About the Presenter

- **Steve Karamihas** is a senior research associate at the University of Michigan Transportation Research Institute (UMTRI).
- Steve is a co-author of the Little Book of Profiling.
- Steve has conducted research related to vehicle dynamics, road profile measurement, and road profile interpretation for 30 years.
- Steve has a Ph.D. in mechanical engineering from the University of Michigan.
- Steve is somewhat older than the photo to the right might imply.

1

About the Presenter

- **Jerod Gross** is a Senior Project Manager at Snyder and Associates, Inc.,
- Jerod has provided concrete pavement design, analysis and technical training for the CP Tech Center.
- He has completed research and guidance documents for cement stabilized subgrade soils, concrete trails, concrete overlays and subbase/subgrade foundation performance.
- He has a Bachelor of Science degree in Civil Engineering from Iowa State University and is a LEED Accredited Professional.
- Jerod now has less hair than what is shown.

2

Maintaining Smoothness

Jerod Gross, CP Tech Center and Steve Karamihas, University of Michigan

IOWA STATE UNIVERSITY
Institute for Transportation

National Concrete Pavement Technology Center
CP Tech Center

Maintaining Smoothness

Discussion Items

- Background
- Literature Search
- State of Practice
- IRI Data

Maintaining Smoothness: Background

Topic Areas

- Profile Measurement
- International Roughness Index
- Measurement Issues
  - Texture
  - Curl and Warp
- Areas of Localized Roughness (ALR)

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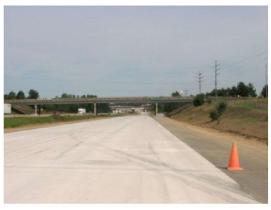
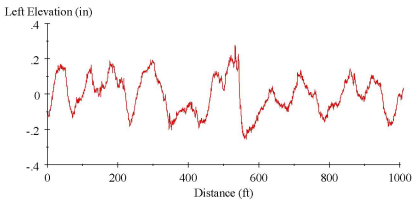
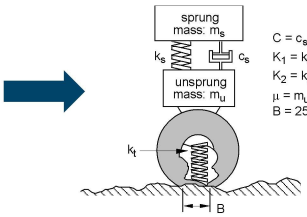
Profile Measurement

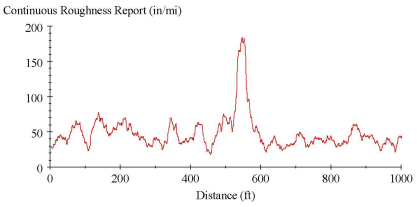






$C = c_s/m_s = 6.0\ sec^{-1}$
$K_1 = k_t/m_s = 653\ sec^{-2}$
$K_2 = k_s/m_s = 63.3\ sec^{-2}$
$\mu = m_u/m_s = 0.15$
$B = 250\ mm$

IRI



Smoothness QA/QC: "Measuring and Specifying Pavement Smoothness." *Tech Brief FHWA-HIF-16-032* (2016) 12 p.
Real-Time Smoothness: https://cptechcenter.org/real-time-smoothness/

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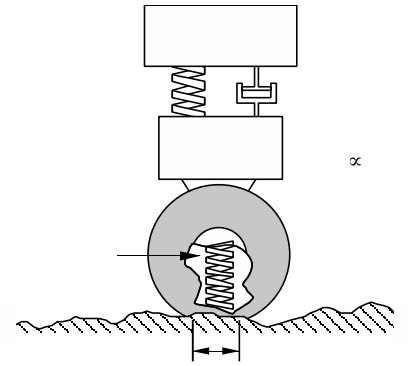
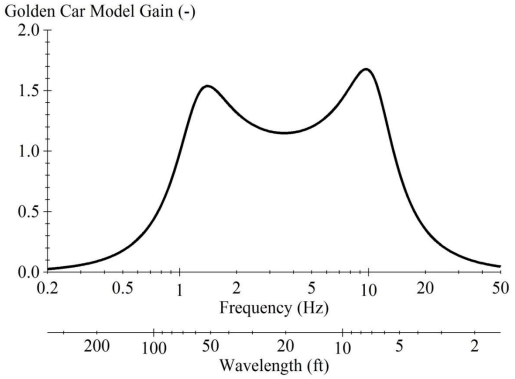
International Roughness Index (IRI)





Basics: Sayers, M.W. and Karamihas, S.M. *The Little Book of Profiling.* University of Michigan Transportation Research Institute (1998) 100 p.
Algorithm: Sayers, M.W., "On the Calculation of International Roughness Index from Longitudinal Road Profile." *Transportation Research Record 1501* (1995) pp. 1-12.
Generality: Karamihas, S.M., Gilbert, M.E., Barnes, M.A., and Perera, R.W., "Measuring, Characterizing, and Reporting Pavement Roughness of Low-Speed and Urban Roads." *National Cooperative Highway Research Program Report 914* (2019) 84 p. (See pages 59-61.)

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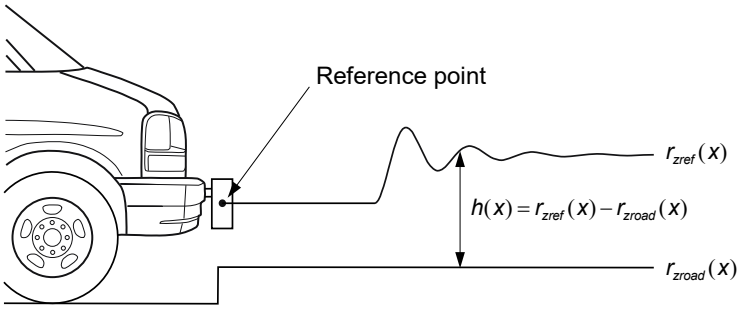
Inertial Profiler Measurement Principle



$$r_{zroad}(x) = r_{zref}(x) - \left(r_{zref}(x) - r_{zroad}(x)\right)$$

Schematic Resembles: Huft, D. L., "South Dakota Profilometer." *Transportation Research Record 1000* (1984) p. 1-8.
Basics: Sayers, M.W. and Karamihas, S.M. *The Little Book of Profiling.* University of Michigan Transportation Research Institute (1998) 100 p.
Pertinent Reference List: Karamihas, S.M., *Improvement of Inertial Profiler Measurements of Urban and Low-Speed Roadways*. Ph.D. Dissertation, University of Michigan (2021) 214 p.

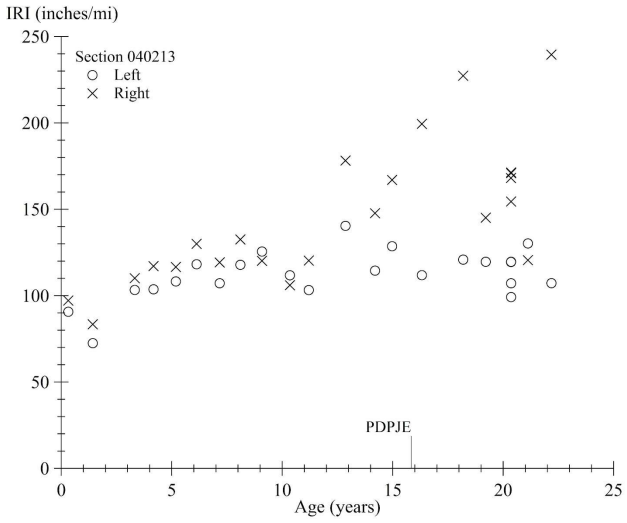
8

Measurement Issues: Texture

Start Here, Follow the Reference Chain: Perera, R.W. and Karamihas, S.M., "Study for Establishing Regional Certification Centers for Inertial Profilers." Federal Highway Administration (2014).

9

Measurement Issues: Curl and Warp



LTPP Section 040213
- Arizona SPS-2 section
- Jointed plain PCC
- 15-ft joint spacing
- lower flexural strength (550 ksi)
- lower slab thickness (8 inches)
- dense graded aggregate base

PDPJE – partial depth patching at joints and elsewhere

Source: Karamihas, S.M., Punnackal, T., Dufalla, N, and Senn, K., "Advancing Profile-Based Curl- and Warp Analysis Using LTPP Profile Data." *Federal Highway Administration Report FHWA-HRT-20-066* (2020) 485 p.

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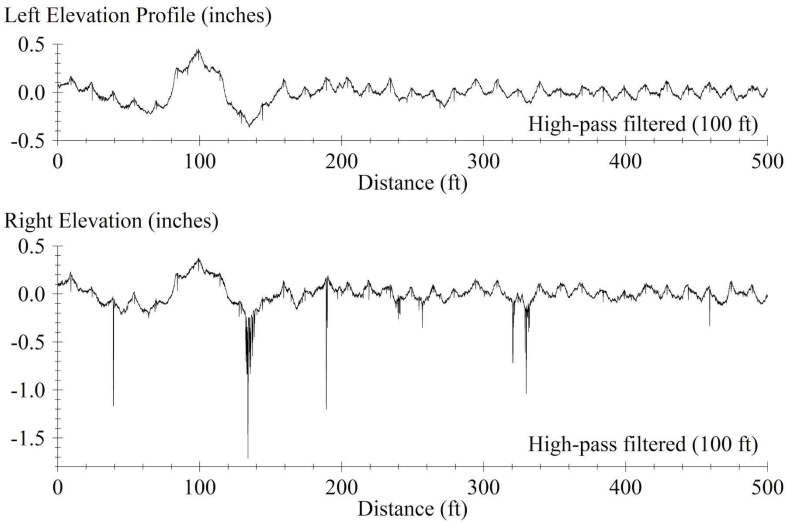
Measurement Issues: Curl and Warp



LTPP Section 040213
14.3 years after construction

Left IRI: 114 in/mi
Right IRI: 145 in/mi

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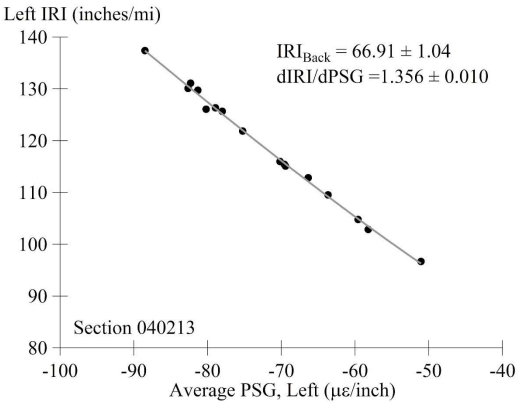
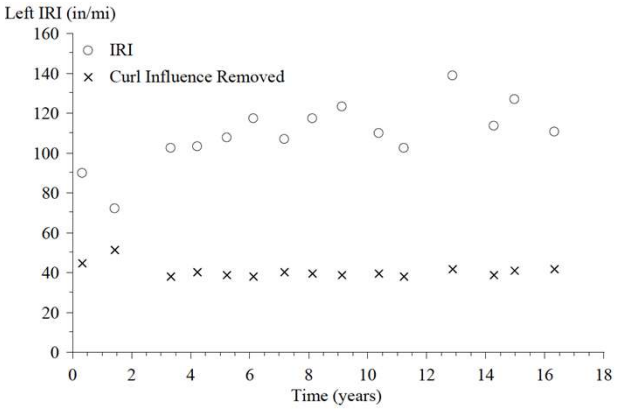
Measurement Issues: Curl and Warp





Cyclic Roughness Data Source: Chang, G.K., et al. *Impact of Temperature Curling and Moisture Warping on Jointed Concrete Pavement Performance. Volume I. Data Collection.* Contract DTFH61-02-C-00077, FHWA, Washington, DC. (2007).
Pertinent Reference List: See FHWA-HRT-20-066 Appendix A.

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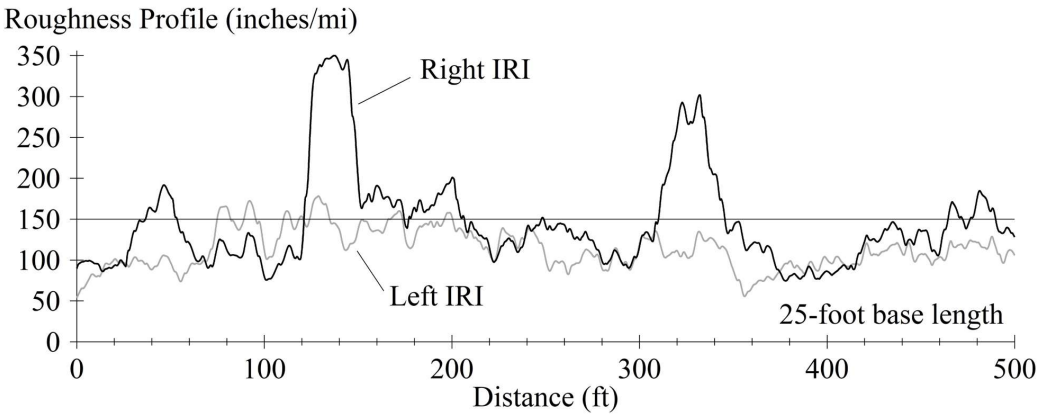
ALR: Roughness Profile



Basics: Sayers, M. W. "Profiles of Roughness." *Transportation Research Record 1260*. (1990) pp. 106–111.
ALR on Jointed PCC: See FHWA-HRT-20-066 Appendix J.

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Literature Search

NCHRP 1-31, Smoothness Specifications for Pavements,1997

- Smoother pavements last longer
- Data showed initial pavement smoothness has a significant effect on future smoothness

Average Percent Increase in Performance Life			
Reduction in roughness	10%	25%	50%
Alabama PCC	11	28	55
Arizona PCC	7	18	36
Illinois CRC	5	11	22
Minnesota PCC	6	15	30
Illinois AC/PCC	4	9	18
Alabama AC	8	20	39
Arizona AC	3	9	18
Minnesota AC	5	11	23

Smoothness Modeling Sensitivity Analysis

	Average % Increase in Pavement Life		
Reduction in Roughness	10%	25%	50%
HMA	5.3	13.3	26.7
PCC	7.3	18	36

The Transtec Group

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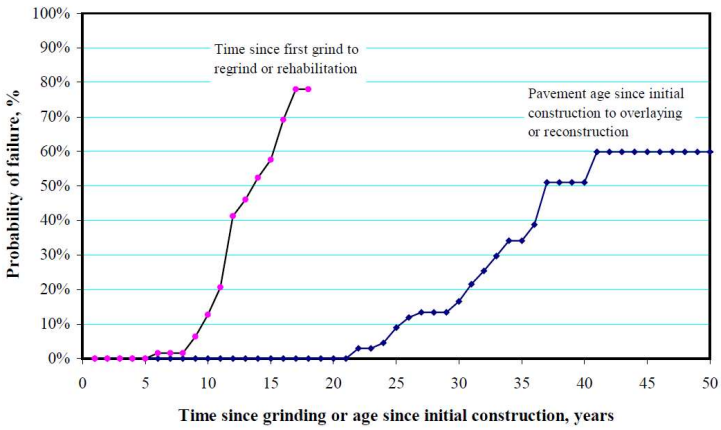
Literature Search

Longevity of Diamond-Ground Concrete Pavements, Rao et al., 1999

- 60 pavement sections in 18 states + 133 sections from earlier study along with LTPP
- LTPP allowed for comparison of diamond ground pavements with other CPR alternatives
- Evaluated performance of diamond-grinding and faulting as well as longevity of texture



Survival Curves for Diamond-Ground Concrete Pavements

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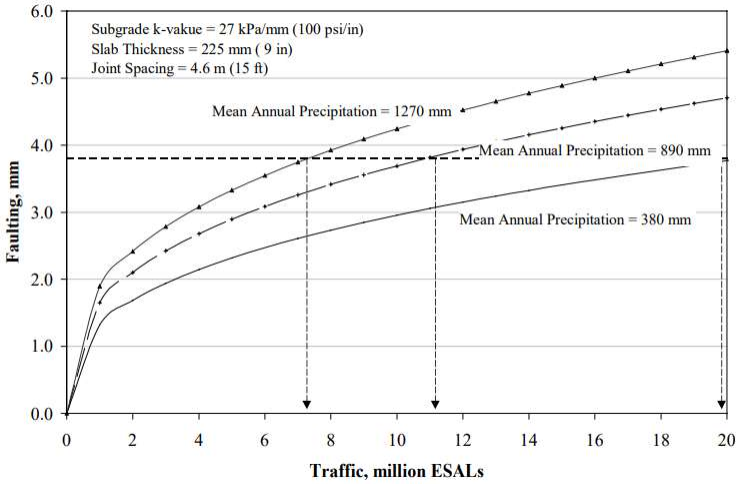
Literature Search

Longevity of Diamond-Ground Concrete Pavements, Rao et al., 1999

- Mechanical Empirical performance model
- Support structure plays a role



Effect of Precipitation on Faulting for Non-Doweled Pavements after Diamond Grinding

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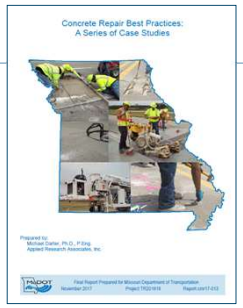
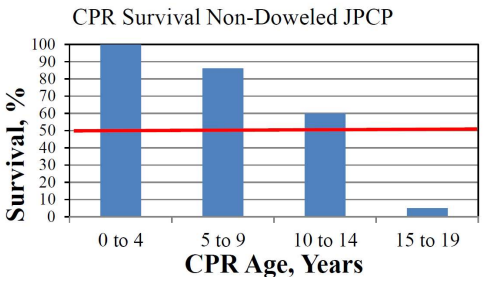
Literature Search



Concrete Repair Best Practices: A series of case studies, Darter, 2017 (MODOT – Const. Materials Division)
Includes CPR best practices (cross-stitching, DBR, Diamond Grinding, Full and Partial Depth Repairs, Slab stabilization)

Best Practices for Diamond Grinding focuses on Utah DOT specifications, case histories and data

- Diamond grinding in Utah shows a service life ranging from 10 to 20 years for undoweled JPCP.



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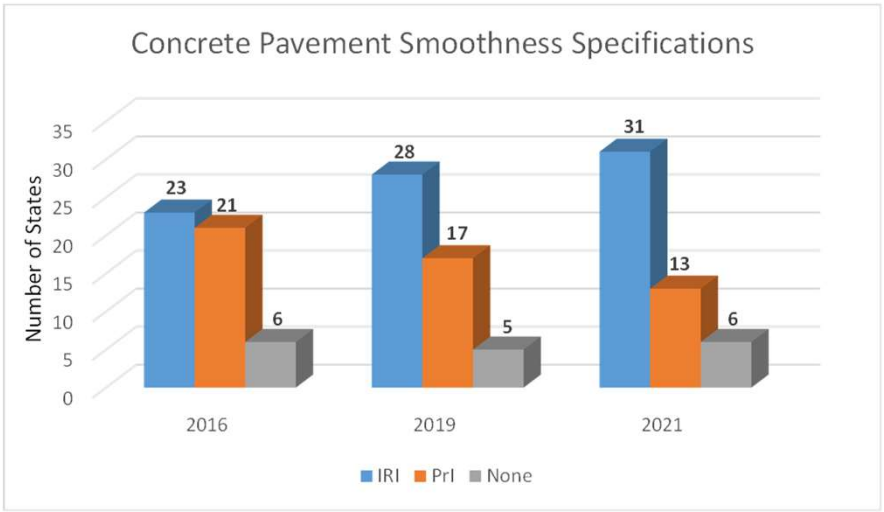
State of Practice
Concrete Pavement Smoothness Specs (2021)



2016 data: Merritt et al., 2015. 2019 data: The Transtec Group, 2020 CP Tech webinar

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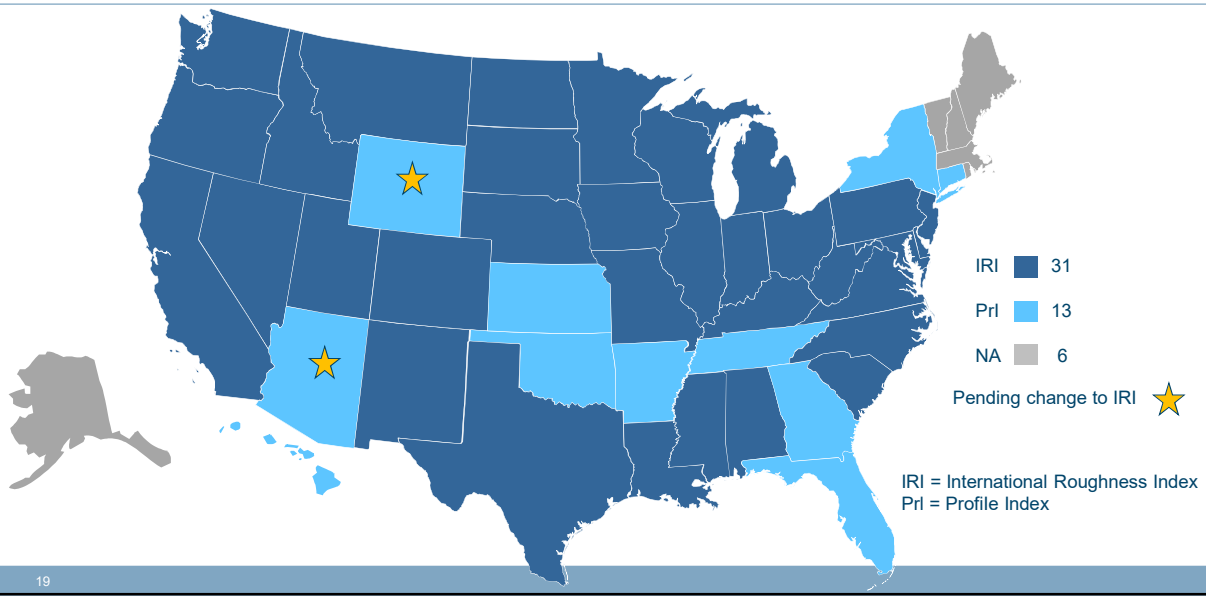
State of Practice
Concrete Pavement Smoothness Specs (2021)



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State of Practice - The Move to IRI

Research related to assist in the conversion from Profile Index to IRI specification / development of Smoothness Specification

- Pavement Smoothness Index Relationships, Smith, et al., 2001
- Evaluation of INDOT Construction Smoothness Specifications, Pellinen and Chou, 2003
- Implementation of an International Roughness Index for MNDOT Pavement Construction and Rehabilitation, Wilde, 2007
- ACPA/IGGA Guide-Pavement Smoothness Requirements, 2013 Task Force

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State of Practice – Survey of NCC States

Category	Number of States
Incentives / Disincentives	34
Areas of Localized Roughness	16
Specify wide laser	9
Specify wheel base for grinder	7 (5 states min. 12', 2 states 25')

	< 150 Inches per mile	> 150 Inches per mile
Trigger to Grinding (Preservation)	6 states	4 states

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State of Practice – State Specifications

IRI Acceptance	Number of States Low Speed (<45 mph)	Number of States High Speed (≥45 mph)
<40 inches per mile		4
40 – 60 inches per mile		4
60 – 90 inches per mile	5	20
115 – 135 inches per mile	3	
10' straight edge	3	
16' straight edge	3	

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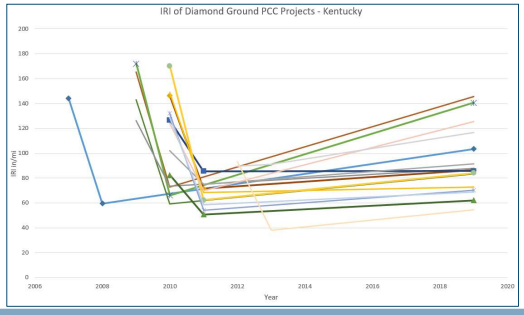
State IRI Data

- Aug 2015 IGGA Case Study: https://www.igga.net/wp-content/uploads/2018/08/CSAug2015_KY_diamond_grinding_CPP_PMS.pdf
- From 2007 and 2012, 536 interstate lane miles were diamond ground statewide (Louisville area)
- IRI performance from 307 of the 536 lane miles was studied
  - After grinding, the IRI decreased from an average of 134 (in./mi.) to 64 (in./mi.)
  - Based on the 2019 IRI data, the average increase in IRI was 2.7 (in./mi.) per year over an average of 9.4 years after grinding.



IRI > 130 in./mi. general trigger

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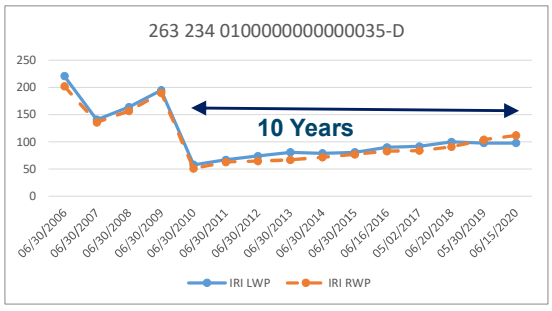
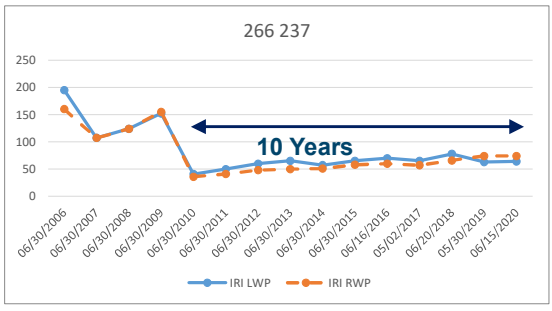
Data from Kentucky Transportation Cabinet

State IRI Data





Data indicates at least a 10 year performance

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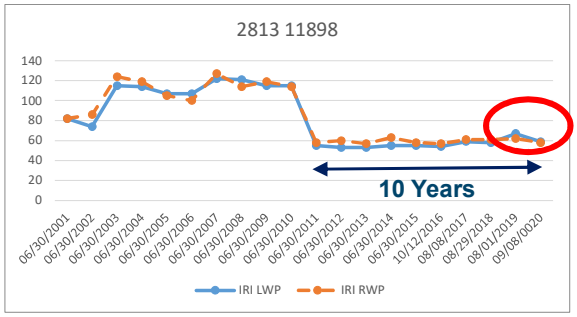
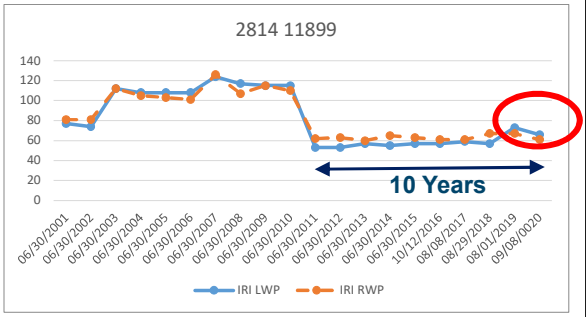
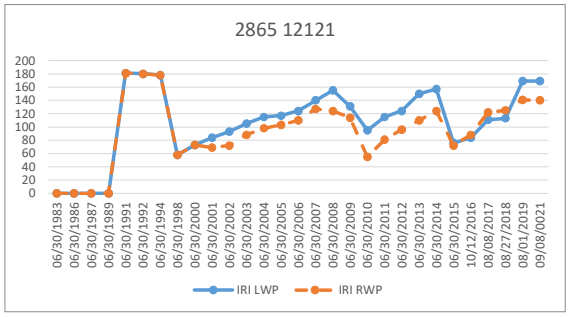
State IRI Data

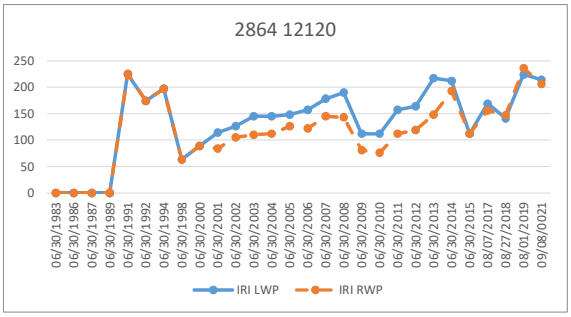




Single point lasers until 2019, Wide line lasers used in collection starting in 2020

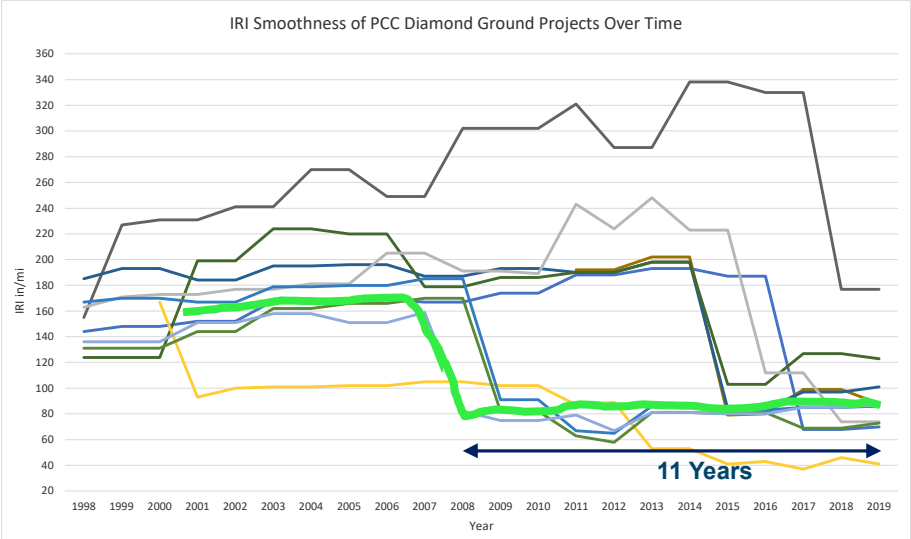
State IRI Data





'Roller Coaster' - may indicate a structural deficiency, fatigue or support issue
Note the variance between LWP and RWP IRI

State IRI Data



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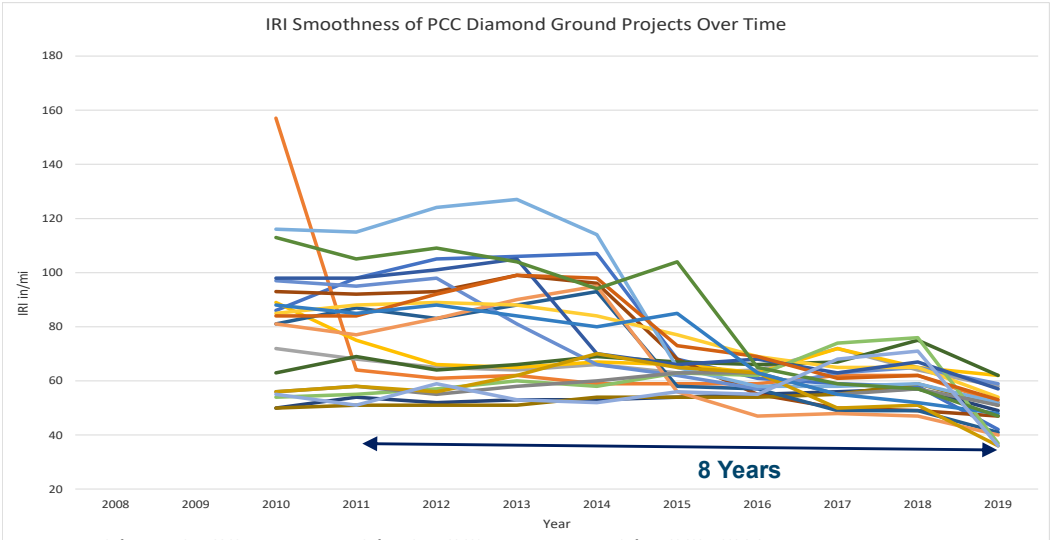
State IRI Data



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Evaluating Performance

Many variables effecting IRI data

- Traffic, age, environment, support
- Panel size (curling & warping)
- Load transfer (dowel bars)
- Sensor type (spot laser or line laser)
- Time and temperature of test

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Evaluating Performance

We know the following:

- Public wants smooth pavements
- Building smooth pavements stay smoother
- Smoother pavements last longer
- Smoother pavements are safer
- Smoother pavements save money
- Advancements in technology provide more accurate data

Lets continue to collect and share data

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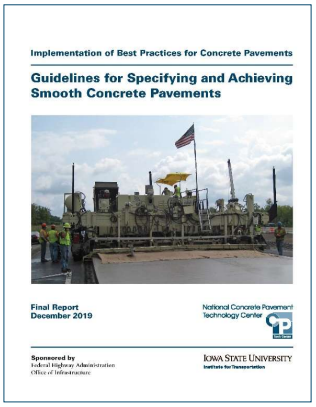
Achieving Smoothness

- Guidelines for Specifying and Achieving Smooth Concrete Pavements, Fick, Merritt, Taylor, 2019
  - Design
  - Construction
  - Measuring Smoothness
- Investigation of the Effect of Curling on as Constructed Smoothness and Ride Quality of KDOT Portland Cement Concrete (PCC) Pavements, Siddique, 2004
- Constructing Smooth Concrete Pavements, ACPA wikipave
  https://wikipave.org/index.php?title=Constructing_Smooth_Concrete_Pavements



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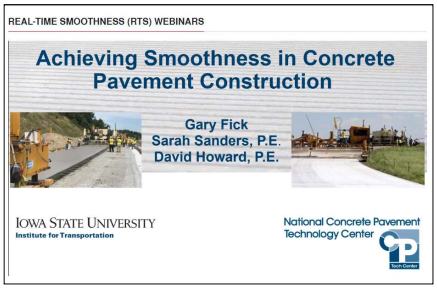
Other Resources

- Real-Time Smoothness (RTS) Webinars – CP Tech Center 2020
  - https://cptechcenter.org/webinars-and-videos/
- RTS Page
  - https://cptechcenter.org/real-time-smoothness/



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Questions?

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Jerod Gross, Snyder & Associates/CP Tech Center
jgross@snyder-associates.com

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