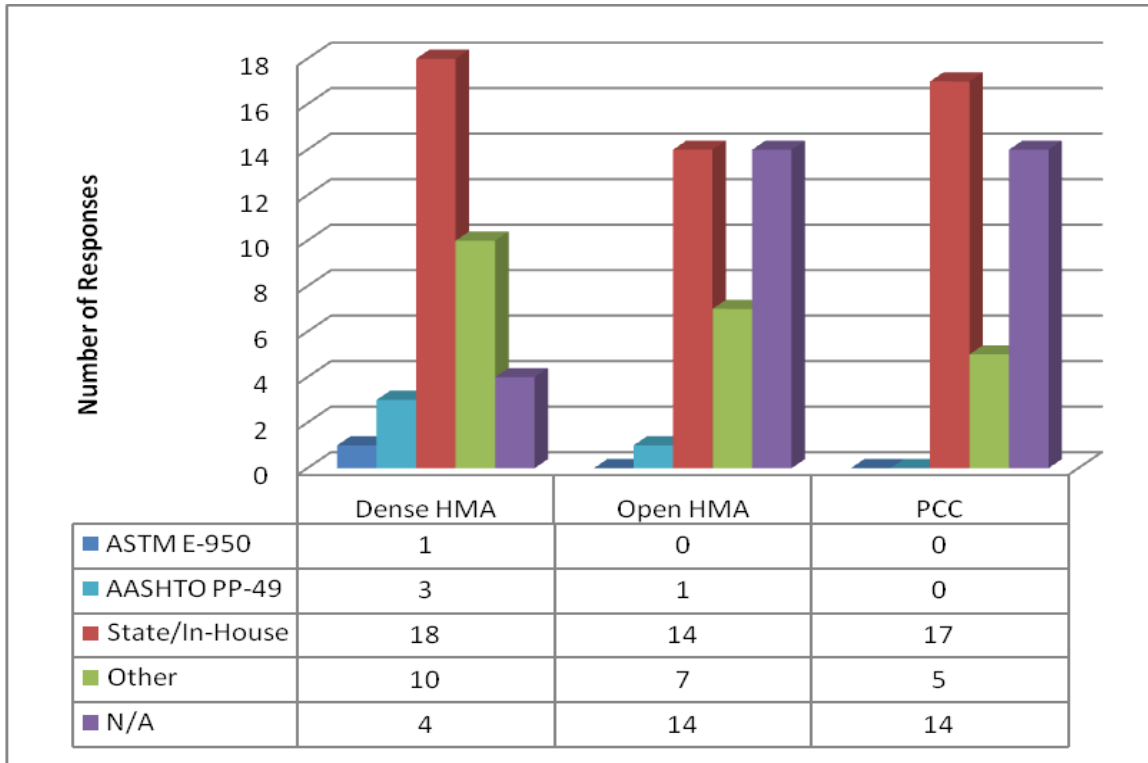
- Dense-Graded Hot Mix Asphalt
- Open-Graded Hot Mix Asphalt
- Portland Cement Concrete



**Figure 15 Agencies with smoothness retest requirement(s)**

**Question 10: What protocol do you follow to certify an inertial profiler used for your project acceptance?**

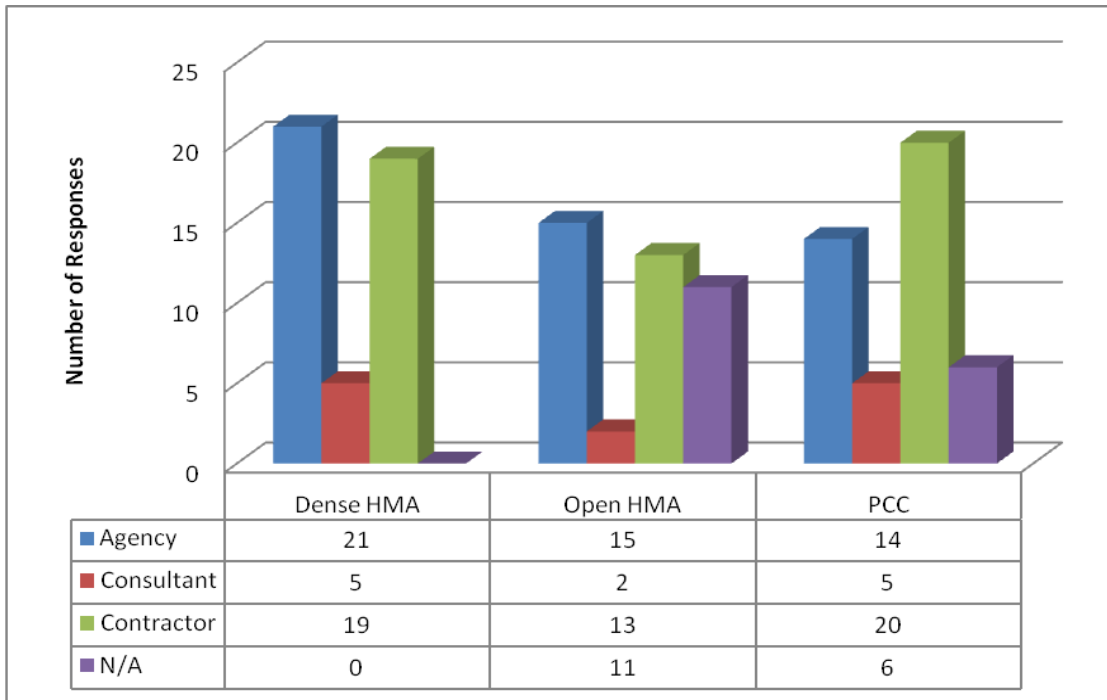
- Dense-Graded Hot Mix Asphalt type
- Open-Graded Hot Mix Asphalt
- Portland Cement Concrete



**Figure 16 Agencies with an inertial profiler certification protocol**

**Question 11: Is the acceptance testing performed by the state, consultant, or contractor?**

- Dense-Graded Hot Mix Asphalt
- Open-Graded Hot Mix Asphalt
- Portland Cement Concrete



**Figure 17 Responsible party to conduct smoothness acceptance test**

**Question 12: What challenges/problems have you encountered in implementing smoothness specifications for**

- Dense-Graded Hot Mix Asphalt
- Open-Graded Hot Mix Asphalt
- Portland Cement Concrete

Different agencies reported different challenges in implementing their smoothness specification(s). Due to the open-ended nature of this question, it was decided not to summarize the responses for this question. Instead, the submitted responses are provided in Appendix A for the interested readers.



## 4 *Observations*

The following observations were made from the survey results:

- Out of 36 agencies that responded to the survey, 31 agencies (86%) collect data for smoothness only, four (11%) collect data for both smoothness and rutting, and one agency (3%) collects data for smoothness, rutting and cross-slope.
- 76% of agencies use HSIP to evaluate open-graded HMA while 86% use HSIP on dense-graded HMA. The results were evenly split (50/50) between HSIP and profilographs for PCC.
- Regardless of the surface types, the narrow-spot sensor footprint is the most commonly used sensor in conjunction with inertial profilers. Most agencies that allow use of wide spot sensors also allow the use of the narrow-spot sensors.
- There is no discernable trend among agencies regarding profile sampling interval except that they all use an interval that is less than 6 inches.
- ProVal and manufacturer supplied programs are used equally by agencies for all HMA surface profile analysis. A slight majority (11 vs. 10) of agencies use manufacturer supplied programs over other analytical software for PCC profile analysis.
- Only four agencies use warranty specifications on dense-graded HMA, and three agencies use warranty specifications on open-graded HMA and PCC pavements. A one year warranty period was specified by one agency on dense-graded HMA, but this requirement is only applied when paving is completed outside of the defined paving season, which is not routinely done. Another agency uses 3-year criteria for all HMA surfaces and 5-year for PCC surfaces. The rest of the agencies did not specify a warranty period(s).
- All agencies use smoothness acceptance specifications for all surface types.

- Smoothness incentives/disincentives are used by 95% of agencies on dense-graded HMA surfaces while 88% use them on open-graded HMA and PCC surfaces.
- 95% of agencies require a retest after smoothness corrections on dense-graded HMA; all agencies require a retest on open-graded HMA and PCC surfaces.
- 56% of agencies conduct an in-house certification of HSIP for dense-graded HMA surfaces; 64% and 77% of agencies conduct an in-house certification for open-graded HMA and PCC surfaces, respectively. One agency uses the ASTM E-950 method on dense-graded HMA surfaces. AASHTO PP-49 method is used by three agencies for dense-graded HMA surfaces and only one agency uses this standard for open-graded HMA surfaces. ASTM E-950 and AASHTO PP-49 standards were not used on PCC surface by any agency.
- For all HMA surfaces, 50% of agencies perform their own acceptance testing, 40% allow contractors to perform the testing, and the remaining 10% contract out the testing services. For PCC surfaces, 35% of agencies perform their own acceptance testing, 50% allow contractors to perform the testing, and the remaining 15% contract out the services.

## 5 *References*

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## **6**            ***Disclaimer***

The survey results provided in this report are summarized based on the recorded responses of the participating agencies interpreted by the authors of this report. As such, the responses had been categorized and summarized to the best of the authors' knowledge and the responses deemed irrelevant to the questionnaire had been subsequently removed and excluded from the report. Comments and questions arising from any misinterpretation may be submitted to the authors for corrective actions and/or further clarification. However, the Florida Department of Transportation and the authors assume no liability for the contents of this report or use thereof.

# Appendix A

## Question 12

### Question Statement

What challenges/problems have you encountered in implementing smoothness specifications for?

- Dense-Graded Hot Mix Asphalt
- Open-Graded Hot Mix Asphalt
- Portland Cement Concrete

### Responses:

STATE	Q12		
	Dense HMA	Open HMA	PCC
Alabama	N/A	N/A	N/A
Alaska	Most of the time, contractor thinks that the pavement is smoother than what the profiler measures.		
Arizona	N/A	N/A	N/A
Colorado	Testing every project with the CDOT profiler. We switched to having the contractor measure smoothness and having the data submitted to the state for analysis. CDOT verifies at least 25% of a contractor's projects statewide	N/A	Longitudinal tinning has kept us from using IRI. We are currently in the process of upgrading the CDOT profiler to Roline laser to switch to IRI for the 2010 construction season.
FHWA	Overcoming "Black Box Syndrome" and trying to get pay incentives and disincentives to be similar to what we paid under Pri smoothness specification.	Overcoming "Black Box Syndrome" and trying to get pay incentives and disincentives to be similar to what we paid under Pri smoothness specification.	N/A
Florida	Current Spec treats Dense-Graded pavement the same as Open-Graded even though texture of Open Graded surface typically causes RN to be rougher, especially with pin-point laser sensors. Often get complaints from contractors claiming that the laser data is not valid or that it agrees with their perception of the smoothness of the project. Some of this appears to be due to a lack of understanding of how the laser profiler works, or because of resistance to change.	Current Spec treats Dense-Graded pavement the same as Open-Graded even though texture of Open Graded surface typically causes RN to be rougher, especially with pin-point laser sensors. Often get complaints from contractors claiming that the laser data is not valid or that it agrees with their perception of the smoothness of the project. Some of this appears to be due to a lack of understanding of how the laser profiler works, or because of resistance to change.	Because placement of PCC pavement in Florida is rather rare, refresher training and technical support is often needed by project personnel when dealing with the profilograph testing.

STATE	Q12		
	Dense HMA	Open HMA	PCC
Georgia	When SP mix design was not customized for GA conditions, mixes were drier and were harder to compact, which in turn made the final ride not as smooth as it used to be.	OGFC's are used on Interstates and higher volume State routes. OGFC's become smoother after one to two weeks due to additional seating / compacting.	Narrow footprint sensors are highly variable on ground PCC surfaces.
Idaho	Questions regarding the value of smoothness, i.e. are we overpaying with our incentives? Initial buy in from the contractors regarding purchasing the profilers and change in specifications.	N/A	Industry buy-in of the limits for the IRI specification. Equipment requirements, wide footprint sensor. This discussion is ongoing
Iowa	Developing reasonable incentive-disincentive levels.	N/A	Developing reasonable incentive-disincentive levels.
Kansas	None	None	None
Kentucky	Concern from HMA industry that HMA specifications are more stringent than PCC. Occasionally have problems when smoothness is specified on projects where project limitations make smoothness difficult to obtain.	N/A	Concerns from PCC industry that tinning of concrete pavements causes higher IRI values that do not accurately reflect the ride experienced by motorists.
Louisiana	Training on ProVAL. Our IRI spec does not adequately address bumps.	N/A	N/A
Maryland	It is difficult to accommodate the varying conditions encountered by the contractor in different geographical and functional sections of the state: urban vs. rural, flat vs. mountainous, interstate vs. streetscape. This year we modified our specification to include a clause to address conditions encountered that are beyond the control of the contractor.	We have very little OG HMA	We have very little (non bridge) Portland Cement Concrete
Massachusetts	Establishing test sites for verification and certification of contractor roughness equipment	N/A	N/A
Minnesota	N/A	N/A	N/A
Mississippi	We are currently developing new specifications to switch from P.I. to an IRI based acceptance. We are in the latter stages of this process and is obviously in depth and detailed. Feel free to contact me for any information regarding this process.	We are currently developing new specifications to switch from P.I. to an IRI based acceptance. We are in the latter stages of this process and is obviously in depth and detailed. Feel free to contact me for any information regarding this process.	We are currently developing new specifications to switch from P.I. to an IRI based acceptance. We are in the latter stages of this process and is obviously in depth and detailed. Feel free to contact me for any information regarding this process.
Missouri	N/A	N/A	N/A
Nevada	N/A	N/A	N/A
New Hampshire	none	none	N/A

STATE	Q12		
	Dense HMA	Open HMA	PCC
New Jersey	Contractors unable to attain positive PA complain spec is unattainable. We don't get the same complaints from contractors gaining positive PA (majority of tests.)	Contractors unable to attain positive PA complain spec is unattainable. We don't get the same complaints from contractors gaining positive PA (majority of tests.)	Inertial profiler not yet implemented for PCC.
New York	There has been debate between the State and Industry regarding how to best deal with manholes, DI's and other obstructions in the travel lanes being tested. We currently omit these sections. The State currently only uses smoothness specs on controlled-access highways (Interstates and Parkways). We would like to expand to secondary roads but are trying to decide the best way to do it.	N/A	The State would like to switch from a Profile Index spec to IRI. Industry seems ok with using IRI however they are hesitant until they can be assured there will be no problems with error due to the texturing of PCC pavements. Hopefully multi-point and line lasers will solve this problem.
North Carolina	Getting a feel for the IRI numbers compared to our PI numbers. Cost of the high speed profilers. Establishing a profiler calibration track.	N/A	N/A
North Dakota	Contractors are not familiar with non-contact laser profiling. Equipment must operate at minimum speeds; making collection of data up to and through intersections difficult. * Speed limits and traffic through urban sections makes it difficult to maintain constant speed and collection path.	N/A	Currently using California Profilograph. It has been a challenge to win contractor acceptance of smoothness results from non-contact laser profilers. NDDOT has collected data from PCC projects for several years in preparation for the transition to laser profiling. Data has been shared with contractors to prepare them when the change occurs.
Ohio	Getting contractors to follow reporting requirements to the letter. Getting state project staff to enforce localized roughness criteria/limits; getting all to understand IRI based rideability; getting contractors to finally recognize that tools within ProVAL are really there to help them achieve incentives, that light bulb recently came on for the contractors in general	We use very little OGSF. When we do, we measure the course just below the OGSF for smoothness acceptance.	Getting PCC contractors to understand IRI and what material issues and construction practices affect such. Those guys get one shot at it which is much more difficult than the AC boys. Further, the animal continues to changes shape after the contractor has finished touching it as it cures.
Ontario, Canada	Getting the contractors on side was extremely difficult at first and we ended up phasing in the penalties over several years. There was also an issue over contracts carried over the winter and the effect that traffic on the upper binder would have on the surface course placed in the spring. As far as the inertial profilers go, the greatest challenge has been switching from QC for acceptance to QA for acceptance.	Getting the contractors on side was extremely difficult at first and we ended up phasing in the penalties over several years. There was also an issue over contracts carried over the winter and the effect that traffic on the upper binder would have on the surface course placed in the spring. As far as the inertial profilers go, the greatest challenge has been switching from QC for acceptance to QA for acceptance.	N/A
Oregon	Certification site location. Certification of inertial profiler based upon the Profile Index (PI)	Certification site location. Certification of inertial profiler based upon the Profile Index (PI)	Certification site location. Certification of inertial profiler based upon the Profile Index (PI)

STATE	Q12		
	Dense HMA	Open HMA	PCC
Saskatchewan, Canada	none, since we have both penalty and bonus clauses	N/A	N/A
South Carolina	Work quality issues.	Work quality issues.	Work quality issues. Also, for bridge decks, some issues with correcting for errors in readings due to longitudinal texture (diamond grinding).
South Dakota	N/A	N/A	N/A
Tennessee	Initial transition from Mays Meters to Road Profilers in 2000/2001 was challenging. We performed many miles of side by side testing to produce correlation curves and maintained industry involvement throughout the process of changing equipment and updating acceptance specifications.	Initial transition from Mays Meters to Road Profilers in 2000/2001 was challenging. We performed many miles of side by side testing to produce correlation curves and maintained industry involvement throughout the process of changing equipment and updating acceptance specifications.	Initial transition from Mays Meters to Road Profilers in 2000/2001 was challenging. We performed many miles of side by side testing to produce correlation curves and maintained industry involvement throughout the process of changing equipment and updating acceptance specifications.
Texas	N/A	N/A	N/A
Utah	Requiring one set of smoothness numbers in Table 1 no matter what the original condition of the road that the contractor starts with. Also, keeping the must grinds under 20 square yards per 0.1 mile section.	Not wanting to allow grinding of the Open Graded surface. The debate between the grinding damage and the bump if left in place.	Holding PCC pavement to the same standards of HMA.
Virginia	Industry too focused on penalty portion of the spec overlooking the incentive side. Complains from the industry about alleged "mis application" of ride spec. Too sensitivity of small issues arising out of measuring ride number. AASHTO and ASTM standards for calibration and maintaining of profilers too complicated and difficult to follow.	Industry too focused on penalty portion of the spec overlooking the incentive side. Complains from the industry about alleged "mis application" of ride spec. Too sensitivity of small issues arising out of measuring ride number. AASHTO and ASTM standards for calibration and maintaining of profilers too complicated and difficult to follow.	Industry too focused on penalty portion of the spec overlooking the incentive side. Complains from the industry about alleged "mis application" of ride spec. Too sensitivity of small issues arising out of measuring ride number. AASHTO and ASTM standards for calibration and maintaining of profilers too complicated and difficult to follow.
Washington	N/A	N/A	N/A
West Virginia	meeting repeatability and accuracy requirements from AASHTO PP49	N/A	N/A
Wisconsin	N/A	N/A	Air temperature causes ride quality data to differ, sometimes by the hour.