Best Practices for Achieving and Measuring Pavement Smoothness, Synthesis of State-of-Practice

Project 14-1PF Summary
STC Annual Meeting
21 October 2014

THE TRANSTEC GROUP
The World's Pavement Engineering Specialists

Agenda

- Project Overview
- Literature Search
- SOM Survey Results
- Summary of State Practices
- Summary of Best Practices
- Conclusions and Knowledge Gaps

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Project Objectives

- Develop a Synthesis of State-of-Practice Documenting:
  - Ongoing and completed research
  - Best construction practices/techniques for achieving smoothness requirements
  - State smoothness specifications
  - Technologies and practices for IRI data collection and processing
  - Best practices for educating and training DOT and contractor personnel

Work Tasks

- Literature Search
- Compile Current State Specifications and Practices
  - SOM Survey
  - Synthesizing current state specifications
- Document Best Practices for Construction
- Final Synthesis Report

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- Summary of Best Practices
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Literature Search

- Limited sources of “new and innovative” work related to pavement smoothness
- Recent and Ongoing work
  - Effects of PCCP curling and warping on smoothness
  - Benchmark Testing for Reference Profilers
  - “Urban IRI”
  - Profiler Footprint Studies
  - Intelligent Construction Technologies

Literature Search

- Limited sources of “new and innovative” work related to pavement smoothness
- Recent and Ongoing work
  - Intelligent Construction Technologies
    - Real-Time Smoothness for PCCP
    - Stringless PCC paving
    - Thermal Imaging for HMA
    - Intelligent Compaction

Literature Search

- Effects of PCCP curling and warping on smoothness
  - PCCP smoothness (primarily JPCP) can be highly affected by slab curling and warping
  - Changes in IRI of 10-15 in/mi possible during the day
  - Seasonal changes dues to slab warping/creep effects
  - Evaluation of LTPP SPS sites in AZ
  - CDOT study to evaluate causes and effects of JPCP slab curing on roughness

Literature Search

- Benchmark Testing and Validation of Reference Profilers
  - Benchmark profiler (“Golden Profiler”) developed by University of Michigan
  - Provides the standard for evaluating the validity of reference profiler measurements
  - FHWA study underway to evaluate various reference profilers against the Benchmark Profiler during a series of “rodeos”

Literature Search

- "Urban IRI"
  - NCHRP Study underway (10-93) "Measuring, Characterizing, and Reporting Pavement Roughness of Low-Speed and Urban Roads"
    - Seeks to identify/develop a means for measuring, characterizing, and reporting pavement roughness on low-speed and urban roads.
  - FHWA Federal Lands project developing an "Urban Profiler"

Literature Search

- Profiler Footprint Studies
  - "Tire Bridging" and "Tire Enveloping"
  - University of Michigan study to determine the best way to replicate a tire footprint with profiler sensors
  - 2005 ACPA Profiler Repeatability Study

Device	Test Section			
	Grinding	Trans. Tining	Long. Tining	Drag Texture
ICC SurPro 2000				
Ames LISA w/TriODS *		●	○	●
Ames LISA w/RoLine *	○	●	●	●
Ames HSP w/TriODS		●	○	●
Dynatest Mark IV		●		○

● — Excellent ○ — Good

* Used Guidance Control

Literature Search

- Intelligent Construction Technologies
  - Real-Time Smoothness for PCCP
  - Stringless PCC paving
  - Thermal Imaging for HMA
  - Intelligent Compaction

Literature Search

- Intelligent Construction Technologies
- Real-Time Smoothness for PCCP
  - SHRP2 Project R06E
  - Allows contractors to monitor smoothness behind the paver
  - Corrections can be made while concrete is still plastic
  - Two commercially-available systems: GOMACO GSI, Ames Engineering RTP
  - SHRP2 Implementation Underway

Literature Search

- Intelligent Construction Technologies
- Real-Time Smoothness for PCCP

Literature Search

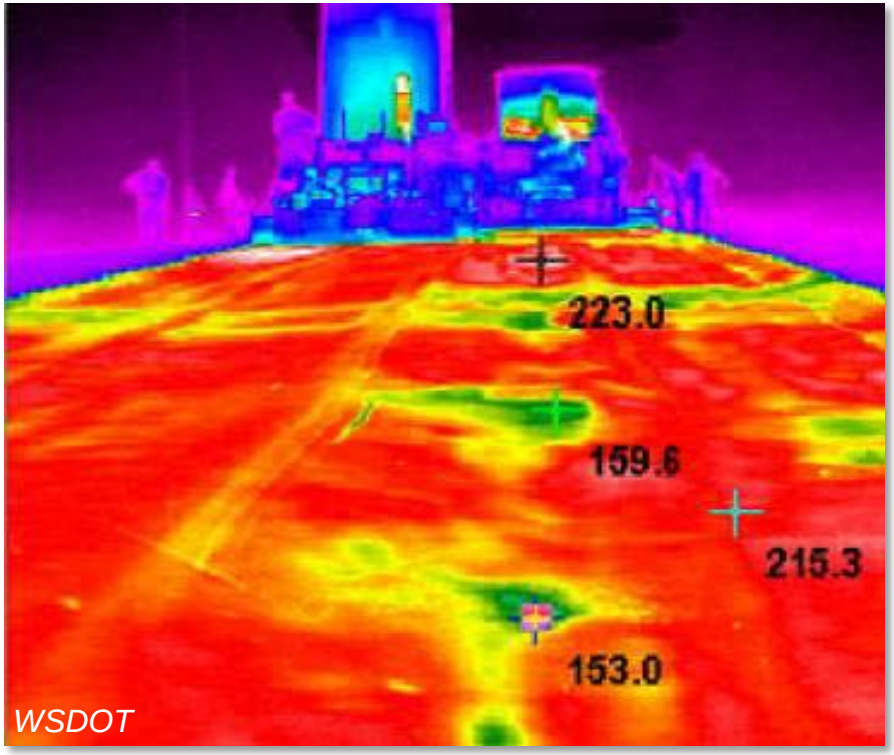
- Intelligent Construction Technologies
- Stringless PCC paving
  - Eliminates need for stringlines and potential issues they can cause
  - Not adopted for smoothness measurement/ monitoring yet

Literature Search

- Intelligent Construction Technologies
- Thermal Imaging for HMA
  - Infrared temperature monitoring of the mat behind the paver
  - Used to identify areas in the mat with significant temperature differences
  - Temperature differences can lead to non-uniform densities at the screed and after compaction

Literature Search

- Intelligent Construction Technologies
- Thermal Imaging for HMA



Literature Search

- Intelligent Construction Technologies
- Intelligent Compaction
  - Base/Subgrade: find “soft” areas that could affect rideability before surface layers are placed
  - Surface Course: track mat temperature and roller passes – issues that could affect ride quality

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SOM Survey Results

- Survey sent to AASHTO SOM representatives by Louisiana DOT
- 36 responses received (including 1 Canadian province – MTO)
- Focus on construction acceptance practices, not network monitoring practices.

SOM Survey Results

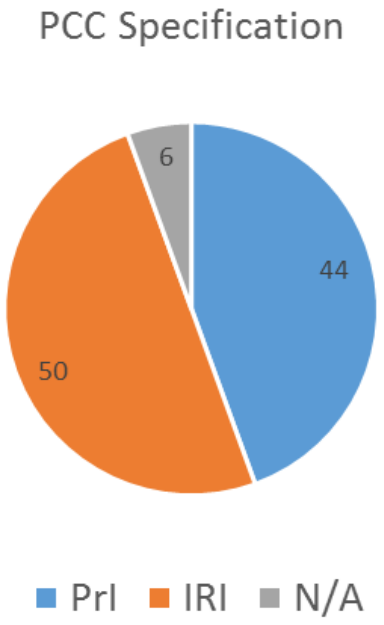
1. What equipment is used for Measuring Smoothness?
   - Inertial Profilers: High Speed, Lightweight
   - Profilograph: California, Rainhart (GA,TN)
   - Straightedge: Hearne RSE (NC)
   - Walking Profiler (certification tracks)

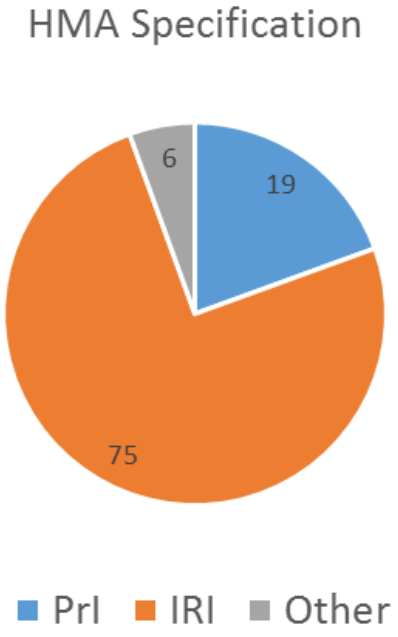
SOM Survey Results

1. What equipment is used for Measuring Smoothness?
   - Lightweight profilers with profilograph simulation permitted in AR, DE, IA, KS, MI, NV, NJ
   - Wide footprint (e.g., line laser) sensors used in CA, GA, IA (PCC only), MT, ND, SD, WA

SOM Survey Results

2. What Smoothness Index are your pavement smoothness specifications based on?





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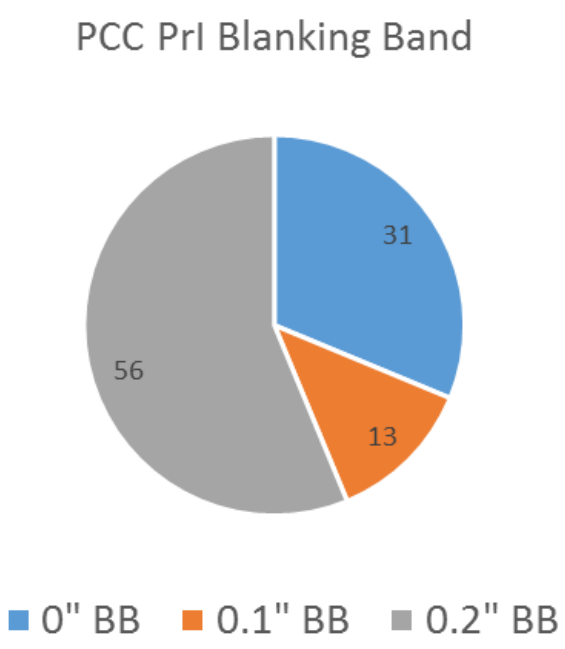

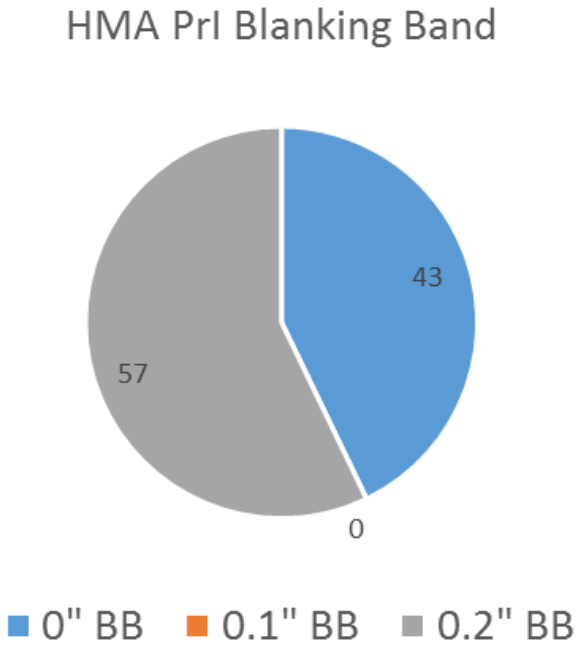

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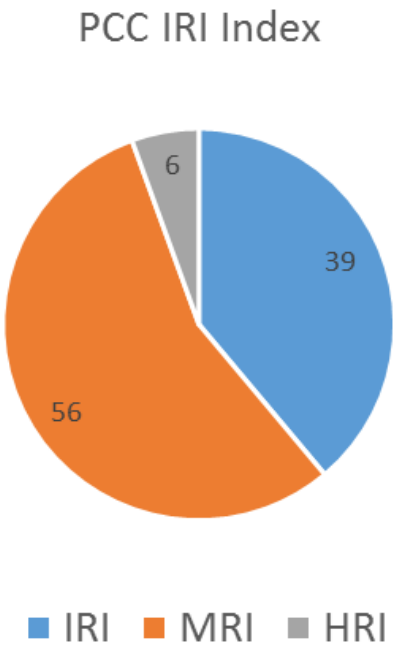
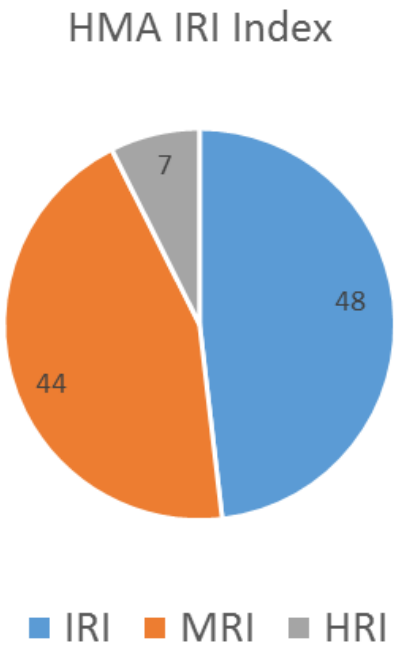
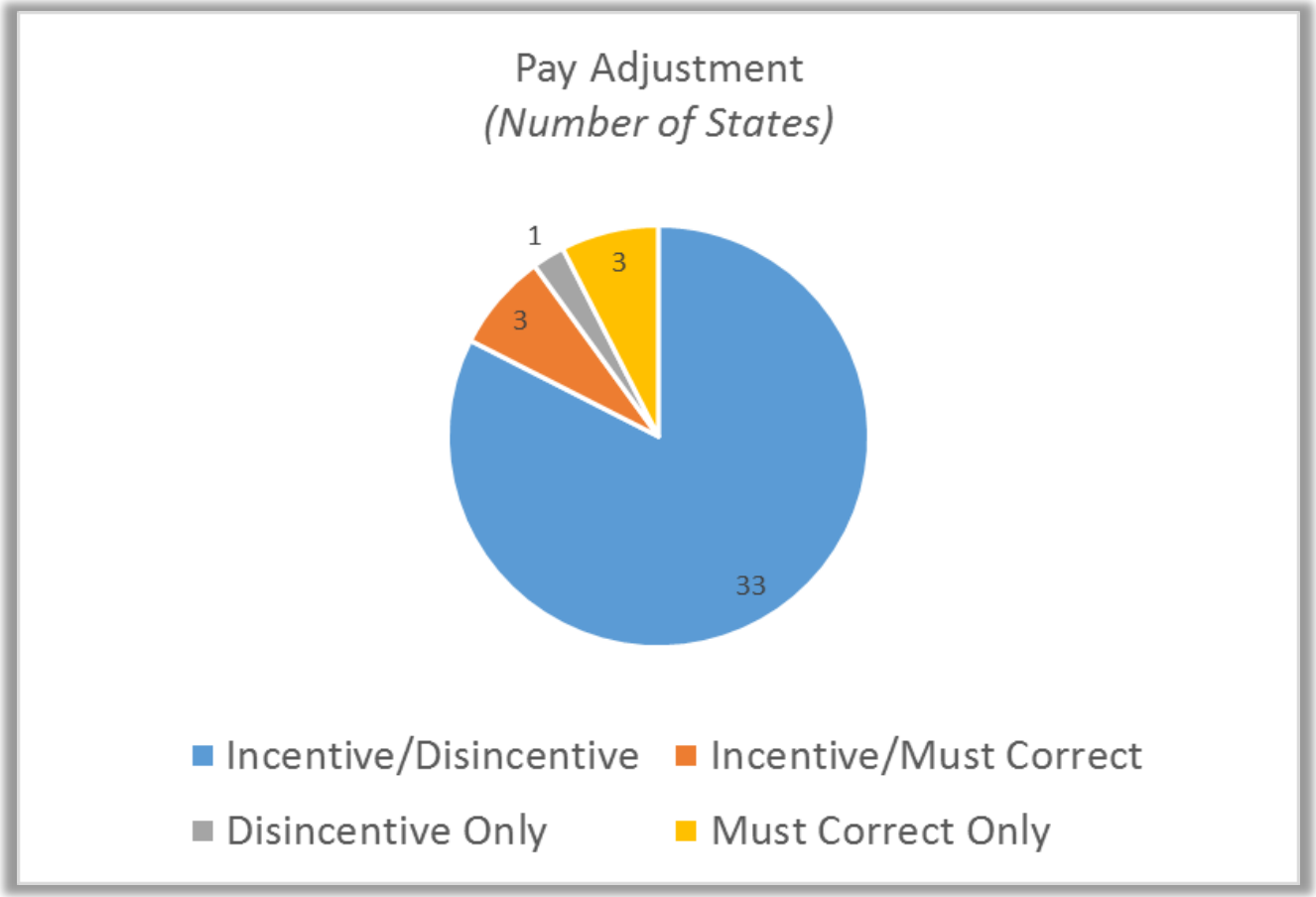




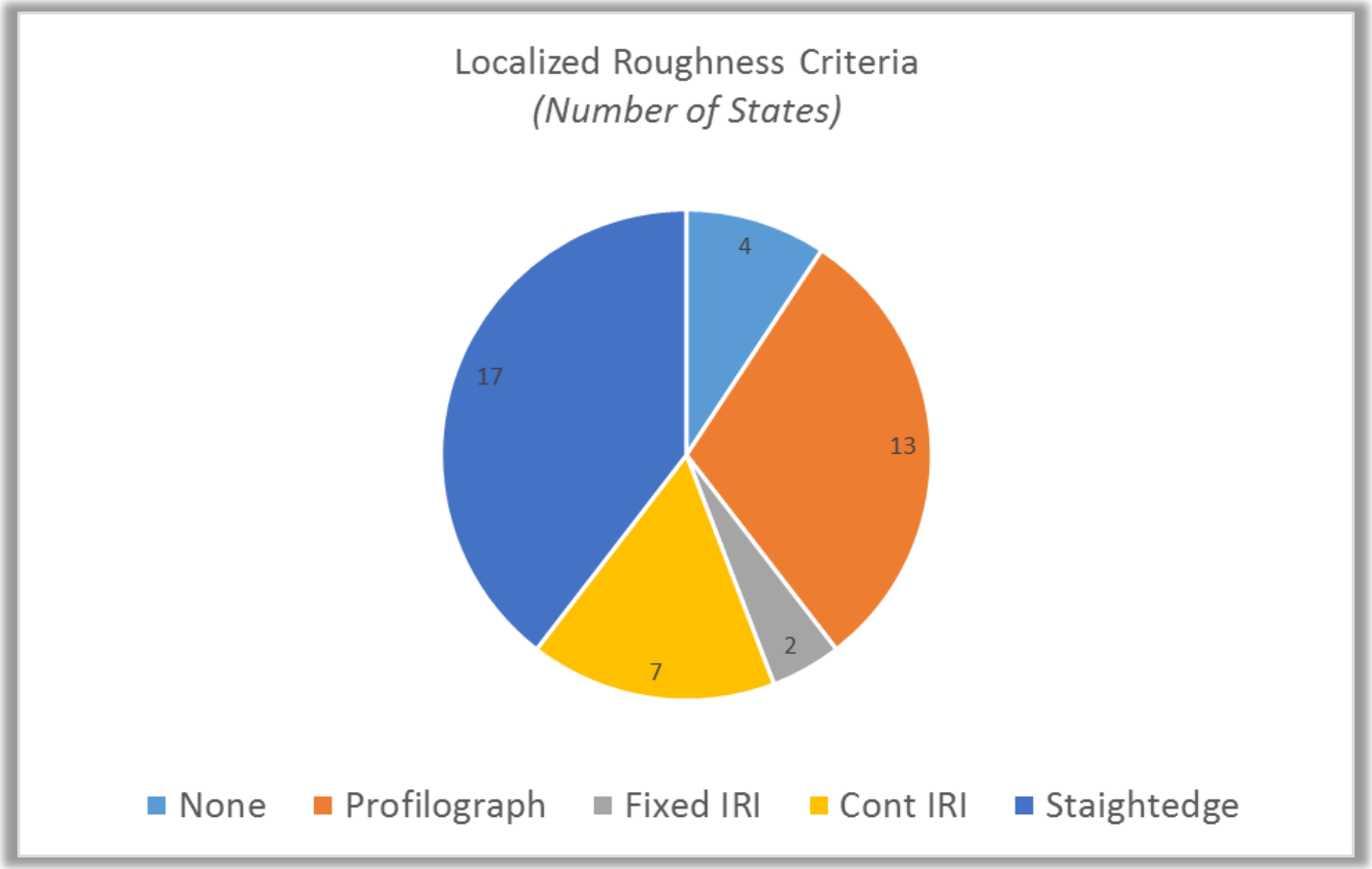
SOM Survey Results

3. What is the basis for Pay Adjustments for pavement smoothness?



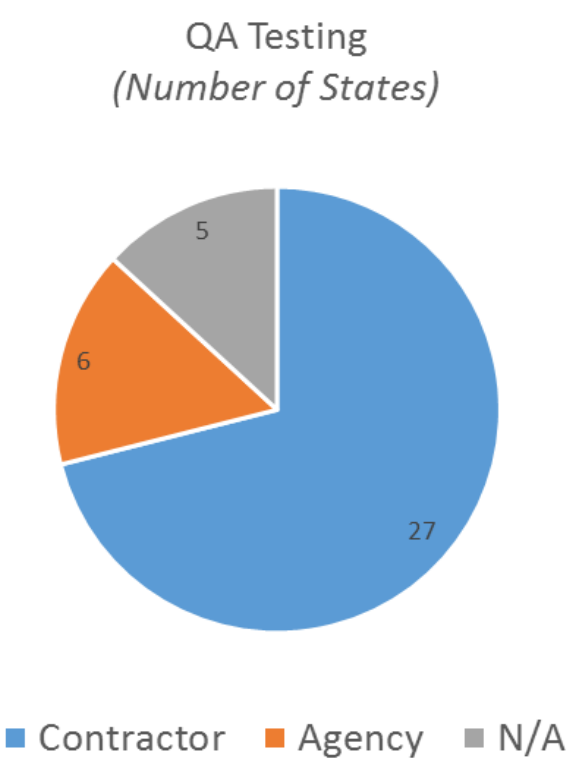
SOM Survey Results

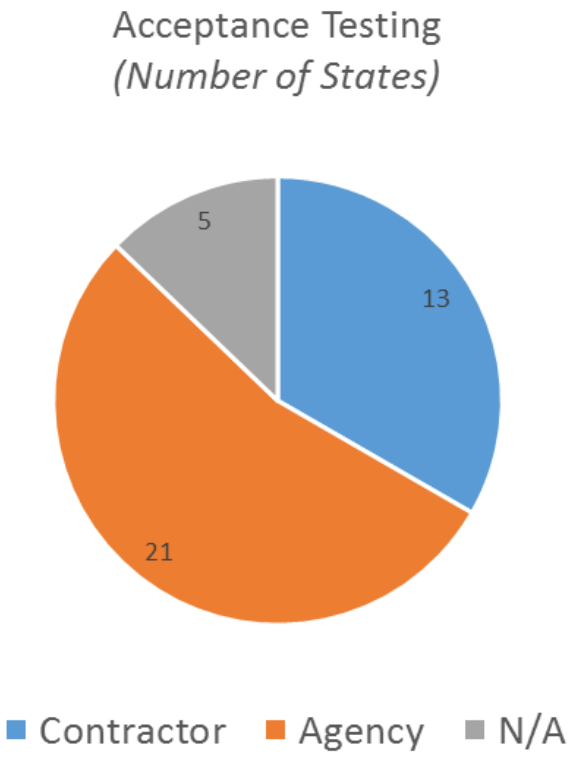
4. What are criteria for Localized Roughness/Must Grinds?



SOM Survey Results

5. Who conducts Pavement Smoothness Testing During and After Construction?



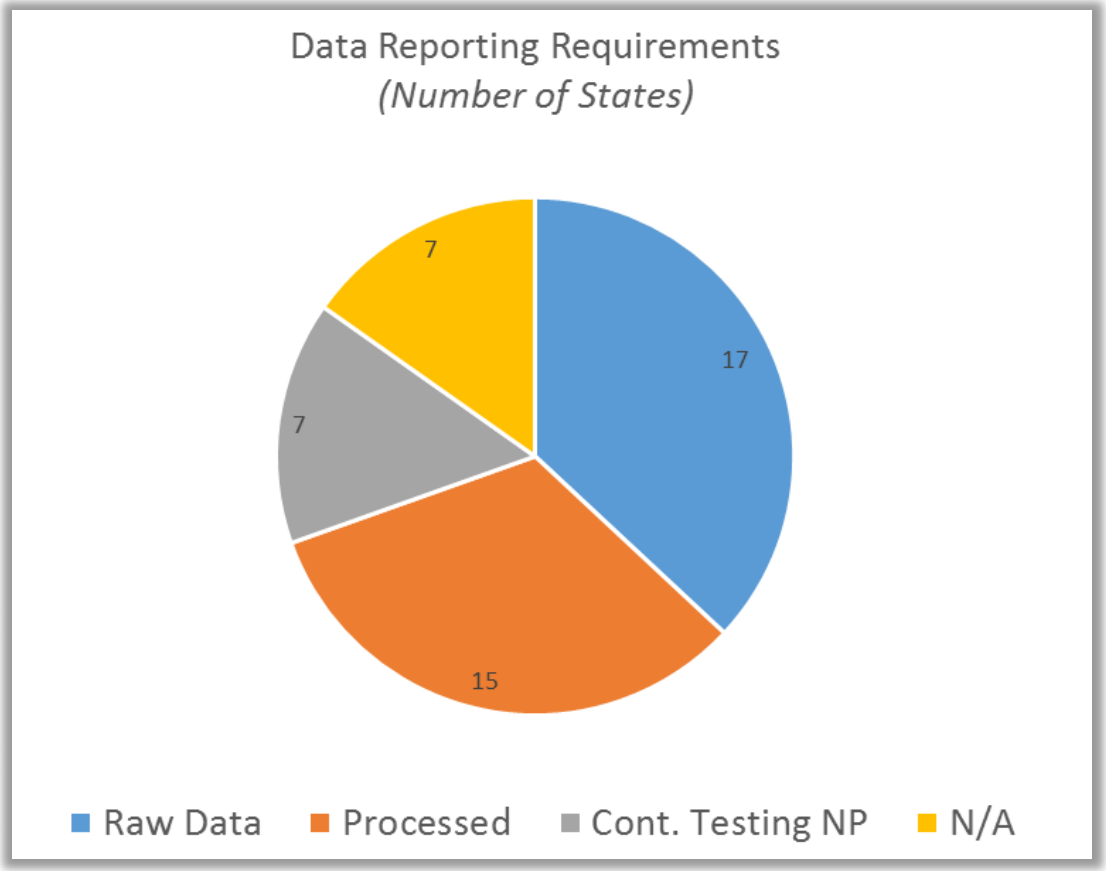


SOM Survey Results

5. Who conducts Pavement Smoothness Testing During and After Construction?
   - Some agencies do 10% verification testing of contractors acceptance testing (IA, MS, NE)

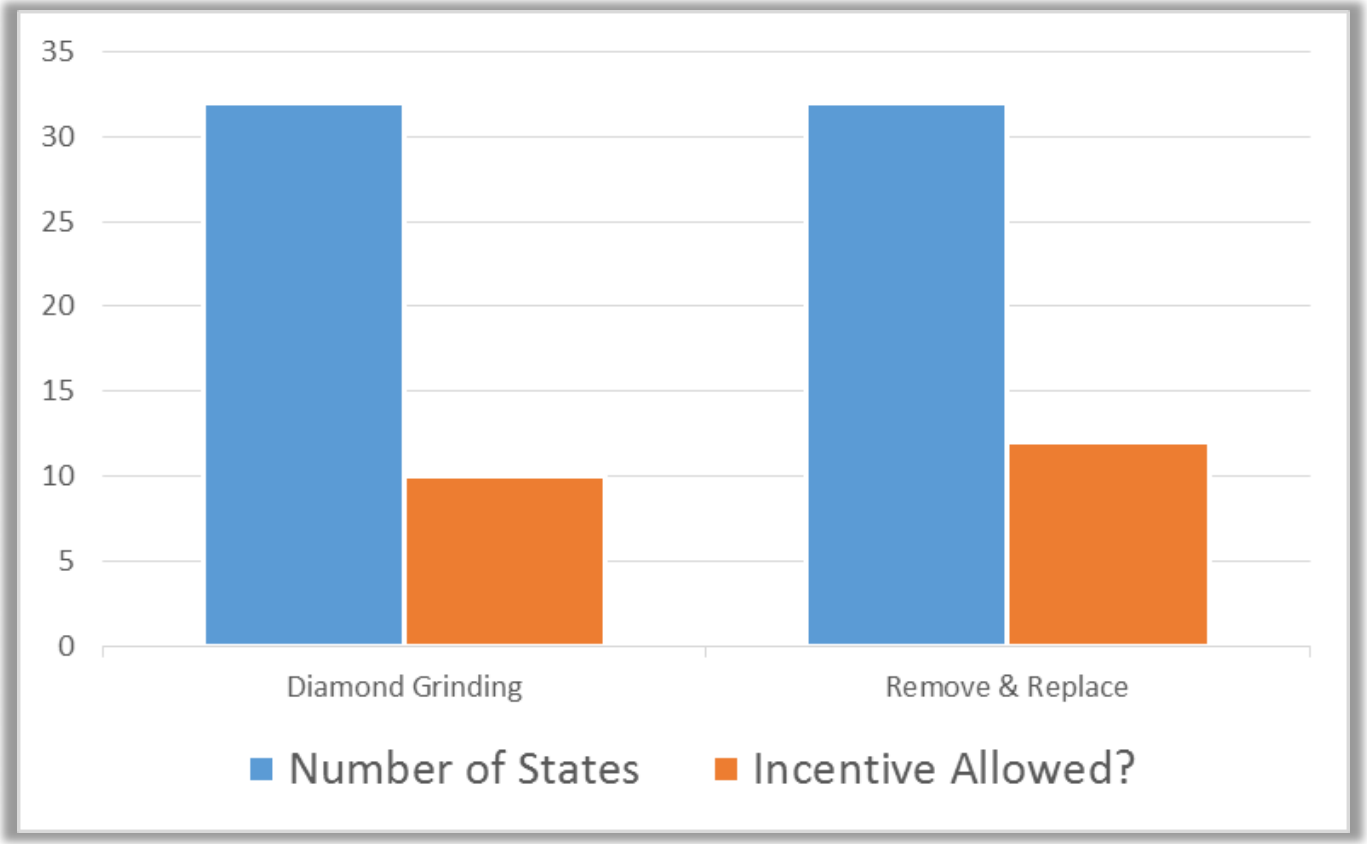
SOM Survey Results

6. What are data reporting requirements for contractor testing?



SOM Survey Results

7. What forms of corrective action are permitted?

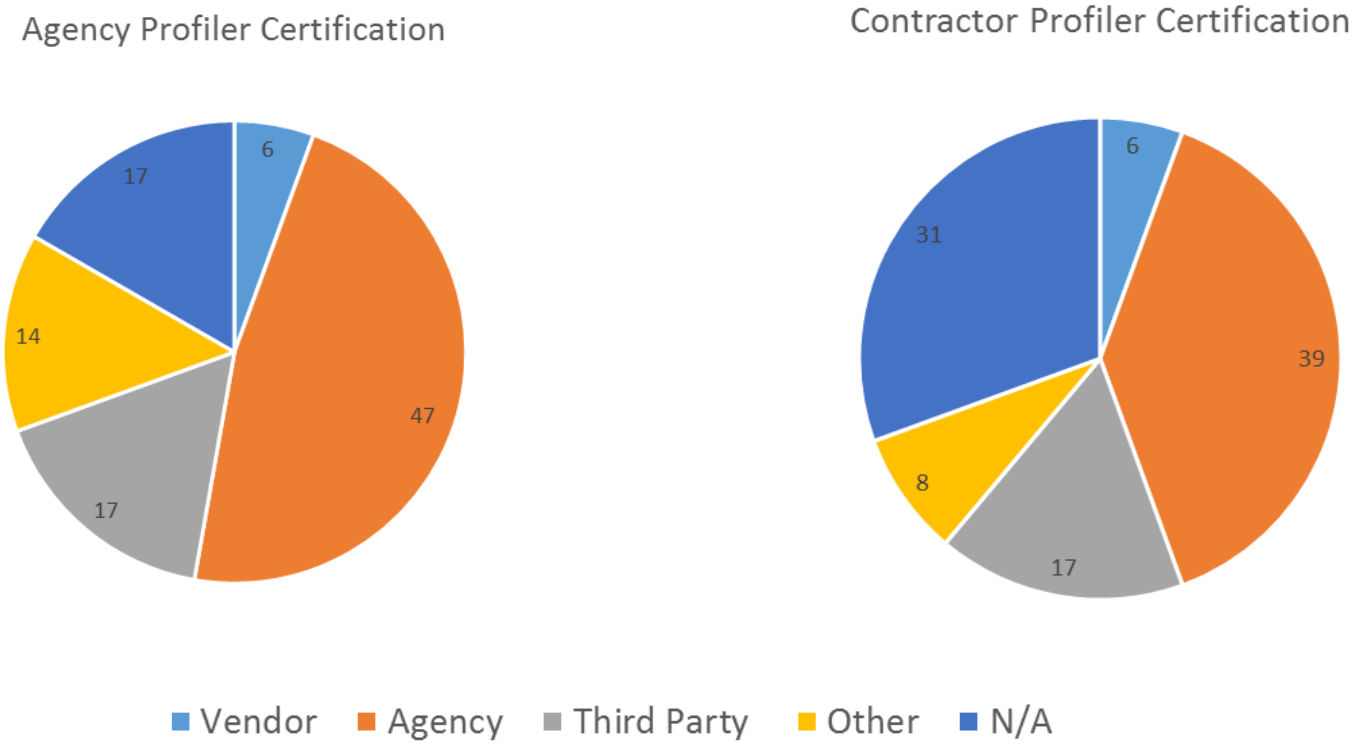


SOM Survey Results

7. What forms of corrective action are permitted?
   - Most states permit Remove & Replace, but few report it occurring with any frequency
   - A few states do now allow diamond grinding of HMA pavement

SOM Survey Results

8. Profiler Certification Requirements?



SOM Survey Results

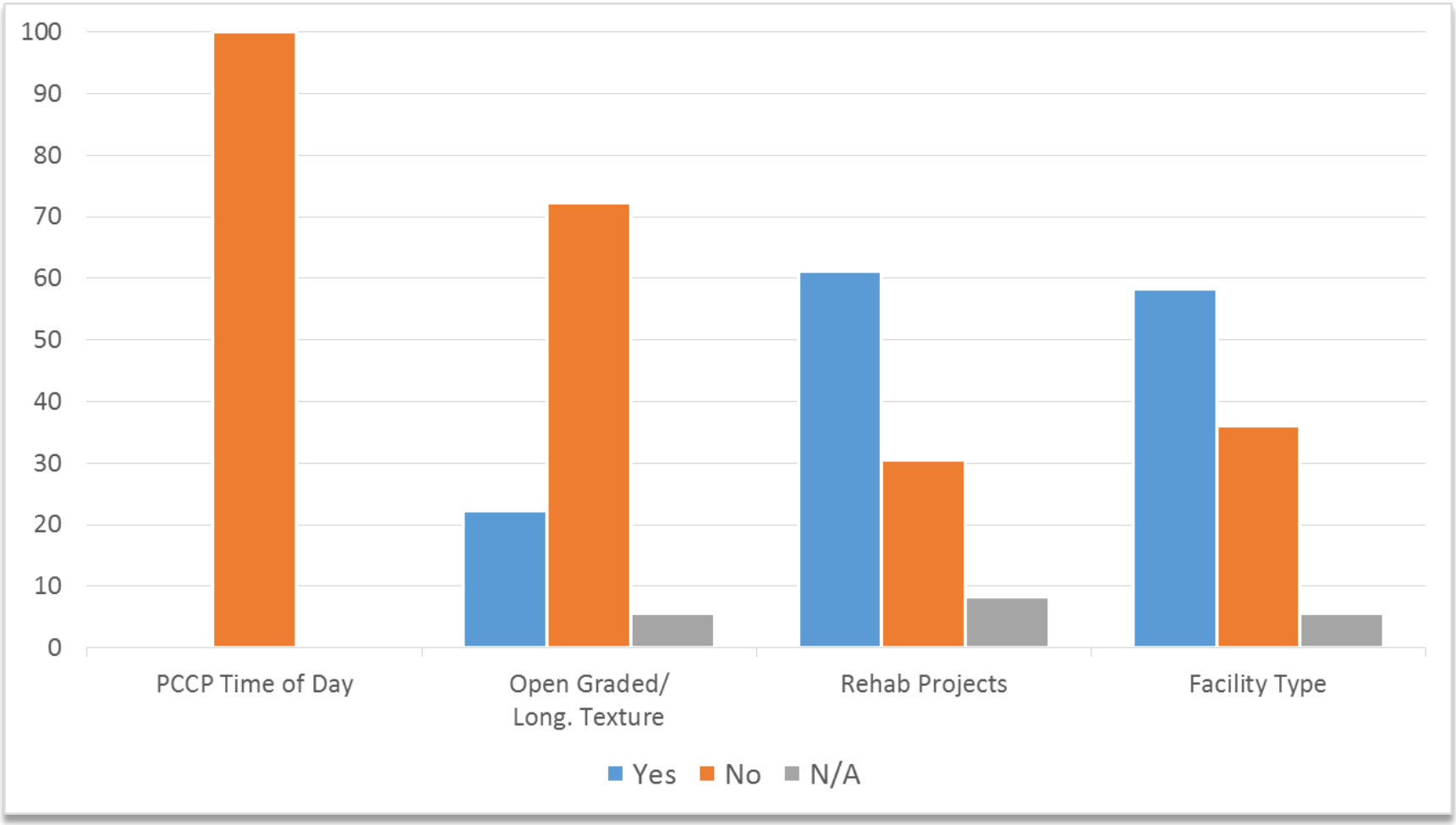
8. Profiler Certification Requirements?
   - Most agencies have some certification site / sanity check site within the state
   - Third-Party Certification Sites: TTI, NCAT, MnROAD

SOM Survey Results

9. Special Requirements
   - Time of day requirements for concrete pavement?
   - Requirements for profiling open-graded HMA or longitudinally tined/textured PCC?
   - Different requirements for Rehab Projects?
   - Different requirements by facility type?

SOM Survey Results

9. Special Requirements



SOM Survey Results

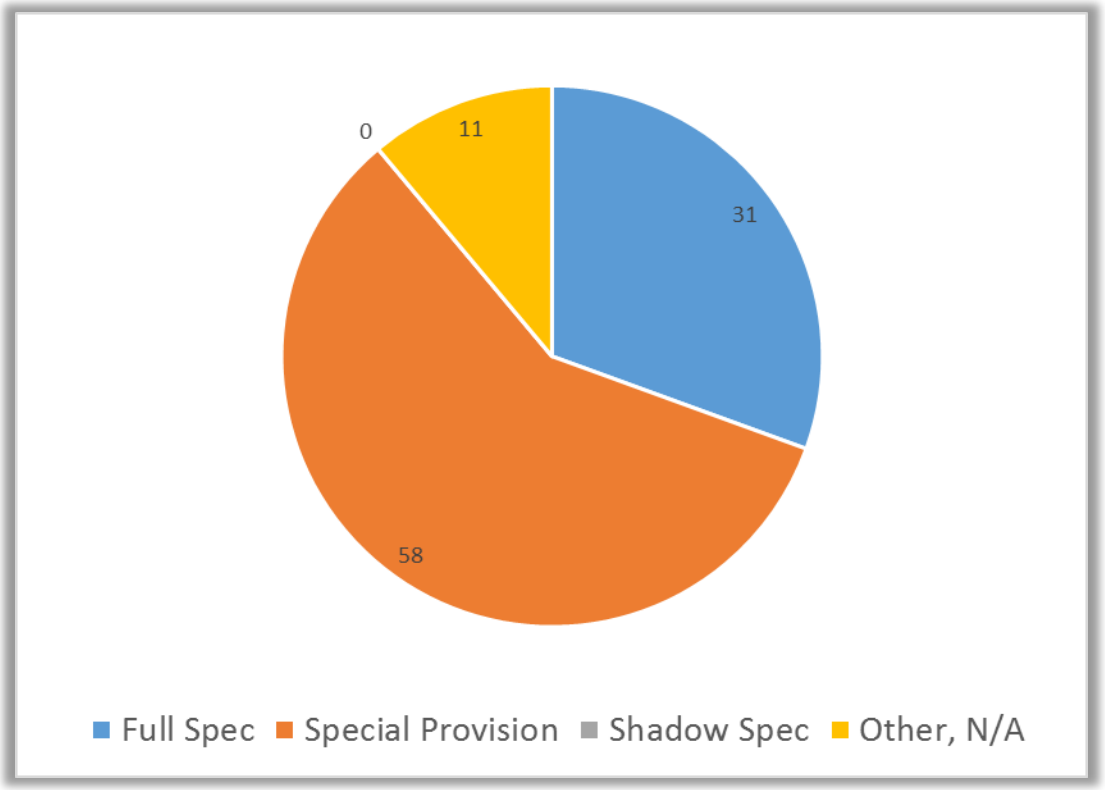
9. Special Requirements
   - Wide footprint laser required on longitudinally tined/diamond ground PCCP and OGFC in several states.
   - Some states accept OGFC based on intermediate course beneath OGFC

SOM Survey Results

9. Special Requirements
   - Most states have some form of “percent improvement” specification for rehab projects with only one opportunity for improvement.
   - Virtually all states have less stringent requirements for non-interstate, non-controlled access, and lower-speed facilities.

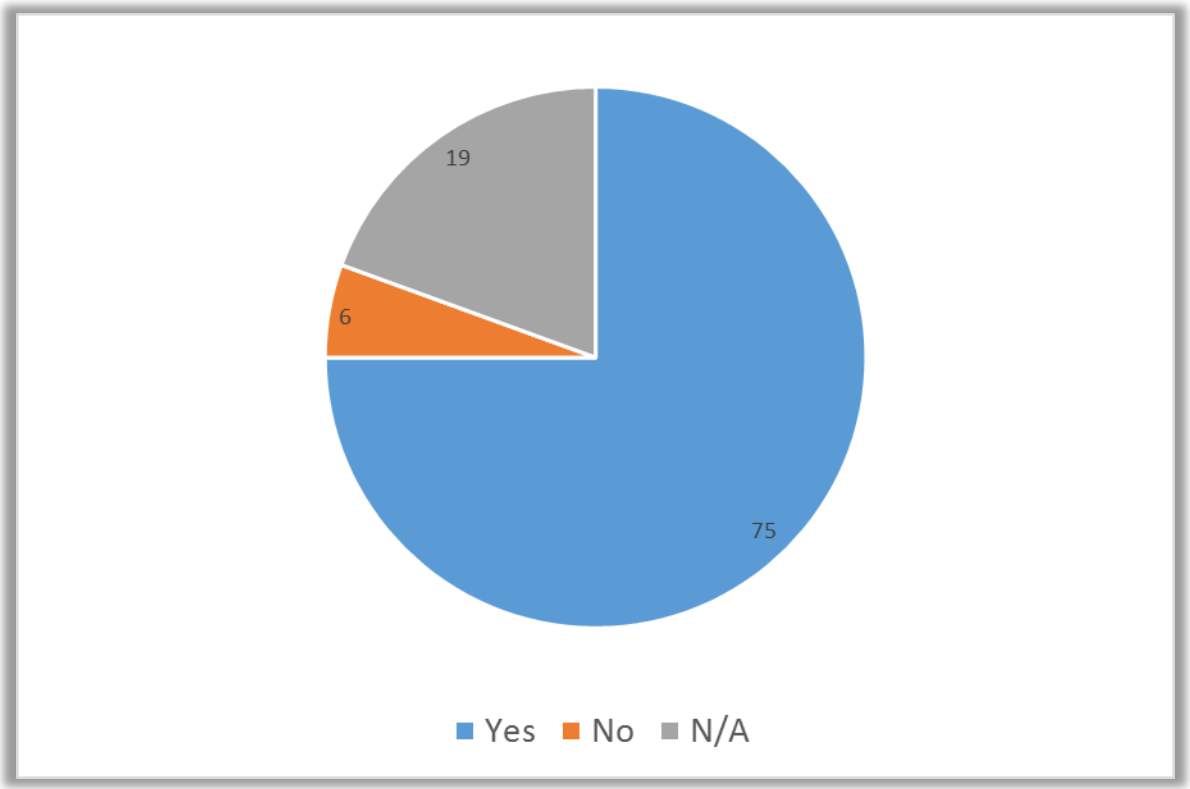
SOM Survey Results

10. How were/are current specifications implemented?



SOM Survey Results

11. Was any training provided to contractors and agency project personnel?

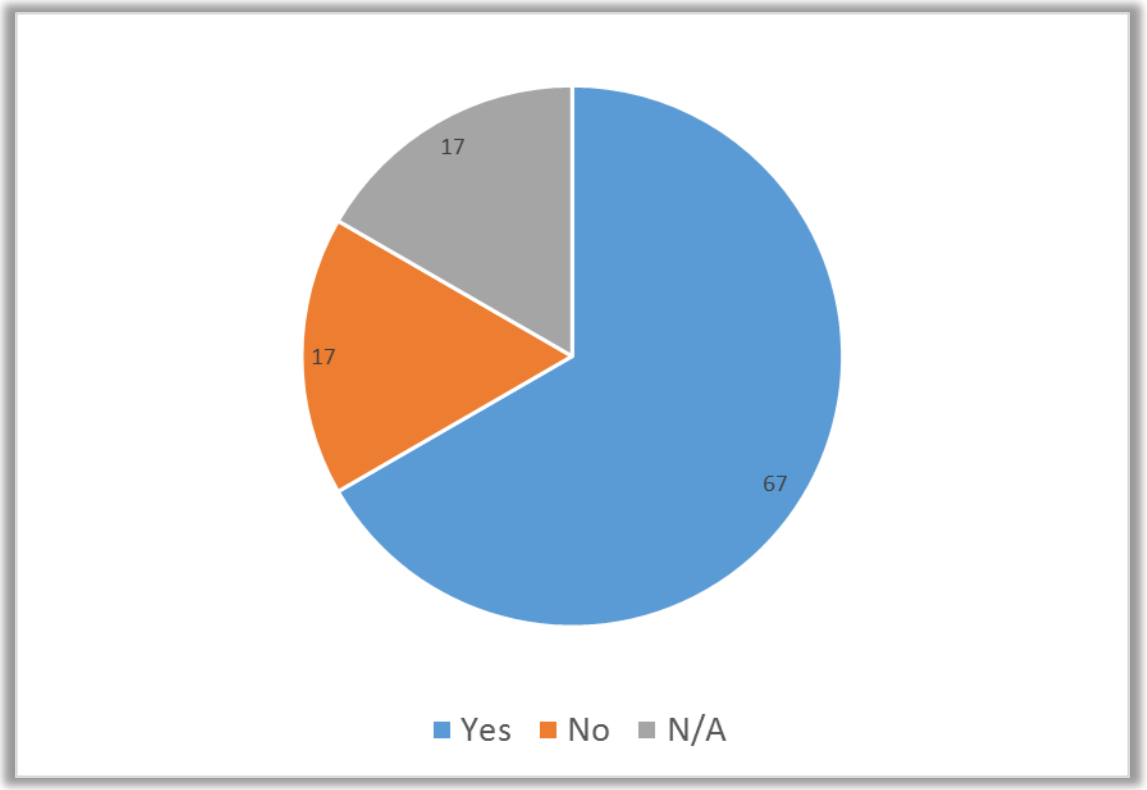


SOM Survey Results

11. Was any training provided to contractors and agency project personnel?
    - ProVAL training
    - Operator certification
    - Training on profiling and IRI basics when specification was deployed

SOM Survey Results

12. What were obstacles to deploying specifications?



SOM Survey Results

12. What were obstacles to deploying specifications?
    - Establishing acceptance thresholds, particularly when transitioning to IRI from PrI
    - Establishing appropriate pay adjustments
    - Getting contractor/industry buy-in - specification compromises
    - Resistance from DOT personnel – “why pay extra for smoothness?”

SOM Survey Results

12. What were obstacles to deploying specifications?
    - Evolution / making changes after specification has been deployed
    - Having adequate data to make decisions
    - Acquiring equipment and equipment affordability
    - Convincing contractors and agency personnel that IRI is a better measure

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Summary of State Practices

SmoothPavements.com

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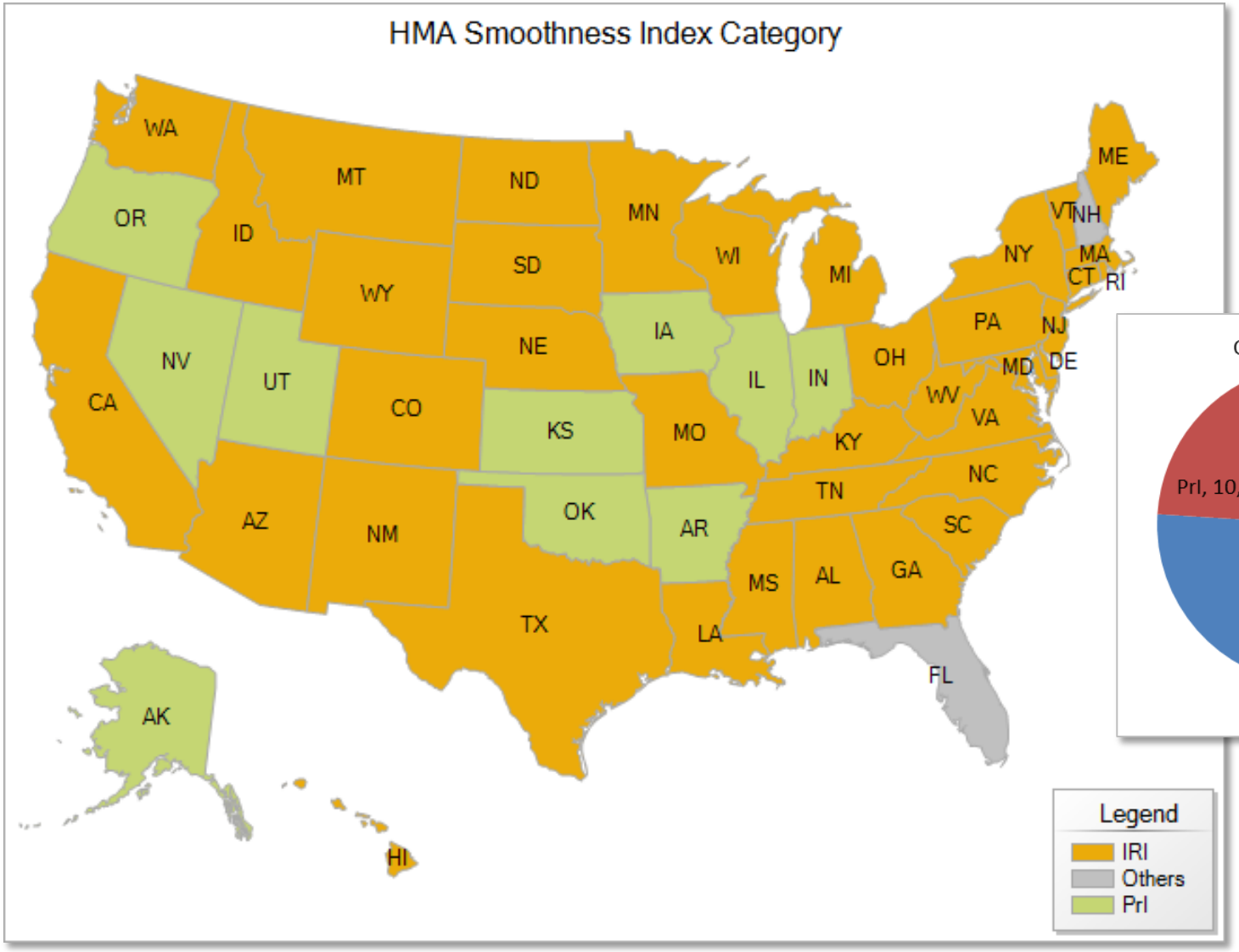
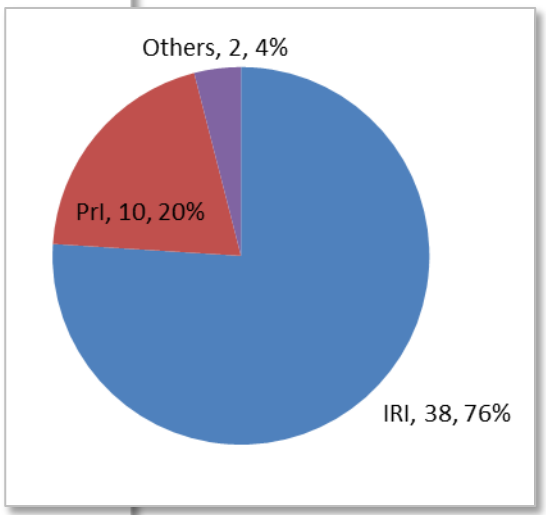
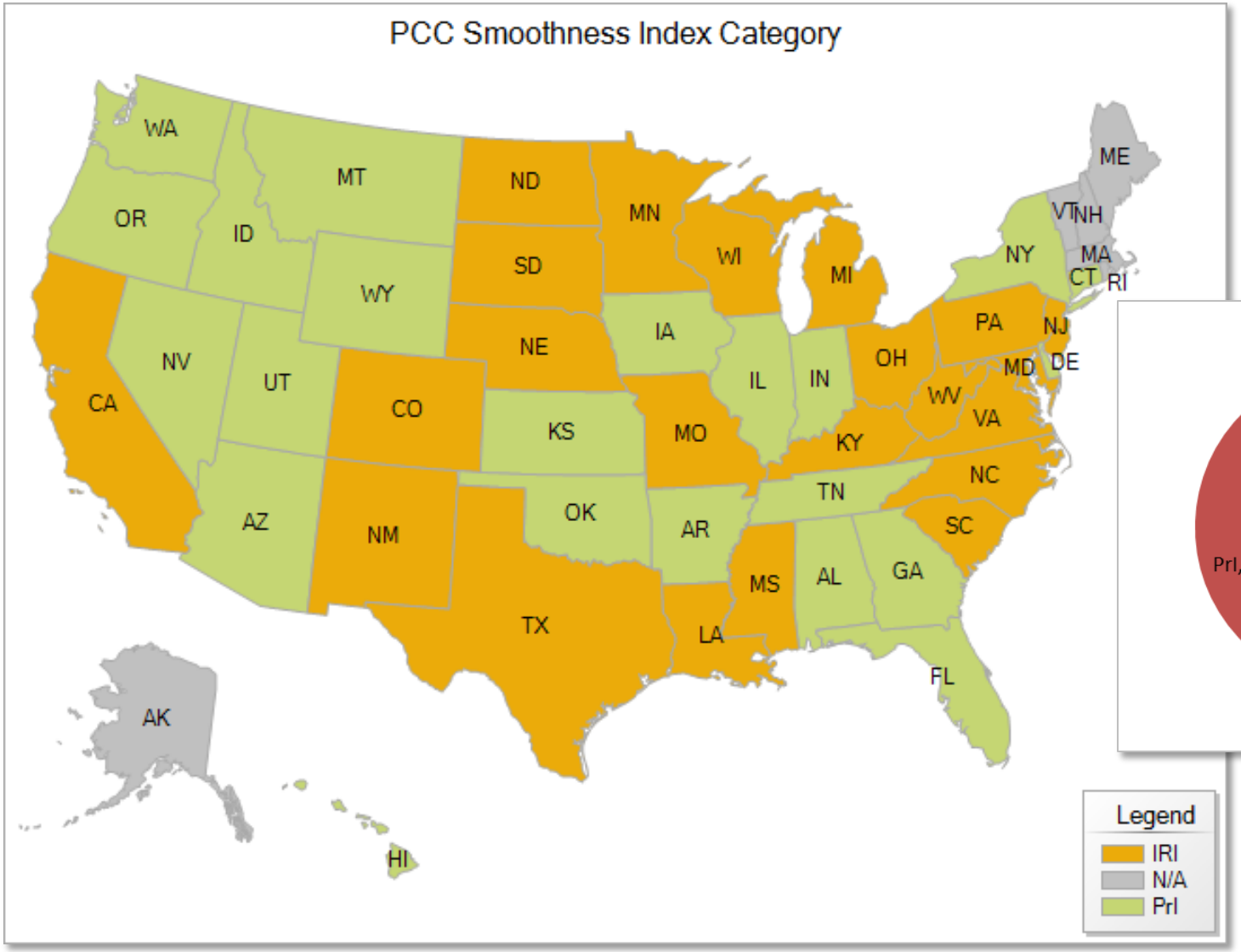


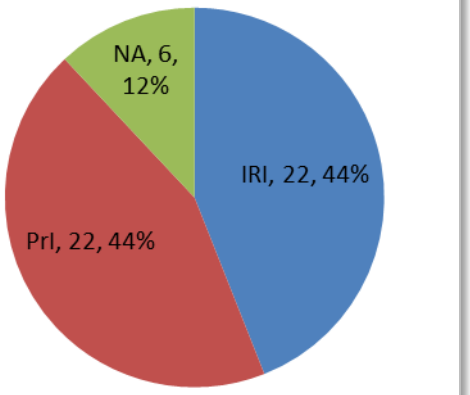


2009 AASHTO SOC Survey (41 states):
IRI: 66%
PrI: 34%

Summary of State Practices

- SmoothPavements.com





2009 AASHTO SOC Survey (42 states):
IRI: 21%
PrI: 69%
N/A: 10%

Summary of State Practices

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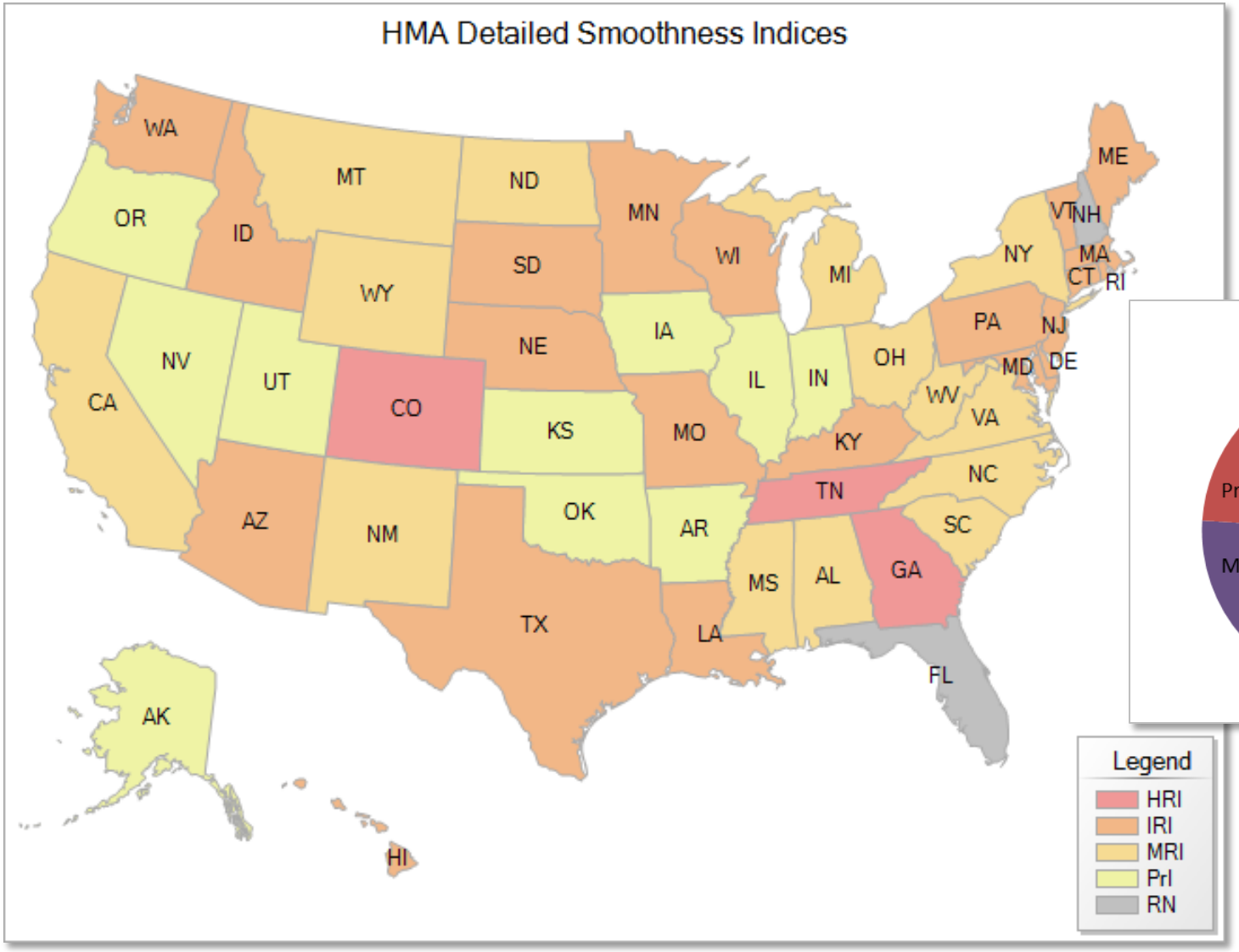

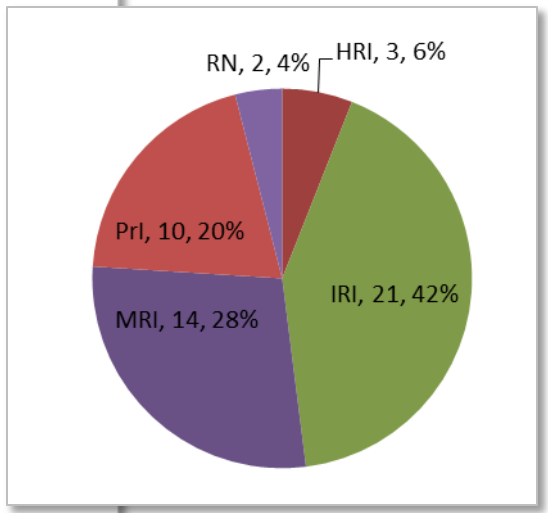

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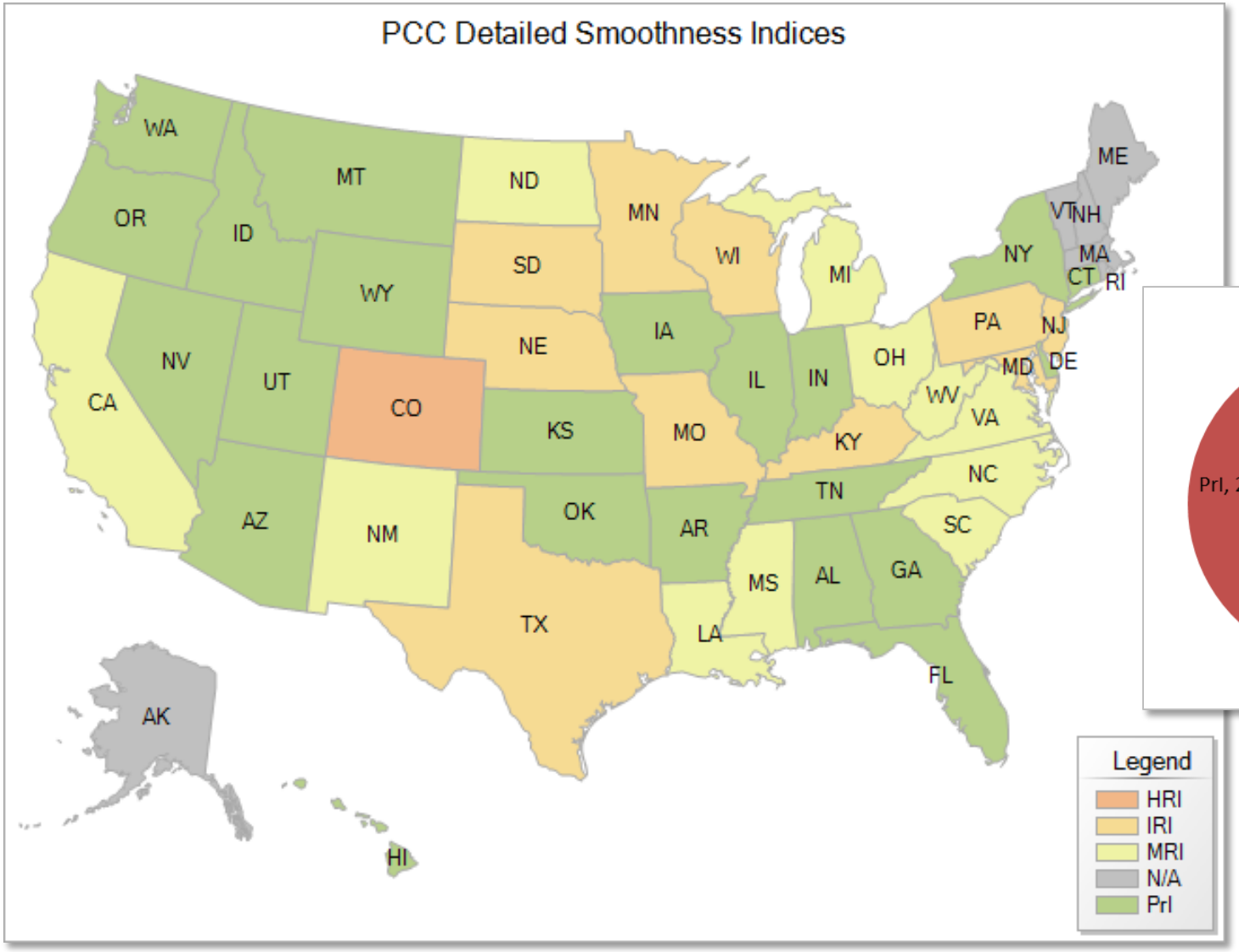

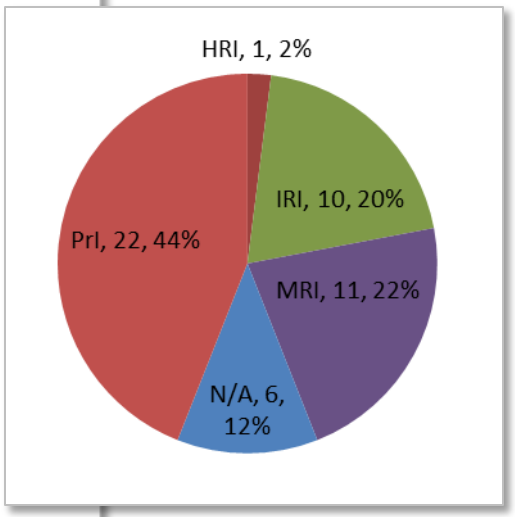

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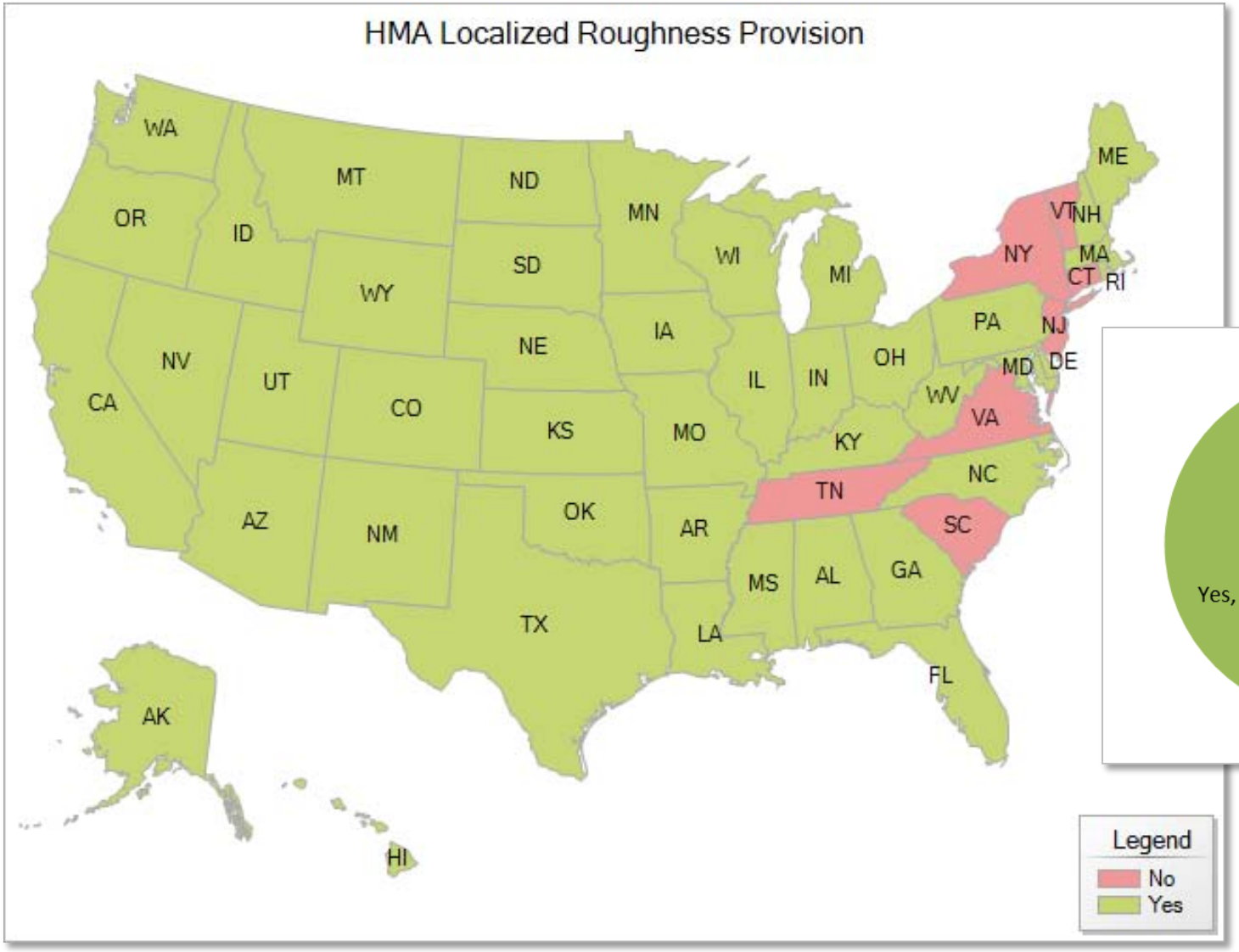

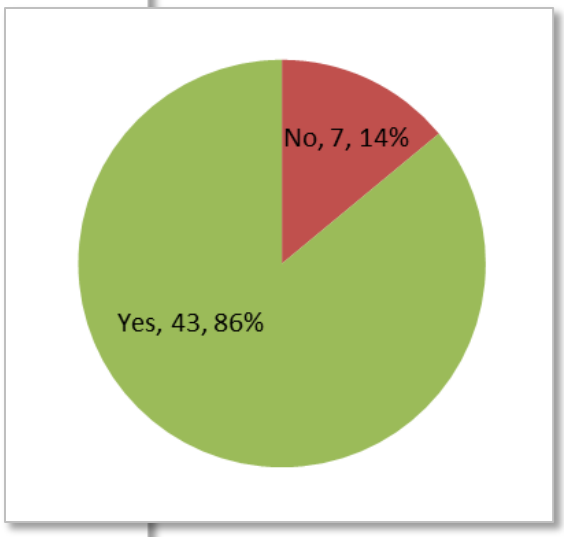

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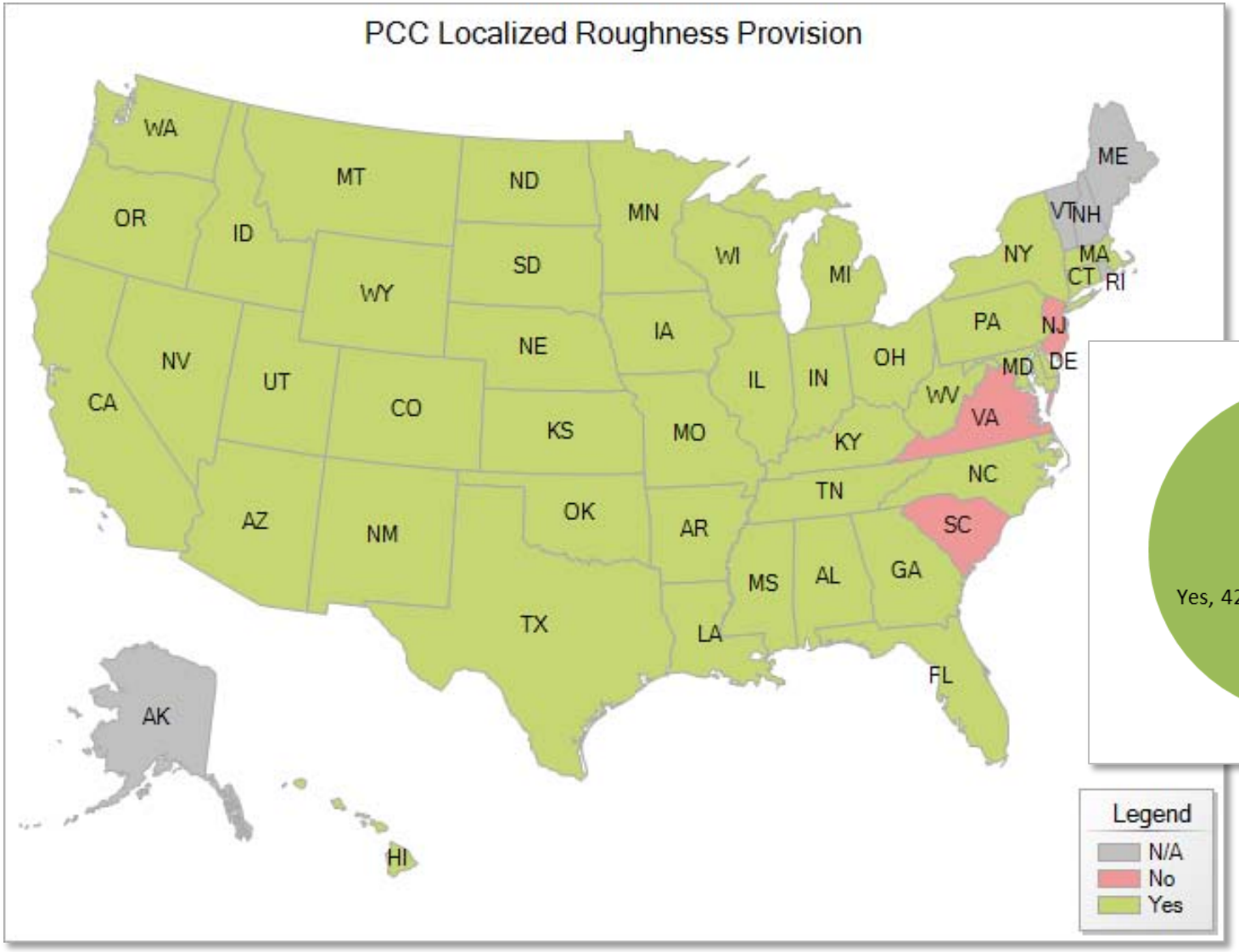

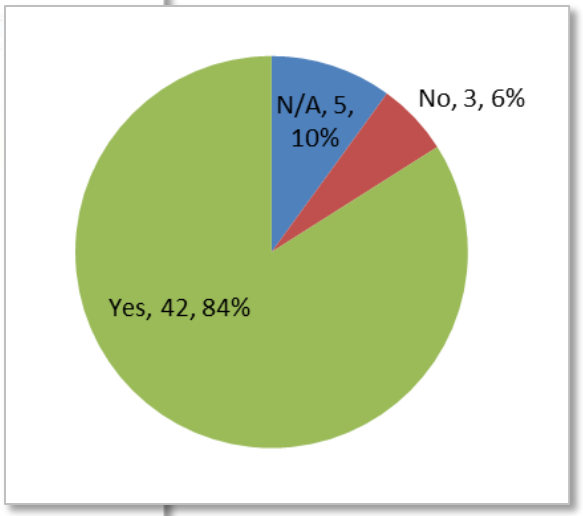

Summary of State Practices

- Localized Roughness:
  - Correct any bumps or dips greater than 0.4 in in 25 ft
  - LA: Correct any 0.05 mi lots with IRI greater than 95 in/mi
  - NJ: Correct any 0.01 mil lots with IRI greater than 100 in/mi
  - NC, MO: Use continuous IRI reporting with a baselength of 25 ft to identify and correct localized roughness greater 125 in/mi.

Summary of State Practices

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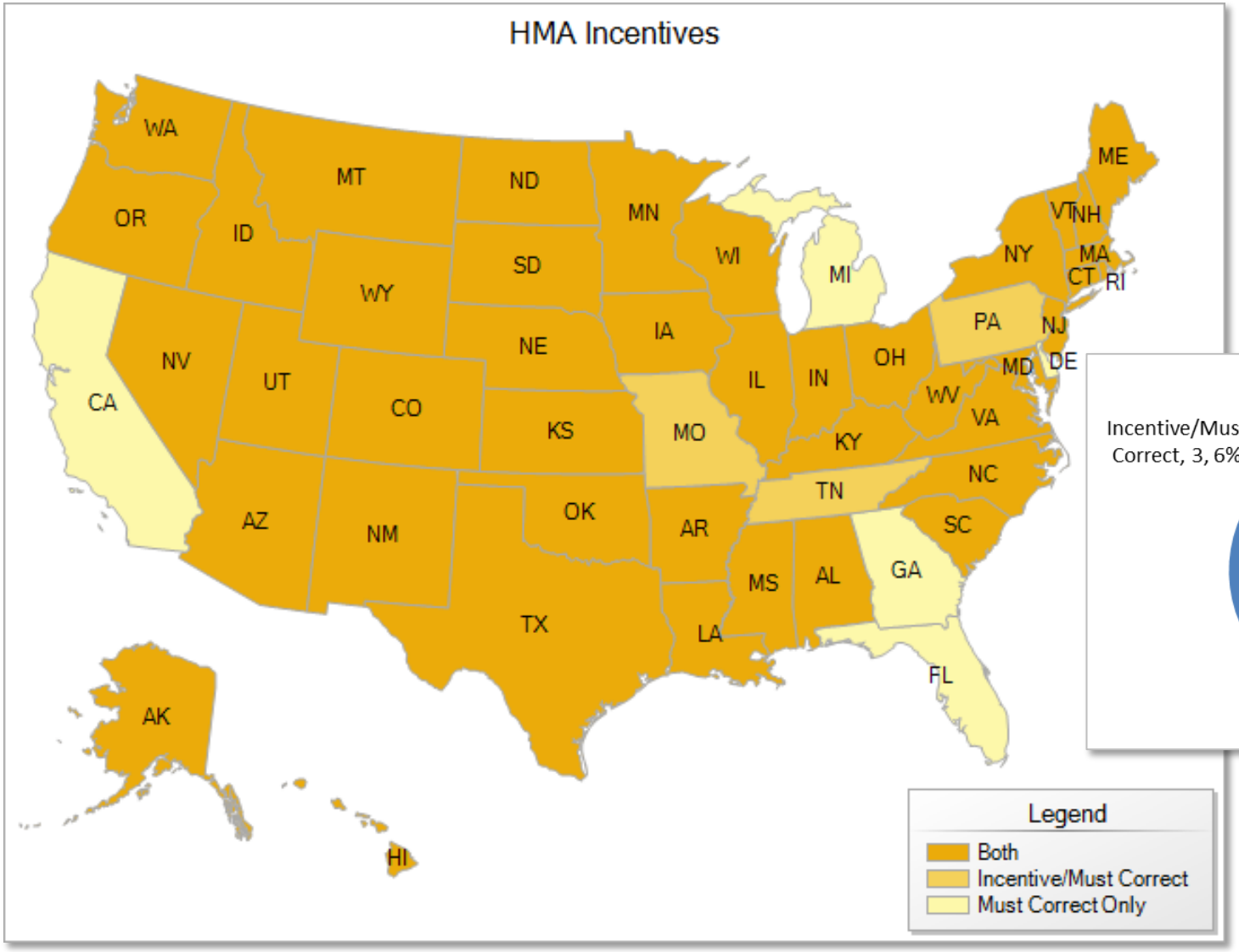

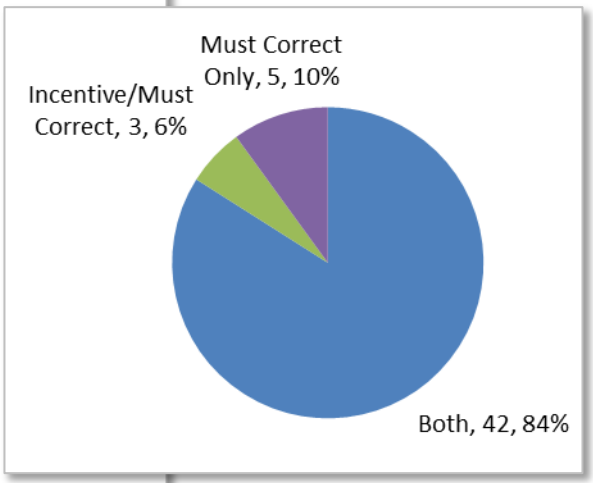

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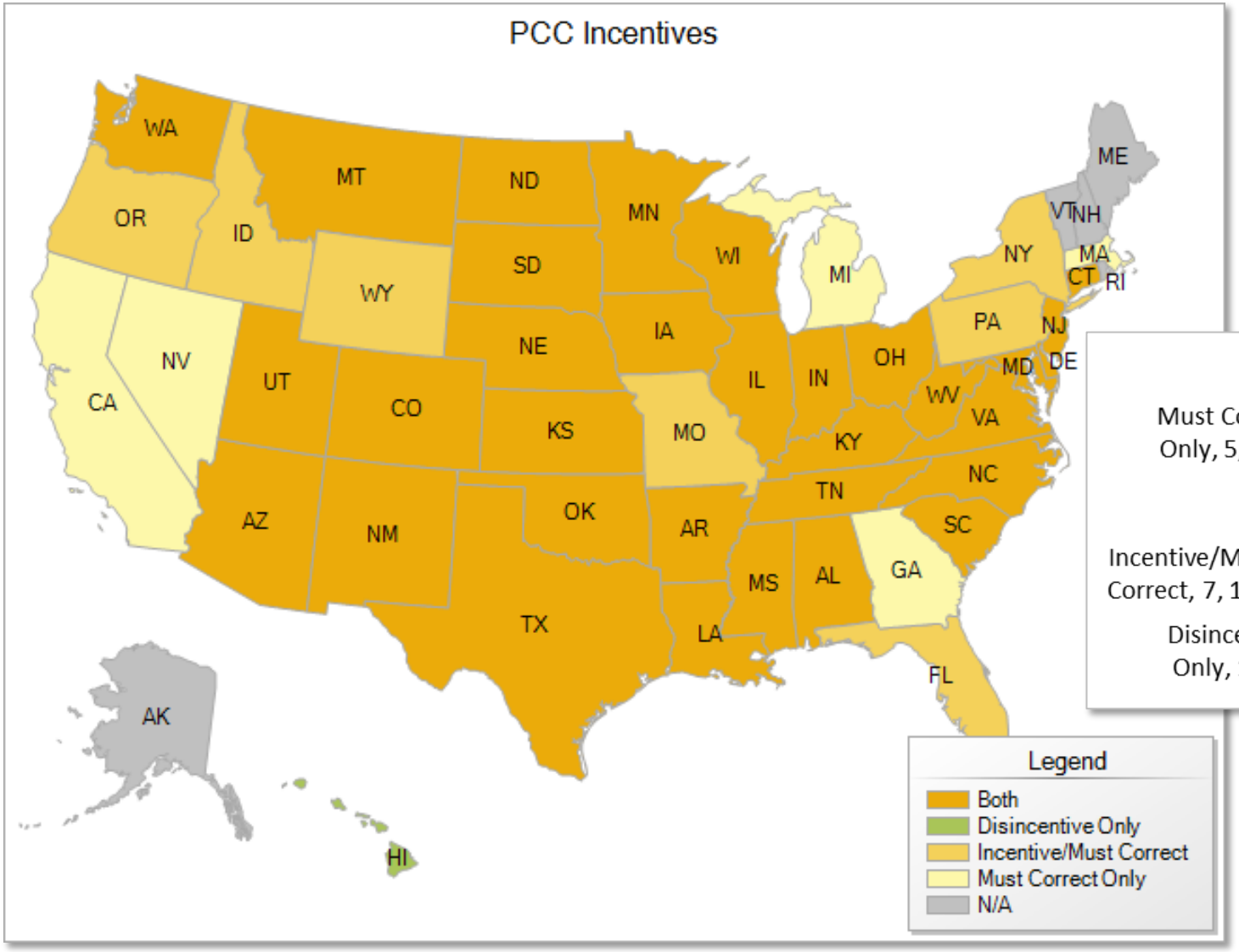

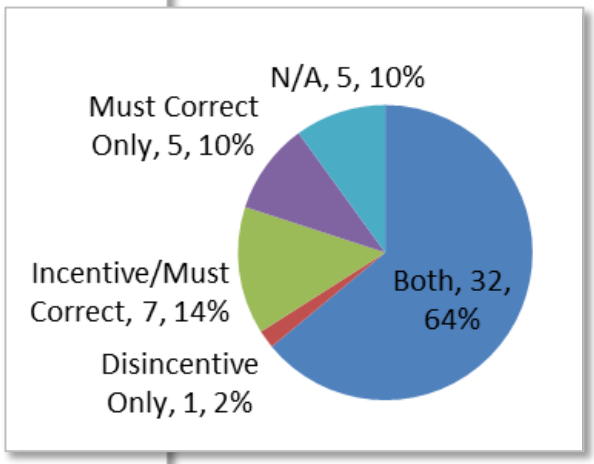

Summary of State Practices

- Summary of Pay Adjustment Thresholds (Only specifications for IRI and MRI)

Bonus / Incentive Payment

	Upper Limit	
	HMA	PCC
Min.	30	50
Max.	79.9	70
Average	51.6	58

Summary of State Practices

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Full Pay

	Lower Limit		Upper Limit	
	HMA	PCC	HMA	PCC
Min.	30	50	43	54
Max.	80	71	100	93
Average	52	58.3	66.4	72.2

Summary of State Practices

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Penalty / Disincentive

	Lower Limit		Upper Limit	
	HMA	PCC	HMA	PCC
Min.	44	54.1	64.3	68
Max.	100.1	93.1	149	140
Average	65.2	73.2	96.6	94.8

Summary of State Practices

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Threshold for Correction

	HMA	PCC
Min.	60	60
Max.	150	140
Average	92.3	92.1

Summary of State Practices

- Summary of Pay Adjustment Thresholds
  - MD sets thresholds for each individual project (e.g., no set standard thresholds)
  - WY uses an equation which factors in average and standard deviation of measurements along with number of opportunities for smoothness

Summary of State Practices

- Summary of Pay Adjustment Thresholds
  - Roughly half of states make pay adjustment to contract unit price (e.g., per ton of asphalt)
  - Roughly half of states make pay adjustments based on dollars per lot tested.
  - Two states use PWL: ME, MA

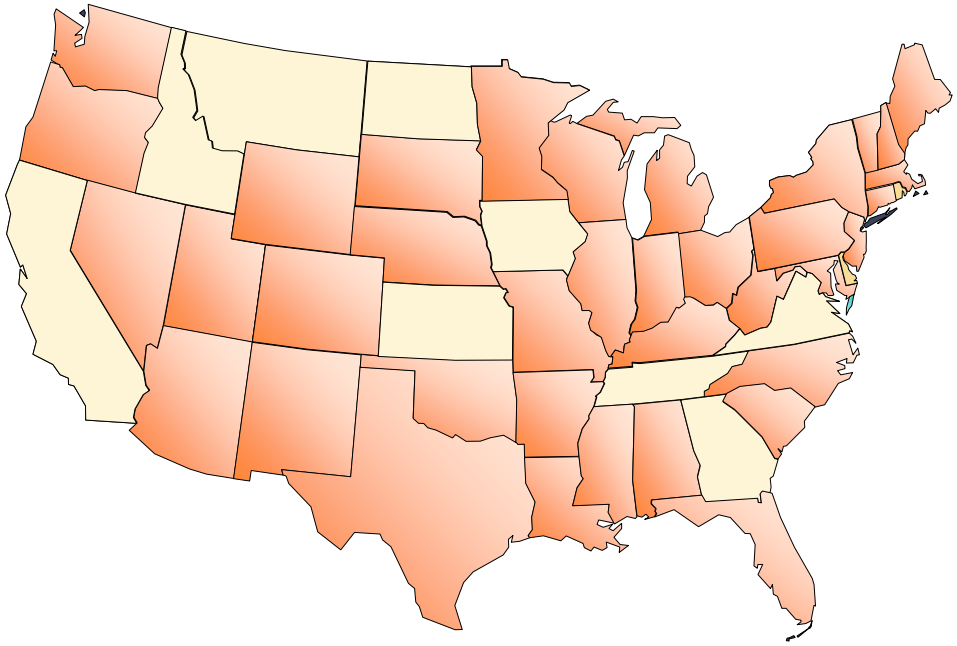
Summary of State Practices

- Continuous Roughness Reporting Specification (MS):
  - 528 ft baselength: 60 in/mi
  - 25 ft baselength: 160 in/mi

RPUG Profiler Certification Survey

Summary of State Practices

- 2012 Survey of Profiler Certification Methods
  - RPUG 2013, courtesy of David Huft
  - Aimed at guaging need/interest in profiler certification



Plus:

Alaska

Puerto Rico

British Columbia

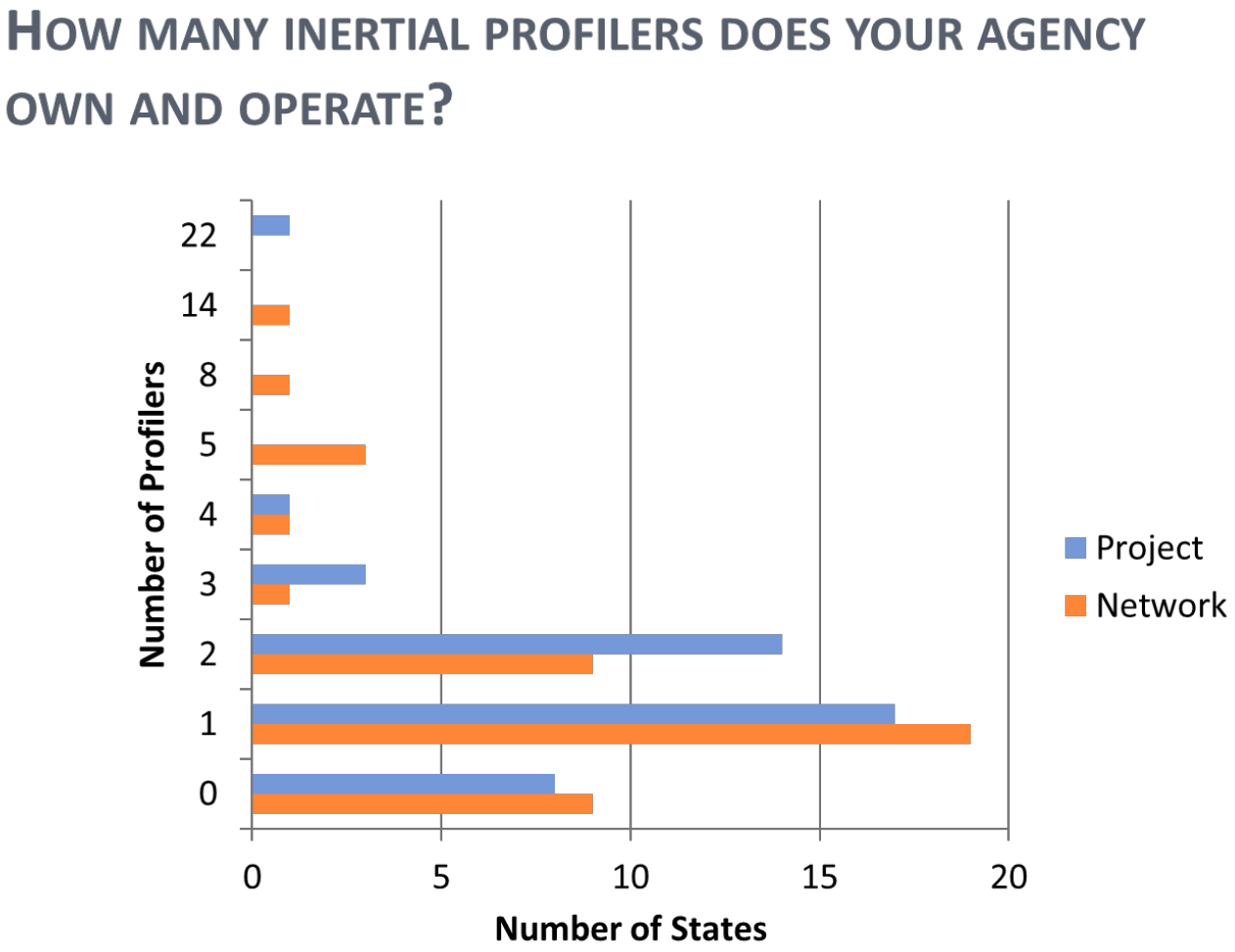
Quebec

Ontario

FHWA LTPP

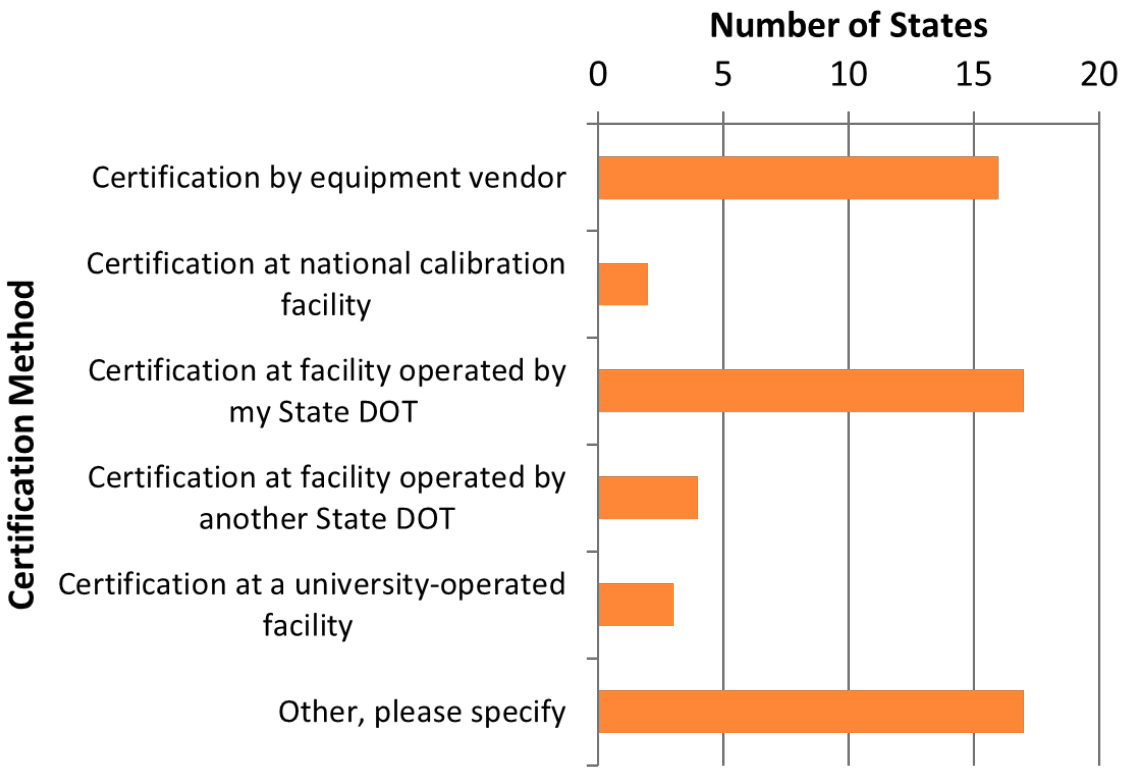
Summary of State Practices

- 2012 Survey of Profiler Certification Methods



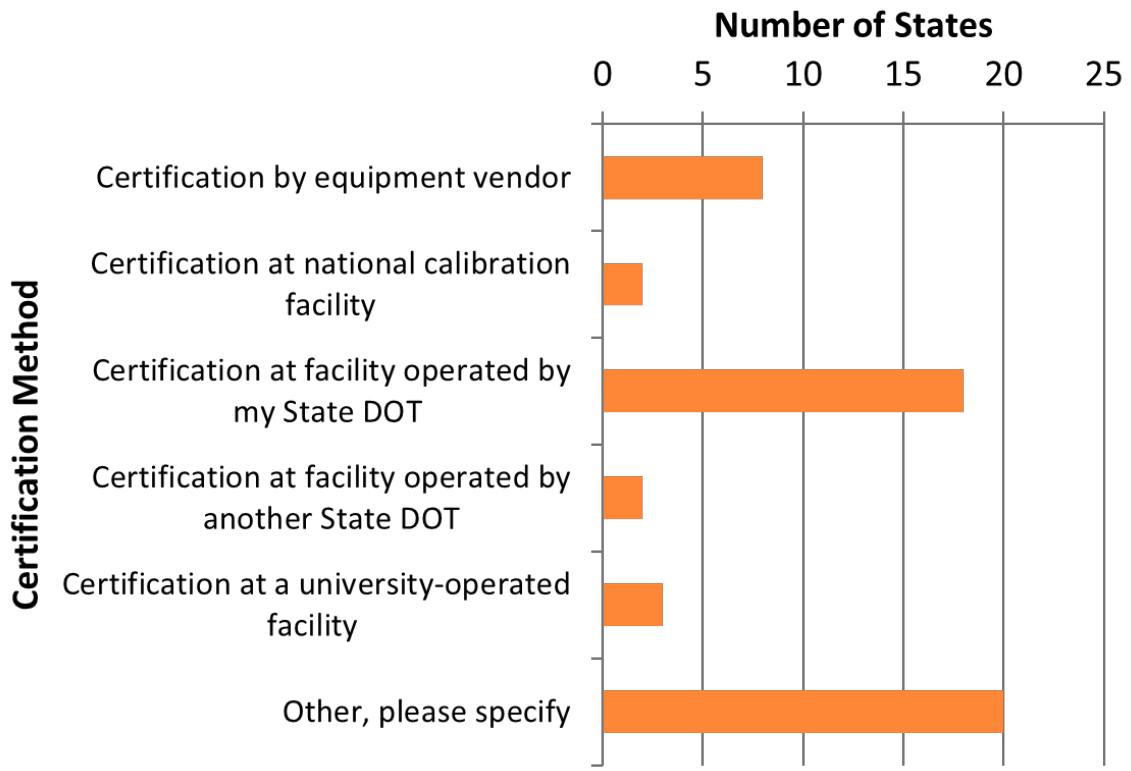
Summary of State Practices

- 2012 Survey of Profiler Certification Methods



Summary of State Practices

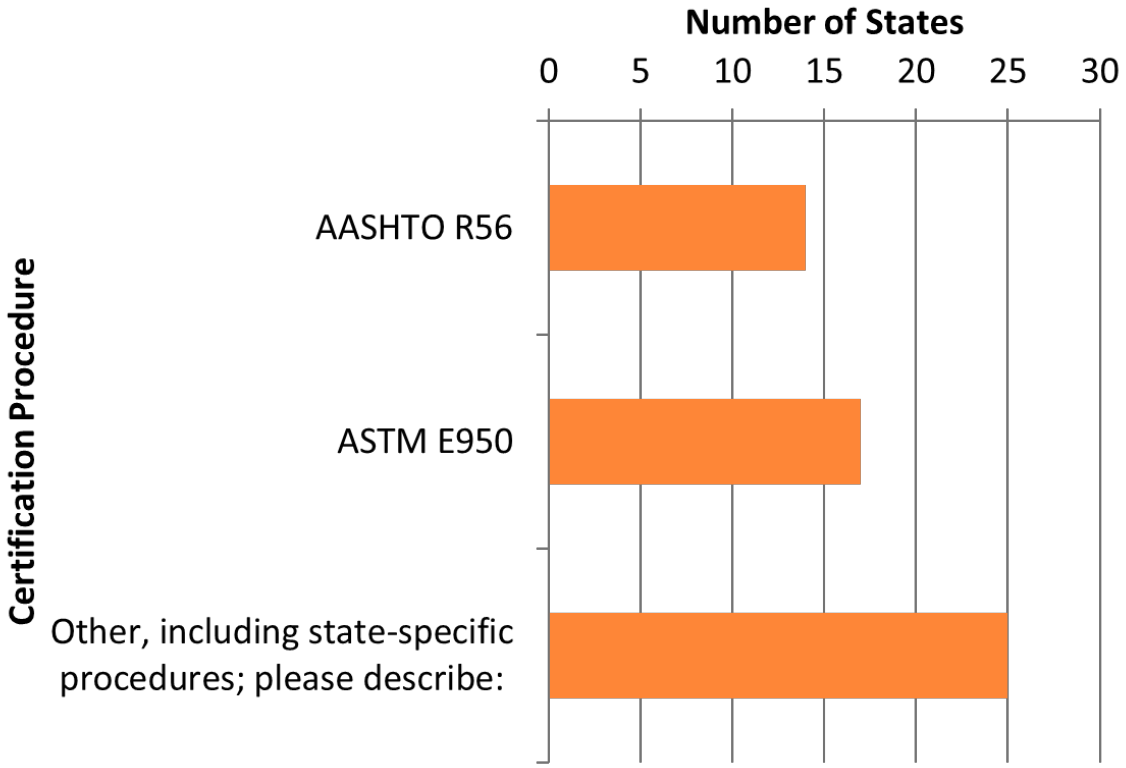
- 2012 Survey of Profiler Certification Methods



Summary of State Practices

- 2012 Survey of Profiler Certification Methods

WHAT STANDARD PROCEDURES DOES YOUR AGENCY REQUIRE FOR CERTIFICATION?



Summary of State Practices

- 2012 Survey of Profiler Certification Methods
  - Agencies own and certify a large number of devices
  - Many agencies use their own procedures & facilities
  - Most agencies do not accept other agencies' certification
  - Some agencies apparently do not certify

Summary of State Practices

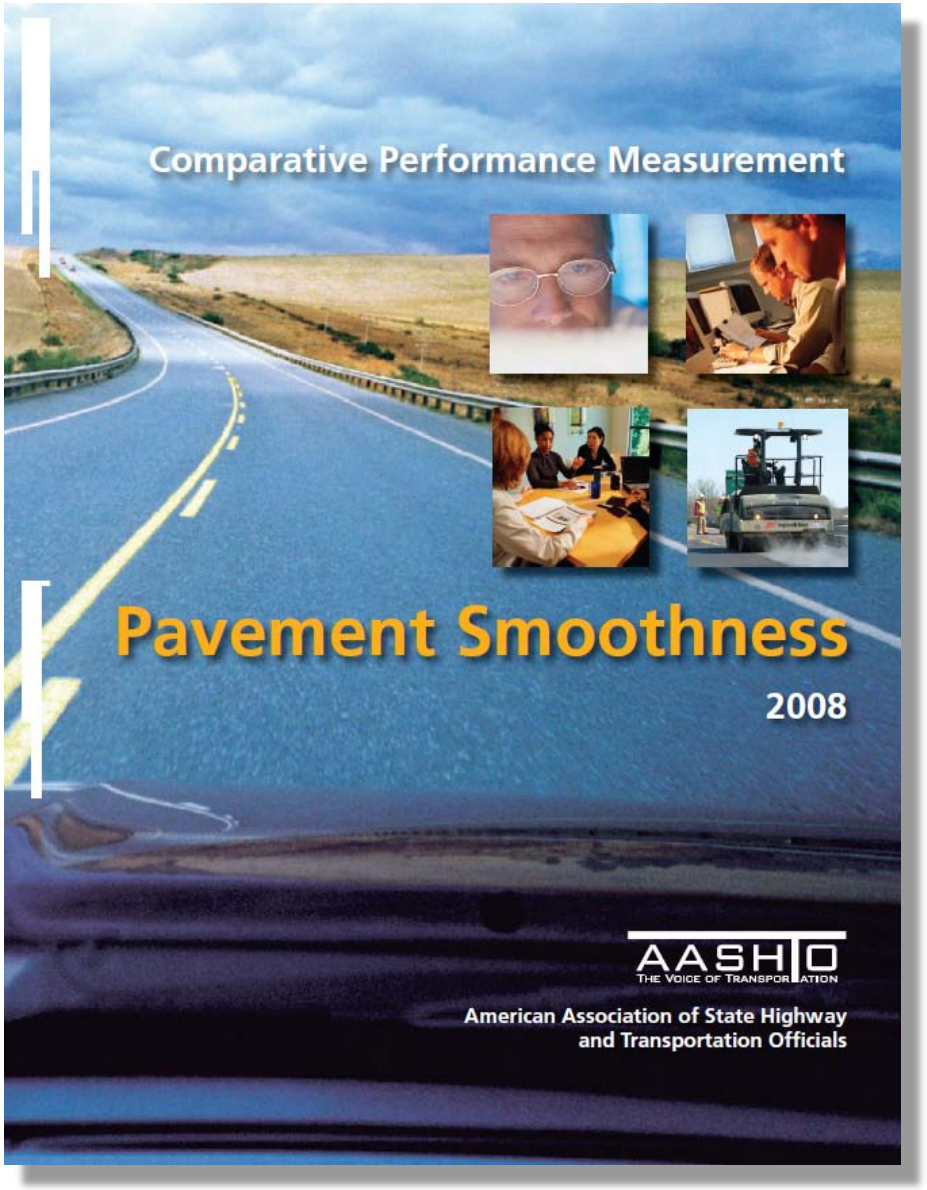
- 2012 Survey of Profiler Certification Methods
  - Perceived value of certification is credibility, technical validity
  - Perceived value for both network & project work
  - Travel authorization, distance, & cost are potential barriers to regional certification facilities
  - Survey results may change post MAP-21

Agenda

- Project Overview
- Literature Search
- SOM Survey Results
- Summary of State Practices
- Summary of Best Practices
- Conclusions and Knowledge Gaps

Best Practices for a Smooth Pavement Program

Summary of Best Practices



Summary of Best Practices

- AASHTO Comparative Performance Measurement Report
- Key Themes from “top performing” states:
  - Use of end-result smoothness specifications with financial incentives for good performance
  - Establishment of close working relationships with contractor community.

Summary of Best Practices

- AASHTO Comparative Performance Measurement Report – *Agency Practices*
  1. Strong Performance Management Orientation
     - Establish network-level pavement smoothness targets
     - Deliberate investments, policies, and programs
  2. Use End-Result Pavement Construction Specifications with Incentive Bonuses
     - Minimize prescription of construction methods
     - Give contractors the target and provide flexibility in achieving those targets

Summary of Best Practices

- AASHTO Comparative Performance Measurement Report – *Agency Practices*
  3. Build Close Working Relationships with Paving Contractors
     - Involve contractors in task forces to set end-result specification targets
     - Pre-construction meetings and training
  4. Integrate Customer Input
     - Involve the public in order to gauge acceptable levels of pavement roughness

Summary of Best Practices

- AASHTO Comparative Performance Measurement Report – *Agency Practices*
  5. Pavement Management
     - Sustained commitment to investment in strong pavement bases, preventive maintenance, and rehabilitation of pavements *well before* they become noticeably rough.

Summary of Best Practices

- AASHTO Comparative Performance Measurement Report – *Contractor Practices*
  1. Materials, Placement, and Finishing Techniques
     - Use materials that will better help you achieve smoothness requirements
     - HMA – polymer or rubber-modified mixes
     - PCC – well-graded concrete mixtures; minimizing hand finishing

Summary of Best Practices

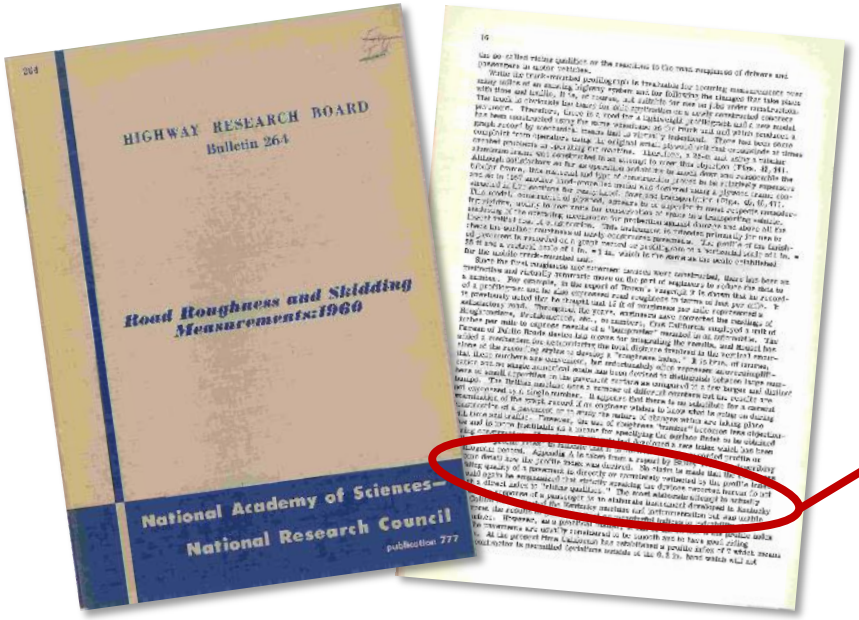
- AASHTO Comparative Performance Measurement Report – *Contractor Practices*
  2. Equipment Deployment
     - HMA: Use material transfer vehicles to reduce risk of bumping the paver
     - Use mobile plants and dedicated trucks to maintain high production rates
  3. Daily Testing and Adjustment
     - Check smoothness numbers daily and make adjustments on the fly
     - Invest in your own equipment for testing

Summary of Best Practices

- AASHTO Comparative Performance Measurement Report – *Agency Practices*
  4. Cultivating a "Quality Mindset"
     - Communicate importance of quality internally
     - Make investments in equipment to achieve smoothness requirements
     - Reward paving crews for quality results.

Summary of Best Practices

- AASHTO Comparative Performance Measurement Report – *Other Recommendations*
  - Use IRI for acceptance testing.



F.N.Hveem (1960):
"No claim is made that the roughness or riding quality of a pavement is directly or completely reflected by the profile index. It should again be emphasized that strictly speaking the devices reported herein do not furnish a direct index to "riding qualities."

Summary of Best Practices

- AASHTO Comparative Performance Measurement Report – *Other Recommendations*
  - Use IRI for acceptance testing.
    - IRI better represents “Ride Quality” not just “Smoothness”
    - IRI matches what is normally used for Network-Level monitoring

Summary of Best Practices

- AASHTO Comparative Performance Measurement Report – *Other Recommendations*
  - If Profilograph is used, compute PrI with 0” blanking band.
  - PrI with 0” BB will pick up “chatter” that a 0.2” BB may hide

Summary of Best Practices

- AASHTO Comparative Performance Measurement Report – *Other Recommendations*
  - Establish specification targets that can be achieved through good construction practices without excessive grinding.
  - Require project kickoff meetings at the start of each project.

Summary of Best Practices

- AASHTO Comparative Performance Measurement Report – *Other Recommendations*
  - Utilize AASHTO standards for Inertial Profilers to improve consistency.
    - **Profiling Equipment**: M 328-10 *Standard Specification for Inertial Profiler*
    - **Equipment Certification**: R 56-10 *Standard Practice for Certification of Inertial Profiling Systems*

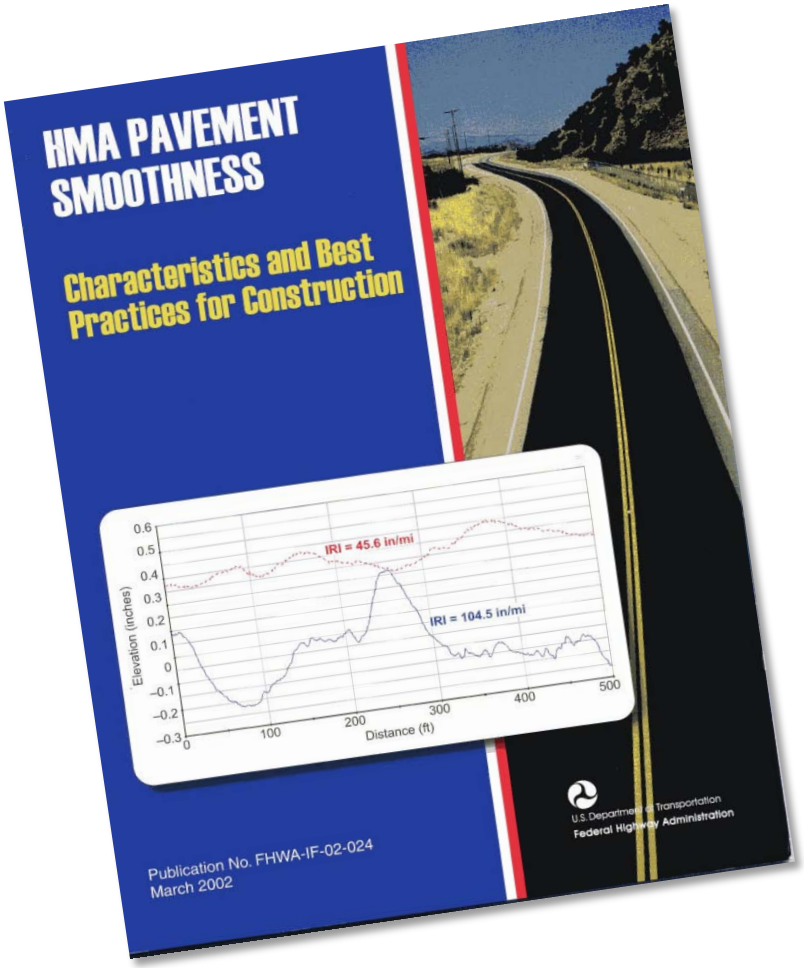
Summary of Best Practices

- AASHTO Comparative Performance Measurement Report – *Other Recommendations*
  - Utilize AASHTO standards for Inertial Profilers to improve consistency.
    - **Operation and Evaluation**: R 57-10 *Standard Practice for Operating Inertial Profiling System*
    - **Pavement Ride Quality**: R 54-10 Standard Practice for Accepting Pavement Ride Quality when Measured Using Inertial Profiling Systems

Best Practices for Construction

Summary of Best Practices

- Key References



Richard Petty's **Ten Tips** for **Smoother Pavement**

1. PLAN BEFORE YOU START... The entire crew should have an organizational meeting long before any work begins.

2. KEEP THAT FOCUS ON COMMUNICATION AFTER THE JOB STARTS. Just because the job's underway is no reason to stop communicating.

3. GO SLOW, IF NECESSARY, BUT GO STEADY. The entire paving job should be a continuous, coordinated process.

4. TRY OUT SOME SKIS. Check out alternative ski setups for best control.

5. WATCH WHAT YOU'RE READING. Take sensor readings off the smoothest surface possible.

6. CONSISTENCY STARTS AT THE HOT PLANT. Make sure temperatures of the hot mix are kept as consistent as possible.

7. NO BUMPING! Minimize the contact between paver and hauling units.

8. KEEP THE ROLLERS MOVING. If you have to stop to take a break, don't park on the new mat.

9. STAY ON THE MAT. Keep the rollers on the mat when pinching a joint.

10. EVALUATE. Once the project is complete, review the successes as well as the areas where you could have improved.

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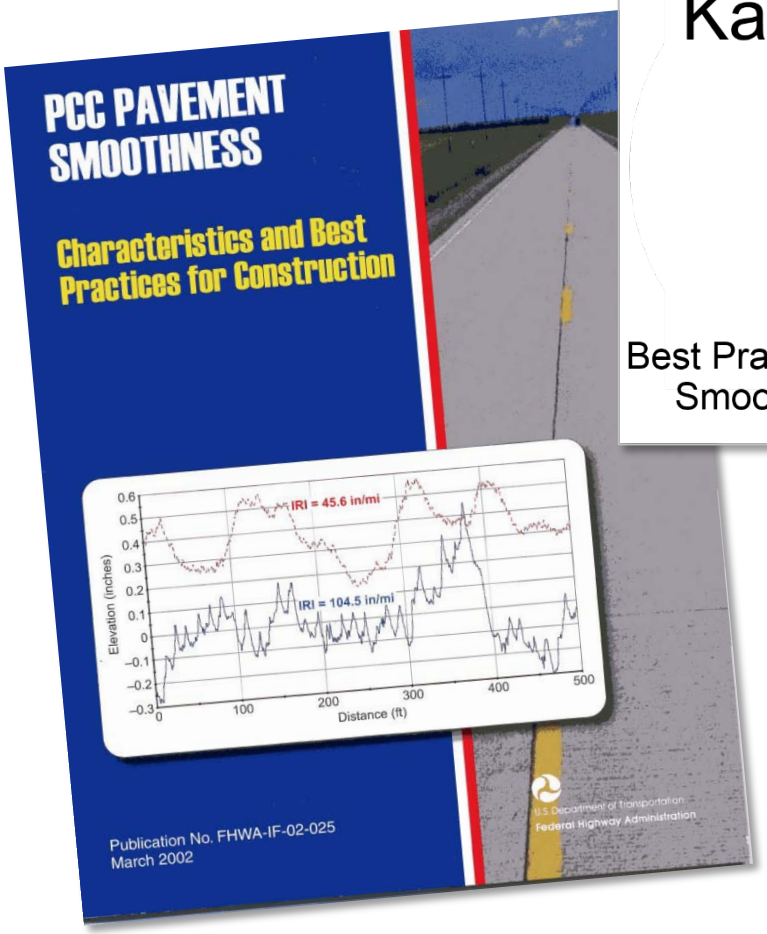
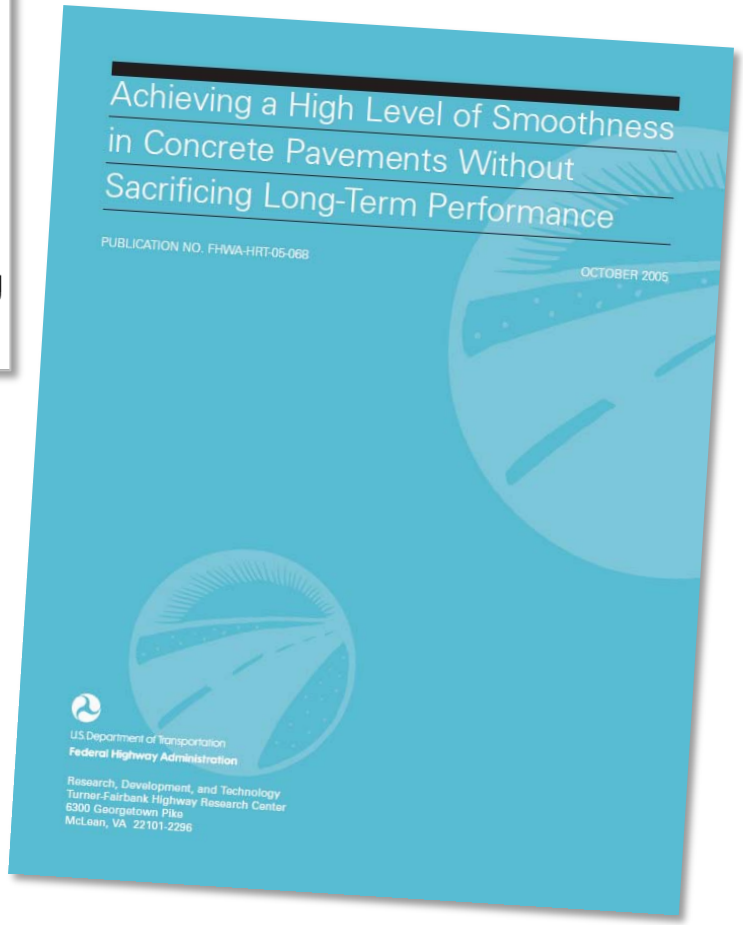
Summary of Best Practices

- Key References



Kansas DOT

"Great Eight"
Best Practices for Constructing Smooth PCC Pavements



Summary of Best Practices

- Best Practices for PCC
  1. Build From the Ground Up
     - Stable platform and trackline
     - Surface preparation for overlays
  2. Precise Grade Reference
     - Automated grade controls (dual stringline or stringless)
     - Continually monitor grade control (sensors, stringline, etc.)
  3. Watch Paving Speed and Delivery Rate
     - Consistent, steady supply of material
     - Maintain constant speed – slow and steady vs. start and stop

Summary of Best Practices

- Best Practices for PCC
  - 4. Control Concrete Head
    - “A slipform paver is a finisher, not a dozer.”
    - Maintain constant head of material in front of strike-off bar.
  - 5. Strive for Mix Consistency
    - Uniform workable material that is consistent from batch to batch
    - Watch for segregation when placing material in front of paver.

Summary of Best Practices

- Best Practices for PCC
  - 6. Minimal Hand Finishing
    - Keep finishing to edging, sealing with float
    - Apply texture and curing in a timely manner
    - Sawcut at proper time, dependent upon weather conditions
    - Pay special attention to header joints
  - 7. Use Good Equipment
    - Take care of your investment
    - Dedicated haul equipment if necessary
  - 8. Motivate Workforce
    - “Quality Mindset” at all levels of the company.

Summary of Best Practices

- Best Practices for HMA
  1. Surface Preparation
     - Stable platform, trimmed to grade
     - “Roughness can be reduced by half (at best) with each pavement layer.”
  2. Paver Operation
     - Continuous paver movement – minimize starts and stops
     - Quick but smooth starts and stops

Summary of Best Practices

- Best Practices for HMA
  - 3. Mix Production and Delivery
    - Consistent mix temperature
    - Remix at the paver if possible (e.g., MTV)
    - Avoid letting hopper run completely empty
    - Don’t bump the paver with the delivery truck
    - Remove residual material that falls in front of the paver
  - 4. Grade Control
    - Use grade control for every layer possible (milling, binder course, surface course, etc.)
    - Mobile reference – skis or floating beam, joint matching shoe

Summary of Best Practices

- Best Practices for HMA
  - 5. Compaction
    - Use correct combination of rollers for the mix
    - Keep drums and wheels clean
    - Slow, smooth changes in direction
    - Always moving, matching roller patterns to production
    - Don’t stop or park on the hot mat

Summary of Best Practices

- Best Practices for HMA
  - 6. Joint Construction
    - Use starting blocks under screed when starting up
    - Ensure a normal head of material before pulling off blocks
    - Bring paver up to normal speed as quickly as possible
    - Don’t overwork the joint by hand.
  - 7. Special Circumstances
    - Pay close attention to leave-outs, curb and gutter, drainage structures.
    - Hand place only as much as absolutely necessary.

Summary of Best Practices

- Key Themes
- Planning and Communication is critical
  - Thinking through the whole operation: batch plant, material delivery, project location, traffic control, paving sequence.
  - Communicate the whole plan to everybody – don’t have a “need to know” mentality.
  - Pre-paving meeting with everyone involved, including DOT personnel

Summary of Best Practices

- Key Themes
- Quality materials and material handling
  - What you put through the paver matters
  - Segregation will affect how the paver operates and the finished surface
    - Segregated material from delivery
    - Temperature segregation behind the paver (HMA)
  - Carefully plan haul route and haul times

Summary of Best Practices

- Key Themes
- What you pave on matters
  - Roughness in paving platform (prepared base, overlay surface, etc.) will reflect into finished surface.
  - The more uniform the surface, the smoother the final pavement.

Summary of Best Practices

- Key Themes
- Continually monitor your work
  - Check your smoothness numbers every day and make corrections if necessary
  - RTS provides real-time feedback for PCCP
  - Use software tools like ProVAL to identify “patterns” of roughness that need to be corrected

Agenda

- Project Overview
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- Conclusions and Knowledge Gaps

Conclusions

- Pavement Smoothness continues to move towards IRI measurement
  - Most HMA specs are there, PCC is quickly catching up
- Measurement Equipment limitations have largely been overcome
  - Wide footprint sensors (e.g. line lasers) have addressed issues with longitudinally textured and open graded surfaces

Conclusions

- Most states have fostered good relationships with the industry to help ease specification transitions
- New technologies are helping contractors with process control for achieving smoothness requirements
  - Real-Time Smoothness for PCC
  - Intelligent Compaction and Thermal imaging for HMA

Knowledge Gaps

- PCCP Profiling (specifically, JPCP)
  - Time of day
  - Understanding change over time due to curl/warp
- Localized Roughness
  - Finding the best method to quantify it
  - Finding the best way to locate and correct it

Knowledge Gaps

- Profiler Certification
  - Setting up local certification sites
  - Evaluation of reference profilers
- Smoothness Index Thresholds
  - How smooth is smooth enough?
  - Based on what vehicle?
  - Based on what facility type?

Knowledge Gaps

- Pay Adjustments
  - How long do we keep paying for smooth pavements?
  - Are we getting the Return on Investment for incentives?
    - How much additional life are we getting for various levels of smoothness
  - Do disincentives cover the true “cost” of a pavement that does not have specified smoothness?