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International Experience and Perspective of Pavement Texture Measurements and Evaluation

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International Experience and Perspective of Pavement Texture Measurements and Evaluation

Synopsis of a Workshop:
94th Annual Meeting of the Transportation Research Board, Session 123

Prepared by
Brian L. Schleppi
Magdy Y. Mikhail
George K. Chang

Sponsored by
Standing Committee on Pavement Surface Properties and Vehicle Interaction

Cosponsored by
Standing Committee on Pavement Structural Modeling and Evaluation
Standing Committee on Surface Requirements of Asphalt Mixtures
Standing Committee on Transportation-Related Noise and Vibration

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Lea Camarda, Production Editor; Jennifer Correro, Proofreading and Layout

Contents

PUBLISHER'S NOTE

The content of the presentations are those of the individual authors and do not necessarily represent the views of standing committees, TRB, or the National Academies of Science, Engineering, and Medicine.

Introduction

This Transportation Research E-Circular includes a synopsis of five presentations at the workshop "International Experience and Perspective of Pavement Texture Measurements and Evaluation" held at the 94th Annual Meeting of the Transportation Research Board. This workshop was sponsored by the Standing Committees on Pavement Surface Properties and Vehicle Interaction, Pavement Structural Modeling and Evaluation, Characteristics of Asphalt–Aggregate Combinations to Meet Surface Requirements, and Transportation-Related Noise and Vibration.

The publication of this E-Circular is timely and likely will serve as a valuable reference for pavement researchers and professionals throughout the transportation field.

BACKGROUND

Pavement texture is defined by the irregularities on a pavement surface that deviate from an ideal perfectly flat surface. Texture influences many surface characteristics, which in turn describe the functional performance of a pavement. Specific surface characteristics include measures of road safety and comfort including friction, smoothness (evenness), splash and spray, noise, rolling resistance and more. Many techniques measure and analyze texture, particularly texture that influences tire–pavement noise and friction. Specialized measurements also directly evaluate the various surface characteristics. Most profilers in use today measure texture using a single-point laser, which results in a two-dimensional (2-D) texture profile; distance along the pavement surface is one dimension and the texture elevation is the second. Pavement texture is complex, though; it often is anisotropic, meaning that the texture varies depending on the direction of the measurement: longitudinal or transverse. A 2-D profile therefore fails to completely describe characteristics of the texture that are important to many surface characteristics. To overcome this, three-dimensional (3-D) texture profiles now can be readily measured using line-laser–based devices and 3-D cameras.

The relationship between texture and surface characteristics is not simple, however; there have been many advancements in recent years. As this trend continues, texture measurements will permit construction guidance and pavement management to advance, resulting in even smoother, safer, and quieter pavements.

The workshop presented the U.S. and international experience with pavement texture measurements and interpretation.

The stationary methods used in the United States to measure texture include sand patch, Hydro-timer, stereo-photographs, laser texture scanner, circular texture meter, photometric stereo, and stereo vision systems. For dynamic, low-speed methods used to measure texture, the Robotex is the most common procedure. Dynamic high-speed texture measurements use the following methods: high-speed texture laser systems, a V-texture system developed by the Texas Department of Transportation, and the 3-D laser scanners that can measure mean profile depth (MPD) and also can simulate the sand patch test. The pavement community in the United States has realized the need for improved procedures for verifying the accuracy of texture data collected by high-speed devices. High-frequency laser sensors may be noisy, thereby affecting MPD values. A research project has been initiated by the National Cooperation Highway Research

Program (NCHRP) to address all the challenges with texture measurements.

The pavement community in the United Kingdom realizes that high-speed wet friction is heavily dependent on the texture on the surface of the pavement. Initially texture was measured statically using the sand-patch test, but it soon was realized that an estimate of texture could be obtained at traffic speed using a noncontact method based on lasers, with the first prototype developed in the early 1970s. This texture depth parameter is now routinely collected over most of the UK road network by a fleet of multifunction road surface monitoring vehicles of TRACS (Traffic Speed Condition Surveys) under the annual Highways England contract for the collection of surface condition information. SCANNER (Surface Condition Assessment of the National Network of Roads) is the equivalent contract for the English and Scottish local road network. In the United Kingdom, texture measurements also are used for predicting surface type and for estimating tire-generated noise levels, surface deterioration, rolling resistance, and splash and spray.

The pavement community in Europe also has realized the importance of pavement texture and texture measurements. The project ROSANNE was initiated in Europe to study rolling resistance, skid resistance, and noise emission measurement standards for road surfaces. This project will advance harmonization of measurement methods for skid resistance, noise emission, and rolling resistance of pavements. This project also looks at the feasibility and usefulness of 3-D texture measurements.

The International Standardization Organization (ISO) currently is working on updating the ISO standards for measurement and analysis of texture data, including the computation of MPD. This effort was undertaken because it recently was noted that MPD obtained from different texture measuring devices had poor reproducibility and that some results seemed to be out of the reasonable range that was expected. A draft updated standard has been developed and currently is being reviewed and submitted for balloting.

WORKSHOP INFORMATION

This e-circular is based on Session 123 (a workshop) of the 94th Annual Meeting of the Transportation Research Board, held January 11–15, 2015, in Washington, D.C.

International Experience and Perspective of Pavement Texture Measurements and Evaluation

Brian L. Schleppi, Ohio Department of Transportation; Magdy Y. Mikhail, Texas Department of Transportation, presiding. Sponsored by the Standing Committees on Pavement Surface Properties and Vehicle Interaction, Pavement Structural Modeling and Evaluation, Characteristics of Asphalt–Aggregate Combinations to Meet Surface Requirements, and Transportation-Related Noise and Vibration.

Presentations:

Fundamentals of Pavement Texture Measurement and Interpretation (P15-5056)
Robert Otto Rasmussen, Transtec Group, Inc.
UK's Experiences on Pavement Texture Measurement and Interpretation (P15-5057)

Brian Walter Ferne, Transport Research Laboratory, United Kingdom
US' Experiences on Pavement Texture Measurement and Interpretation (P15-5058)
Edgar David de León Izeppi, Virginia Tech Transportation Institute
New and Improved ISO Standards for Texture Measurements (P15-5059)
Ulf Sandberg, Swedish National Road and Transport Research Institute
EU project ROSANNE — ROlling resistance, Skid resistance, ANd Noise Emission Measurement Standards for Road Surfaces (P15-5060)
Luc Goubert, Belgian Road Research Centre
Q&As and Panel Discussion on Pavement Texture Measurement and Interpretation (P15-5061)

ACKNOWLEDGMENTS

Thanks to the presenters for sharing research. Thanks also go to Brian Schleppi of the Ohio Department of Transportation, who assembled this document, and to Magdy Y. Mikhail of the Texas Department of Transportation who presided at the workshop. Thanks also to Karen Febey, Senior Report Review Officer, TRB.

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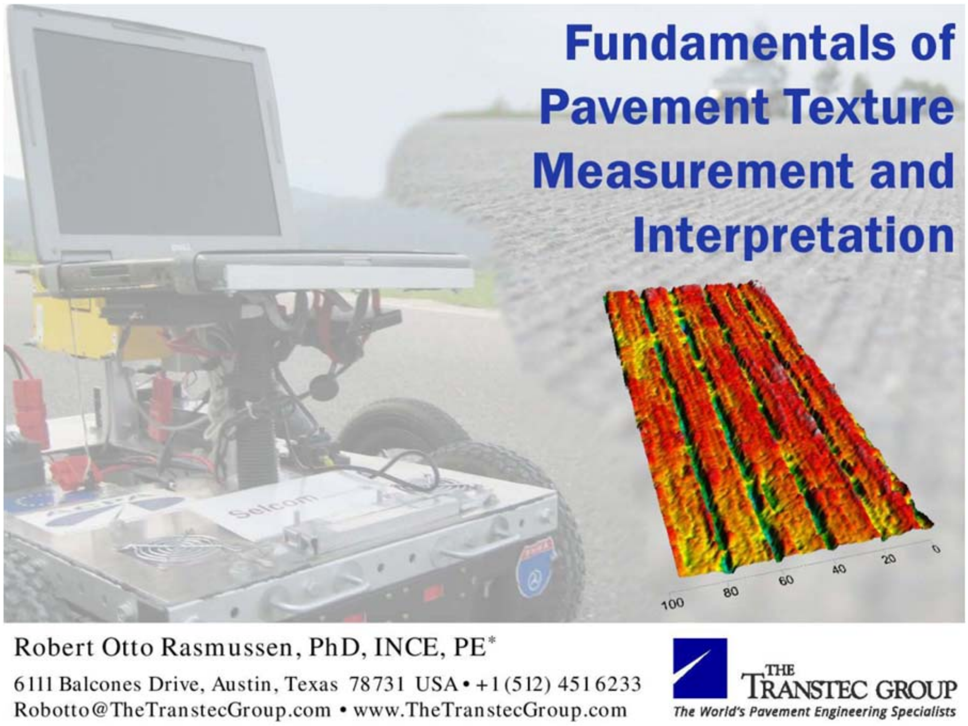
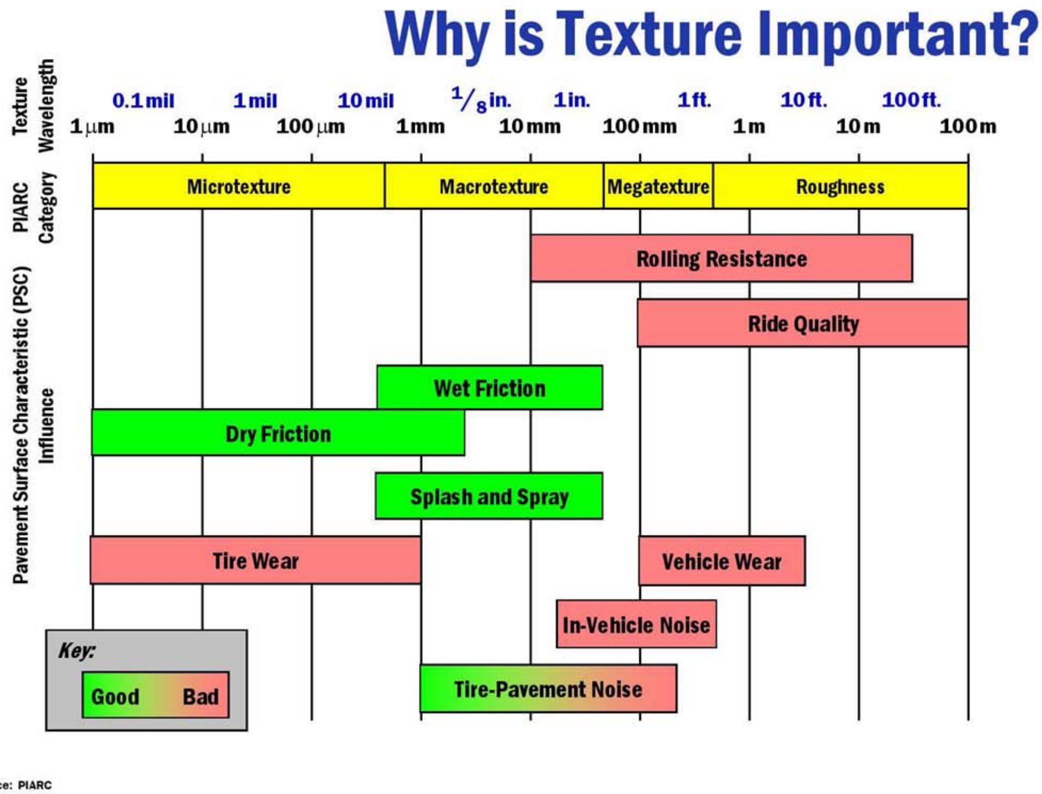
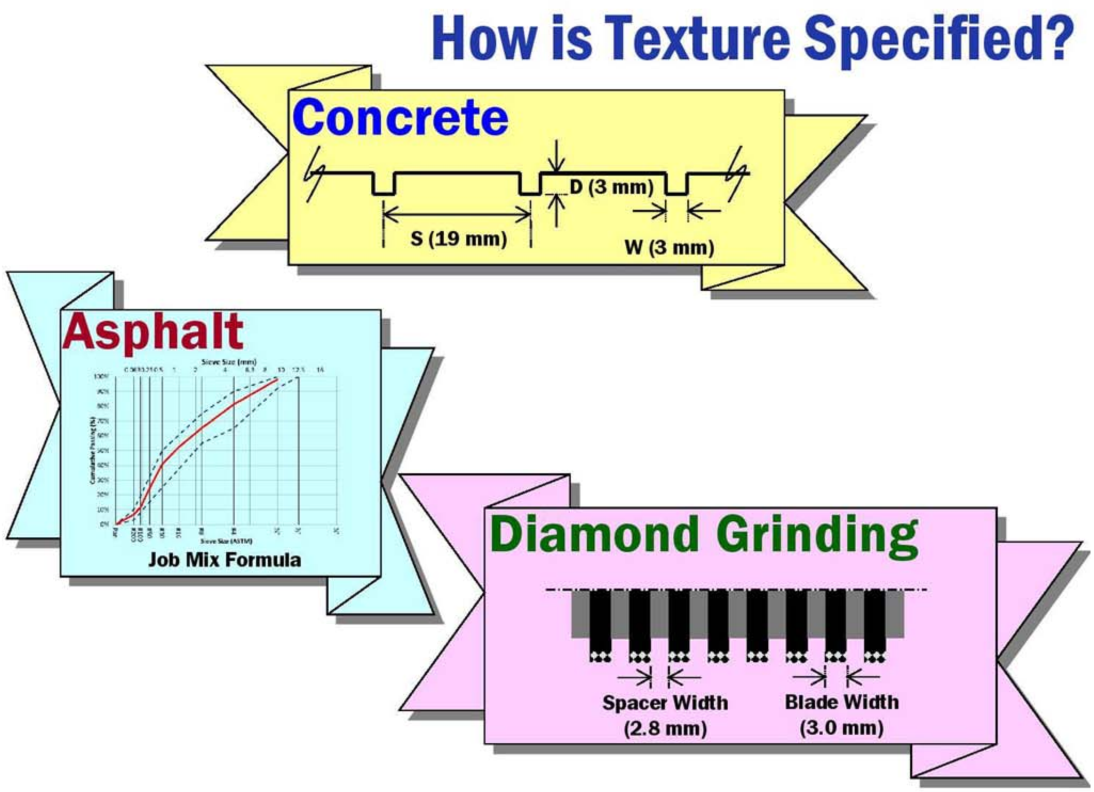
Fundamentals of Pavement Texture Measurement and Interpretation

ROBERT OTTO RASMUSSEN
The Transtec Group

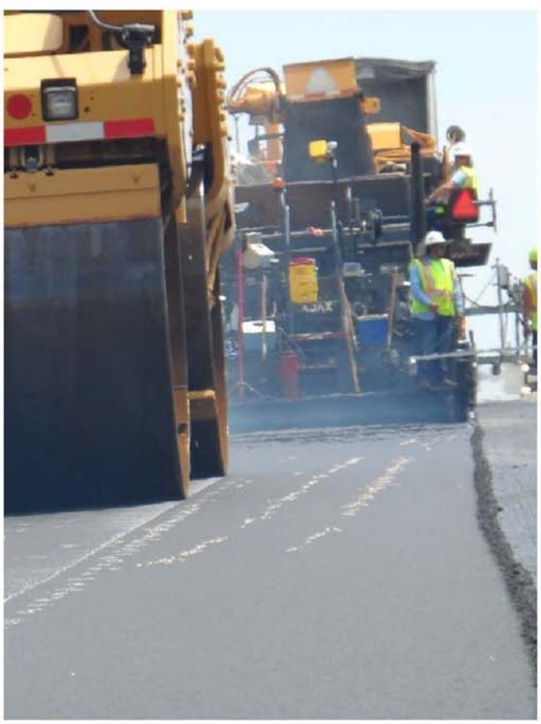


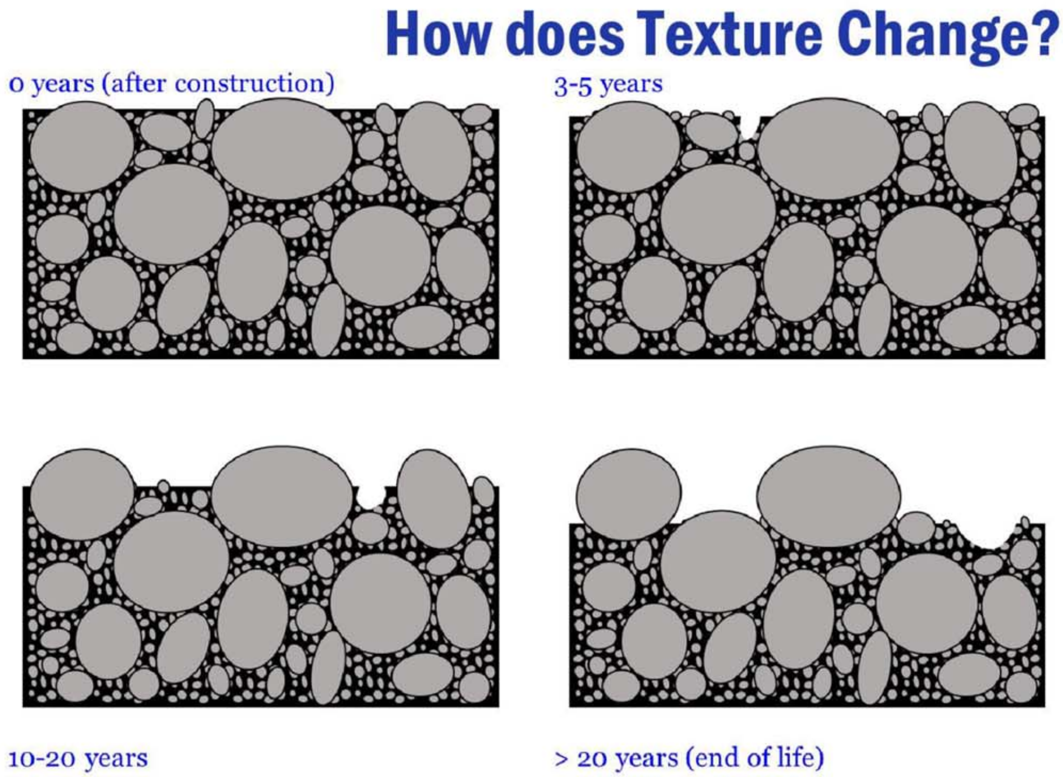

Why is Texture Important?
Texture Wavelength
0.1 mil
1 mil
10 mil
1/8 in.
1 in.
1 ft.
10 ft.
100 ft.
1 μm
10 μm
100 μm
1 mm
10 mm
100 mm
1 m
10 m
100 m
PIARC Category
Microtexture
Macrotexture
Megatexture
Roughness
Pavement Surface Characteristic (PSC) Influence
Rolling Resistance
Ride Quality
Wet Friction
Dry Friction
Splash and Spray
Tire Wear
Vehicle Wear
In-Vehicle Noise
Tire-Pavement Noise
Key:
Good
Bad
Source: PIARC

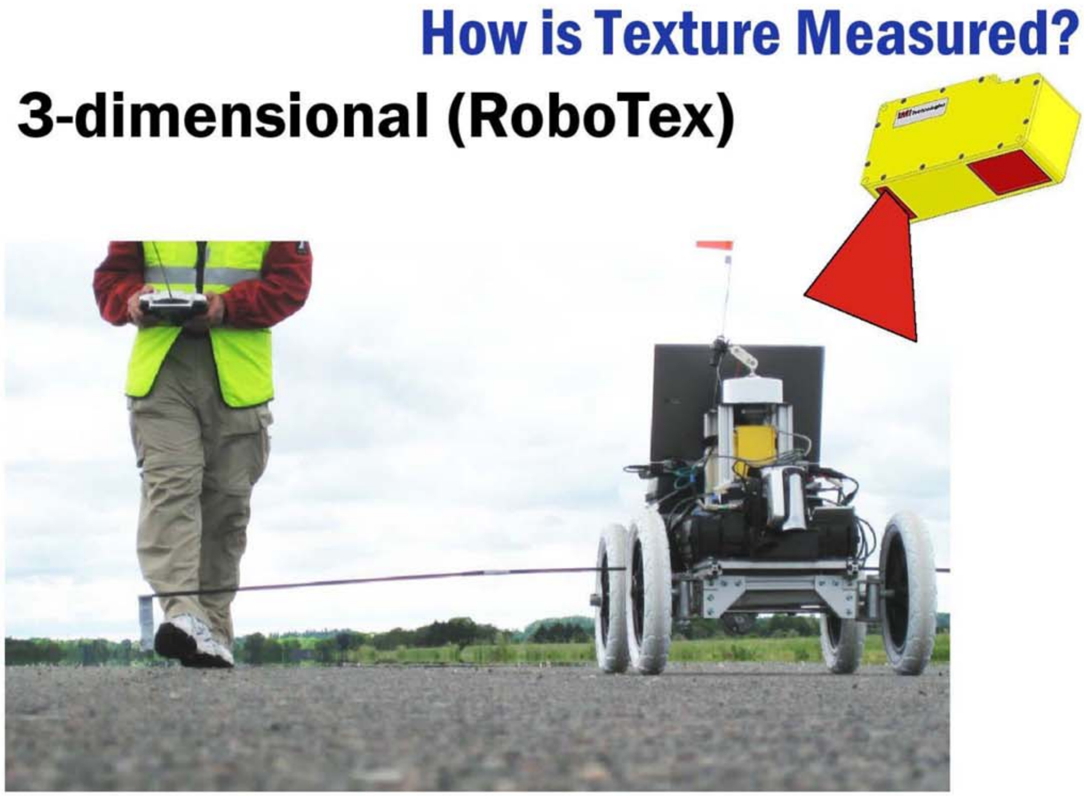

How is Texture Specified?
Concrete
D (3 mm)
S (19 mm)
W (3 mm)
Asphalt
Job Mix Formula
Diamond Grinding
Spacer Width
(2.8 mm)
Blade Width
(3.0 mm)

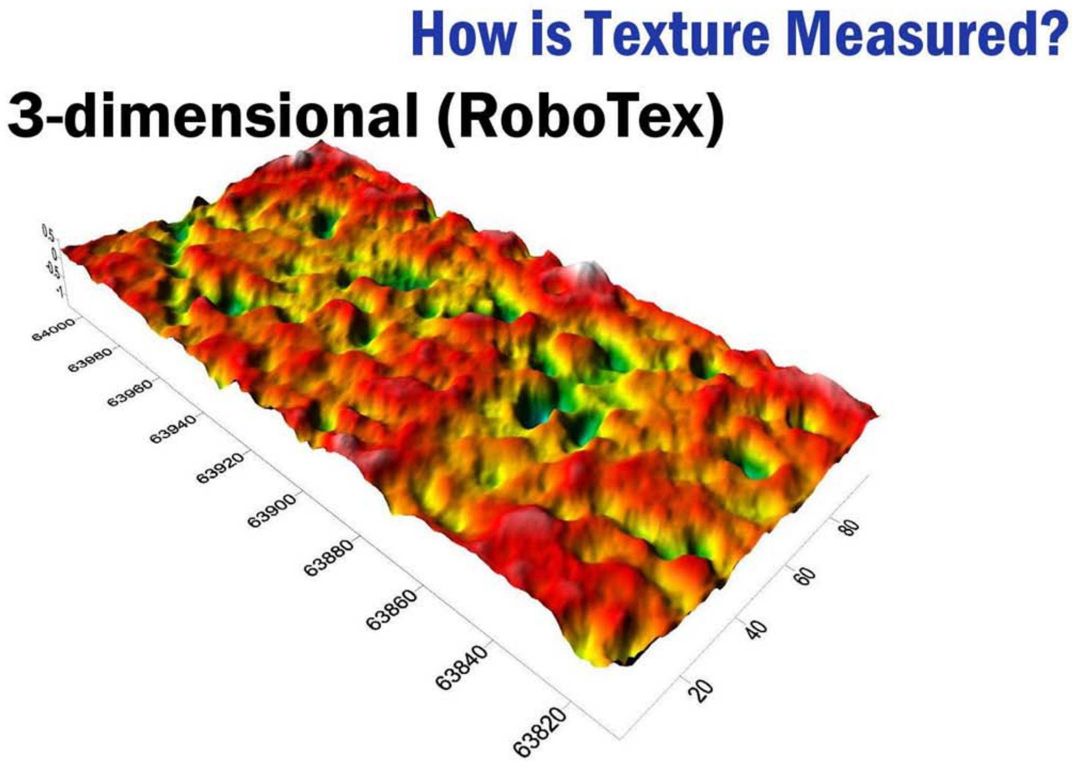
How is Texture Constructed?

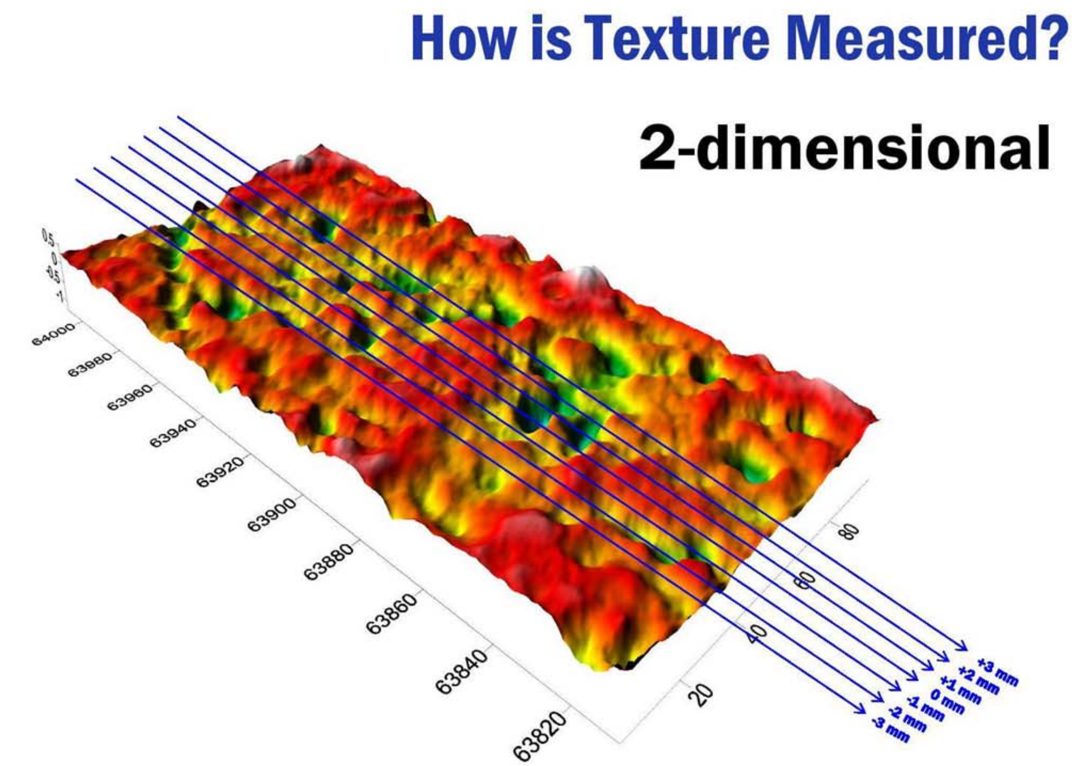
How is Texture Constructed?

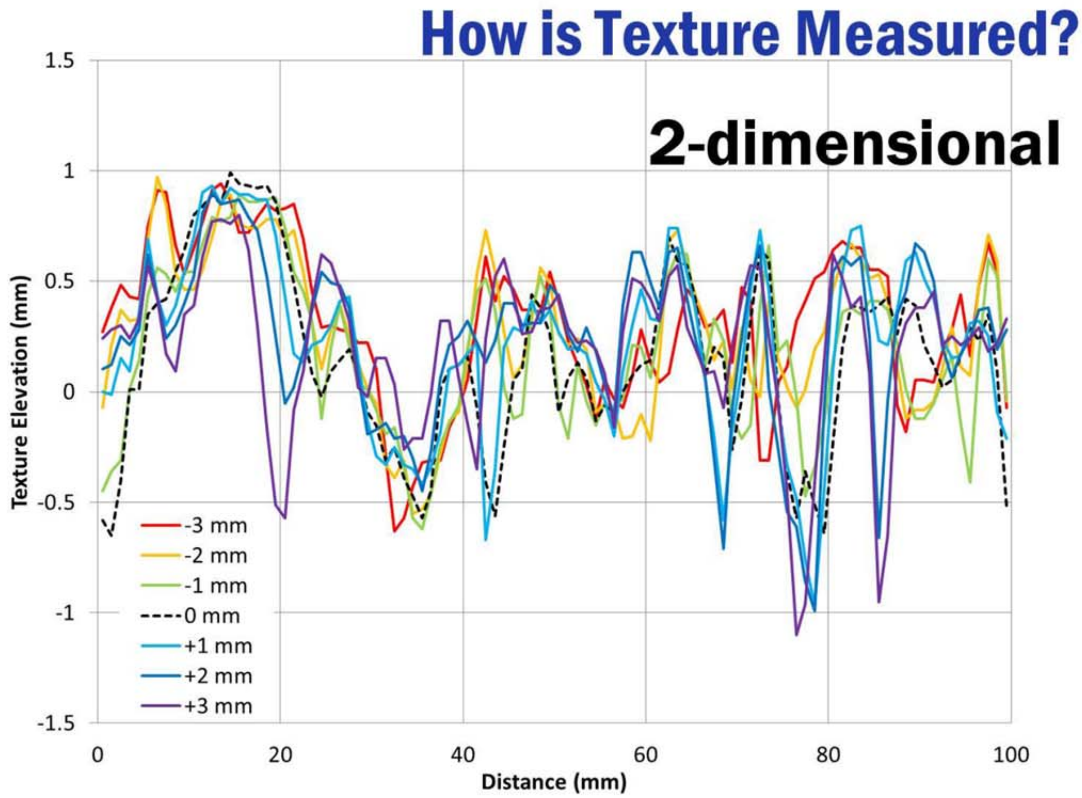


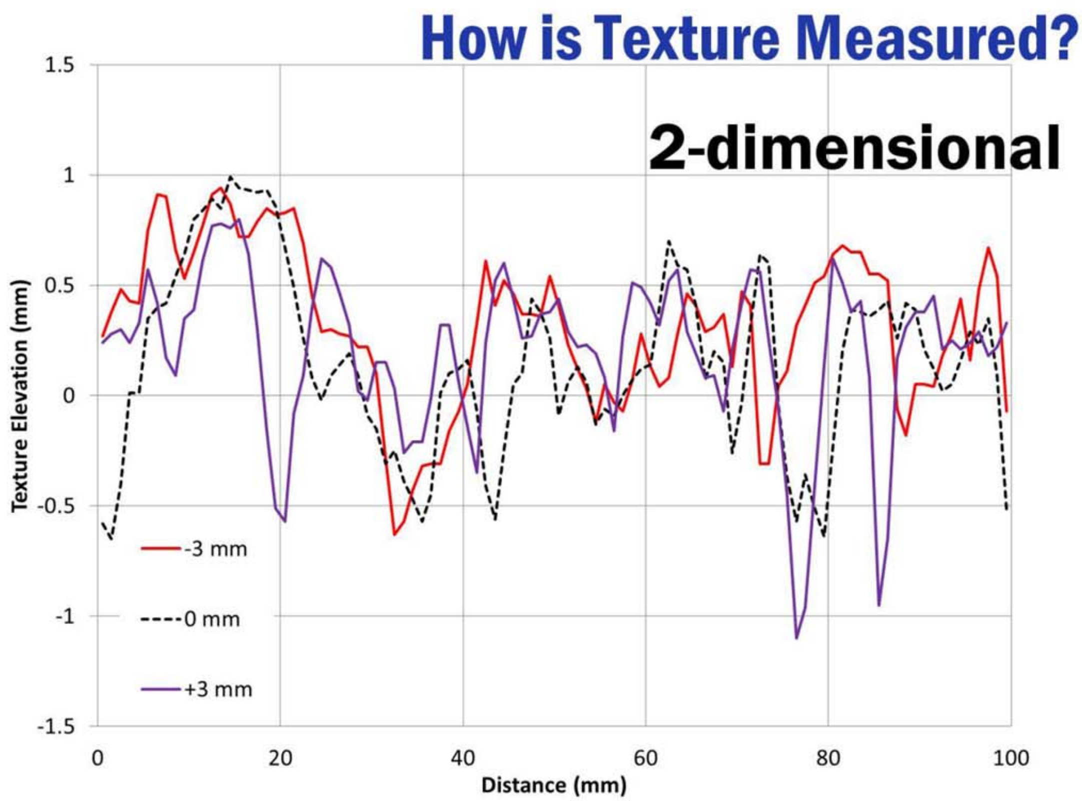

How does Texture Change?
0 years (after construction)
3-5 years
10-20 years
> 20 years (end of life)


How is Texture Measured?
3-dimensional (RoboTex)


How is Texture Measured?
3-dimensional (RoboTex)
0.5
0
-0.5
-1
64000
63980
63960
63940
63920
63900
63880
63860
63840
63820
20
40
60
80


How is Texture Measured?
2-dimensional
0.5
0
-0.5
-1
64000
63980
63960
63940
63920
63900
63880
63860
63840
63820
20
40
60
80
+3 mm
+2 mm
+1 mm
0 mm
-1 mm
-2 mm
-3 mm


How is Texture Measured?
2-dimensional
Texture Elevation (mm)
Distance (mm)
-3 mm
-2 mm
-1 mm
0 mm
+1 mm
+2 mm
+3 mm
1.5
1
0.5
0
-0.5
-1
-1.5
0
20
40
60
80
100

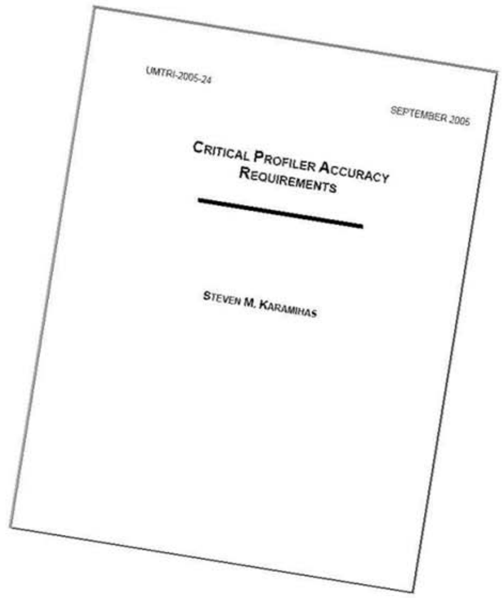

How is Texture Measured?
2-dimensional
Texture Elevation (mm)
Distance (mm)
-3 mm
0 mm
+3 mm
1.5
1
0.5
0
-0.5
-1
-1.5
0
20
40
60
80
100

How is Texture Evaluated?

- Texture "frequency"
- Texture "depth"
- Texture "geometry"

RELEVANCE is key !!

- Tire dynamics
- Drainage
- Aerodynamic


UMTRI-2005-24

SEPTEMBER 2005

CRITICAL PROFILER ACCURACY REQUIREMENTS

STEVEN M. KARAMIHAS

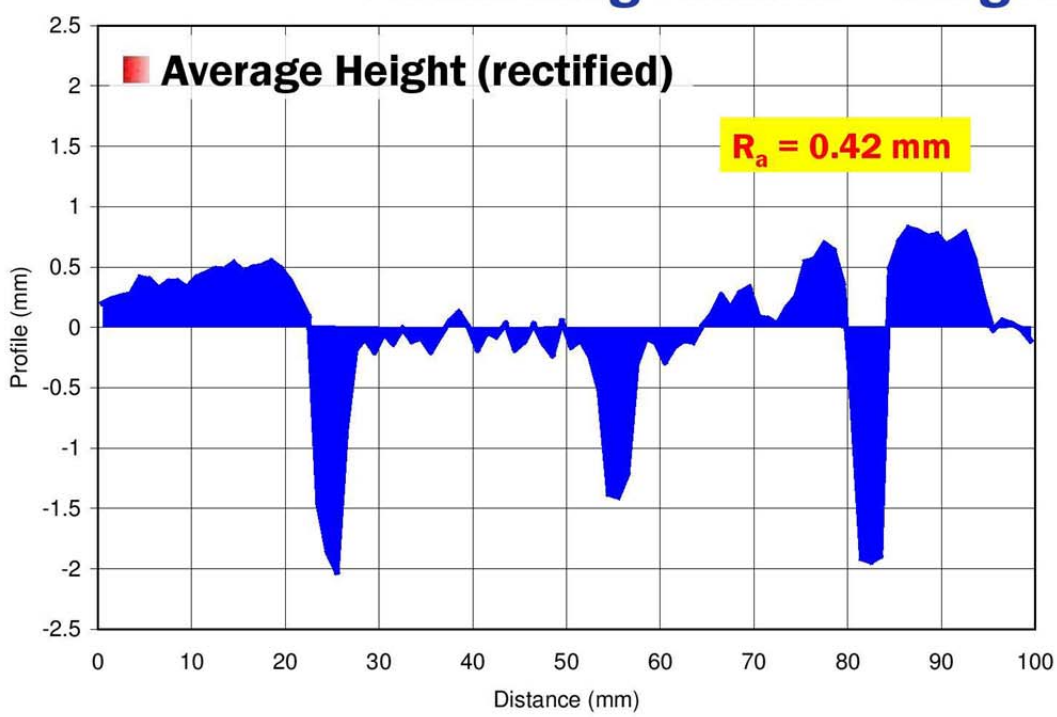
Describing Texture

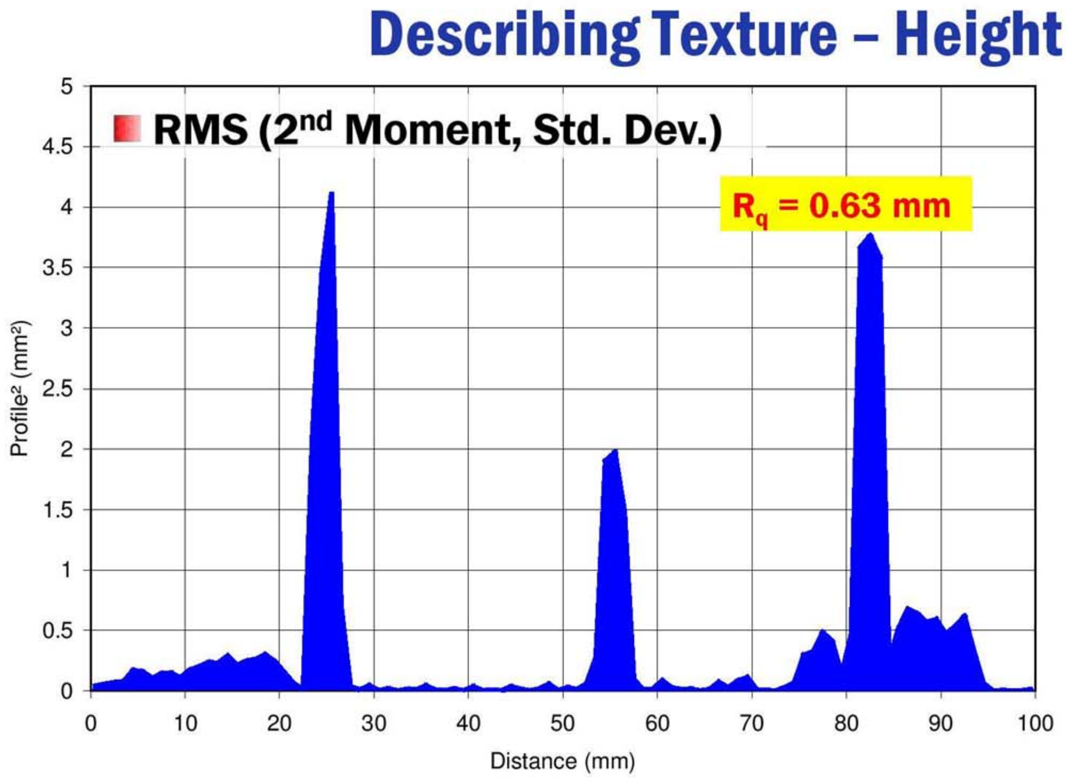
- Height (Amplitude)
- Spacing
- Spectral
- Functional

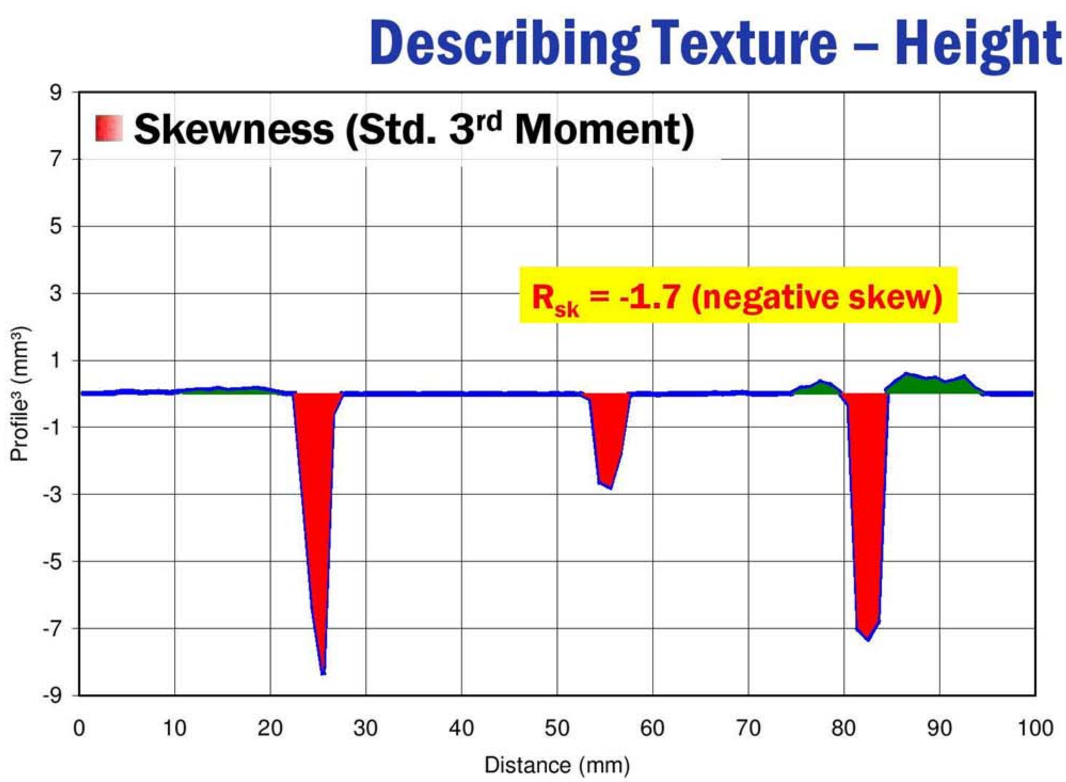
Describing Texture

- **Height (Amplitude)**
- Spacing
- Spectral
- Functional

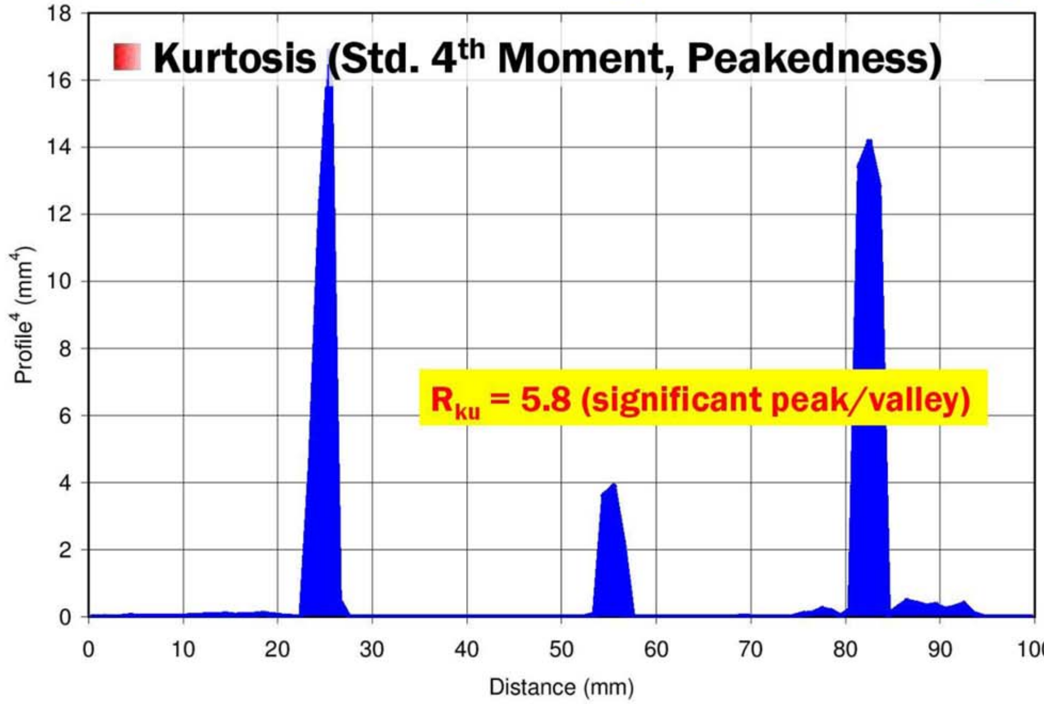
Describing Texture – Height



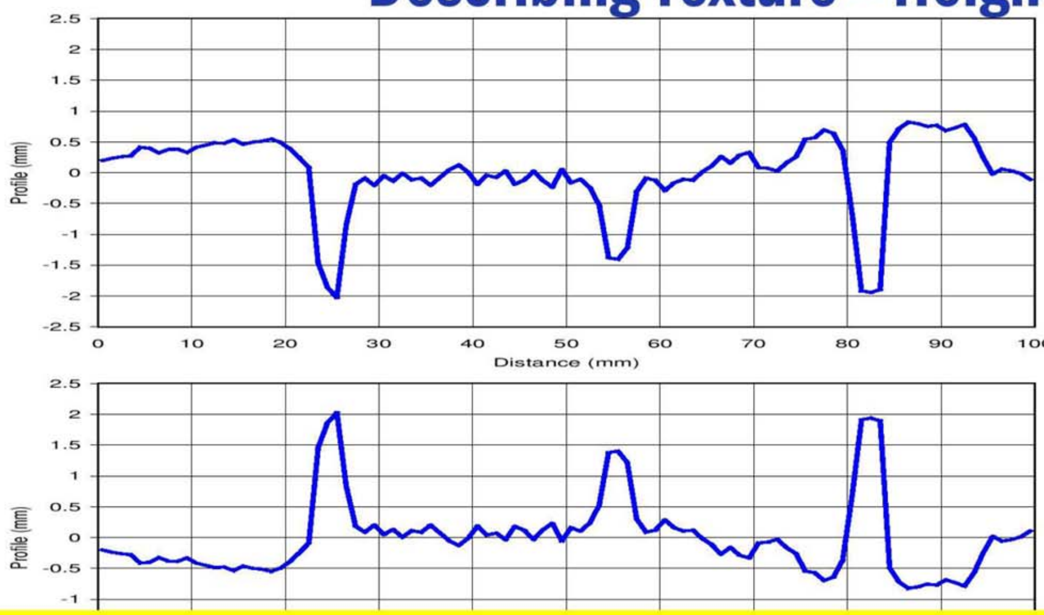

Describing Texture – Height
RMS (2nd Moment, Std. Dev.)
Rq = 0.63 mm
Profile² (mm²)
Distance (mm)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
10
20
30
40
50
60
70
80
90
100


Describing Texture – Height
Skewness (Std. 3rd Moment)
Rsk = -1.7 (negative skew)
Profile³ (mm³)
Distance (mm)
9
7
5
3
1
-1
-3
-5
-7
-9
0
10
20
30
40
50
60
70
80
90
100

Describing Texture – Height

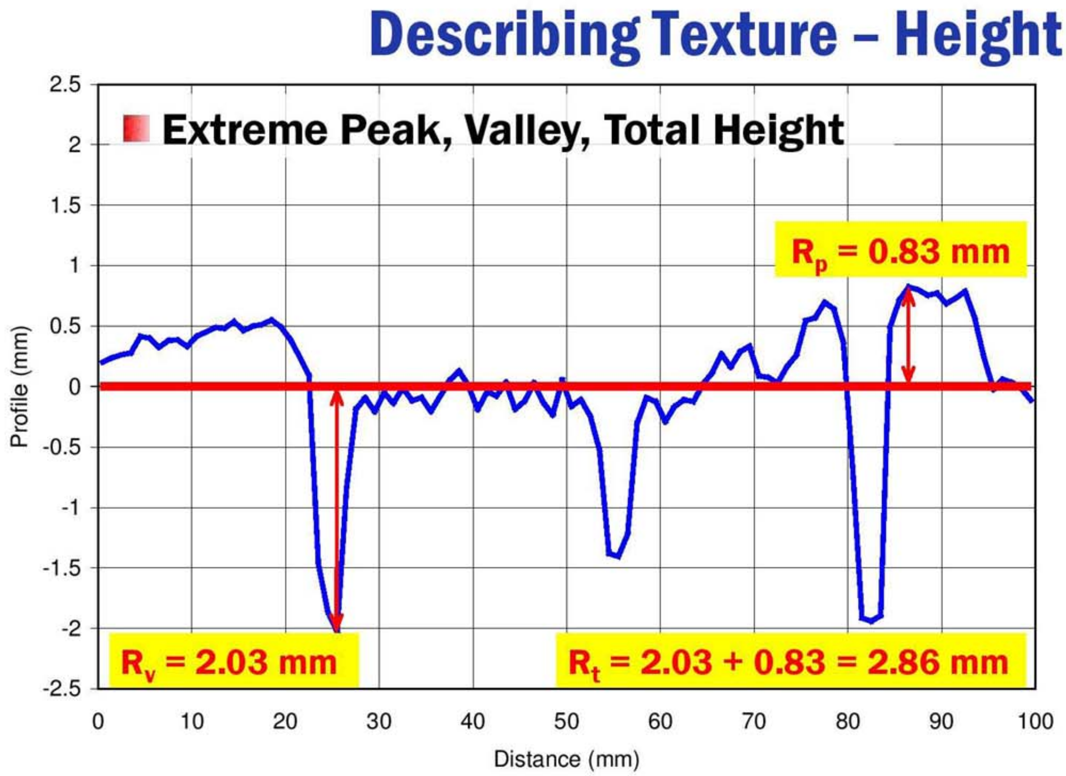


Describing Texture – Height

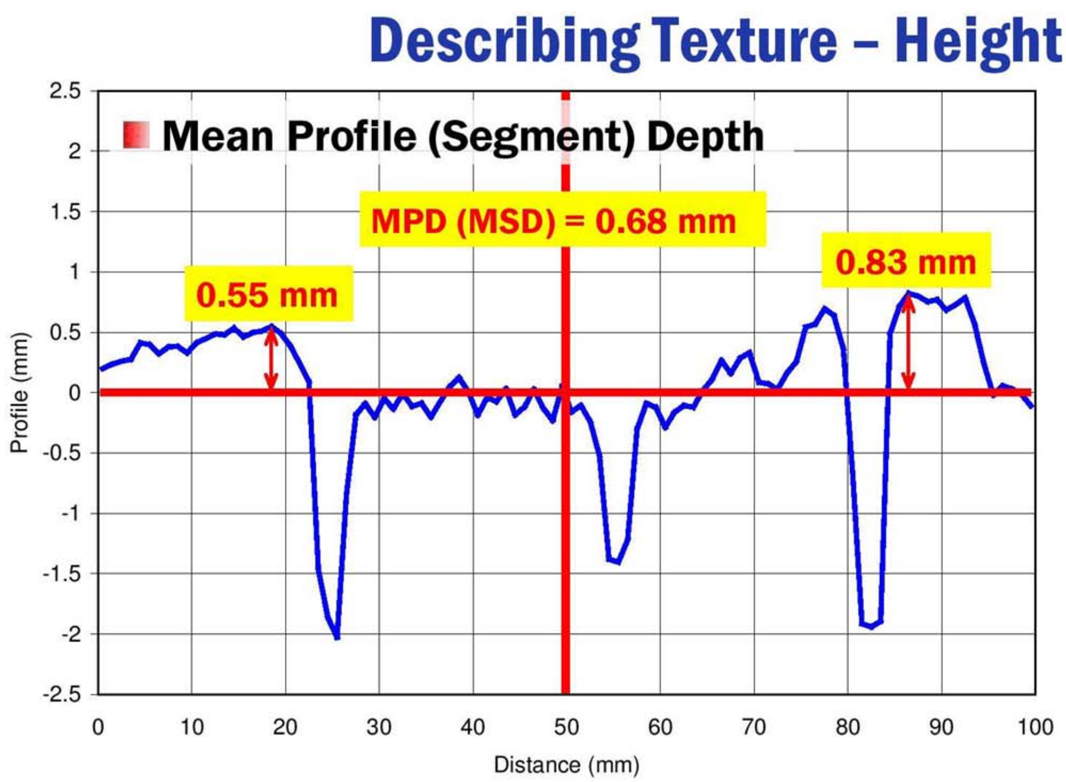


Same Average Height, RMS, Kurtosis, but...

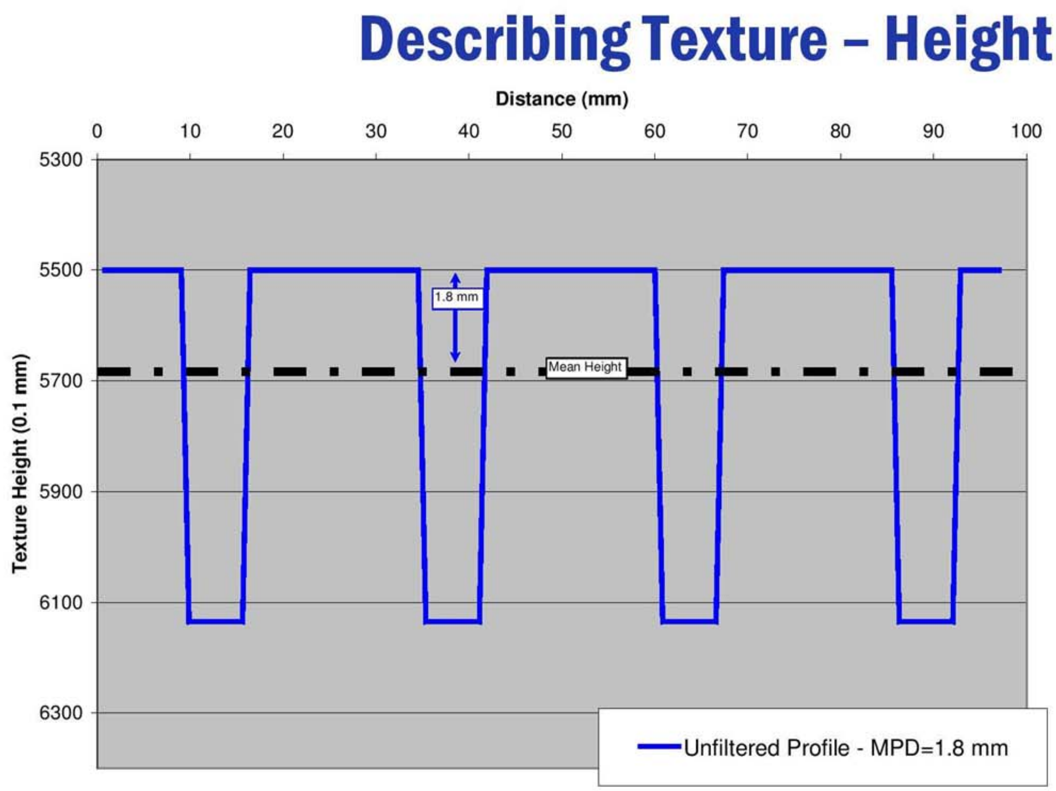
Skewness is opposite sign.

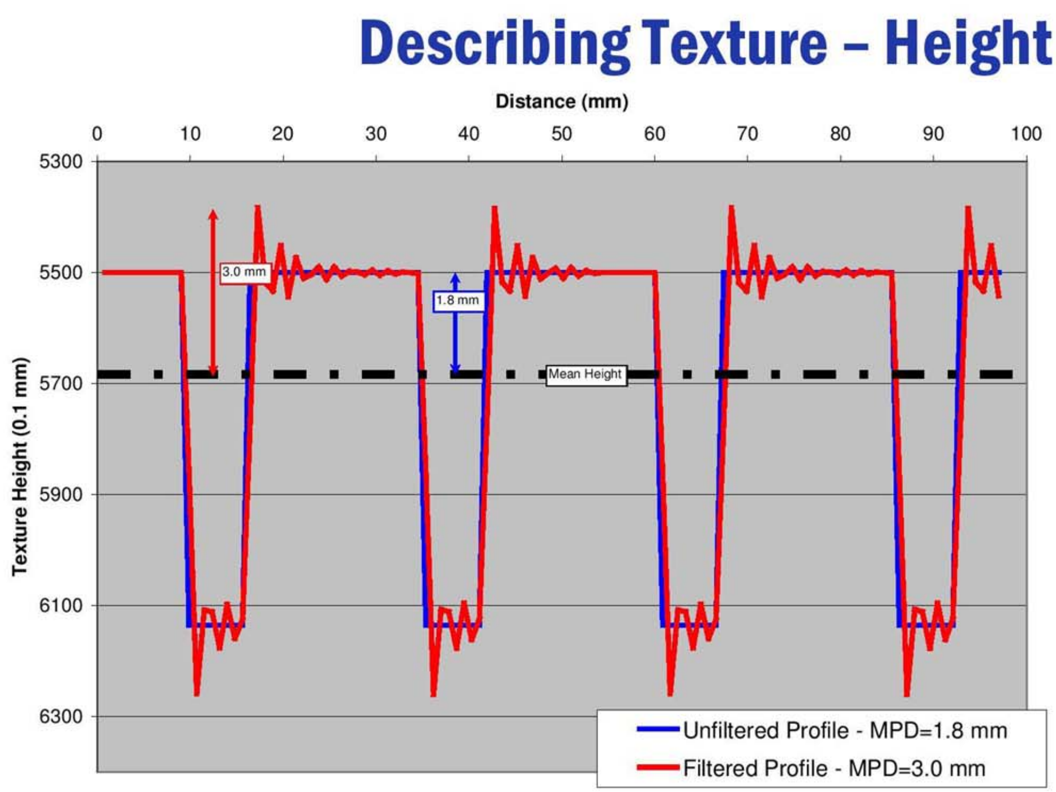


Describing Texture – Height
Extreme Peak, Valley, Total Height
R_p = 0.83 mm
R_v = 2.03 mm
R_t = 2.03 + 0.83 = 2.86 mm
Profile (mm)
Distance (mm)



Describing Texture – Height
Mean Profile (Segment) Depth
MPD (MSD) = 0.68 mm
0.55 mm
0.83 mm
Profile (mm)
Distance (mm)


Describing Texture – Height
Distance (mm)
0
10
20
30
40
50
60
70
80
90
100
Texture Height (0.1 mm)
5300
5500
5700
5900
6100
6300
1.8 mm
Mean Height
Unfiltered Profile - MPD=1.8 mm


Describing Texture – Height
Distance (mm)
0
10
20
30
40
50
60
70
80
90
100
Texture Height (0.1 mm)
5300
5500
5700
5900
6100
6300
3.0 mm
1.8 mm
Mean Height
Unfiltered Profile - MPD=1.8 mm
Filtered Profile - MPD=3.0 mm

Describing Texture – Height

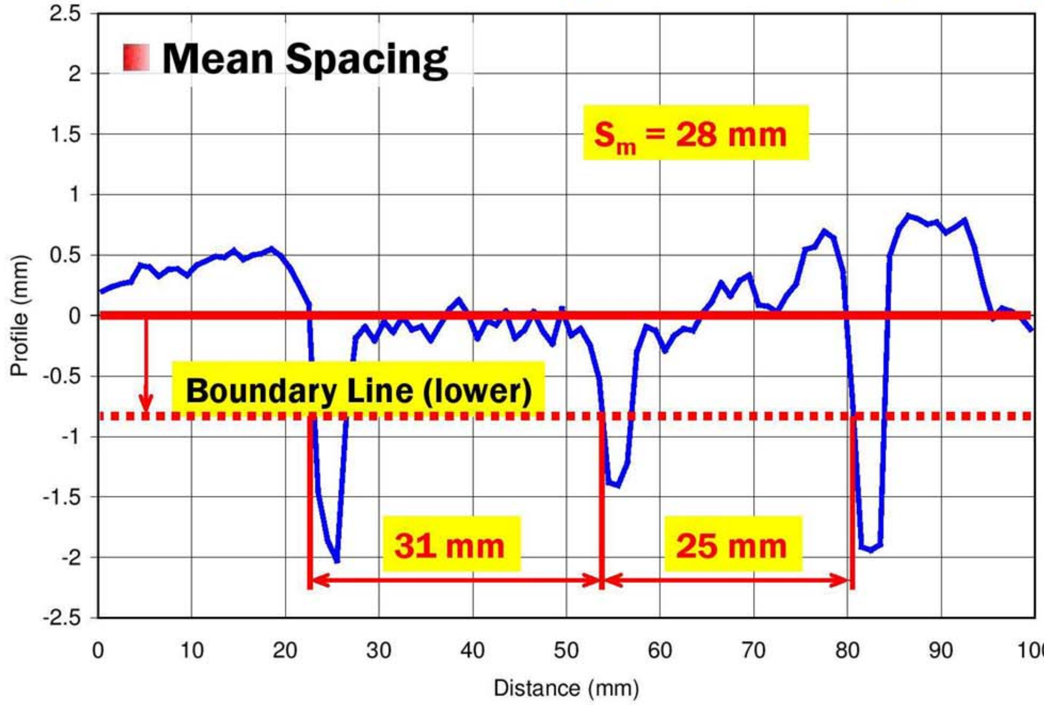
Skewness, Kurtosis, and MPD are sensitive to "extreme" peaks...

...both real or artifacts from the measurement or analysis.

Describing Texture

- ❑ Height (Amplitude)
- ■ **Spacing**
- ❑ Spectral
- ❑ Functional

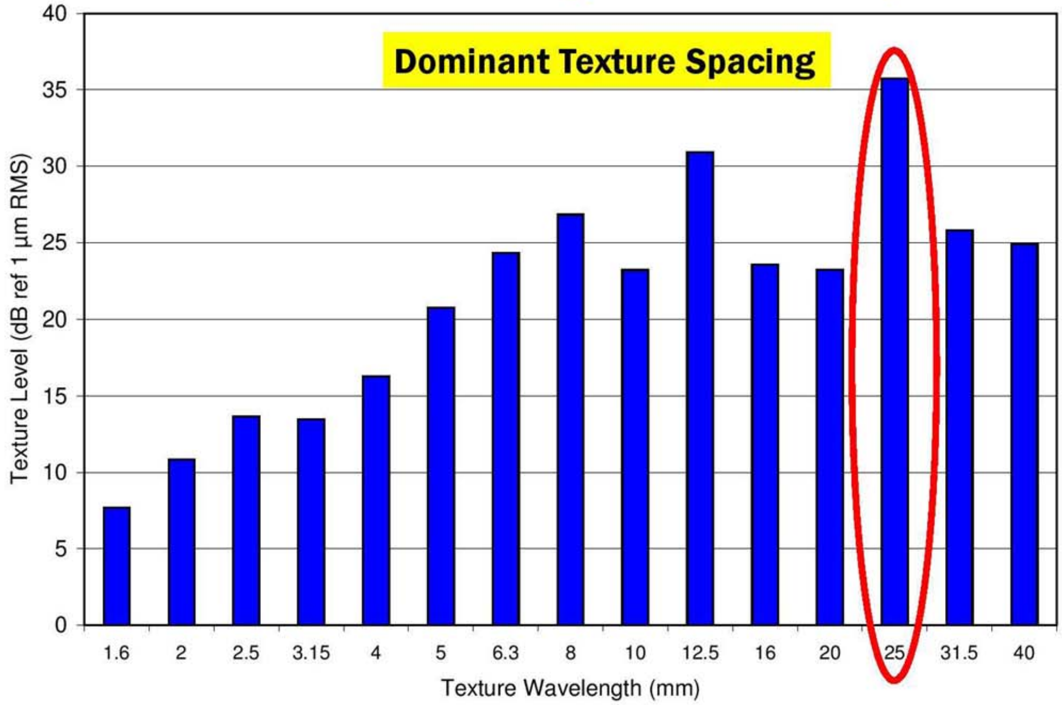
Describing Texture – Spacing



Describing Texture

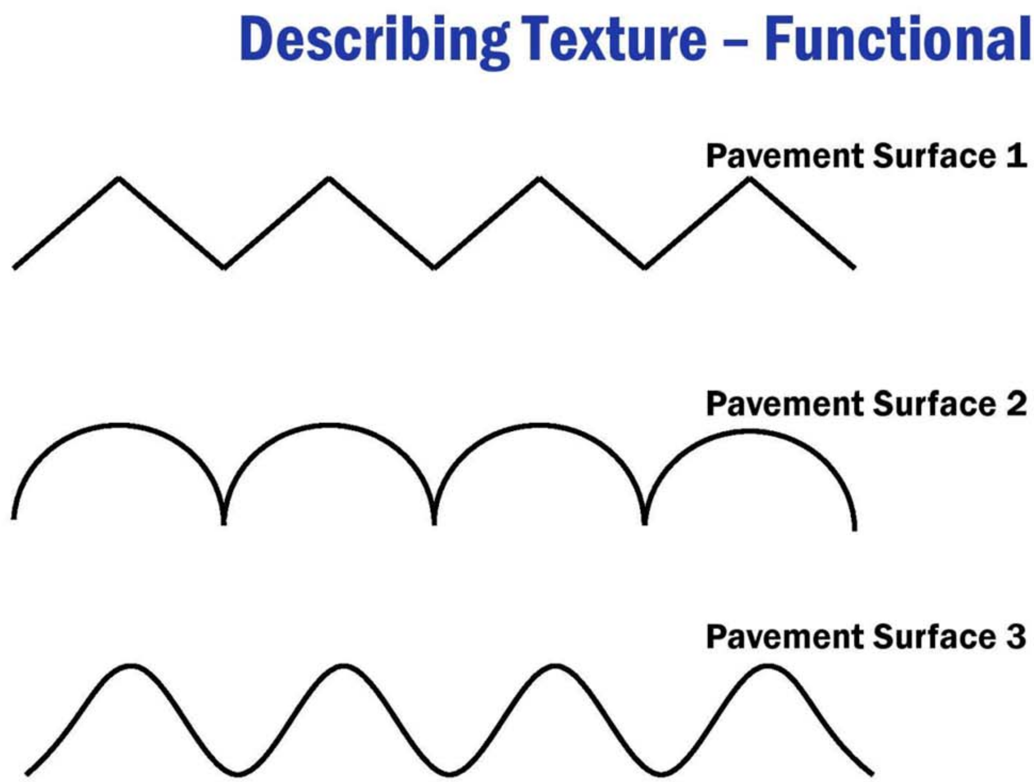
- ❑ Height (Amplitude)
- ❑ Spacing
- **Spectral**
- ❑ Functional

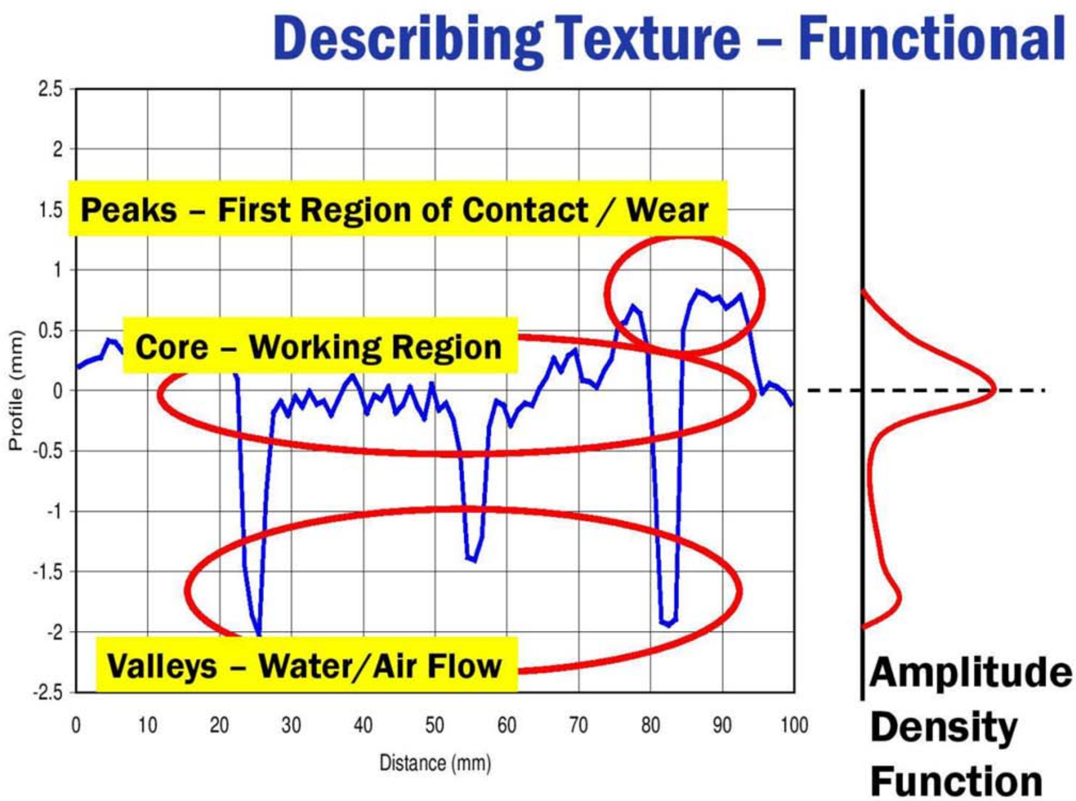
Describing Texture – Spectral

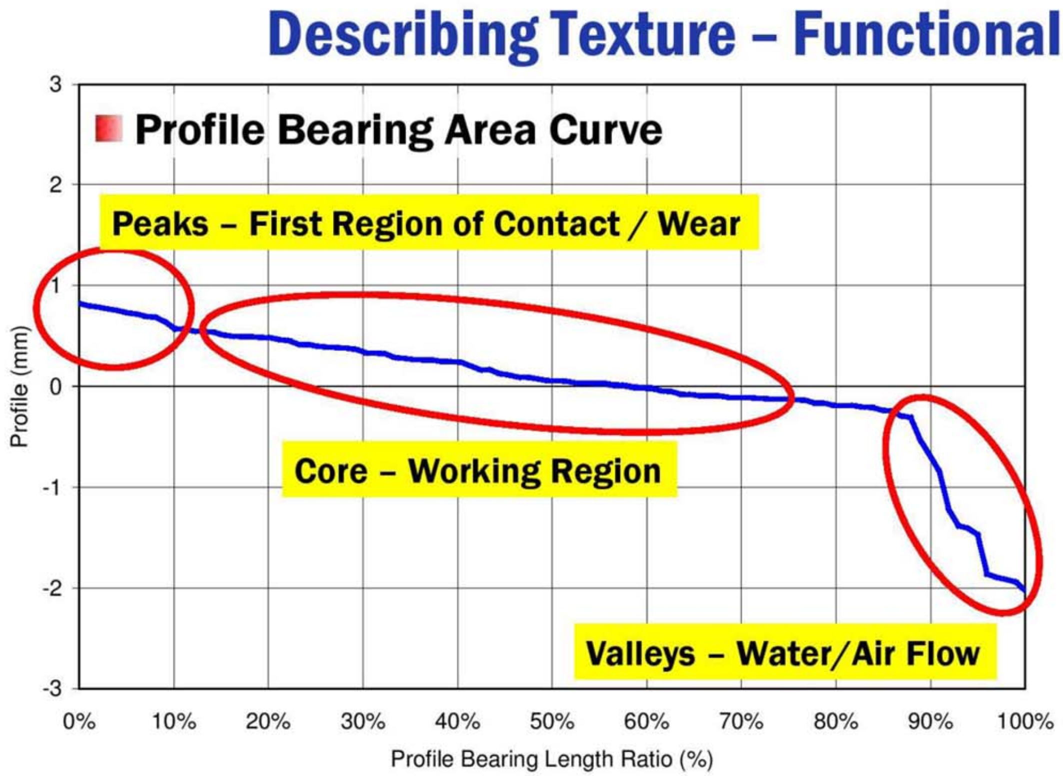


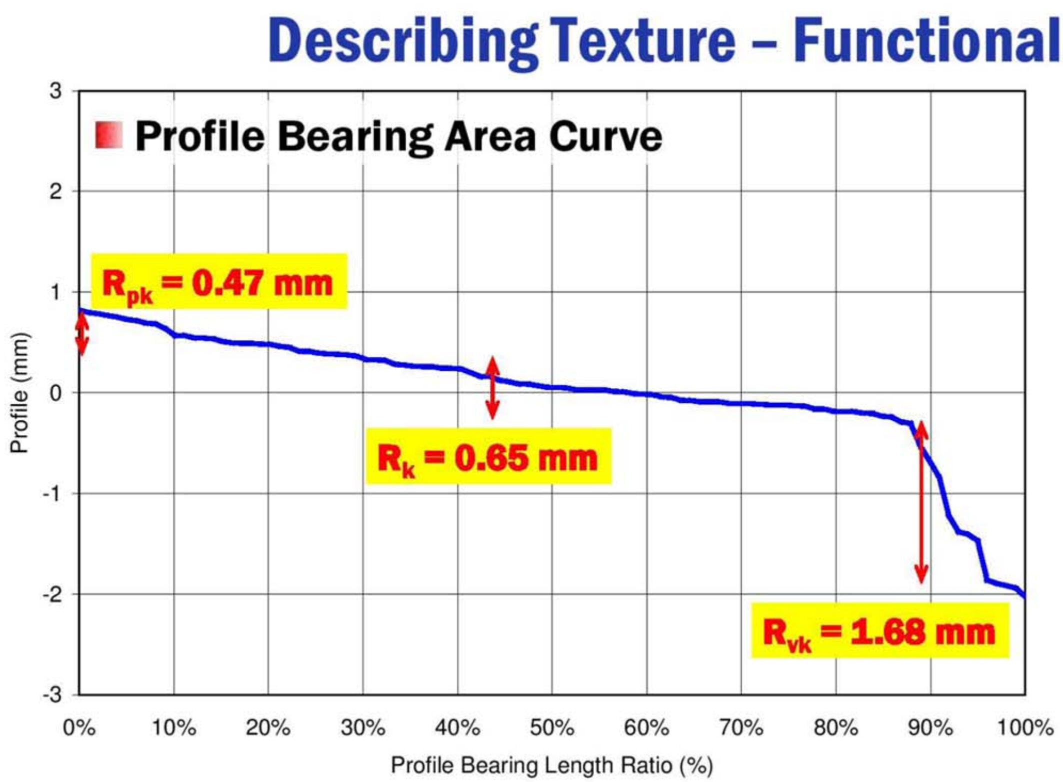
Describing Texture

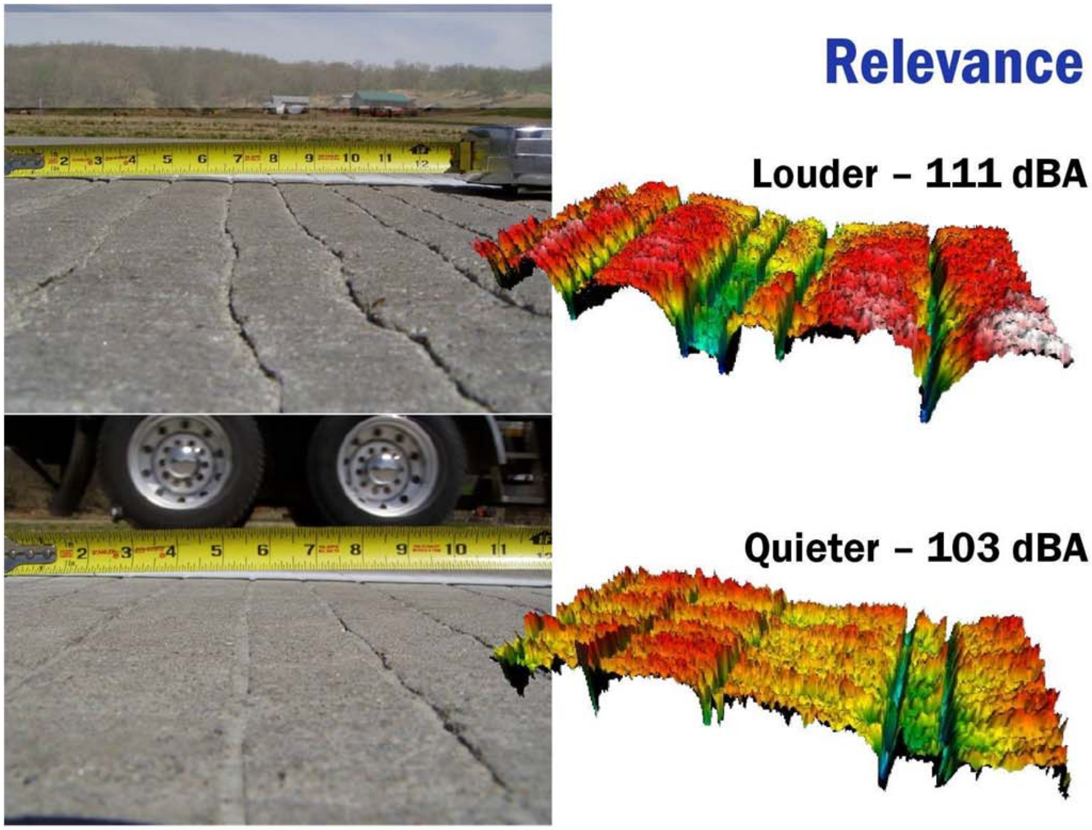
- Height (Amplitude)
- Spacing
- Spectral
- **Functional**

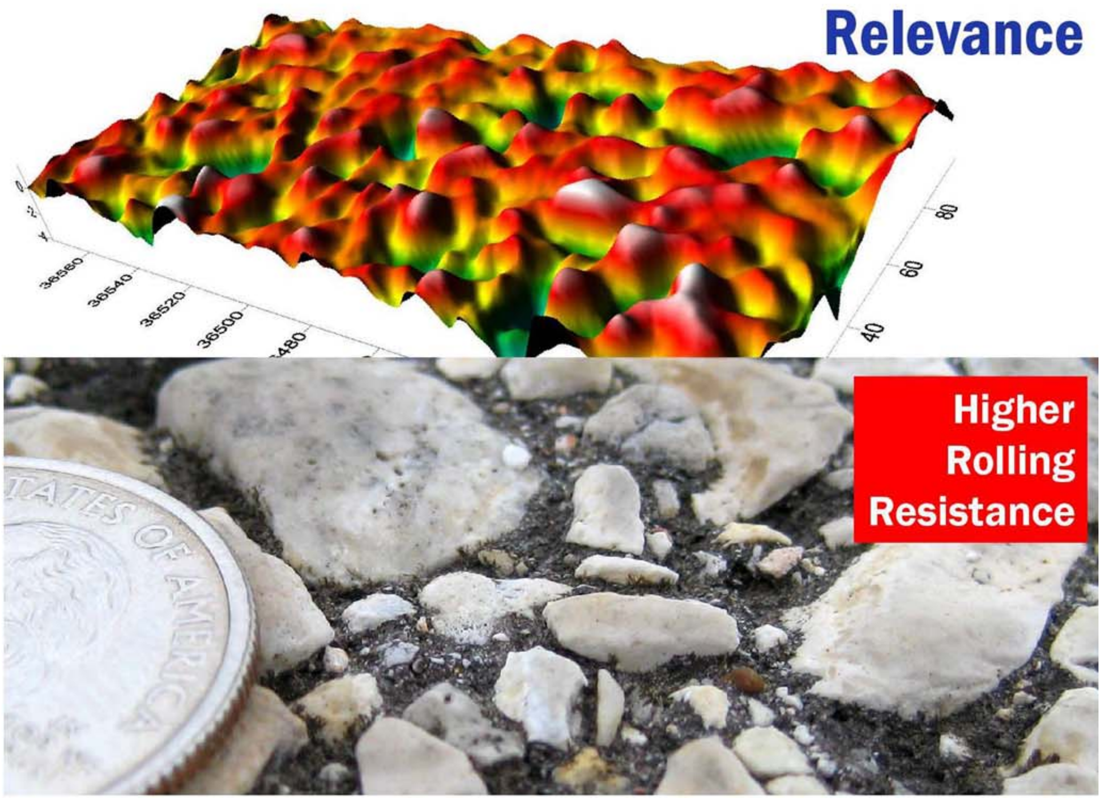

Describing Texture – Functional
Pavement Surface 1
Pavement Surface 2
Pavement Surface 3

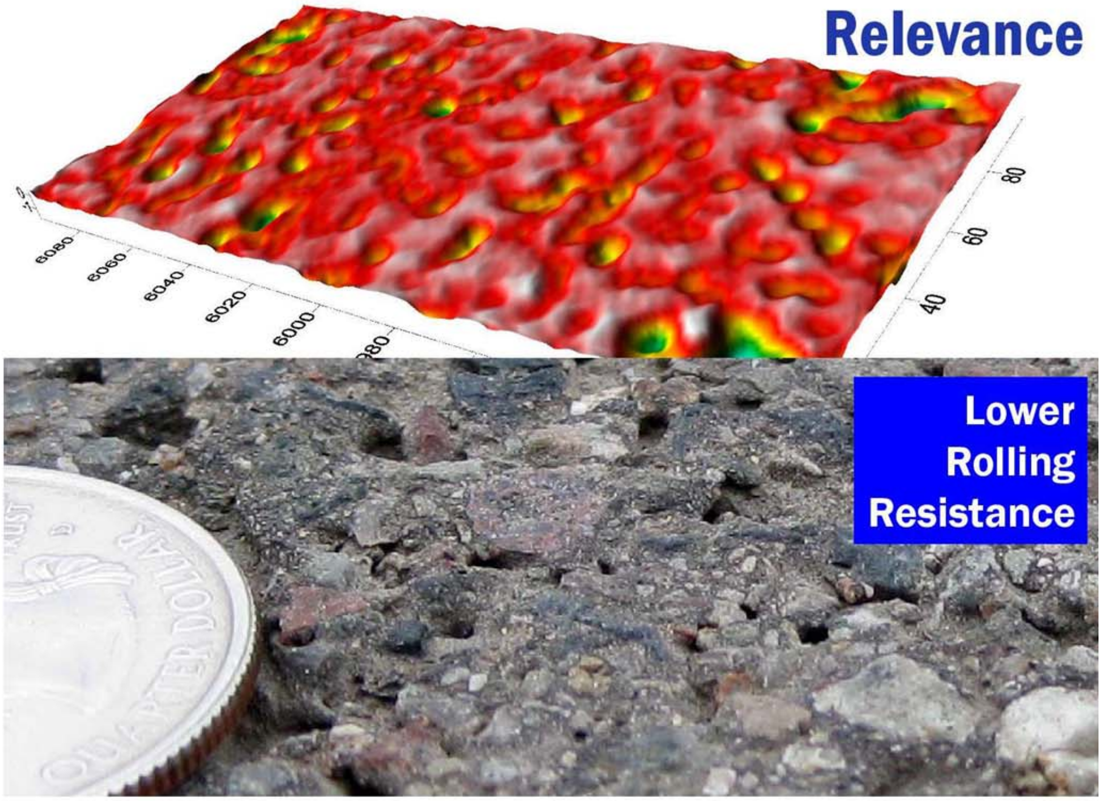

Describing Texture – Functional
Peaks – First Region of Contact / Wear
Core – Working Region
Valleys – Water/Air Flow
Profile (mm)
Distance (mm)
Amplitude Density Function


Describing Texture – Functional
Profile Bearing Area Curve
Peaks – First Region of Contact / Wear
Core – Working Region
Valleys – Water/Air Flow
Profile (mm)
3
2
1
0
-1
-2
-3
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Profile Bearing Length Ratio (%)

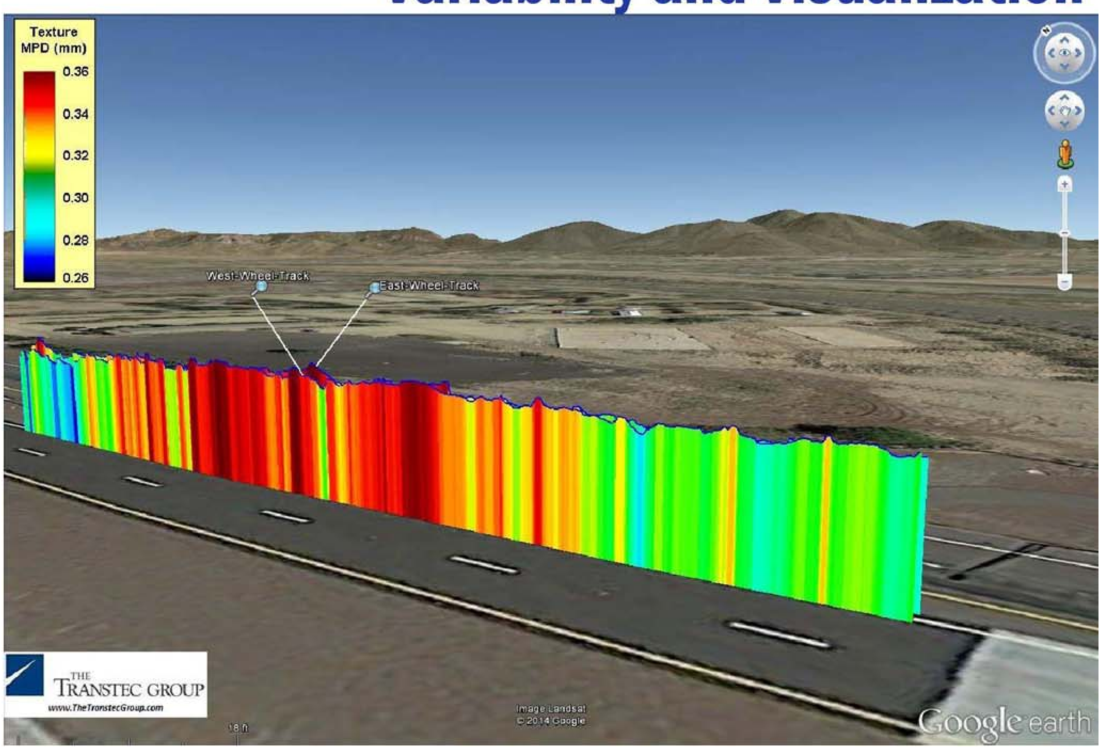

Describing Texture – Functional
Profile Bearing Area Curve
R_{pk} = 0.47 mm
R_k = 0.65 mm
R_{vk} = 1.68 mm
Profile (mm)
3
2
1
0
-1
-2
-3
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Profile Bearing Length Ratio (%)


Relevance
Louder – 111 dBA
Quieter – 103 dBA


Relevance
36560
36540
36520
36500
80
60
40
Higher Rolling Resistance



Variability and Visualization



Some Closing Thoughts

- Limitations of "peak" metrics
  - Limited relevance (by themselves)
  - Measurement and filtering artifacts
- 3-D versus 2-D textures
  - Improved relevance
  - "3-D" metrics
- Tire envelopment filtering
  - Improved relevance
  - Tire penetration (force, displacement)
  - Void space below tire
- Challenges
  - Measurement of porous or deep textures, glossy surfaces
  - Calibration and validation of texture measurements

Thank You !

THE TRANSTEC GROUP
The World's Pavement Engineering Specialists

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UK Experiences on Pavement Texture Measurement and Interpretation

BRIAN FERNE
Transport Research Laboratory

To maintain safe roads we need to provide adequate friction on pavement surfaces, particularly in wet conditions. Therefore, we need to be able to measure or predict the skid resistance under standardized conditions. In the 1930s, TRL—then the Road Research Laboratory—started the development of a technique to measure skid resistance under slow-speed slip conditions using a freely rotating wheel set at an angle to the direction of travel (Slide 3).

The first version used the wheel of a motorcycle sidecar. Several versions followed using a variety of passenger cars but the current version called SCRIM (sideways coefficient routine investigation machine) is based on a lorry chassis with a smooth-tired instrumented fifth wheel to measure slow-speed friction with a tank to supply a controlled flow of water (Slide 4). This tool has been used since the late 1980s for routine measurement of skid resistance; SCRIM currently covers the whole of the English Strategic Road Network annually.

However, as the speed of traffic increased over the years it was realized that knowledge of the wet friction was required at a greater range of speeds than could be provided by just an angled wheel device, effectively measuring low-speed skid resistance at a slip speed of around 17 km/h. Thus other devices were developed to measure high-speed friction directly (Slide 5). These high-speed measurements started with a fifth wheel braking force trailer towed by a XK120 Jaguar in the 1950s. Most recently these measurements are achieved with a Pavement Friction Tester that was acquired by TRL from K. J. Law from the United States in the 1990s on behalf of the English Highways Agency and this still used for substantial research programs and specialist investigations.

However, the continuous measurement provided by SCRIM is preferred for routine application.

The results from measurements with these machines suggested that high-speed wet friction was heavily dependent on the macrotexture on the surface of the pavement. Initially this was measured statically using the sand patch test but it was soon realized and that an estimate of this could be obtained at traffic speed using a noncontact method based on lasers with our first prototype developed in the early 1970s. This texture depth parameter is now routinely collected over most of the UK road network by a fleet of multifunction road surface monitoring vehicles under the TRACS and SCANNER contracts (Slide 6).

SLIDE 1

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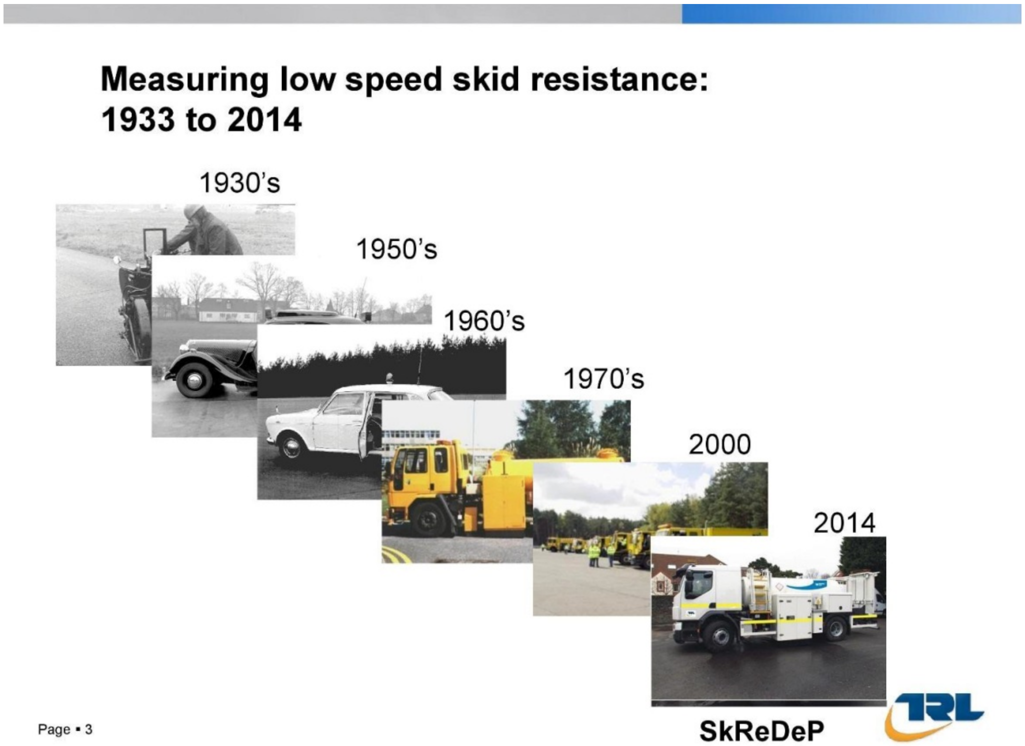
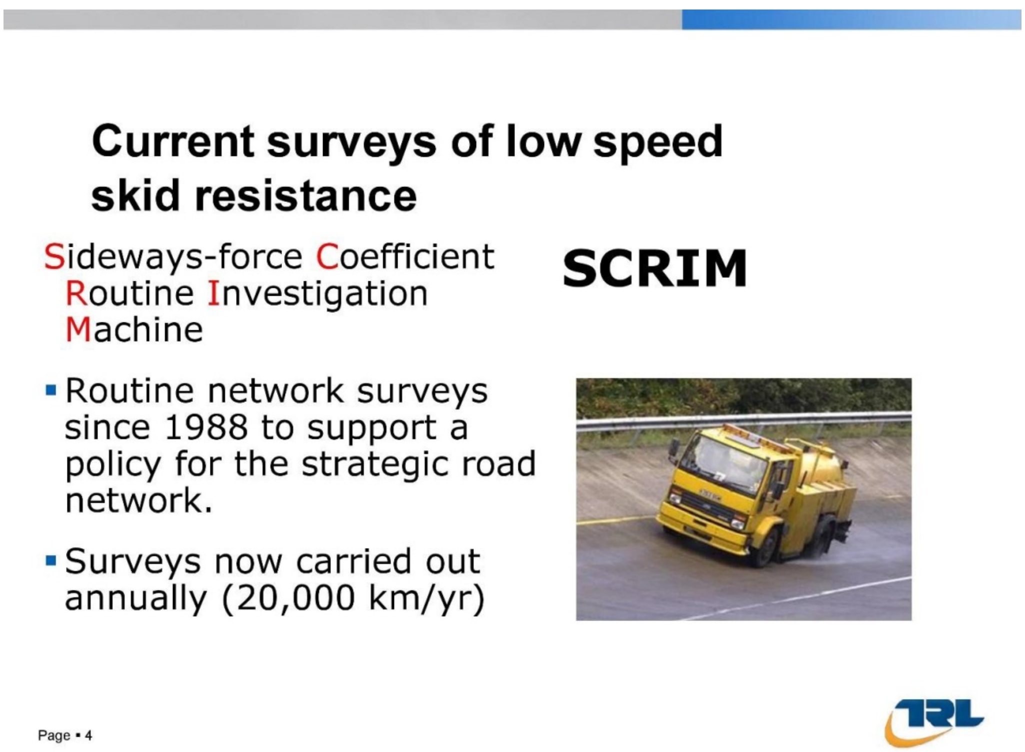
SLIDE 2

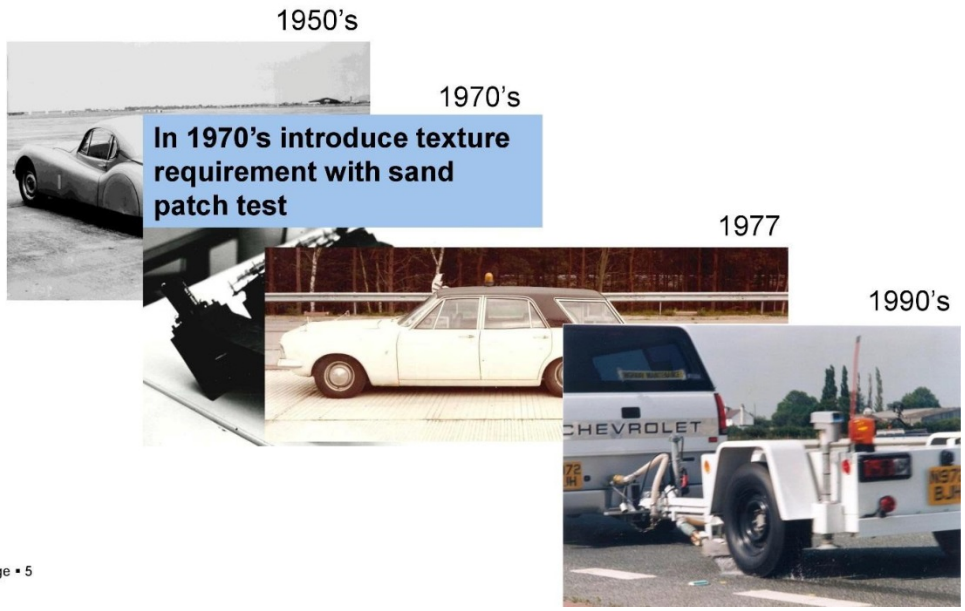


SLIDE 3



SLIDE 4

Measuring high speed friction



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SLIDE 5

Traffic speed (surface) condition surveys – UK contracts

- **TRACS – TRAffic speed Condition Surveys - HA**
  - Approximately 41,000km / year
- **SCANNER - Surface Condition Assessment of the National NEtwork of Roads - the DfT version of TRACS**
  - English and Scottish Local Road Network
  - Approximately 110,000km / year

Measuring:

- Transverse profile (rut depth)
- Longitudinal profile–variance (ride quality)
- "Bump" measure
- Texture depth
- Surface Deterioration
- Lane fretting
- Geometry – curvature and gradient
- Forward facing images
- Downward facing images
- Location

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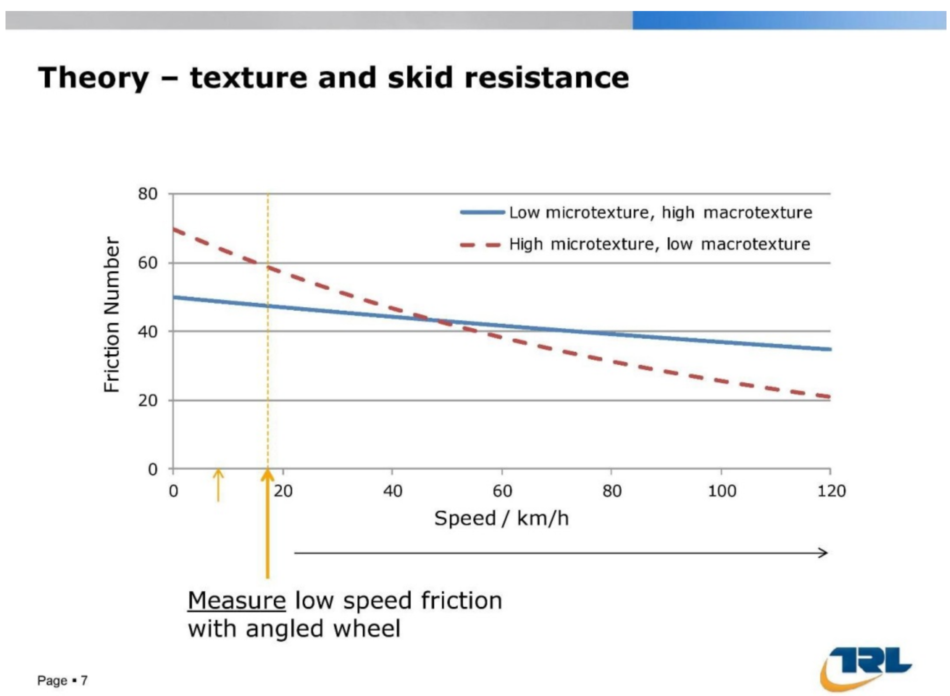
SLIDE 6

TRACS (Traffic Speed Condition Surveys) is the annual Highways England contract for the collection of surface condition information. SCANNER (Surface Condition Assessment of the National Network of Roads) is the equivalent contact for the English and Scottish local road network.

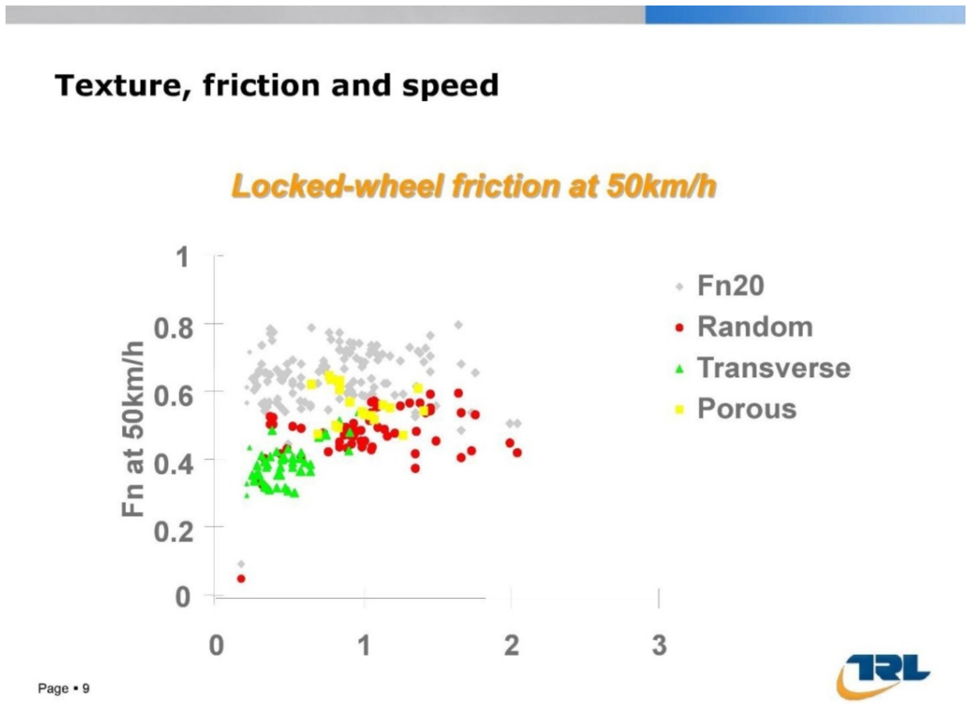
This interaction between friction and vehicle speed is best understood by examining their relationship for two extreme pavement surfaces, one with low microtexture and high macrotexture and on with high microtexture and low macrotexture which is shown diagrammatically in Slide 7.

In the UK the texture depth is expressed in terms of SMTD (Sensor Measure Texture Depth). The practical effect of SMTD values on measured locked-wheel friction at a range of speeds on many sites with different surface types, including random, transverse, and porous surfaces, are shown in Slides 8, 9, 10, and 11.

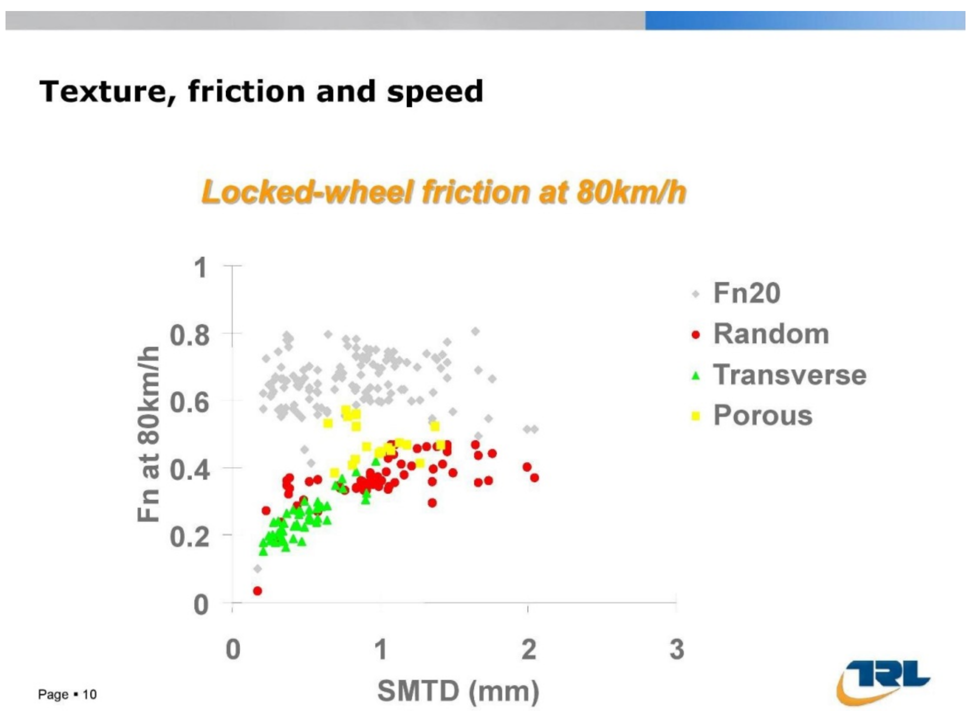
These show the gradual reduction of friction with increasing speed but particularly at SMTD values below 0.8 mm. This 1990s work led to the introduction of a requirement in England for this texture depth on in-service flexible roads. However, the yellow data points from some porous surfaces, highlighted in a red circle in Slide 11, do not fully match the above behavior. Such surfacings are little used currently in England but the unexpected behavior of some porous materials in relation to other surfacings will be discussed later in this presentation.



SLIDE 7

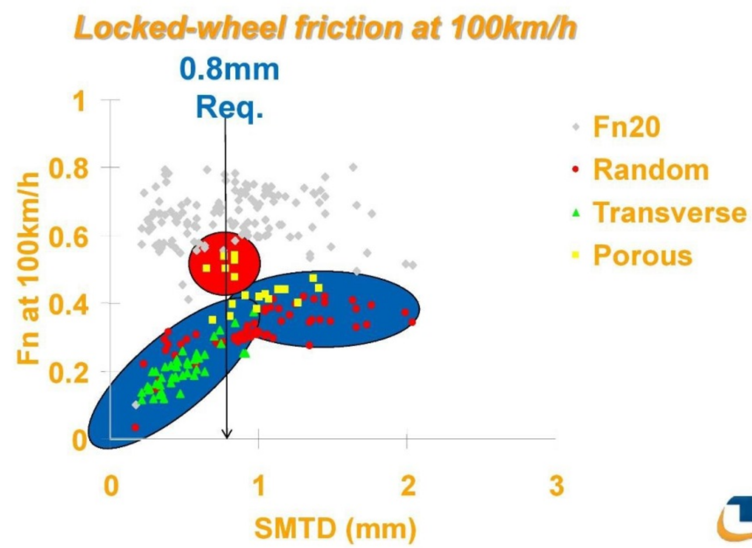


SLIDE 8



SLIDE 9

Texture, friction and speed



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SLIDE 10

Shortcomings of current skid resistance measuring methods and their interpretation

- Routine low speed skid resistance
  - contact method has some limitations
  - better to measure micro-texture directly by non-contact method
- Routine texture measurement (proxy for high speed friction)
  - current parameters do not necessarily correlate well with high-speed wet friction on some surfacing materials

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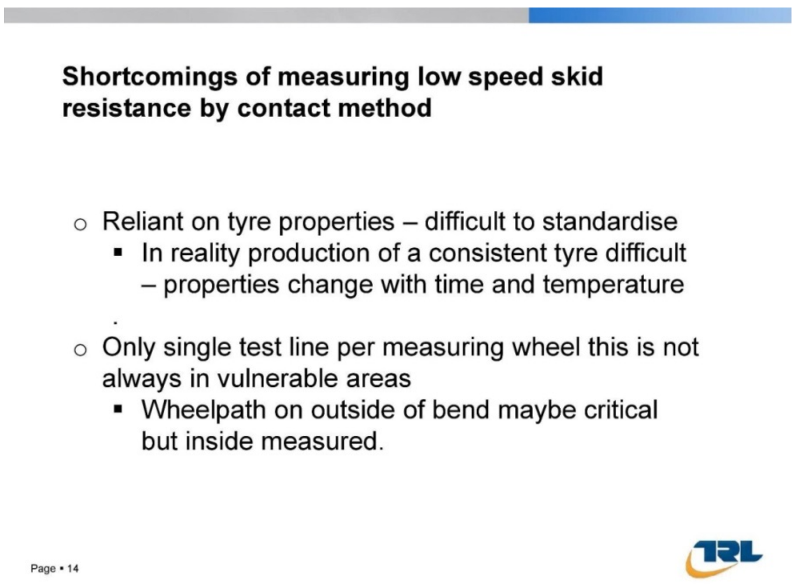
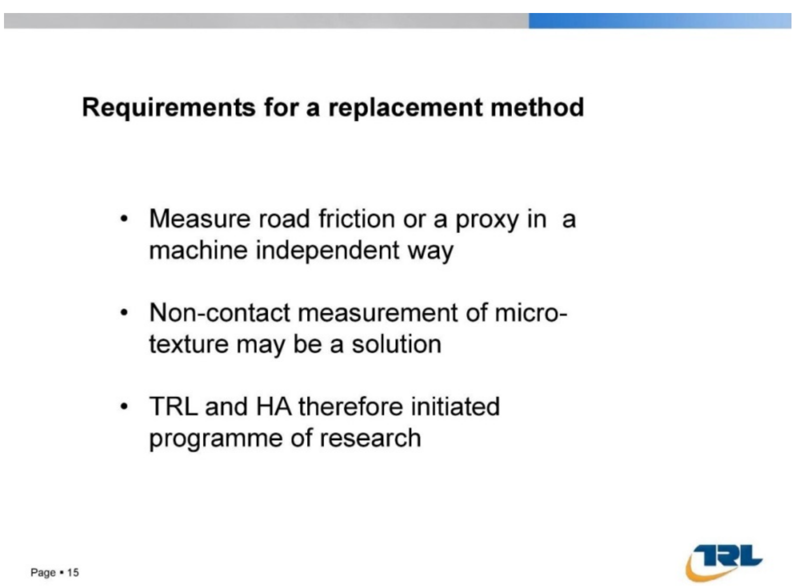
SLIDE 11

Slide 12 summarizes the research described up to this point and Slide 13 raises some shortcomings with the current UK skid resistance measuring methods and their interpretation. Slide 14 expands on the limitations of the current low-speed skid resistance contact measurement methods and Slide 15 suggests the requirements for a replacement method which, since 2000, is being investigated by TRL under funding from the Transport Research Foundation and the Highways Agency, now called Highways England.

This work has covered both the theory relating surface texture and skid resistance as well as the practicality of designing equipment to gather the required data.



SLIDE 12



SLIDE 13

Non contact skid resistance measurement - Overview

- Ongoing work conducted by TRL has investigated the non contact measurement of skid resistance at traffic speed.
- The work has looked at both:
  - the theory relating surface texture and skid resistance
  - as well as the practicality of designing equipment to gather the required data

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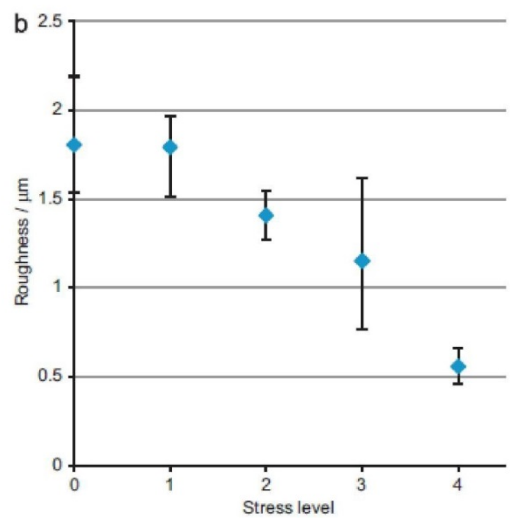
SLIDE 14

Non contact skid resistance measurement - studies confirming theory

- 3D measurements of aggregate surface at ~5µm resolution
- Areal roughness parameter, S_a calculated (y-axis)
- Abrasion stress applied to surface (x-axis)
- Next step: more complicated geology.



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SLIDE 15

Slide 16 highlights the shortcomings of measuring friction at high-speed or using current texture proxies. Recently, this latter issue of whether current texture proxies adequately forecast the reduction of friction with speed have been further examined. In particular, some observations had been made of low textured asphalt materials where the high-speed friction performance was better than expected. These materials have some important advantages: in the United Kingdom the crushing process used to produce suitable aggregate for pavement materials has produced an excess of 6mm material and its use in thin surfacing has shown it to be quieter than using the more normal 10 mm and 14 mm size of aggregate. Research has therefore been undertaken to examine the friction performance of such materials in relation to other thin surfacing (Slide 17).

Slide 18 shows the results of such trials where the locked wheel friction at 100km/h for the 6 mm material shows similar levels to the 10- and 14-mm material despite significantly lower SMTD texture values. A similar behavior is observed when expressing texture in terms of root mean square (RMS) and mean texture depth (MTD) as shown in Slides 19 and 20. There is no obvious explanation for this uncharacteristic behavior but this may suggest that the SMTD algorithm does not adequately characterize the surface in terms of friction performance.

Shortcomings of measuring high speed friction or using current texture proxies

- As per slow slip speed techniques
  - Water etc
- Plus (for direct measurement)
  - High tyre wear
  - Discrete measurements if locked wheel values
- And (for proxy measurement)
  - Poor correlation for some surfacing materials

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SLIDE 16

Examination of performance of other surfacing materials

- Porous asphalt materials showed anomalous performance
- What about other negatively textured materials?
  - 14mm thin surfacings
  - 10mm thin surfacings
  - 6mm thin surfacings
- Therefore English Highways Agency funded trials to examine their friction performance

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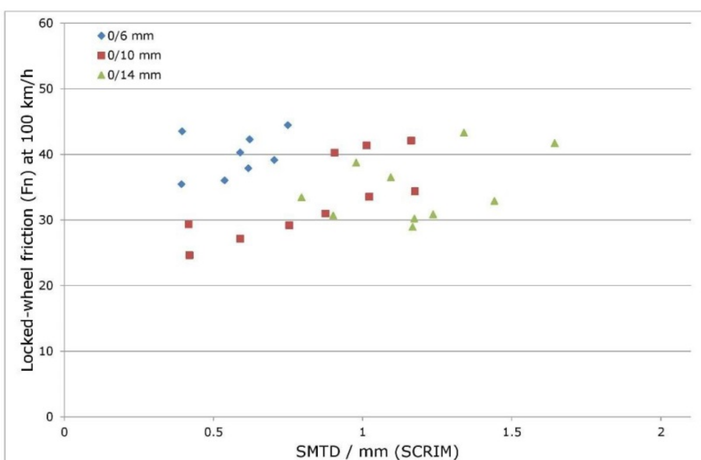
SLIDE 17

Experimental studies with 6, 10 and 14mm TS

SMTD and high-speed friction



Fn100 compared with SMTD texture depth

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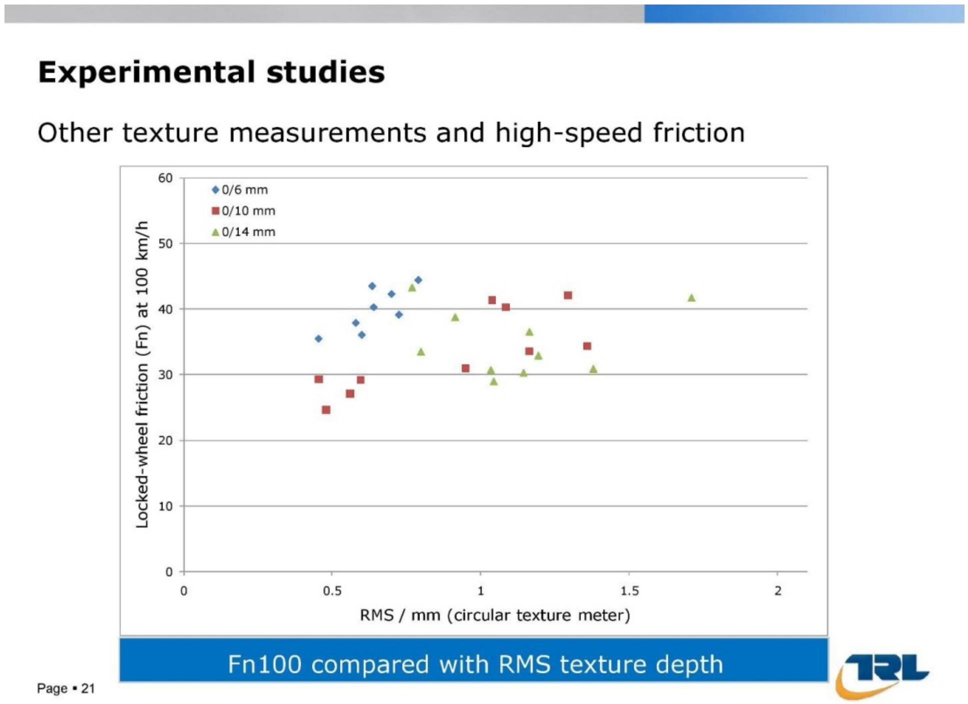
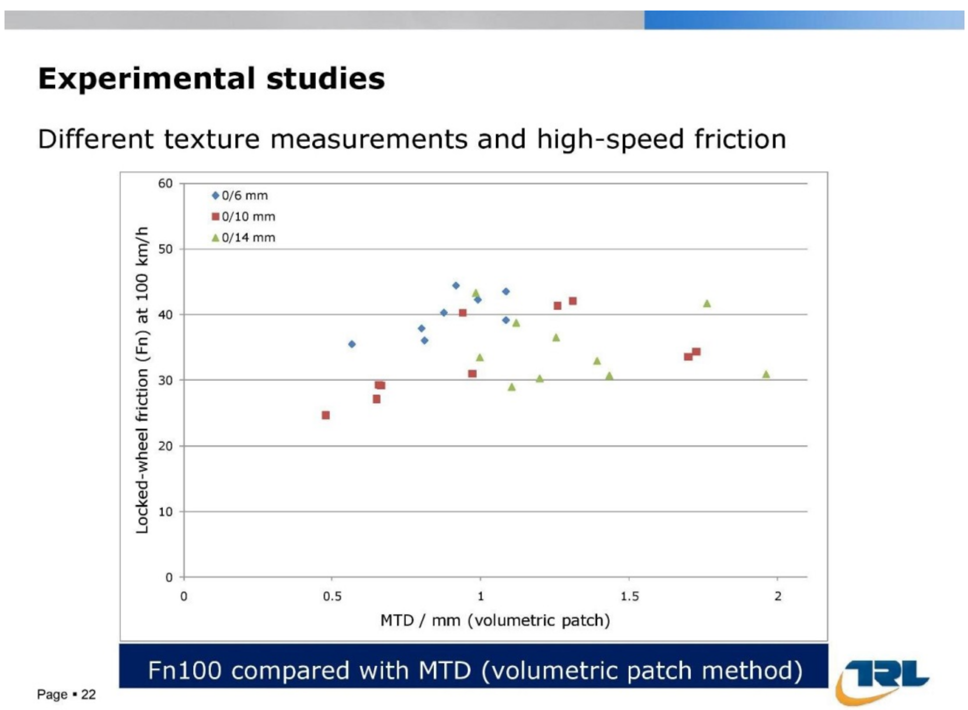
SLIDE 18

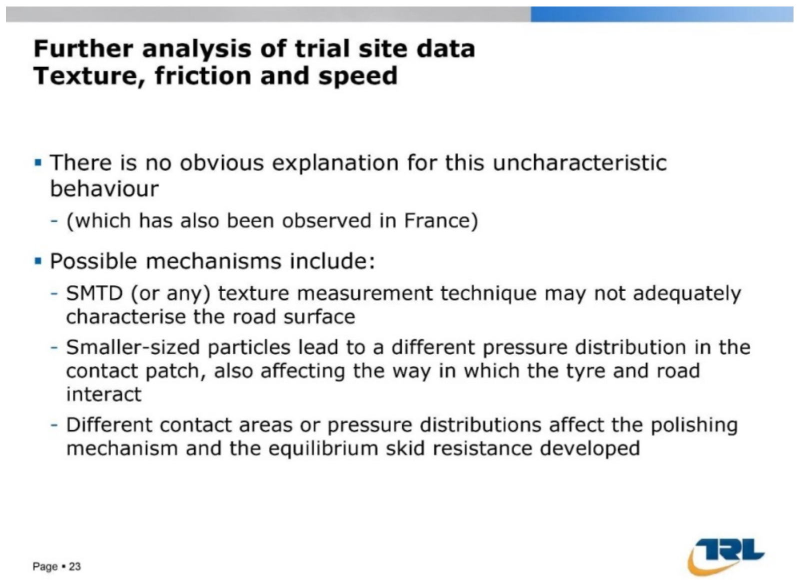


SLIDE 19

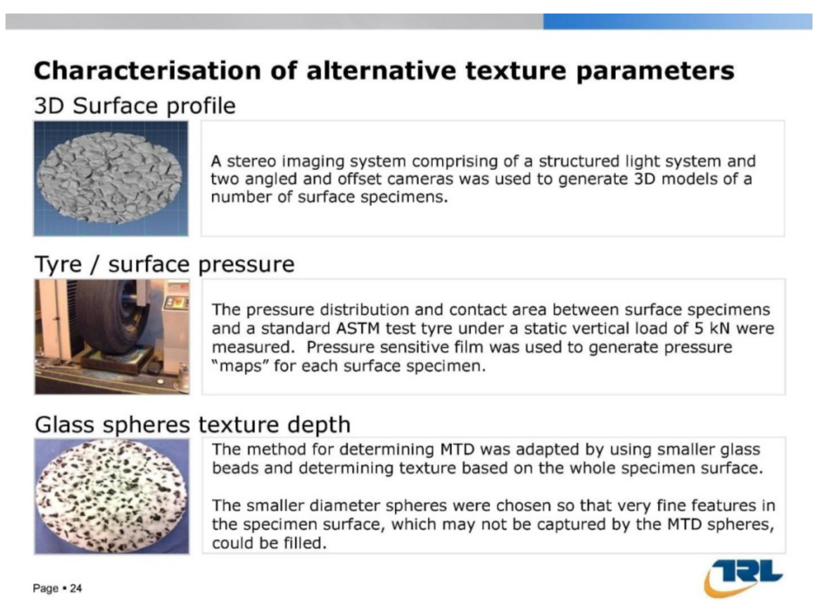


SLIDE 20

We have been further examining the relationships between surface characteristics and high-speed friction properties (Slide 21). Since our long-established relationship between high-speed friction and texture does not seem to apply to certain surfaces we have examined other measures of texture, including the use of three-dimensional (3-D) models of road surfaces, the use of pressure sensitive film to generate ‘pressure maps’ of the road surface and the use of extra fine glass beads to determine the available volume in the surface for the road–tire–water interaction (Slide 22).



SLIDE 21

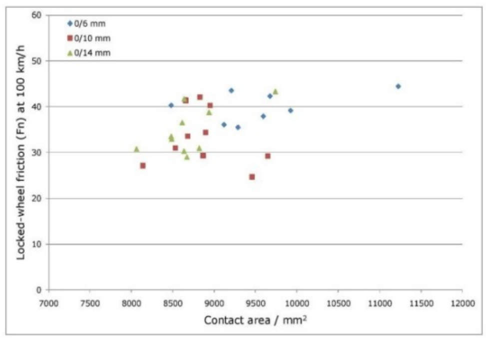


SLIDE 22

Slide 23 shows some of these results. These particular results suggest that considering the potential tire contact area with the road surface produces a relationship with high-speed friction that is more consistent with the behavior of 10 and 14 mm materials than the surface MTD texture parameters. On the basis of this work we have developed five new surface characteristic parameters summarized in Slide 24. One of the most promising is the 3-D surface void volume. This is calculated by using the pressure maps to determine the penetration of the tire into the surface and then estimating the volume of voids in the surface below this tire penetration level.

Experimental studies

Contact area and high-speed friction



- This measure appears to push the 0/6mm more into the main distribution

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SLIDE 23

Characterisation of alternative texture parameters

Using the results from the alternative measurement techniques five new surface characterisations were developed:

- Percentage pressed area
- 3D surface void volume
- Tyre penetration depth
- Volume of void below tyre
- Volume of void occupied by tyre

The glass spheres texture depth was used as an absolute reference of surface texture.

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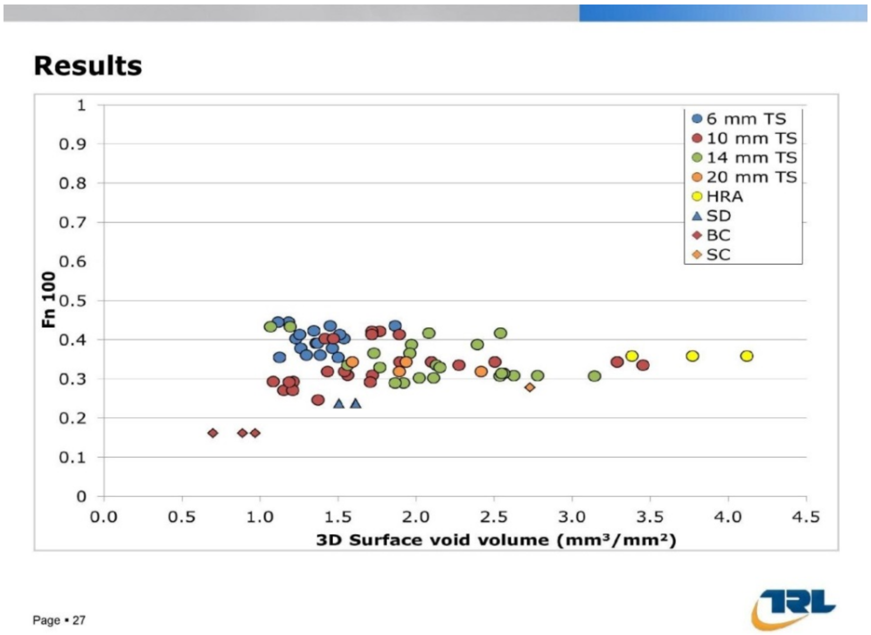
SLIDE 24

Slide 25 illustrates how the use of this parameter is better at grouping the results of high-speed friction for all the different surface types considered in this work. Slide 26 concludes that the current measures of texture in general use are not always good predictors of high speed friction but better alternatives identified may not be very practical so further work is needed to resolve the issue.



SLIDE 25

Conclusion re high speed friction

- Current measures of texture not always good predictors
- Better alternatives impractical?
- More research needed!!!!!!

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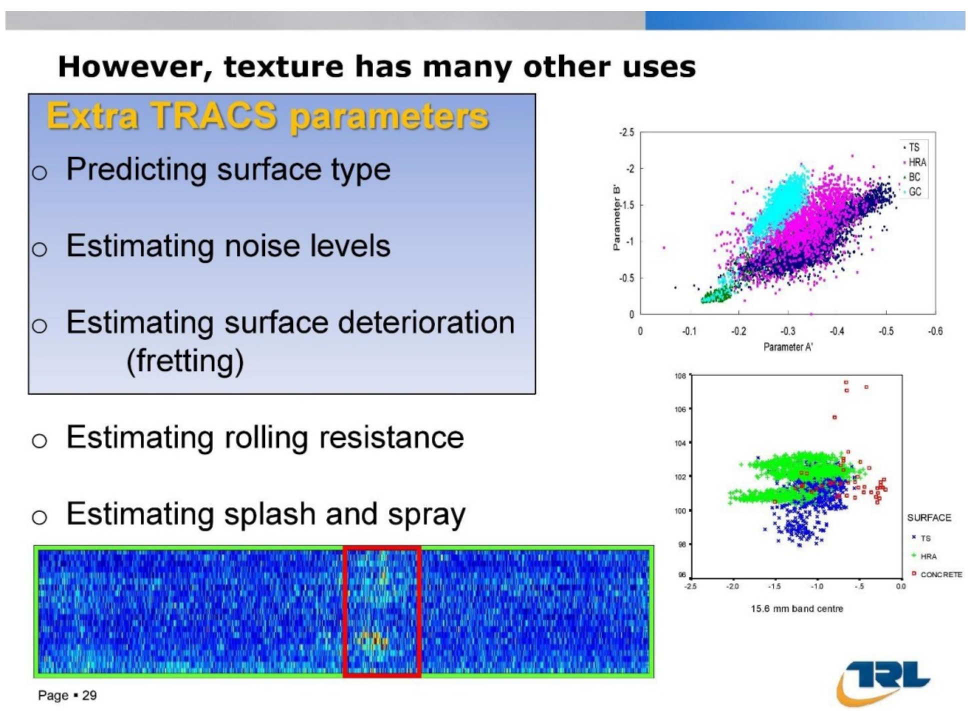
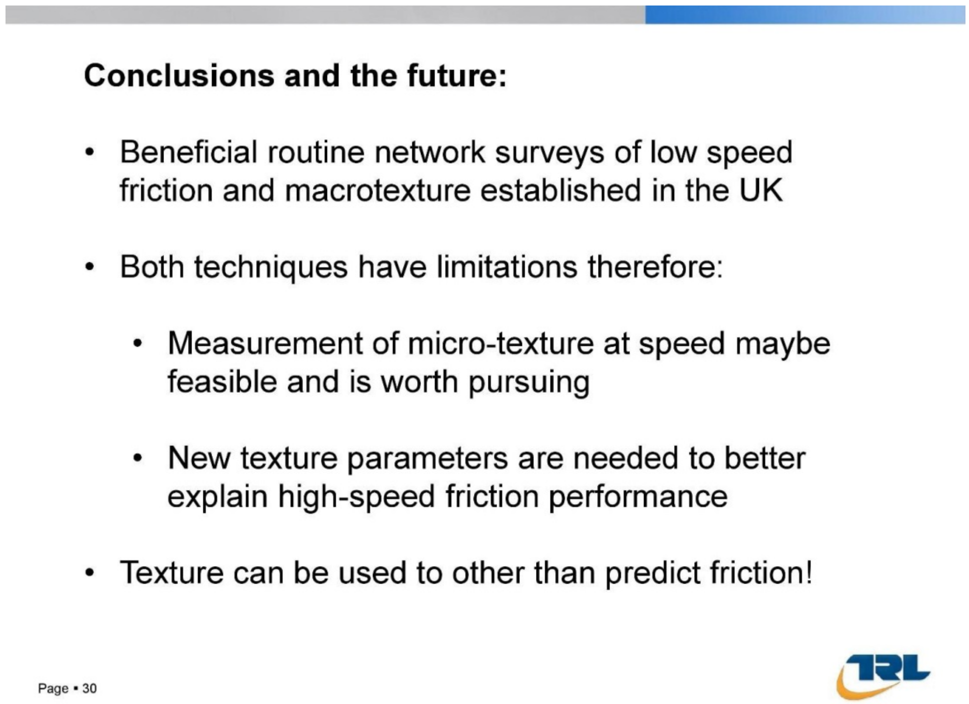
SLIDE 26

The texture measurement has many other uses as well as predicting high speed friction, as summarized in Slide 27. In combination with luminosity it can be used to predict surface type and to estimate tire-generated noise levels, as illustrated in the two right hand plots. Multiple texture line measurements can also be used to predict surface deterioration in terms of aggregate loss, that is, fretting or raveling, as illustrated by the plan view of the road at the bottom of the slide which shows fretting levels by color coding with low levels at blue and higher levels in yellow and red. All these parameters have been implemented in the TRACS contract and made available to the maintaining agents on a central pavement managements system. Research has also shown that certain texture parameters can also be used to predict the rolling resistance and propensity to splash and spray of a road surface but these applications have yet to be implemented.

In conclusion, we can summarize the UK position as shown in Slide 28. Routine surveys of low speed friction and macrotexture have supported an effective UK friction policy but they have limitations particularly with the compromises currently delivering macrotexture to retain high-speed friction whilst obtaining reasonable rolling resistance and noise levels. In the future we consider there is a need for a change in focus, with a better understanding of how the surface texture influences these different parameters, to be able to optimize this balance.



SLIDE 27



SLIDE 28

ABOUT THE AUTHOR

Brian Ferne has more than 40 years of experience in highway engineering research, from studies of the production of road materials to road construction processes to maintenance operations and, over the past 30 years, the methods of evaluating maintenance need. He is an Honorary Chief Research Scientist at the UK Transport Research Laboratory and currently is responsible for the technical and scientific quality of pavement engineering work in the Infrastructure Division. His current research interests include the nondestructive measurement and interpretation of highway condition and the design and maintenance of long-life pavements. He is a member of many international, U.S., European, and UK committees, including the TRB Committee on Pavement Monitoring and Evaluation, and is chairman of the Forum of European National Highway Research Laboratories European Long-Life Pavement Group and of the international Deflection at Road Traffic Speed Group.

ACKNOWLEDGMENTS

This presentation has been based on the work of several TRL colleagues, in particular Helen Viner, Pete Sanders, and Alan Dunford. The research has largely been sponsored by the Transport Research Foundation and the English Highways Agency, now called Highways England.

U.S. Experiences on Pavement Texture Measurement and Interpretation

Edgar de León Izeppi
Virginia Tech Transportation Institute

First, I would like to acknowledge the other authors of the paper on which this presentation is based, Adaptive Spike Removal Method for High-Speed Pavement Macrotexture Measurements by Controlling the False Discovery Rate (E. Izeppi, G. Flintsch, S. Katicha, and D. Mogrovejo. *Transportation Research Record: Journal of the Transportation Research Board, No. 2525*, Transportation Research Board of the National Academies, 2015, pp. 100–110). I also would like to acknowledge the great support and contributions of Kevin McGhee from Virginia Department of Transportation (DOT). We are all working together on this project to improve the accuracy, remove the spikes, and validate the macrotexture measurements obtained from a high-speed laser device (Slide 2).

I will introduce this topic with an overview of the state-of-the-practice of macrotexture measurements in the United States, especially at the network level (Slide 3). We will review the most important applications that macrotexture measurements have been used for and most of the methods or devices used to make the measurements. Following will be the background for the current project that we have initiated, the problem statement, the objectives, the methods utilized to achieve the solution of the problem, examples of the results obtained, and a brief commentary on what is expected to happen next.

SLIDE 1

Team Members

Virginia Tech Transportation Institute (VTTI)

- Dr. Gerardo Flintsch
- Dr. Samer Katicha
- Daniel Mogrovejo

Virginia Center for Transportation Innovation and Research (VCTIR)

- Kevin McGhee

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SLIDE 2

Outline

1. US's experience
   - ✓ Applications
   - ✓ Methods
2. Background
3. Problem Statement/Objectives
4. Methods
5. Field comparisons
6. What next?

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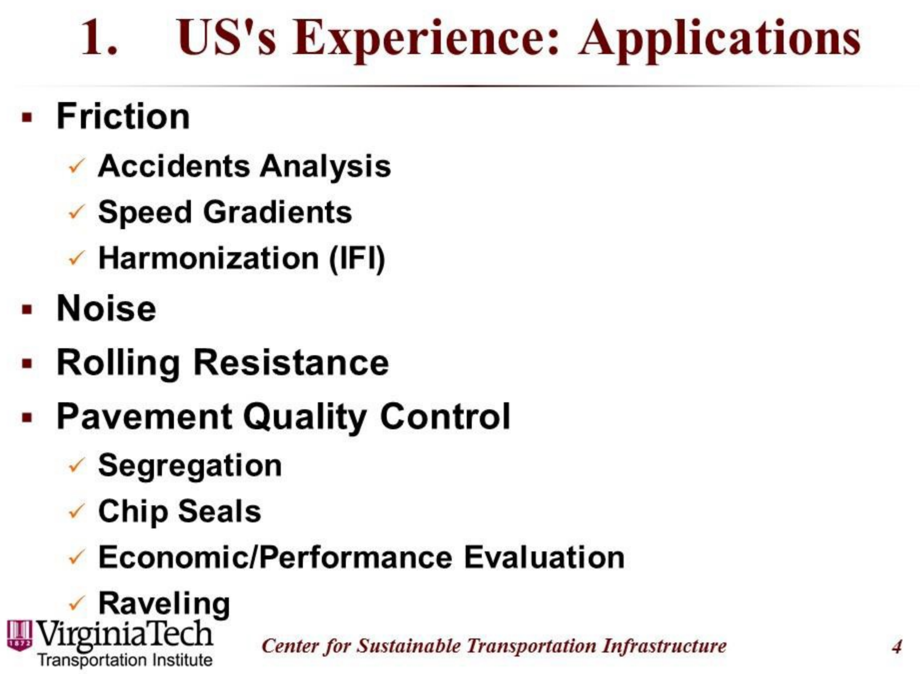
SLIDE 3



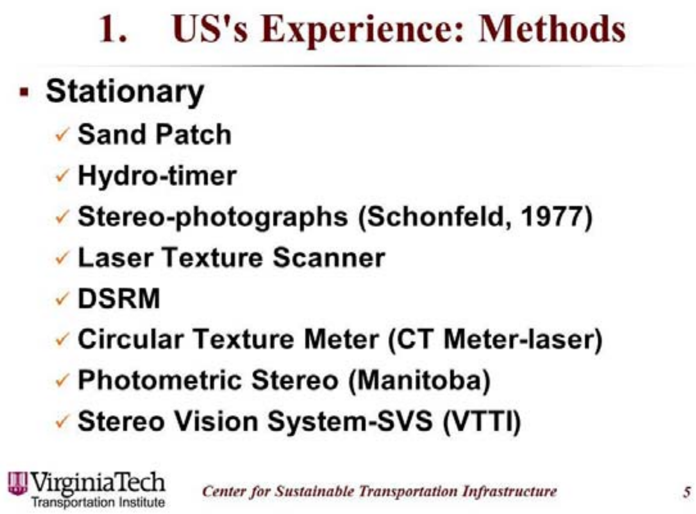
SLIDE 4

The majority of applications that macrotexture measurements have had in the United States have been intended to find effective relationships with the tire–pavement friction characteristics of a pavement. This application has many other specific uses that could be derived if actual relationships can be found in areas such as accident analysis, speed gradient derivations, and the general harmonization of friction measurements, such as those proposed by different indexes such as the international friction index (Slide 4).

Other applications where macrotexture is used are in noise and rolling resistance characterizations; these are going to be covered more in depth by some of the other presenters in this workshop. Other applications of macrotexture measurements found in the United States have been for quality control of pavements:

a. Hot-mix asphalt (HMA) segregation,
b. Chip seal quality,
c. Performance evaluation (portland cement concrete pavements), and
d. HMA raveling detection.

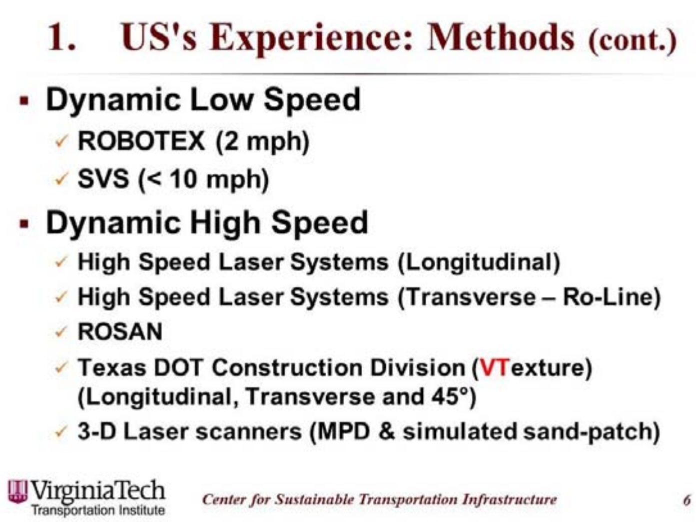
The majority of the present methods to measure macrotexture are stationary methods that require traffic control and are not relevant to the network level that is the objective of this presentation (Slide 5). However, starting with the sand patch and now the circular texture meter which has almost replaced it, all emerging technologies recognize these as the ground-truth measurements against which all other technologies need to be compared. The other methods mentioned in this presentation have had to prove their worthiness and have been graded based on those results.



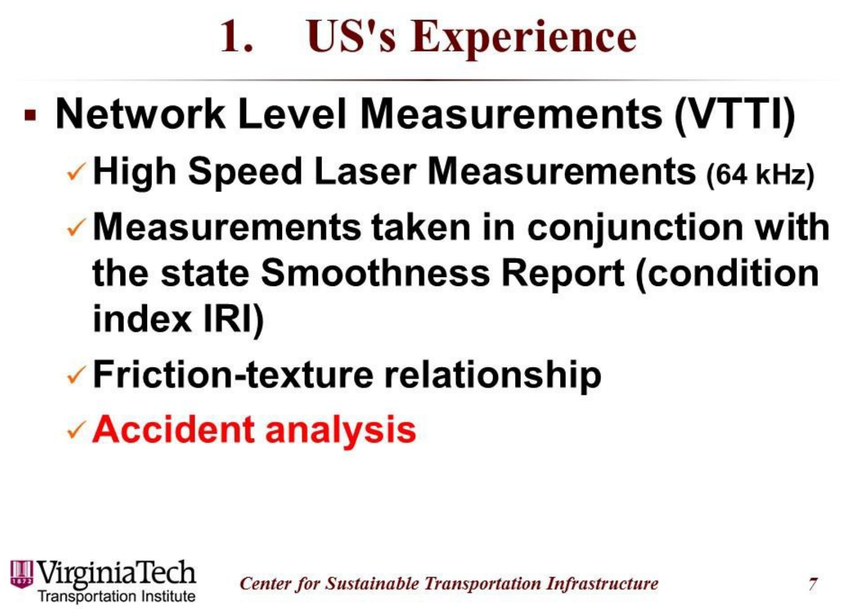
SLIDE 5

Dynamic traffic speed methods are necessary for network-level measurements (Slide 6). The most popular method is the high-speed single-spot (SS) laser profiler van with a dedicated laser for macrotexture measurements. Other methods are being developed with line lasers measurements, especially those that are being used more and more for distress measurements obtaining three-dimensional (3-D) maps of the pavement surface. They have yet to be tested in comparison with the SS systems in an experiment with varied pavement surfaces to determine their accuracy.

This presentation will focus on SS laser profilers systems with a minimum 64-kHz frequency that is normally used by DOT agencies when performing the international roughness index measurements to determine the performance of the agencies pavements (Slide 7). The most important application that we are intent on perfecting is the friction texture relationship that could eventually be used for accident analysis at the network level.



SLIDE 6



SLIDE 7

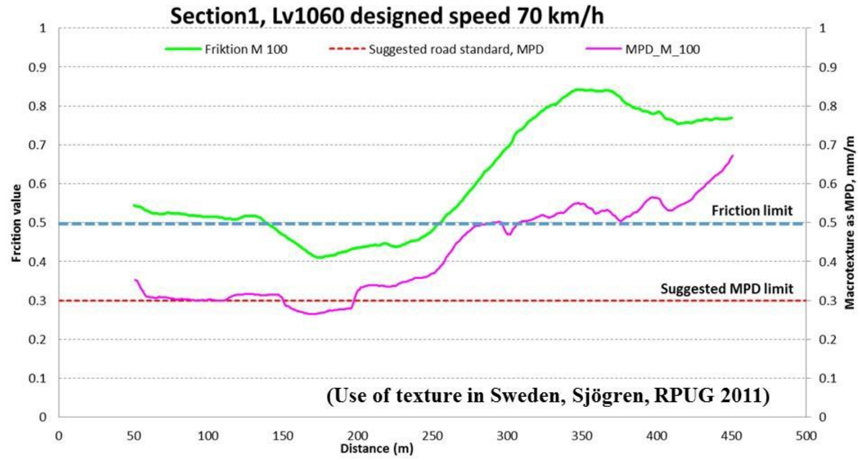
If a single slide could summarize the expected results of what we are trying to achieve with measuring the macrotexture of pavements, it would be the one presented by Leif Sjögren in the Road Profile Users' Group (RPUG) meeting in 2011 (Slide 8). In this slide, a very clear relationship between the friction and the macrotexture measurements is evident along a segment of road, with both profiles following the same trends. If this relationship could be verified for all pavements, macrotexture could be used exclusively to identify the low friction spots in the pavement network, but most importantly, without the use of water, which would increase the productivity of friction measurements for this purpose by a factor of 4 or 5. The impact on the safety performance of the highway networks would similarly be increased by allowing maintenance crews to locate more low friction areas in need of repair, thus proactively avoiding possible low-friction accidents.

The motivation for this project was began with another presentation during RPUG in 2011, where Rohan Perera reported the results of an acceptance testing for several profiling systems that FHWA had received to be used in their long-term pavement performance (LTPP) program, related with macrotexture measurements (Slides 9–12). The acceptance testing process discovered that what has been considered the ground-truth standard, the circular track meter (CTM), exhibited a lot of variability both in repeated measurements in the same spot as well as different measurements in very close proximity (2 m apart).

However, the most important finding was the realization that the presence of spikes in the raw data that apparently is not currently suppressed by most equipment manufacturers, thereby necessitates robust spike detection and elimination algorithms in the data processing in order for these measurements to be accurate (Slide 13). In general, procedures for verifying the accuracy of the macrotexture measurements was pointed out as being a very high priority in order for these measurements to be used by highway agencies.

Our group then decided to investigate this and found exactly what Rohan had pointed out with the results obtained by the manufacturer software. Our priority then turned to develop a solution to this problem and testing it to prove its validity (Slides 14 and 15).

1. US's Experience



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SLIDE 8

2. Background

- **RPUG 2011: Rohan Perera**
  - ✓ **A standardized procedure for texture measurements at the network level is not yet available**
  - ✓ **Studies show that besides the traditional low-pass filtering, slope suppression, and drop out correction; the calculus of MPD values must be free of spikes**

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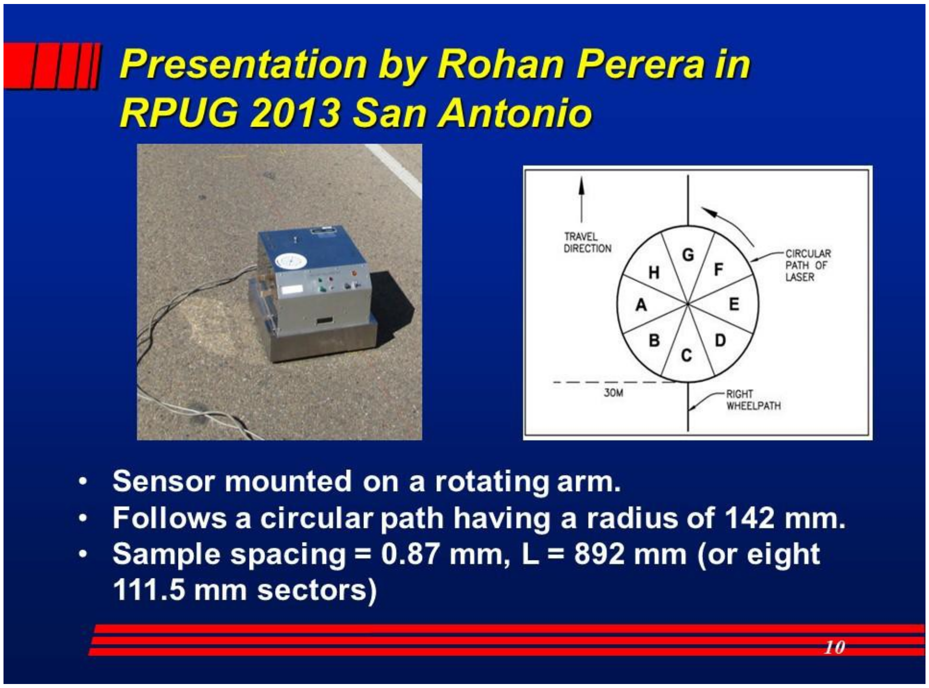
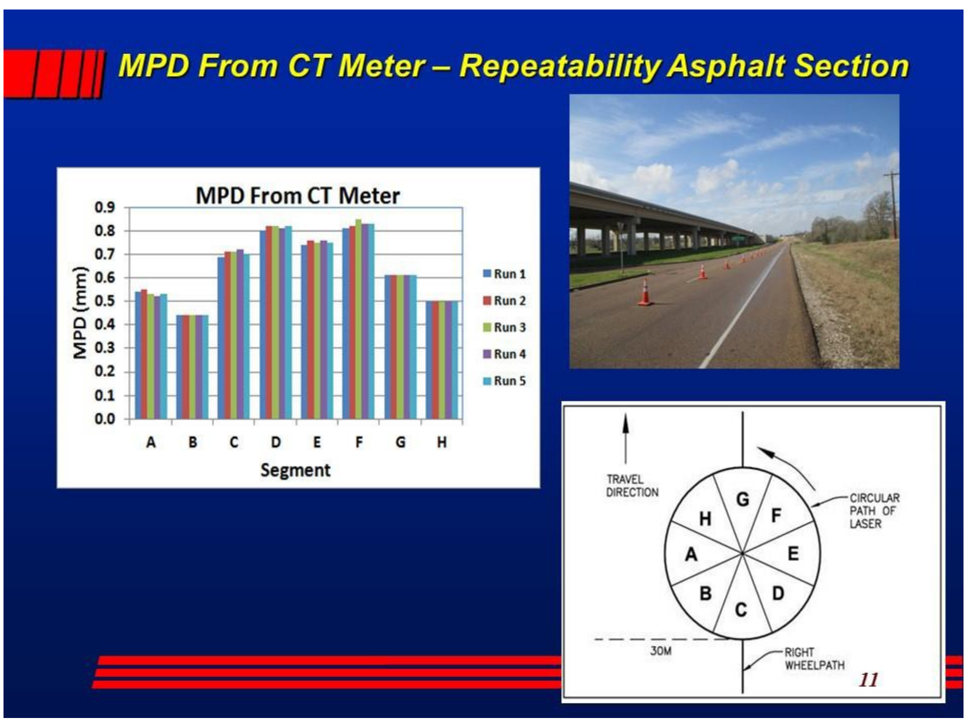
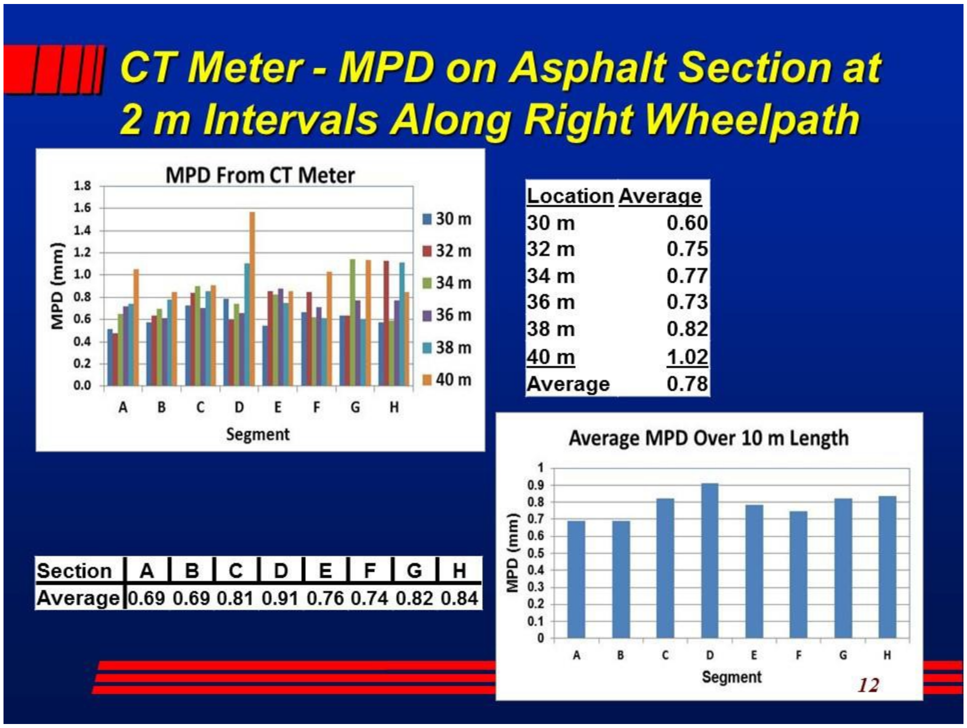
SLIDE 9



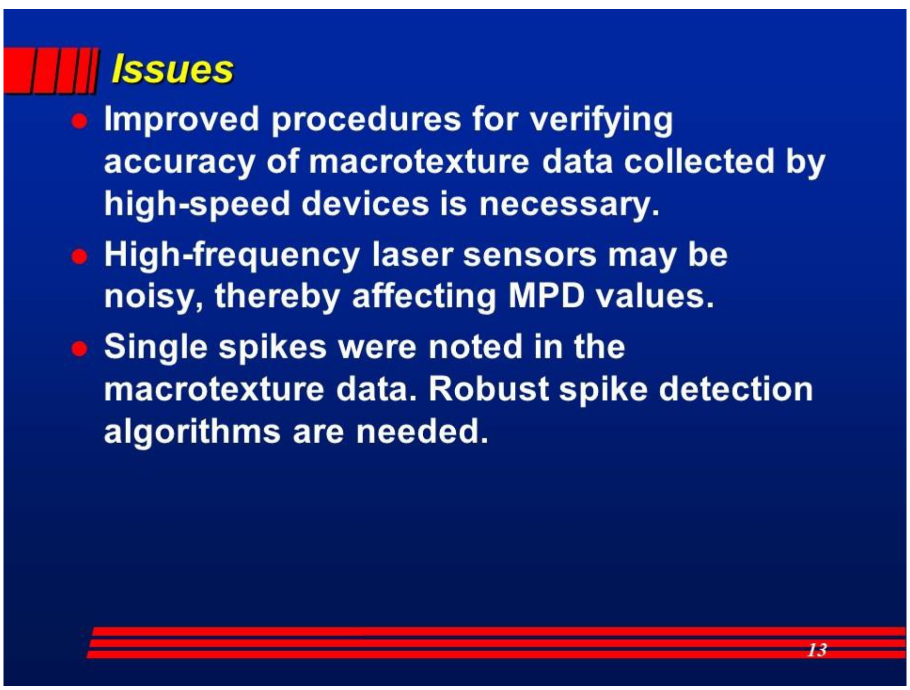
SLIDE 10



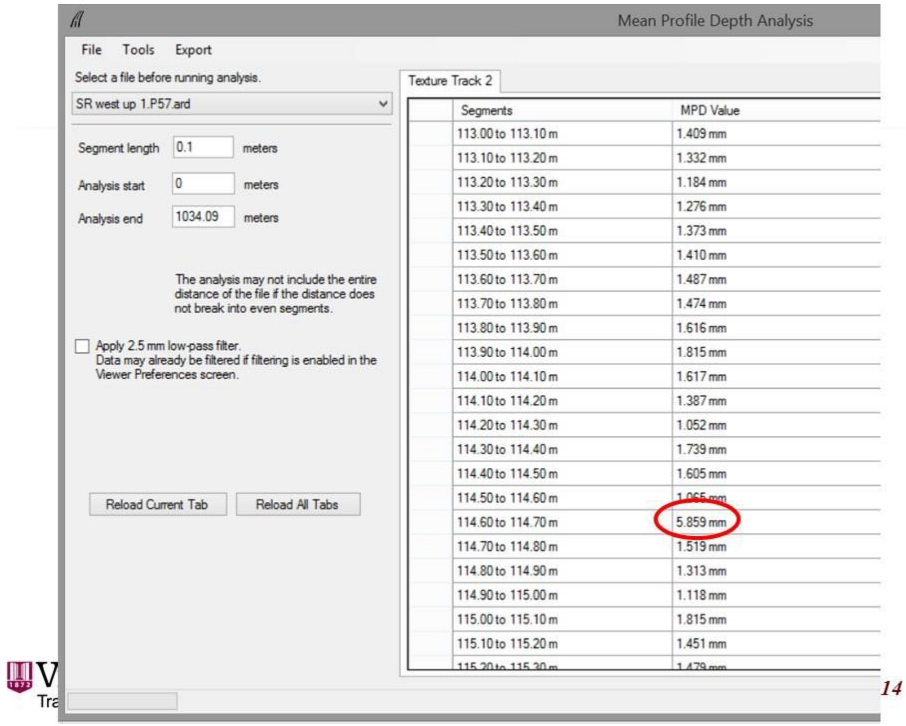
SLIDE 11



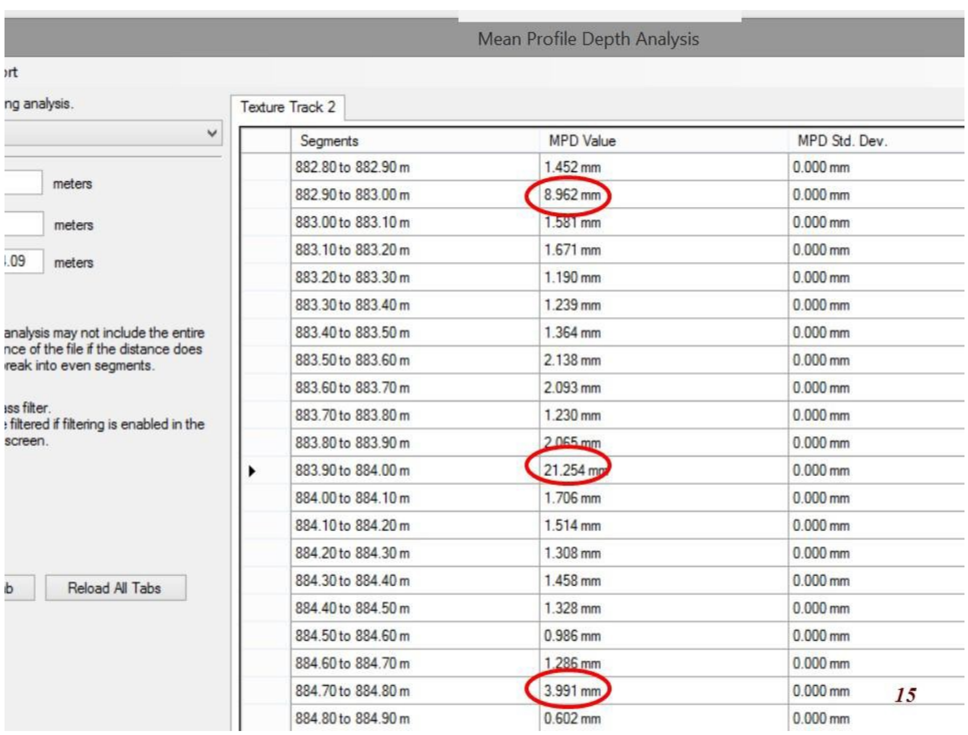
SLIDE 12



SLIDE 13



SLIDE 14



SLIDE 15

SLIDE 16

We are more motivated to do this because we are also a part of a larger FHWA project that is investigating the use of continuous friction measurement equipment that has a strong component of macrotexture measurements to complement the friction (Slide 16). If we can compare truly believable macrotexture measurements with the continuous friction measurements, we might establish the kind of relationships seen on Slide 8 and reap the benefits.

We found out that all laser measurements have spikes (Slide 17). Depending on the laser used, you will have more or less, but because spikes will create biases on the texture measurements, they need to be removed from the calculations of the texture parameters used. In our case, we are using the mean profile depth (MPD) parameter to report the macrotexture of a pavement. We need to take out the spikes from the raw data *before* the MPD computations.

Our group has found an effective and innovative approach of doing this with the false discovery rate (FDR) method, which is further explained in TRB paper 15-4500 (Slide 18). With this approach, the threshold adapts to the data in two stages; first, by correcting them for the large amount of data (with the Bonferroni correction) and second, by controlling the wrongly identified outliers among all identified spikes using the FDR method. The next slides will show the results of the high-speed de-spiked MPD calculations compared with two CTMs for validation.

Testing was done at the Virginia Smart Road at the Virginia Tech Transportation Institute (VTTI) where a series of different pavement surfaces with different textures are available. The 2-mi long test track produced a total of about 6,000 spikes over the more than 4 million measurements (0.13%) (Slide 19).

The results of the raw (blue) and the de-spiked (green) data are shown in Slide 20 for comparison, with a closer look in Slide 21 for more clarity. It is estimated that if the spikes would not have been removed, approximately one third of the MPD computations would have been affected.

3. Problem Statement/Objective

- All laser measurements have spikes
- They create biases on the texture measurements.
- Need to remove those spikes before computing good values for texture such as MPD.

➡ Develop method that can objectively identify and remove spikes.

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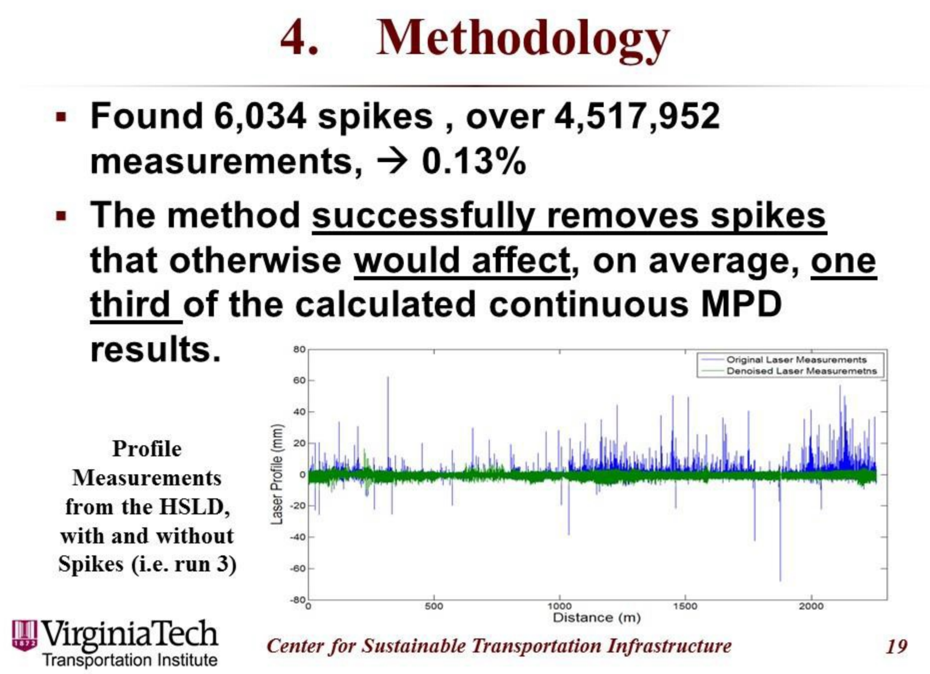
SLIDE 17

4. Methodology

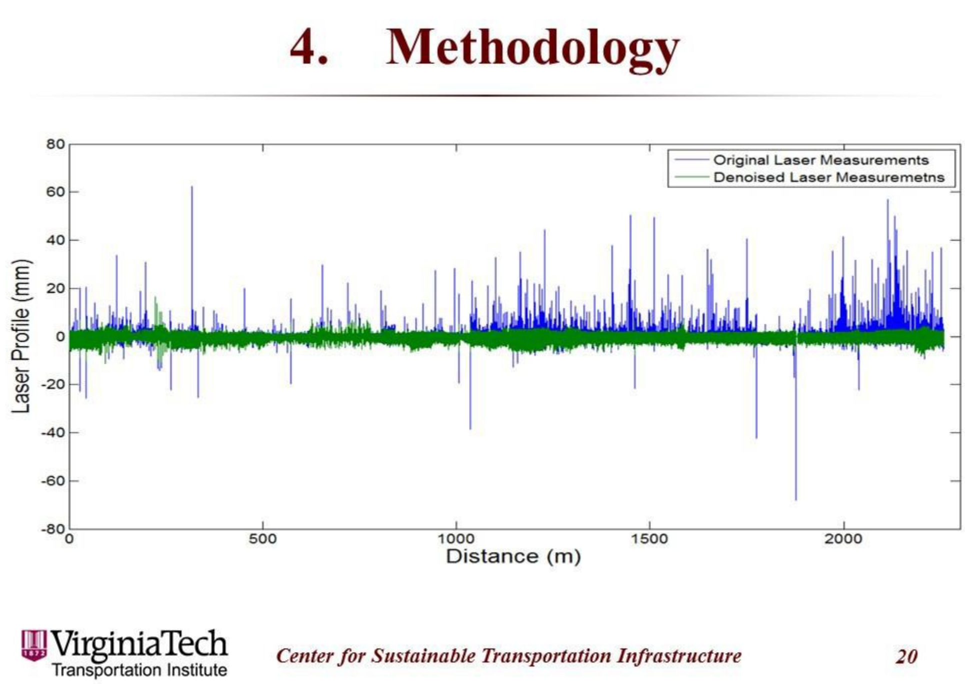
- Adaptive Spike Removal Method for HS Pavement Macrotexture by controlling the False Discovery Rate, TRB Paper 15-4500
- Innovative use of methodology that can objectively identify and remove the spikes
- FDR method controls proportion of wrongly identified spikes and allows adaptive threshold selection by differentiating between valid measurements and spikes
- Validation results were comparable to two CT Meters (MPD) on all sections investigated

VirginiaTech Transportation Institute — *Center for Sustainable Transportation Infrastructure* — *18*

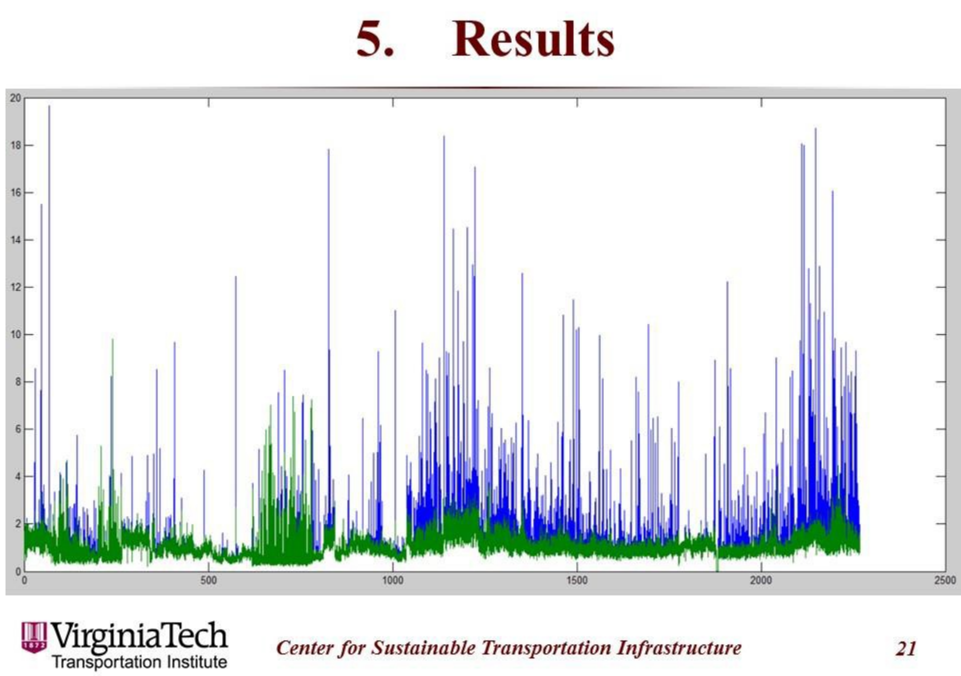
SLIDE 18



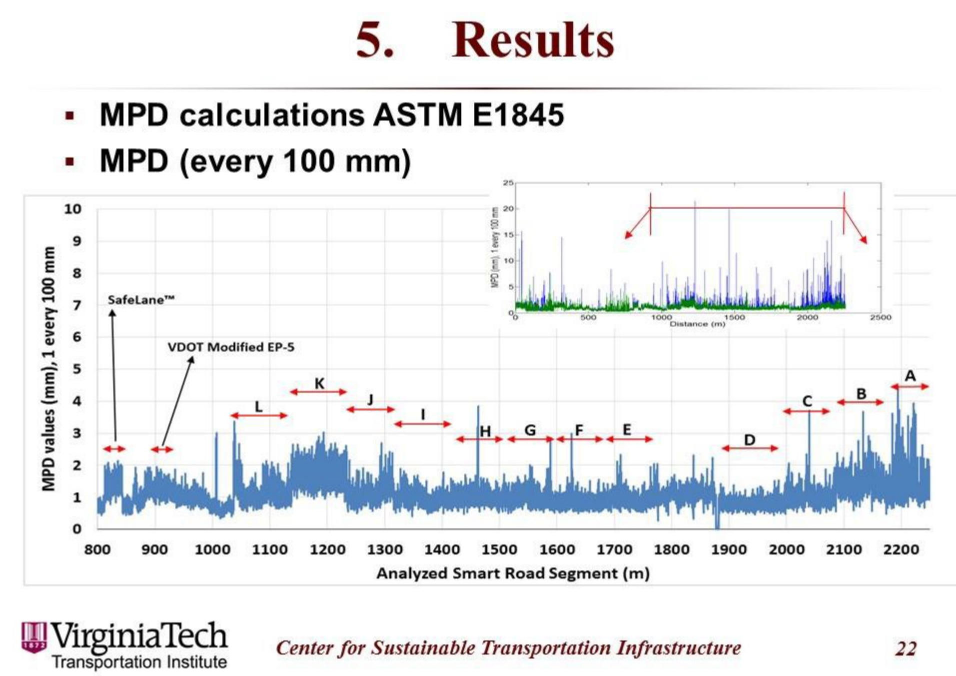
SLIDE 19



SLIDE 20

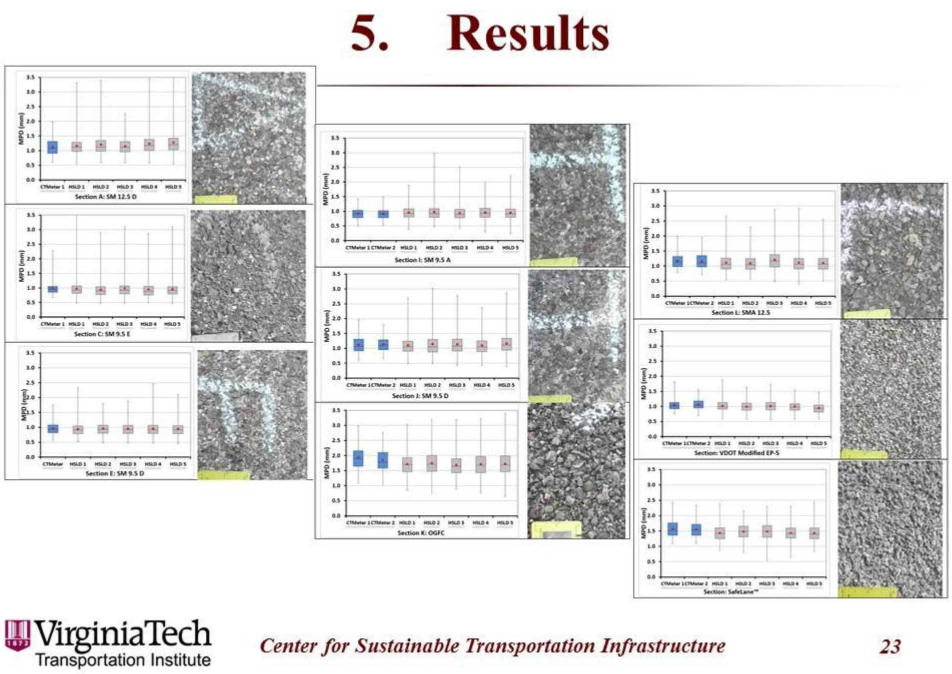


SLIDE 21



SLIDE 22

The results of the computations of MPD at every 100 mm were plotted; it is visible that all of the different sections can be easily differentiated with their macrotexture measurements (Slide 22).



SLIDE 23

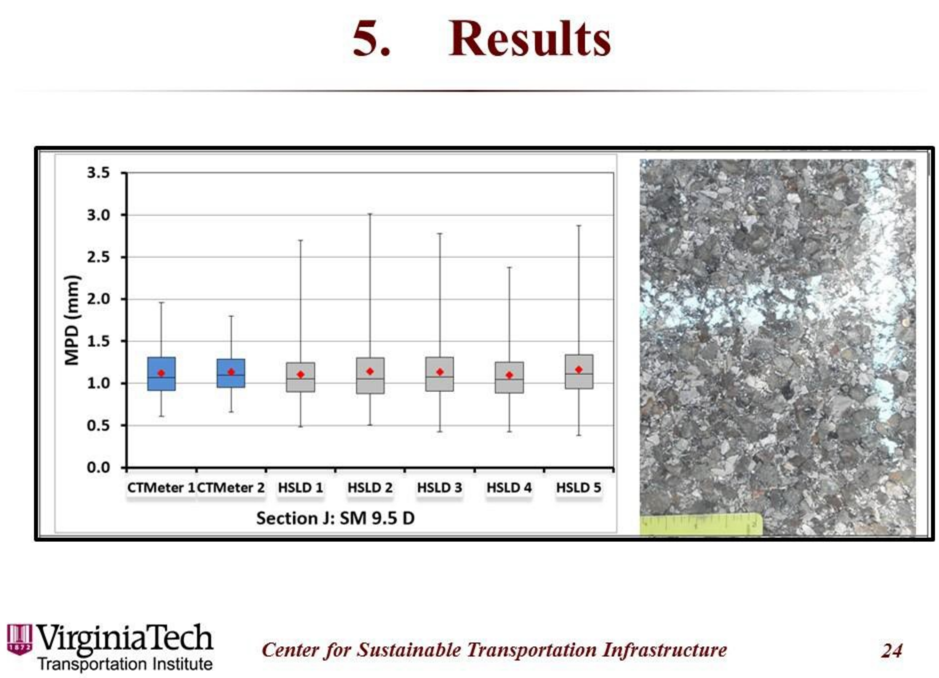
As explained before, all of the sections were also measured with two different CTM devices, and the average of those measurements was then compared for the average of the high-speed SS measurements. The variability of the measurements of both CTMs and different passes of the high-speed profilers were very similar, making it easier to compare the average and the ranges of the variability among these two devices (Slide 23). A strong argument could be made with these results that both devices produce comparable results, making it easier to substitute CTM measurements with these high-speed laser measurements, thus validating the measurements. Slide 24 shows a close-up of what was found in all of the 14 surfaces tested.

Normally, this presentation would have ended with the Slide 24, but chance had it that a series of events would further prove that the FDR method works. At the Pavement Evaluation 2014 Conference (RPUG 2014) where the initial results of this research were presented, the manufacturer of the lasers declared that the spikes observed in the results of the measurements were being caused by a malfunctioning or defective laser.

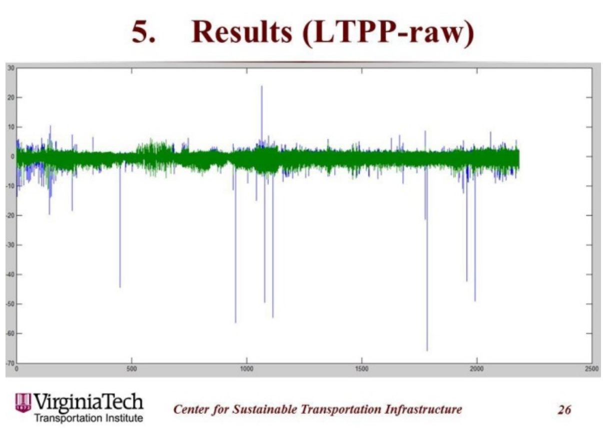
This prompted our investigation and triggered the need for a comparison with the identical system that FHWA had acquired to compare the results and further test our processing method.

On Slide 25*a*, the raw data results obtained with the LTPP profiler system are shown, again in blue for the raw data with spikes and in green after de-spiking.

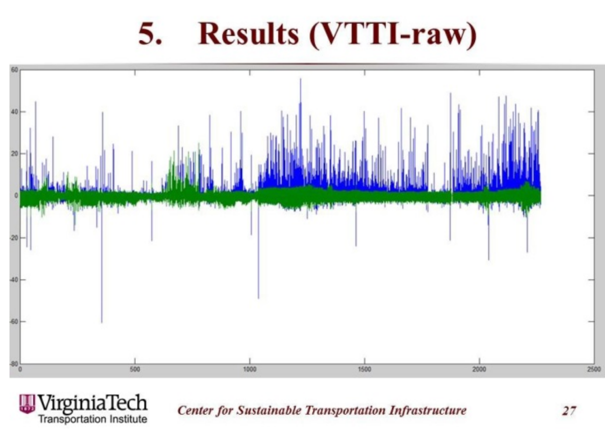
Similarly, the raw data results obtained with the VTTI profiler system are shown, in blue for the raw data with spikes and in green after de-spiking (Slide 25*b*). It is clear looking at these two slides that the VTTI profiler not only has more spikes, they are much larger in magnitude.



SLIDE 24

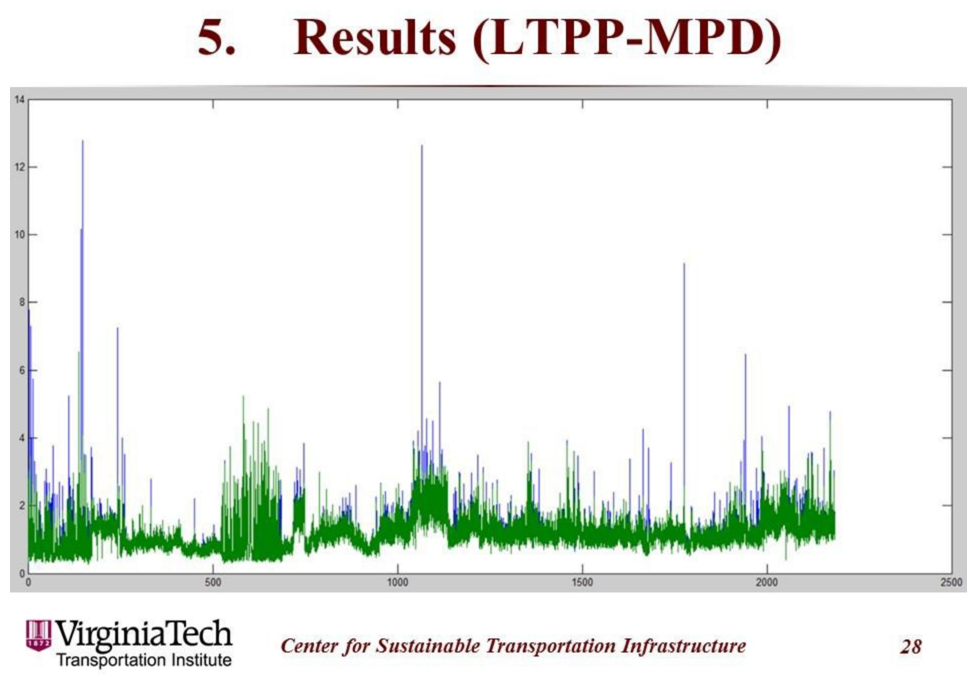


(a)

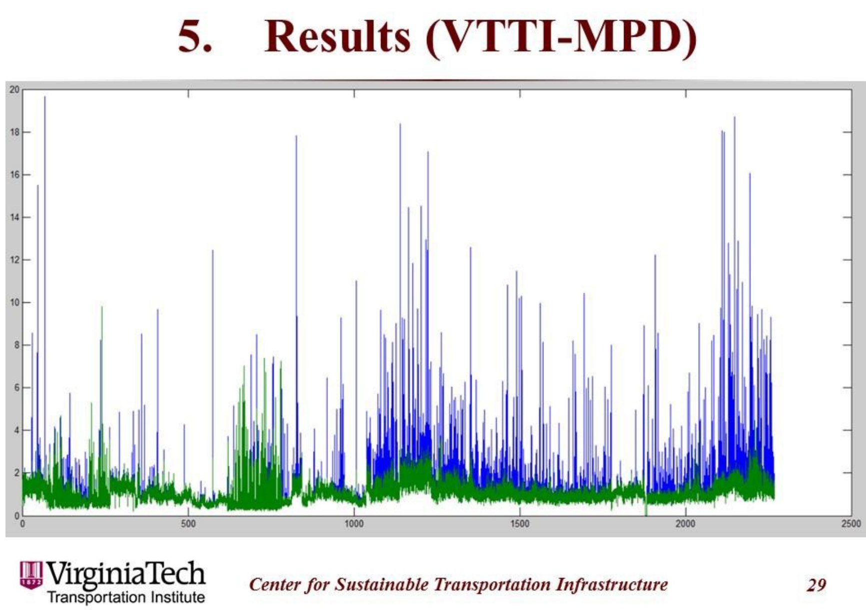


(b)

SLIDE 25



SLIDE 26



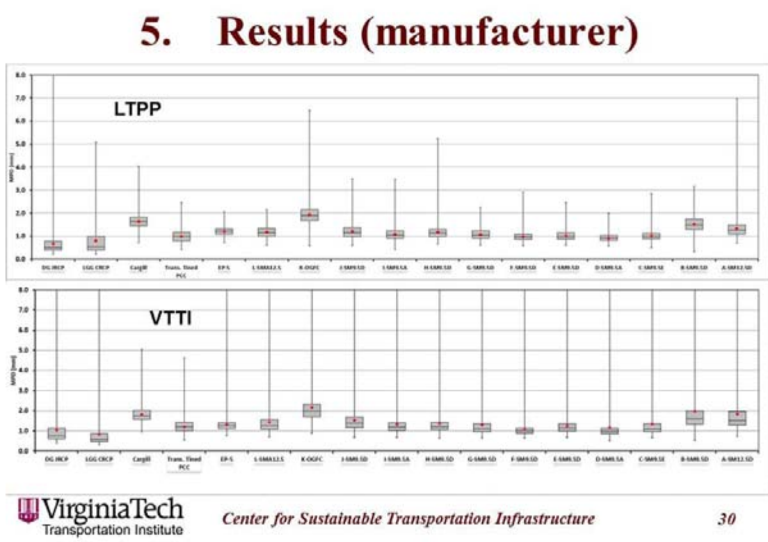
SLIDE 27

On Slide 26, the MPD results obtained with the LTPP profiler system are shown in blue for the MPD with spikes and in green after despiking.

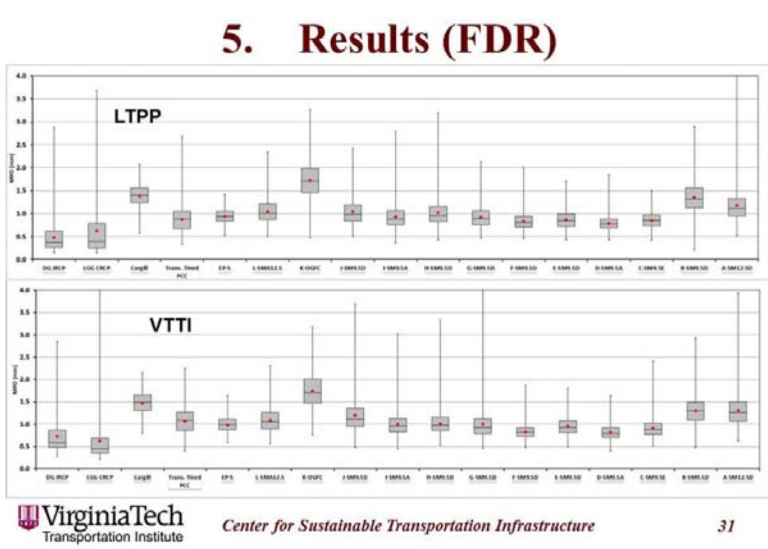
Similarly, the MPD results obtained with the VTTI profiler system are shown, in blue for the MPD with spikes and in green after de-spiking (Slide 27). It is clear looking at Slides 26 and

27 that the VTTI profiler not only had more spikes, but they are also much larger in magnitude. However, both of the green MPD results are very close and very similar in magnitude, especially the mean, median and quartile values, as evident in the next slides (Slides 28 and 29).

On Slide 28, the MPD results for both the LTPP and the VTTI profiler systems are shown, using the manufacturer's software to compute the MPD values. These MPD values are very high in magnitude as shown by the box-plot diagrams, and have very high extreme values (around 6 mm for LTPP and more than 8 mm for VTTI) caused by the computations without de-spiking the data.



SLIDE 28

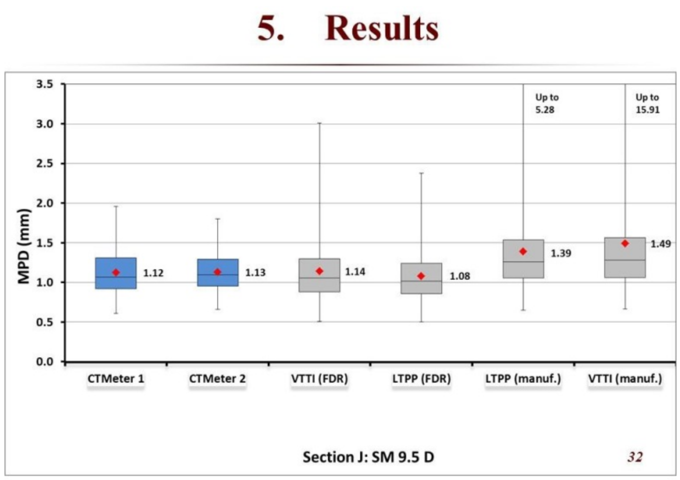


SLIDE 29

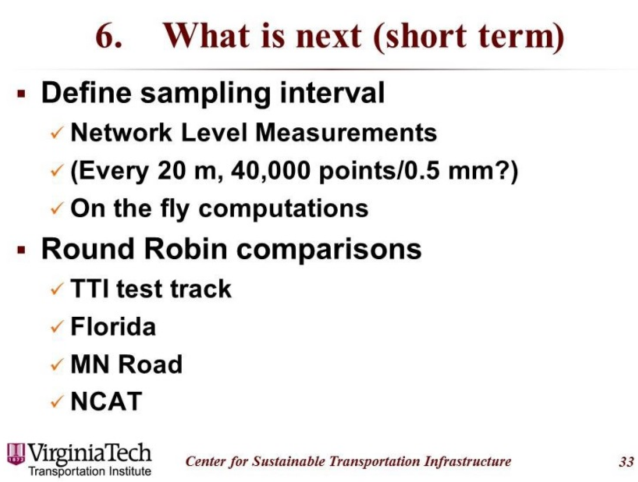
Using the FDR method for both data sets, some extreme values are still high for both MPD computations, but now the mean, median and quartile values are very similar for all sections computed (Slide 29). More importantly, both agree closely with the two CTM values. A closer comparison will be made of a particular section in the next slide (Slide 30).

On Slide 30, the MPD results for both the LTPP and the VTTI profiler systems are shown, comparing both with the manufacturer's software and the FDR method to compute the MPD values. As can be seen, both of the MPD results with the FDR method agree very well with the two CT Meter values, but not so if the manufacturer's software is used.

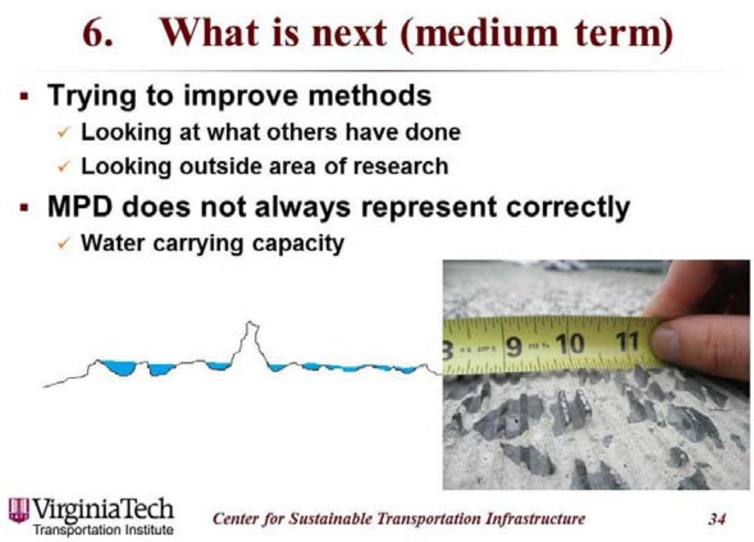
In the short term, our intention is to work with the manufacturer to incorporate the software and solve some of the questions about how to better perform network-level measurements with this equipment (Slide 31). It is expected that a national validation experiment will be made, hopefully with the support of FHWA and other interested parties in achieving, standardizing, and using accurate and reliable macrotexture data.



SLIDE 30



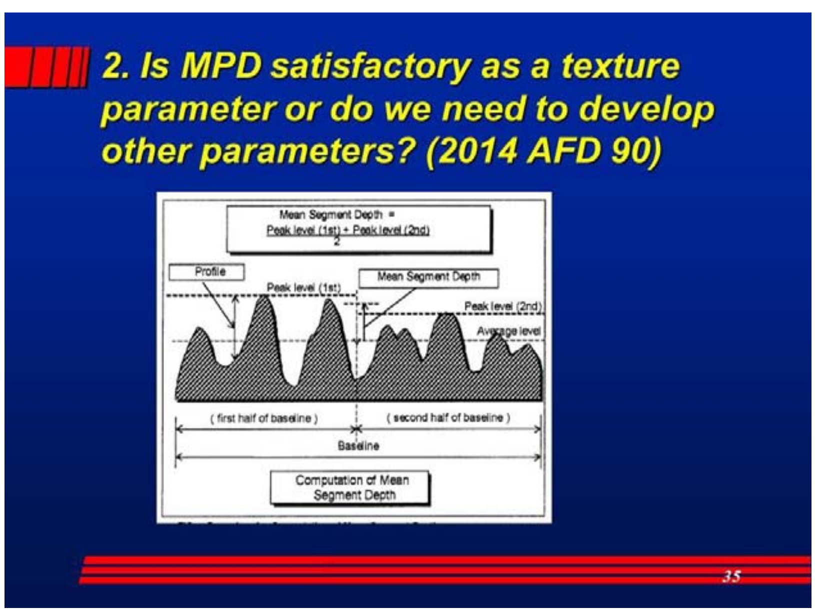
SLIDE 31



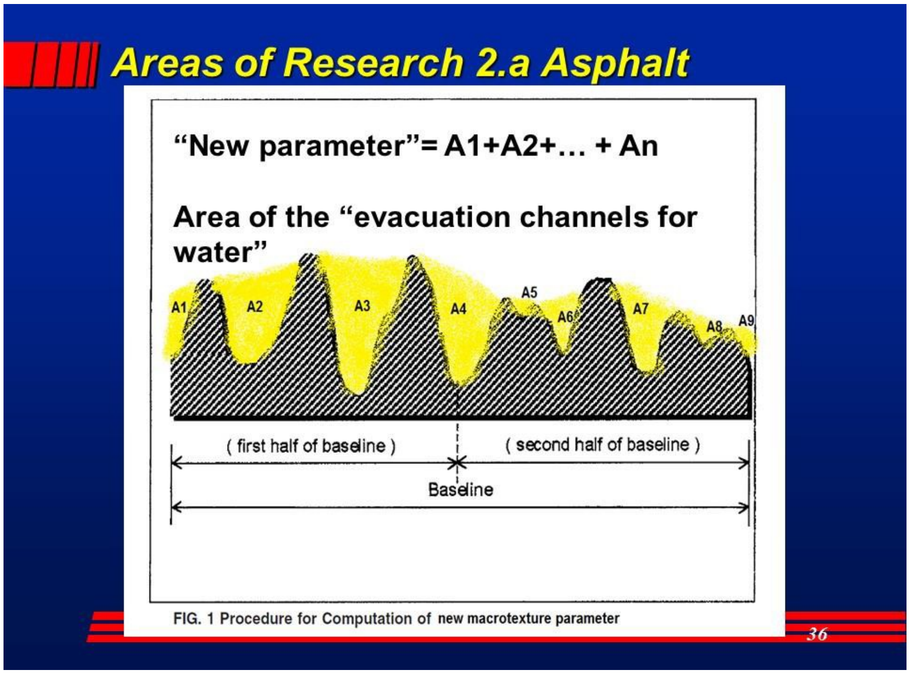
SLIDE 32

In the midterm, a proposal made in the TRB Surface Properties–Vehicle Interaction Committee has generated a research needs statement to further look into the topic of macrotexture (Slide 32). One of the tasks will be looking into the replacement of the MPD as the best index to use to characterize the macrotexture of a pavement. Some of the ideas that Task Force 3 presented in the January 2014 meeting presented a couple of ideas such as the integration of the available areas of the surface that are used as the channels of water for its evacuation in the presence of the tire rolling over it.

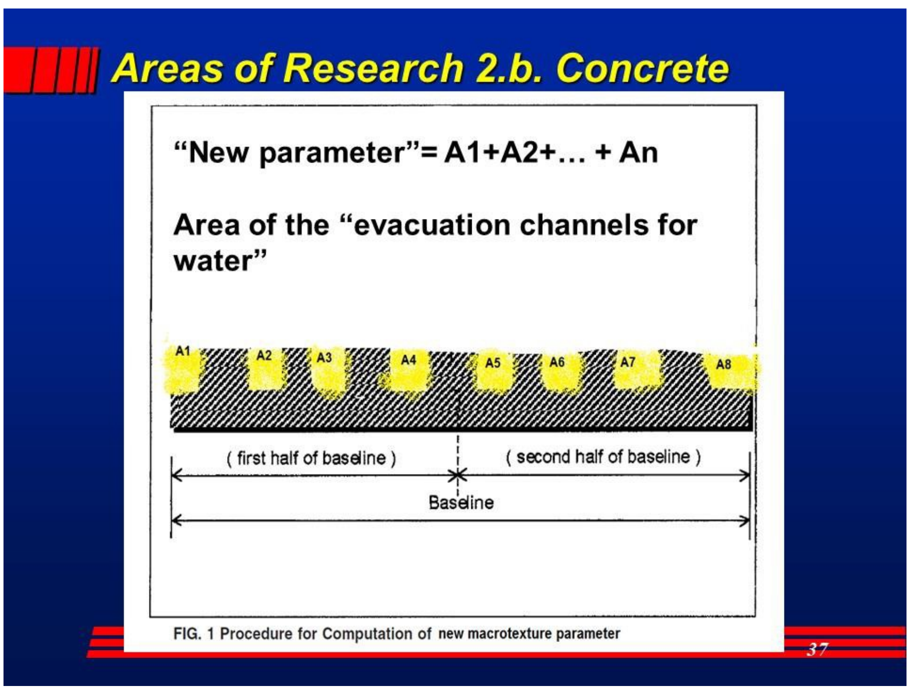
Slides 33 and 34 show very crude representations of this concept that will be refined in the next two slides (Slides 35 and 36).



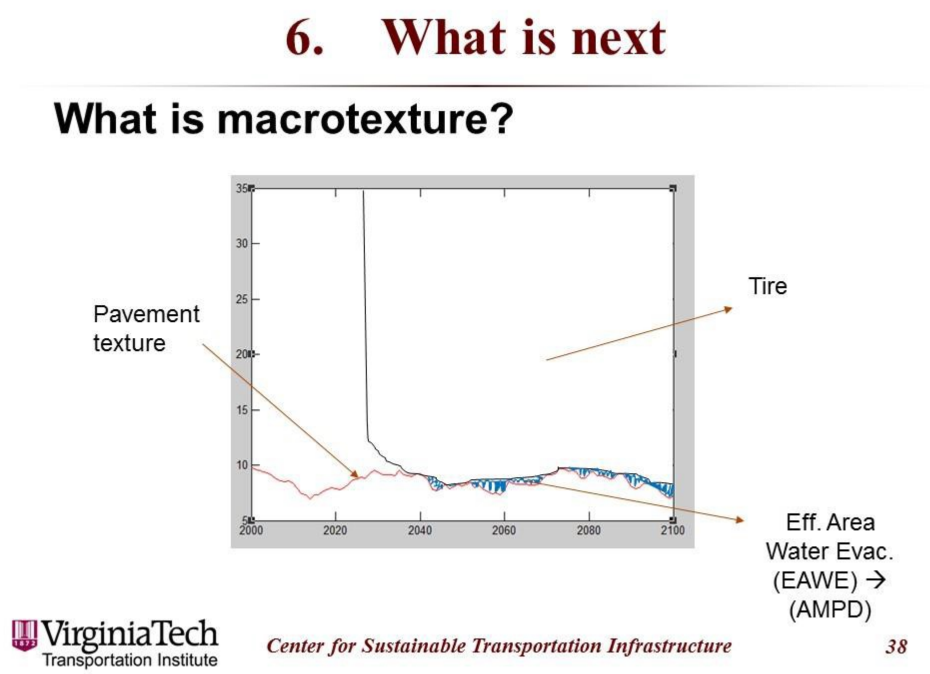
SLIDE 33



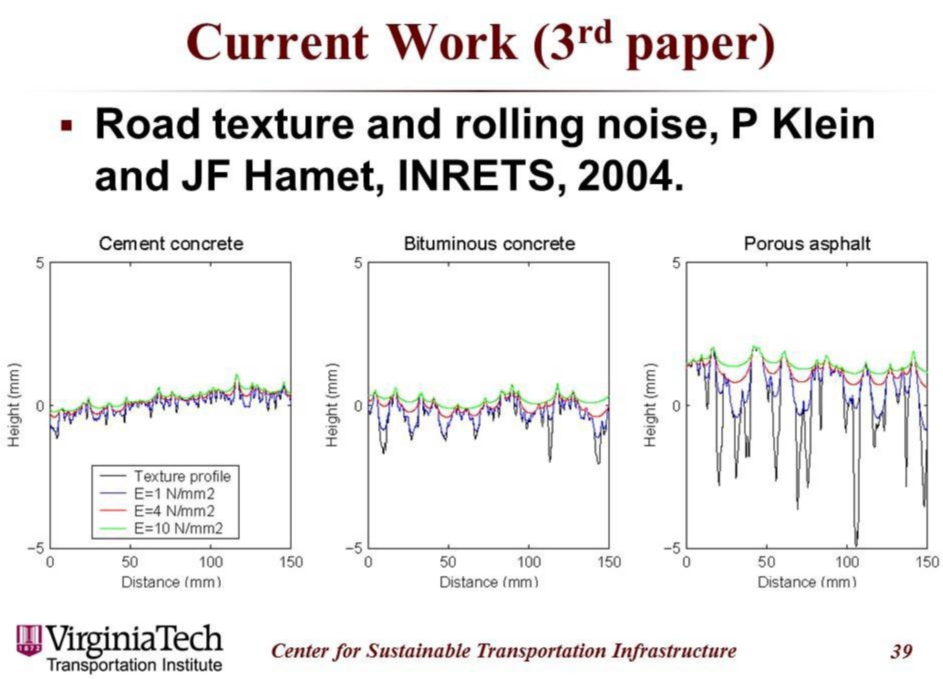
SLIDE 34



SLIDE 35



SLIDE 36



SLIDE 37

Slides 36 and 37 show a conceptual approach to the integration of the area next to the surface of the pavement limited by the tire passing over it, effectively squeezing the water out of its path so that the contact allows braking, cornering, or any other maneuver the vehicle needs to make. If the water is not removed, hydroplaning potential might occur with implicit accident possibilities. Work done by the French National Institute for Transport and Safety Research in 2004 using different stiffness rubber illustrates what could be modeled with the different areas of water evacuation channels made available by the macrotexture of the pavement.

Currently, we are also looking into similar work done with the enveloped profile as an alternative (Von Meier, Van Blockland, and Descornet). It is our hope that more support can be found to further the exploration of this topic with potential benefits in so many areas.

New and Improved ISO Standards for Pavement Texture Measurements

ULF SANDBERG
Swedish National Road and Transport Research

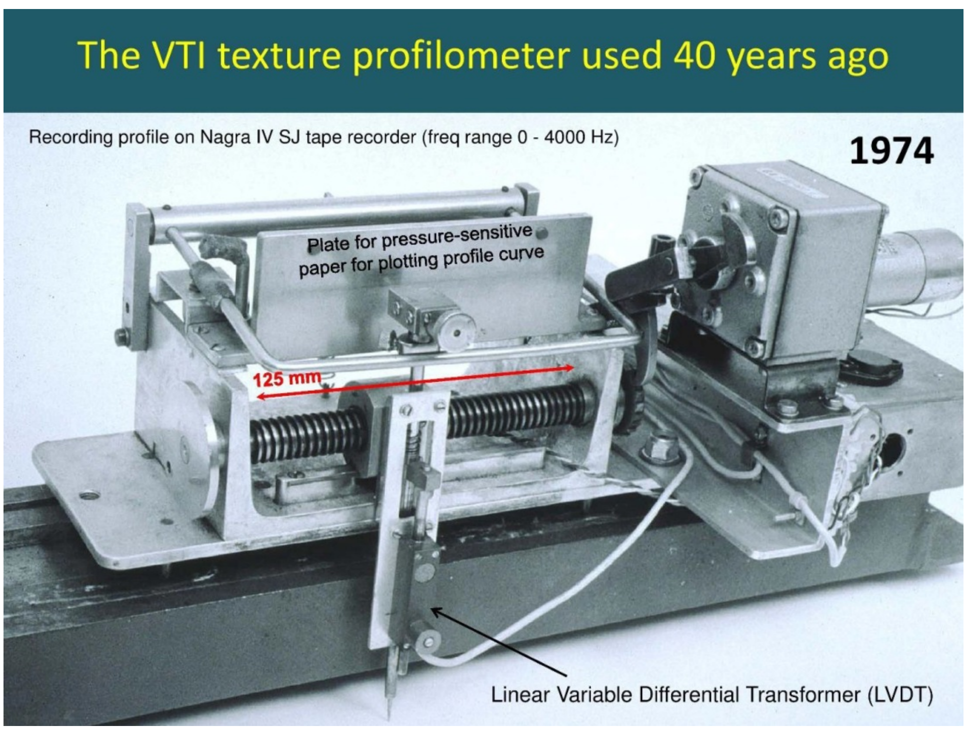
The possibly most commonly applied standard worldwide for pavement texture measurements is ISO 13473-1:1997 which defines a standard for measurement of mean profile depth (MPD). This standard was developed by a working group within the International Standardization Organization (ISO) designated ISO/TC 43/SC 1/WG 39. The working group (WG) 39 is presently busy with revising the standard, and this presentation intends to give an up-to-date report about the development as well as the background and justifications for it.

It was noted some years ago that measurements of MPD had poor reproducibility and the trend was that greater and greater deviations between different equipment were identified, and some measurement results even seemed to be out of a reasonable range. The WG started to analyze the problem and soon found that in some cases not all parts of the standard had been observed; for example, the requirement to filter the profile signal from irrelevant high-frequency content. In other cases, it appeared that some options allowed in the standard gave too high deviations. But most of all it appeared that the users had required much higher performance from the profilometers (in practice the laser sensors) than they were able to deliver in the application for MPD measurements, i.e., too-high measurement speeds, too-high standoff between sensor and pavement, and too-high measurement range. The combination of all problems created more irrelevant "spikes" (transients) in the profile signal and more noise than the standard would allow for acceptable uncertainty.

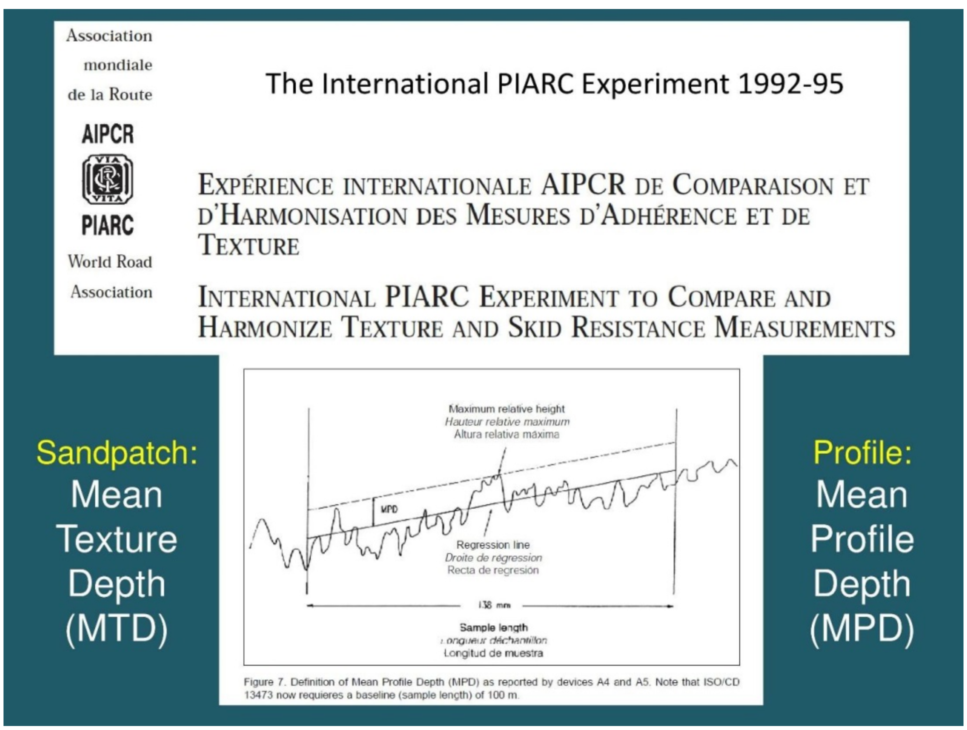
WG 39 thus undertook to improve the standard 13473-1 at the same time as developing a technical specification for verification of the performance of profilometers based on laser sensor technology. The improvement of the ISO 13473-1 included several data-enhancing procedures, such as a slightly modified definition of how MPD is calculated, a procedure to identify and remove spikes in the profile, and removal of certain options, i.e., alternatives in the calculations. Much better specification of low pass and high pass filters limiting the high-frequency performance and sharpness of peaks in the profile. Tightening of tolerances in certain performances.

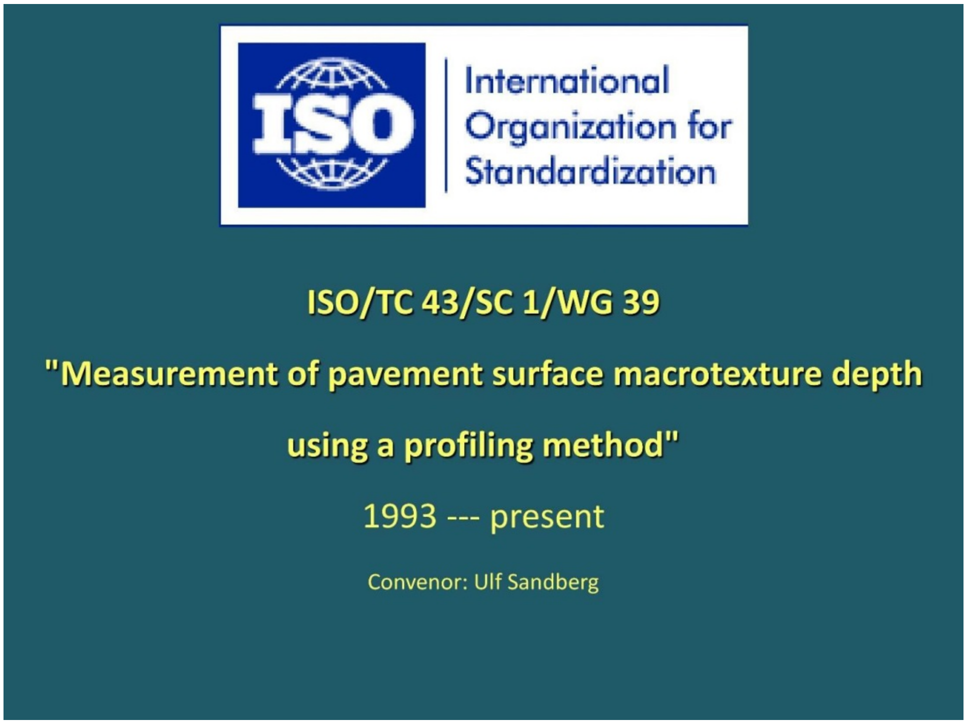
The presentation gives much more information about the above. Simulations and tests made on existing data have verified that substantial improvements are possible with the best techniques and procedures. The draft has also been reviewed by one of the major users of the standards. The new version has been submitted as a committee draft for ballot among the ISO member bodies, which resulted in an approval as a Draft International Standard after considering the comments received in the ballot. The technical specification for verification of the performance of profilometers is still under development.

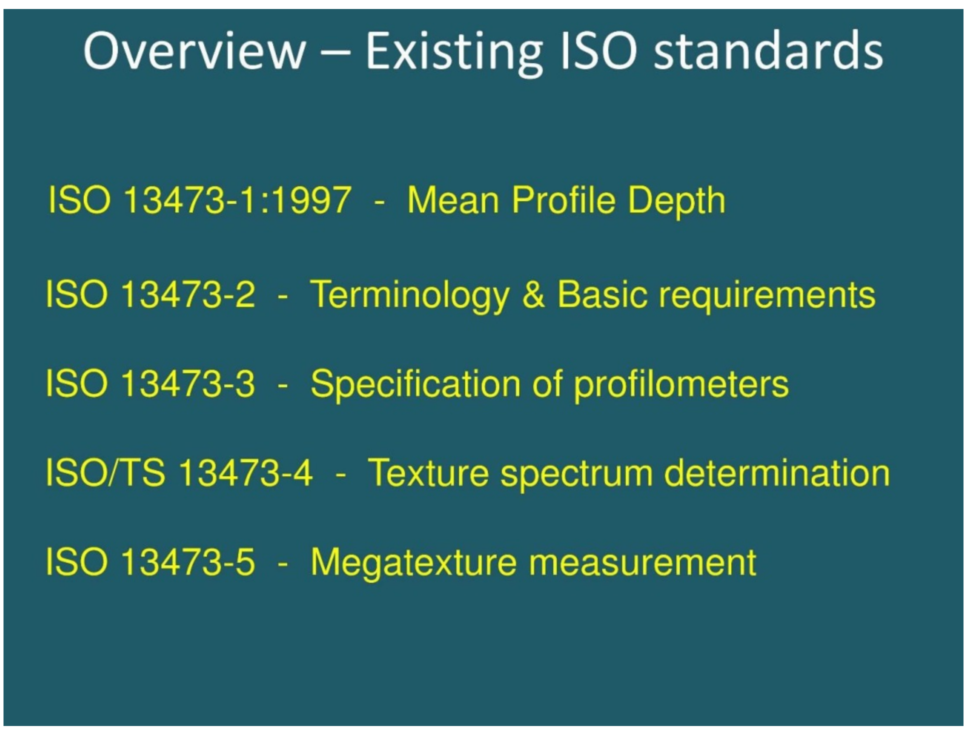

New and Improved ISO Standards
for Pavement Texture Measurements
Ulf Sandberg
Swedish National Road and Transport Research Institute (VTI)
Presented at the workshop ”International Experience and Perspective of Pavement Texture Measurements and Evaluation”
vti
TRB 94th Annual Meeting
January 11–15, 2015 Washington, D.C.


The VTI texture profilometer used 40 years ago
Recording profile on Nagra IV SJ tape recorder (freq range 0 - 4000 Hz)
1974
Plate for pressure-sensitive paper for plotting profile curve
125 mm
Linear Variable Differential Transformer (LVDT)


First sand patch → Volumetric patch
Then came laser profilometers
1979


Association mondiale de la Route
AIPCR
PIARC
World Road Association
The International PIARC Experiment 1992-95
EXPÉRIENCE INTERNATIONALE AIPCR DE COMPARAISON ET D'HARMONISATION DES MESURES D'ADHÉRENCE ET DE TEXTURE
INTERNATIONAL PIARC EXPERIMENT TO COMPARE AND HARMONIZE TEXTURE AND SKID RESISTANCE MEASUREMENTS
Sandpatch:
Mean Texture Depth (MTD)
Maximum relative height
Hauteur relative maximum
Altura relativa máxima
MPD
Regression line
Droite de régression
Recta de regresión
138 mm
Sample length
Longueur d'échantillon
Longitud de muestra
Figure 7. Definition of Mean Profile Depth (MPD) as reported by devices A4 and A5. Note that ISO/CD 13473 now requieres a baseline (sample length) of 100 m.
Profile:
Mean Profile Depth (MPD)


ISO
International Organization for Standardization
ISO/TC 43/SC 1/WG 39
"Measurement of pavement surface macrotexture depth using a profiling method"
1993 --- present
Convenor: Ulf Sandberg


Overview – Existing ISO standards
ISO 13473-1:1997 - Mean Profile Depth
ISO 13473-2 - Terminology & Basic requirements
ISO 13473-3 - Specification of profilometers
ISO/TS 13473-4 - Texture spectrum determination
ISO 13473-5 - Megatexture measurement

Status of the standards

ISO 13473-1:1997 - Mean Profile Depth

Under revision – First draft delivered for ballot

ISO 13473-2 - Terminology & Basic requirements

ISO 13473-3 - Specification of profilometers

Published and valid, but will be revised when time permits

ISO/TS 13473-4 - Texture spectrum determination

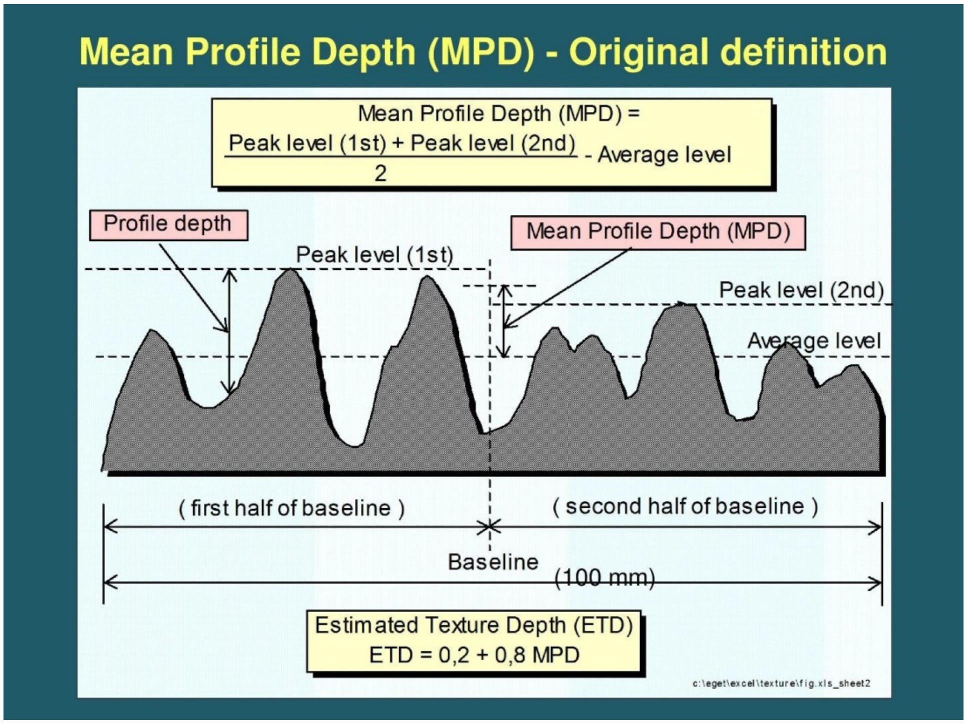
Published and valid, but is next in line for revision

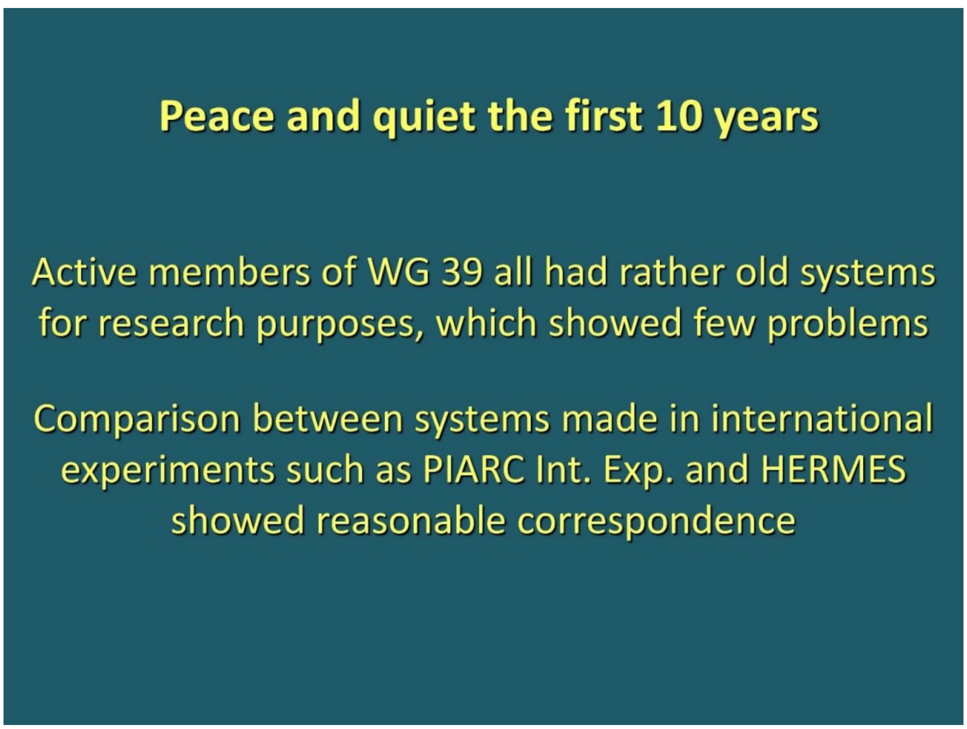
May in next version include PSD for unevenness range too ??

ISO 13473-5 - Megatexture measurement

Published and valid, recently confirmed

ISO 13473-1:1997 Characterization of pavement texture by use of surface profiles - Part 1: Mean Profile Depth


Mean Profile Depth (MPD) - Original definition
Mean Profile Depth (MPD) =
Peak level (1st) + Peak level (2nd)
2
- Average level
Profile depth
Peak level (1st)
Mean Profile Depth (MPD)
Peak level (2nd)
Average level
(first half of baseline)
(second half of baseline)
Baseline
(100 mm)
Estimated Texture Depth (ETD)
ETD = 0,2 + 0,8 MPD
c:\eget\excel\texture\fig.xls_sheet2


Peace and quiet the first 10 years
Active members of WG 39 all had rather old systems for research purposes, which showed few problems
Comparison between systems made in international experiments such as PIARC Int. Exp. and HERMES showed reasonable correspondence

Observations some years ago:

New laser systems acquired did not give same texture values as old system
(example: LCPC, France)

Annual comparison of Spanish texture measurement systems (”national calibration”) showed very high differences between systems

A few commercial laser profilometer systems appeared to give totally unrealistic MPD values and profiles with lots of ”spikes”

Identified causes for the problems (2009-2010)

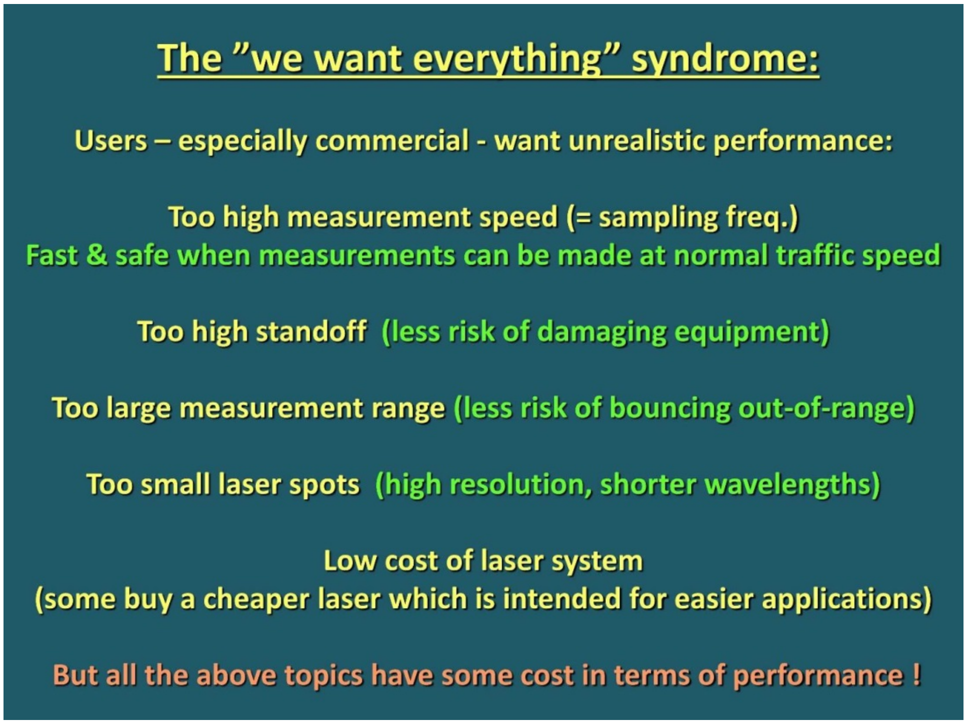
In many cases low-pass filters had not been used
This has caused too high background noise at higher frequencies

There were sometimes or often ”spikes” in the signal, due to insufficient dropout detection
This was manifested as high background noise at higher frequencies

At least in one major case a laser system was used which is unsuitable for pavement texture analysis (has no regulation of laser power)

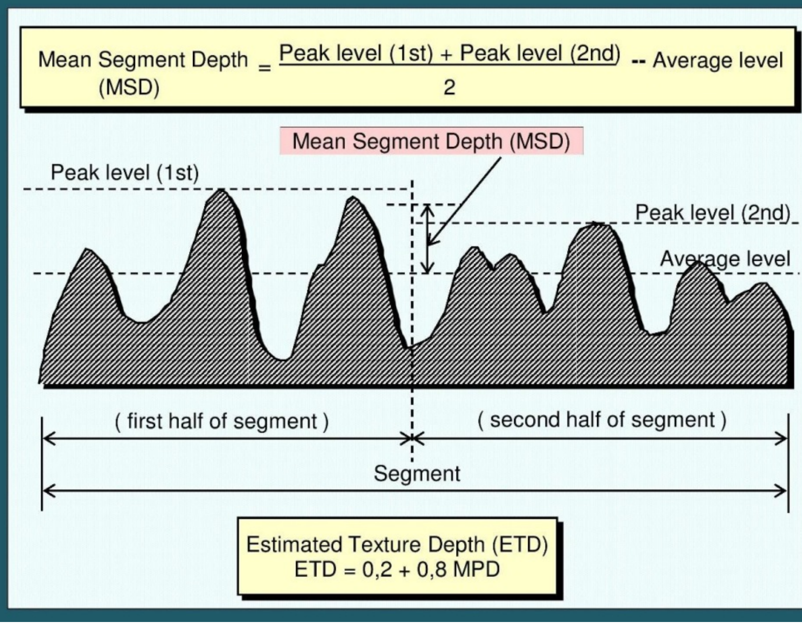
In some cases irrelevant disturbing signals had partly or totally obscured the real texture

The laser spot size varied too much within large measuring ranges


The ”we want everything” syndrome:
Users – especially commercial - want unrealistic performance:
Too high measurement speed (= sampling freq.)
Fast & safe when measurements can be made at normal traffic speed
Too high standoff (less risk of damaging equipment)
Too large measurement range (less risk of bouncing out-of-range)
Too small laser spots (high resolution, shorter wavelengths)
Low cost of laser system
(some buy a cheaper laser which is intended for easier applications)
But all the above topics have some cost in terms of performance !


This resulted in two major actions:
Revision of the MPD standard to improve data quality
Development of a verification procedure for contactless profilometers

Mean Profile Depth (MPD) – New terminology



Remove the freedom to choose some procedures:

~~Slope suppression~~ - Highpass filtering (minimize phase distortion)

Limit profile sampling options

Normalize profile sharpness

Specify the use of lowpass filtering better (minimize phase distortion and overshoot)

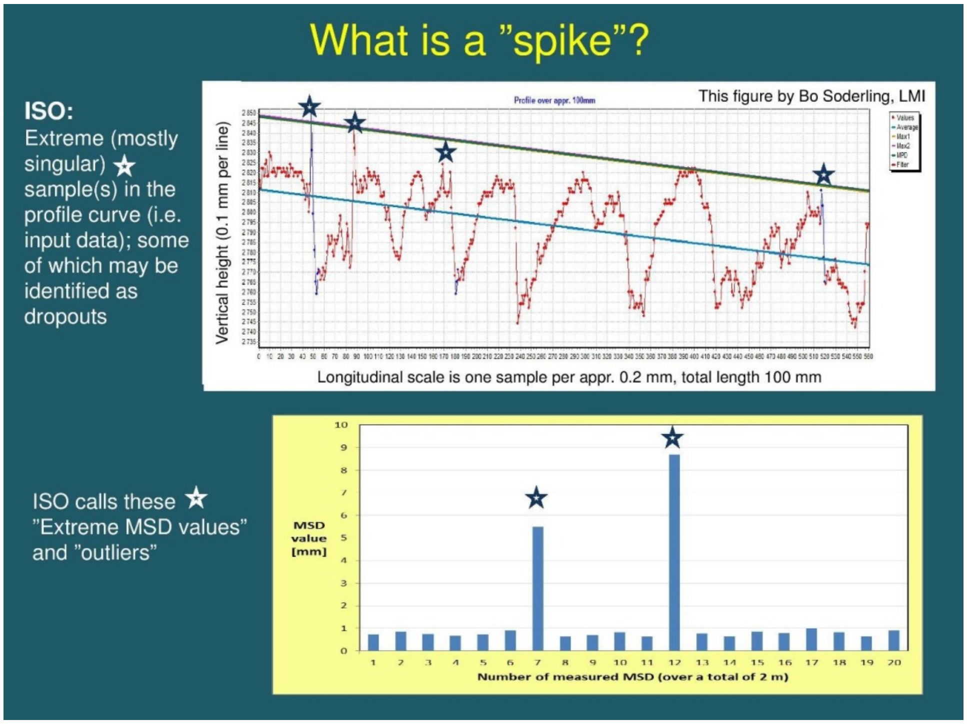
Introduce a number of data quality enhancements

Data quality-enhancing procedures

#	Purpose	Method	Mandatory or optional	Domain	Notes
1a	Drop-out detection	Detection of drop-outs, due to low received laser light	Mandatory	Time (made in hardware)	
1b	Drop-out correction	Linear or pchip interpolation between the adjacent valid samples		Time (software)	
2	Maximum use of measured data	Re-sampling (to at least 0.5 mm and at most 1 mm spacing; prefer 0.5 mm if the system allows it)	Mandatory where applicable	Time to space (software)	Calculate arithmetic average of all samples that fall within the required spacing
3a	Spike identification & reshape profile	Identify spikes, according to Goubert's description in N138	Mandatory	Space (software)	Effect quite small (compared to # 6 below)
3b	Spike identification & reshape profile	Linear or pchip interpolation			May be needed only on critical surfaces, but as it is an "easy" procedure it may well be mandatory
5	Removal of long-wavelength components	High-pass filtering: 2nd order Butterworth, cut-off at 140 mm (for continuous data) or slope suppression (for discrete data)	Mandatory	Space (software)	Removes effect of vehicle bounce and uneven roads
6	Normalization of profile sharpness	Low-pass filtering: 2nd order Butterworth, cut-off at 3 mm	Mandatory	Space (software)	Removes effect of noise, laser spot size & spikes
7	Extreme MSD value removal	Identification of MSD outliers & removal by 3-points median filter	Optional	Post-processing	Only for MSD values, not used when extreme features are of interest

Data quality-enhancing procedures

#	Purpose	Method	Mandatory ?	Domain	Notes
1a	Drop-out detection	Detection of drop-outs, due to low received laser light	Mandatory	Time (made in hardware)	
1b	Drop-out correction	Linear or pchip interpolation between the adjacent valid samples		Time (software)	
2	Maximum use of measured data	Re-sampling (to at least 0.5 mm and at most 1 mm spacing; prefer 0.5 mm if the system allows it)	Mandatory where applicable	Time to space (software)	Calculate arithmetic average of all samples that fall within the required spacing
3a	Spike identification & reshape profile	Identify spikes, according to Goubert's description in N138	Mandatory	Space (software)	Effect quite small (compared to # 6 below)
3b	Spike identification & reshape profile	Linear or pchip interpolation			May be needed only on critical surfaces, but as it is an "easy" procedure it will be mandatory
5	Removal of long-wavelength components	High-pass filtering: 2nd order Butterworth, cut-off at 140 mm (for continuous data) or slope suppression (for discrete data)	Mandatory	Space (software)	Removes effect of vehicle bounce and uneven roads
6	Normalization of profile sharpness	Low-pass filtering: 2nd order Butterworth, cut-off at 3 mm	Mandatory	Space (software)	Removes effect of noise, laser spot size & spikes
7	Extreme MSD value removal	Identification of MSD outliers & removal by 3-points median filter	Optional	Post-processing	Only for MSD values, not used when extreme features are of interest



Data quality-enhancing procedures

#	Purpose	Method	Mandatory?	Domain	Notes
1a	Drop-out detection	Detection of drop-outs, due to low received laser light	Mandatory	Time (made in hardware)	
1b	Drop-out correction	Linear or pchip interpolation between the adjacent valid samples		Time (software)	
2	Maximum use of measured data	Re-sampling (to at least 0.5 mm and at most 1 mm spacing; prefer 0.5 mm if the system allows it)	Mandatory where applicable	Time to space (software)	Calculate arithmetic average of all samples that fall within the required spacing
3a	**Spike identification & reshape profile**	**Identify spikes, according to Goubert's description in N138**	**Mandatory**	**Space (software)**	**Effect quite small (compared to # 6 below)**
3b	**Spike identification & reshape profile**	**Linear or pchip interpolation**			**May be needed only on critical surfaces, but as it is an "easy" procedure it will be mandatory**
5	Removal of long-wavelength components	High-pass filtering: 2nd order Butterworth, cut-off at 140 mm (for continuous data) or slope suppression (for discrete data)	Mandatory	Space (software)	Removes effect of vehicle bounce and uneven roads
6	Normalization of profile sharpness	Low-pass filtering: 2nd order Butterworth, cut-off at 3 mm	Mandatory	Space (software)	Removes effect of noise, laser spot size & spikes
7	Extreme MSD value removal	Identification of MSD outliers & removal by 3-points median filter	Optional	Post-processing	Only for MSD values, not used when extreme features are of interest

Data quality-enhancing procedures

#	Purpose	Method	Mandatory?	Domain	Notes
1a	Drop-out detection	Detection of drop-outs, due to low received laser light	Mandatory	Time (made in hardware)	
1b	Drop-out correction	Linear or pchip interpolation between the adjacent valid samples		Time (software)	
2	Maximum use of measured data	Re-sampling (to at least 0.5 mm and at most 1 mm spacing; prefer 0.5 mm if the system allows it)	Mandatory where applicable	Time to space (software)	Calculate arithmetic average of all samples that fall within the required spacing
3a	Spike identification & reshape profile	Identify spikes, according to Goubert's description in N138	Mandatory	Space (software)	Effect quite small (compared to # 6 below)
3b	Spike identification & reshape profile	Linear or pchip interpolation			May be needed only on critical surfaces, but as it is an "easy" procedure it may well be mandatory
5	**Removal of long-wavelength components (slope)**	**High-pass filtering: 2nd order Butterworth, cut-off at 140 mm wavelength (for continuous data) or slope suppression (for discrete data)**	**Mandatory**	**Space (software)**	**Removes effect of vehicle bounce and uneven roads**
6	**Normalization of profile sharpness**	**Low-pass filtering: 2nd order Butterworth, cut-off at 3 mm**	**Mandatory**	**Space (software)**	**Removes effect of noise, laser spot size & spikes. Makes all systems similar**
7	Extreme MSD value removal	Identification of MSD outliers & removal by 3-points median filter	Optional	Post-processing	Only for MSD values, not used when extreme features are of interest

Data quality-enhancing procedures

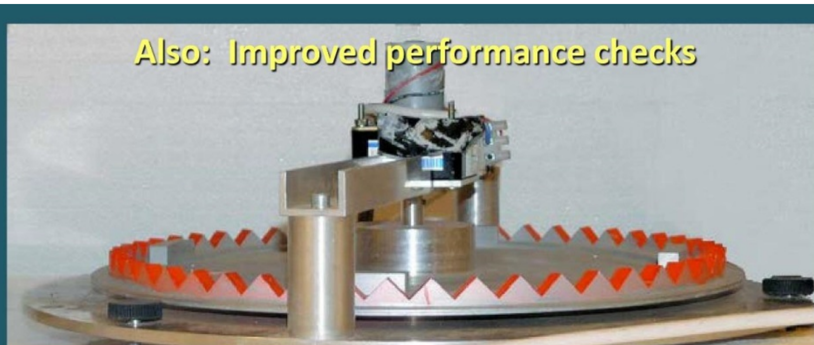
#	Purpose	Method	Mandatory?	Domain	Notes
1a	Drop-out detection	Detection of drop-outs, due to low received laser light	Mandatory	Time (made in hardware)	
1b	Drop-out correction	Linear or pchip interpolation between the adjacent valid samples		Time (software)	
2	Maximum use of measured data	Re-sampling (to at least 0.5 mm and at most 1 mm spacing; prefer 0.5 mm if the system allows it)	Mandatory where applicable	Time to space (software)	Calculate arithmetic average of all samples that fall within the required spacing
3a	Spike identification & reshape profile	Identify spikes, according to Goubert's description in N138	Mandatory	Space (software)	Effect quite small (compared to # 6 below)
3b	Spike identification & reshape profile	Linear or pchip interpolation			May be needed only on critical surfaces, but as it is an "easy" procedure it may well be mandatory
5	Removal of long-wavelength components	High-pass filtering: 2nd order Butterworth, cut-off at 140 mm (for continuous data) or slope suppression (for discrete data)	Mandatory	Space (software)	Removes effect of vehicle bounce and uneven roads
6	Normalization of profile sharpness	Low-pass filtering: 2nd order Butterworth, cut-off at 3 mm	Mandatory	Space (software)	Removes effect of noise, laser spot size & spikes
7	**Extreme MSD value removal**	**Identification of MSD outliers & removal by 3-points median filter**	**Optional**	**Post-processing**	**Only for MSD values, not used when extreme features are of interest**

Limiting performance

The standardized filtering means that we deliberately are limiting the high-frequency performance and sharpness of peaks that we can detect

Better to do so than getting non-comparable results from different equipment, and running at different speeds and conditions

In future revisions of the standard, the performance may be increased by changing the filter cutoff frequencies



Result

The new version should be free of the problems we have noticed. Repeatability and reproducibility should be substantially improved.

New MPD standard was submitted for ballot and comments in December 2014 (approved in March 2015)

Good meas. methods are absolutely necessary for defining and implementing functional requirements of pavements

Next task (already started) – develop:

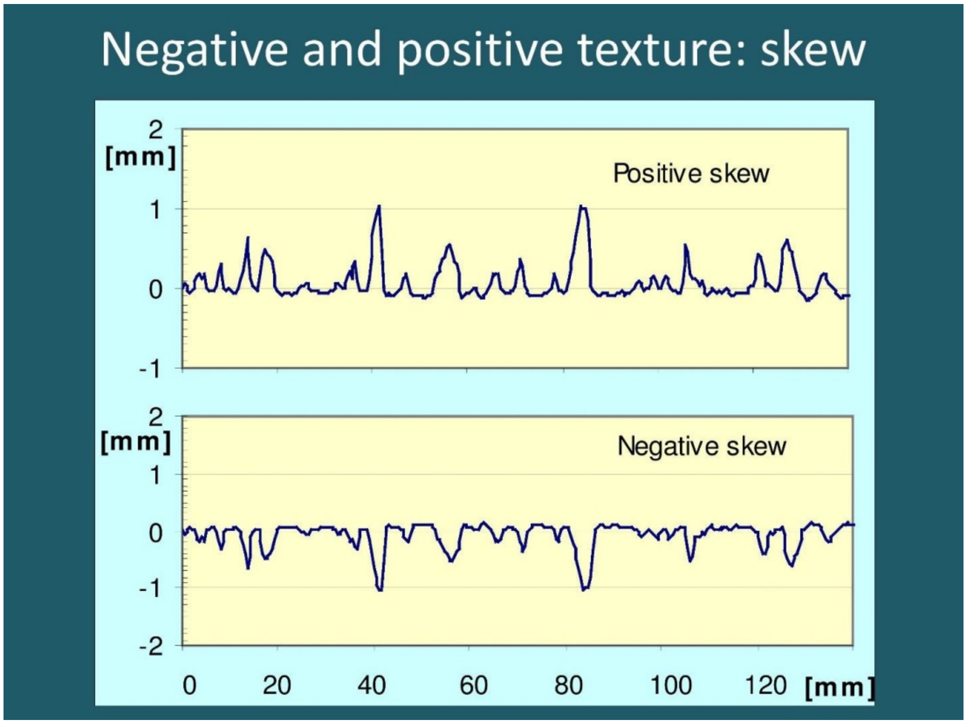
ISO/PAS 13473-6 – Verification procedure for contactless sensors

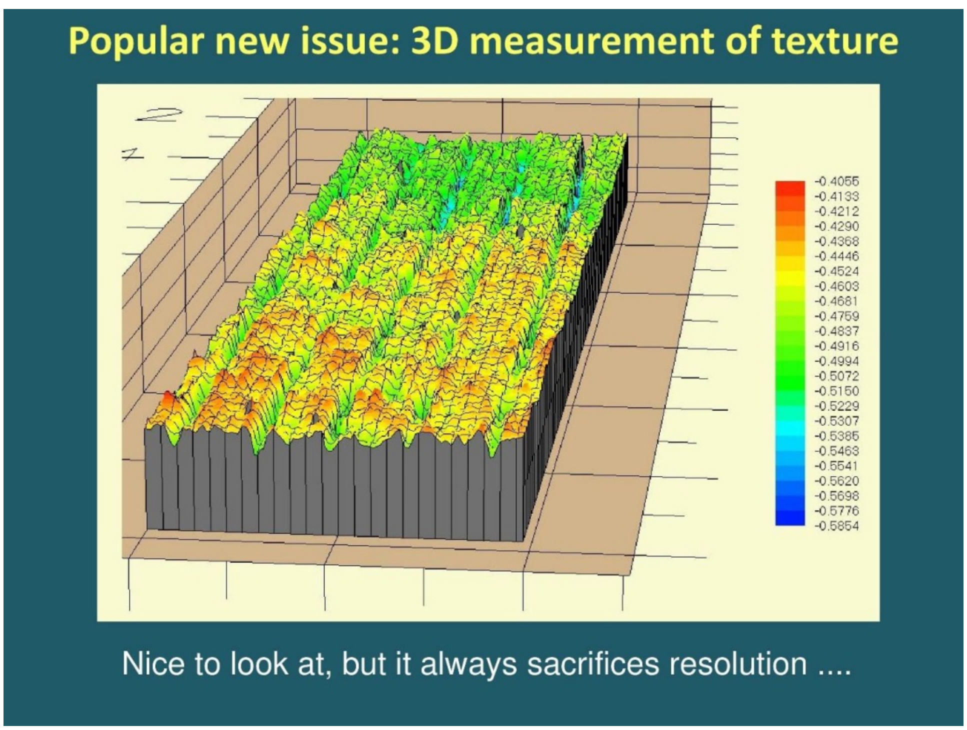
EU project:

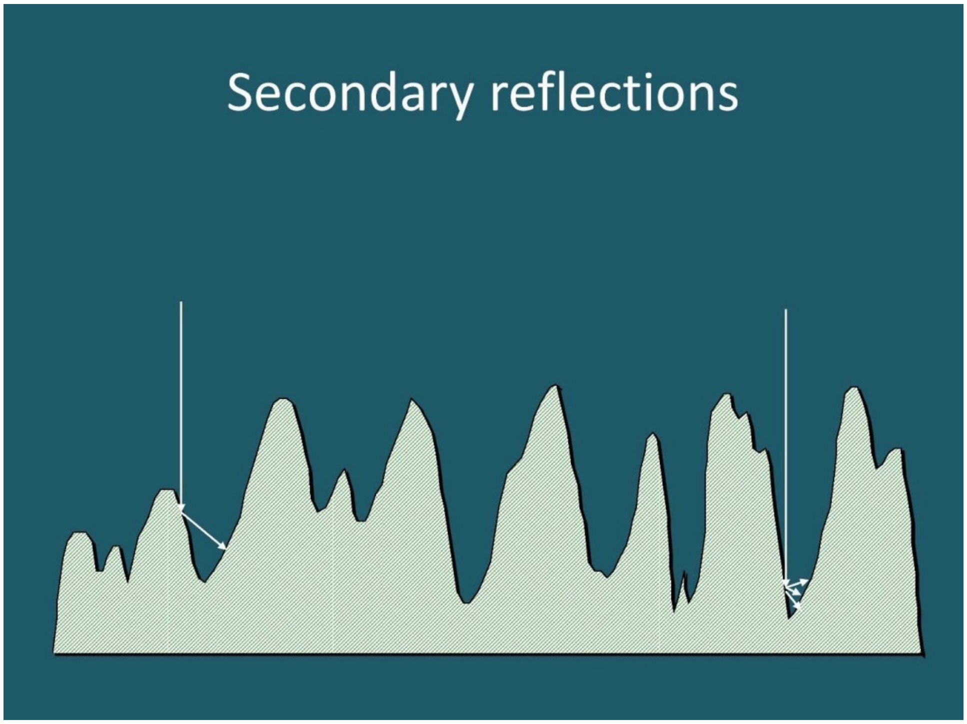
ROlling resistance, Skid resistance, ANd Noise Emission measurement standards for road surfaces

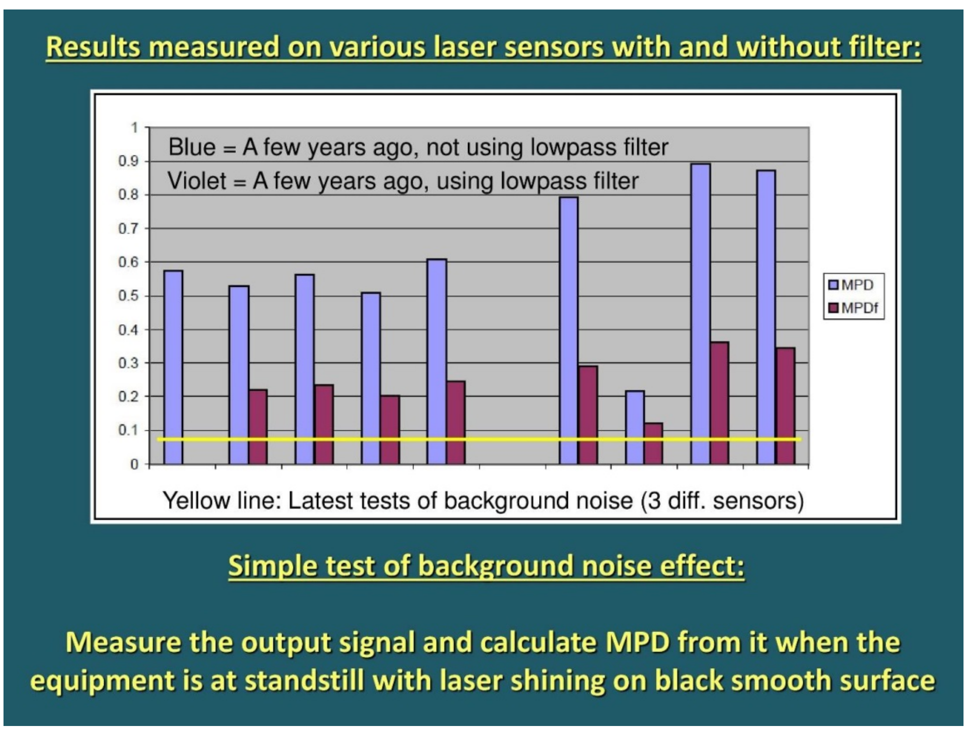
One WP/Task about texture (pre-normative research):

- Comparison of texture measuring equipment
- Is 3D profiling justified (correlation with functional properties)?
- Enveloping (limiting profile to tire-pavement contact)
- Can we find better or supplementing texture descriptors?
- Profiling with finer resolution (bordering microtexture)

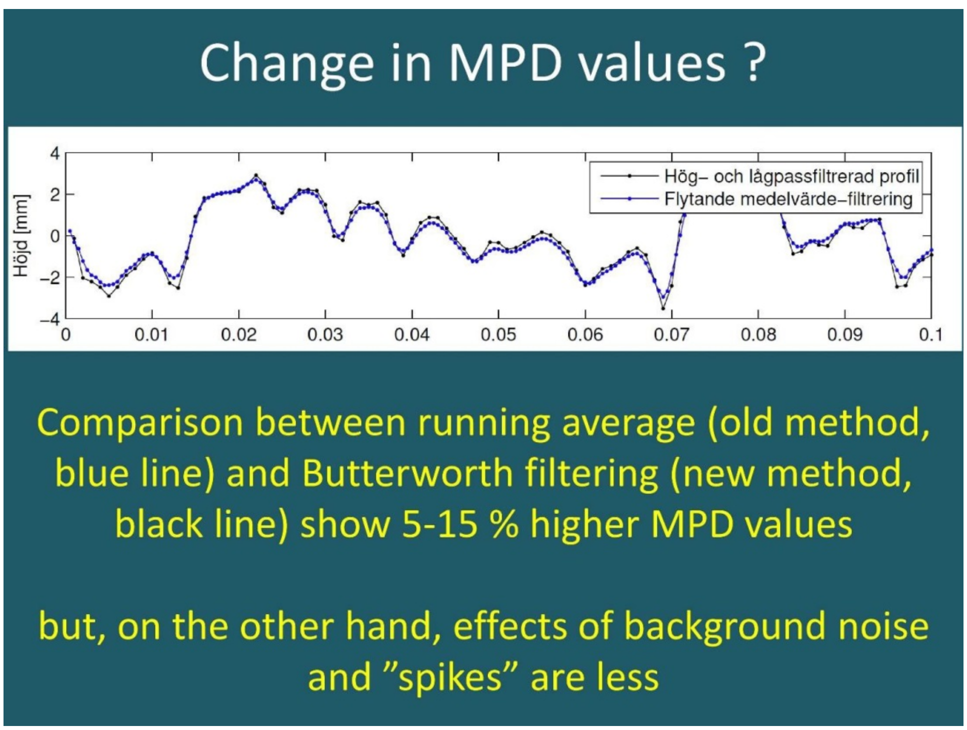

Negative and positive texture: skew
Positive skew
Negative skew
[mm]
[mm]
2
1
0
-1
-2
0
20
40
60
80
100
120
[mm]


Popular new issue: 3D measurement of texture
-0.4055
-0.4133
-0.4212
-0.4290
-0.4368
-0.4446
-0.4524
-0.4603
-0.4681
-0.4759
-0.4837
-0.4916
-0.4994
-0.5072
-0.5150
-0.5229
-0.5307
-0.5385
-0.5463
-0.5541
-0.5620
-0.5698
-0.5776
-0.5854
Nice to look at, but it always sacrifices resolution ....


Secondary reflections


Results measured on various laser sensors with and without filter:
Blue = A few years ago, not using lowpass filter
Violet = A few years ago, using lowpass filter
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
MPD
MPDf
Yellow line: Latest tests of background noise (3 diff. sensors)
Simple test of background noise effect:
Measure the output signal and calculate MPD from it when the equipment is at standstill with laser shining on black smooth surface

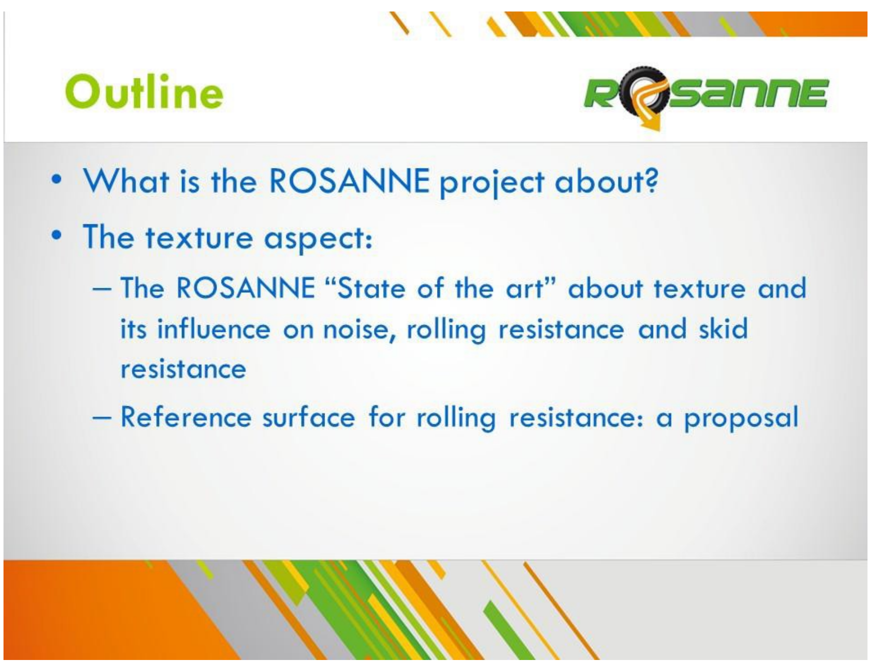

Water covering part of the texture


Change in MPD values ?
Höjd [mm]
Hög– och lågpassfiltrerad profil
Flytande medelvärde–filtrering
4
2
0
−2
−4
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Comparison between running average (old method, blue line) and Butterworth filtering (new method, black line) show 5-15 % higher MPD values
but, on the other hand, effects of background noise and ”spikes” are less


The end

Rolling Resistance, Skid Resistance, and Noise Emission Measurement Standards for Road Surfaces

Luc Goubert
Belgian Road Research Centre. Belgium



NEGOTIATION PHASE

FP7 Coordinated Action

Coordinated Action

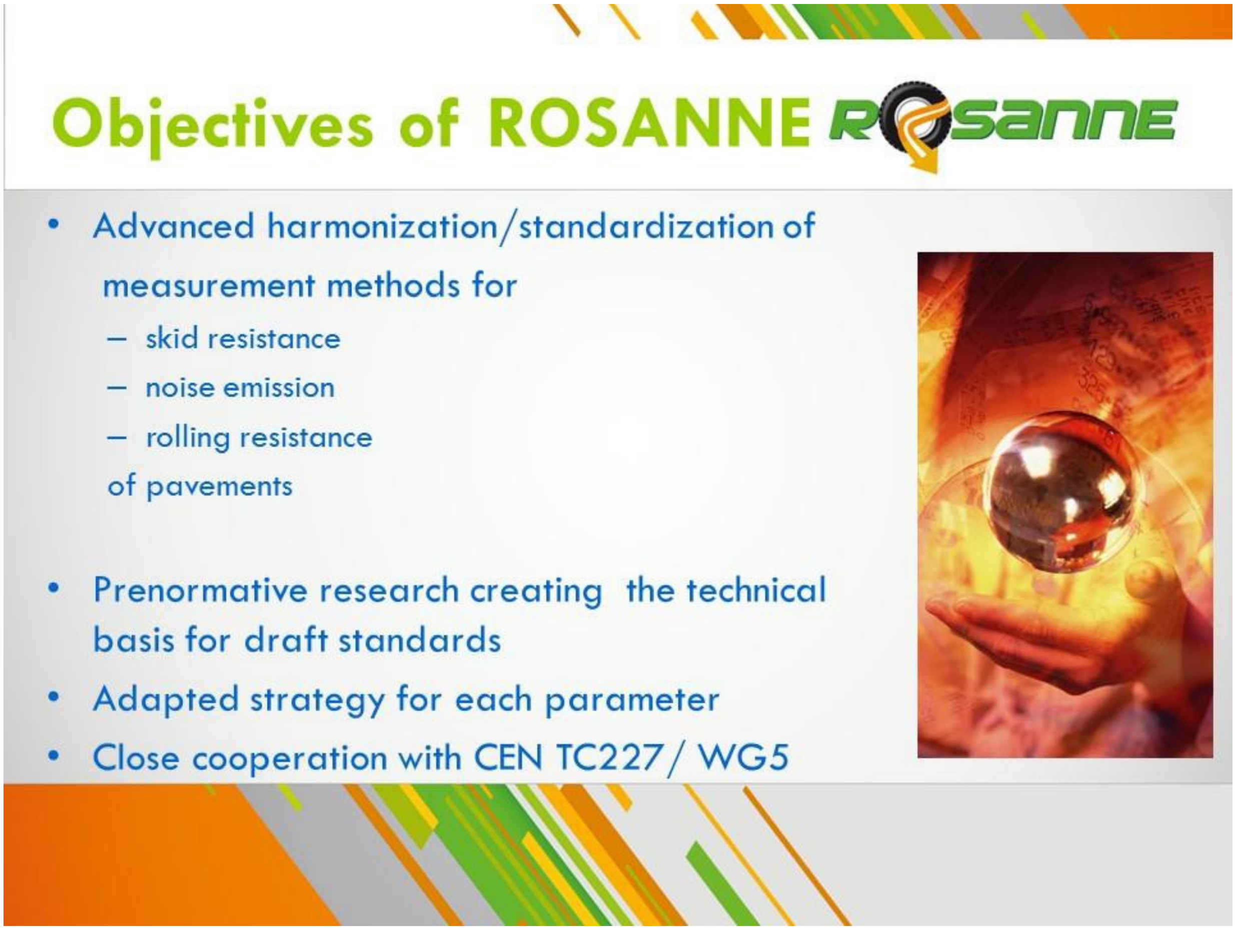
No research issues are possible; gathering and analyzing existing knowledge, recommending future research issues, recommending coordinated approaches on certain issues, organizing workshops, conferences, personnel exchange.

Consortium

Arsenal research (Austria), BASt (Germany), LCPC (France), RWS-DVS (The Netherlands), TRL (UK), ZAG (Slovenia), FEHRL (Belgium).

Forum of European Highway Research Laboratories

Twenty-nine members (transport research institutes) of different European countries; formed task forces to work on certain important issues; not performing research on issues themselves but developing project ideas for pushing research issues forward; consortium: participants of the FEHRL task force, skidding resistance + one partner from the NMS + FEHRL. Duration: 2 years approximately 1.1 MEUR total. Expected starting date: July 1, 2008.

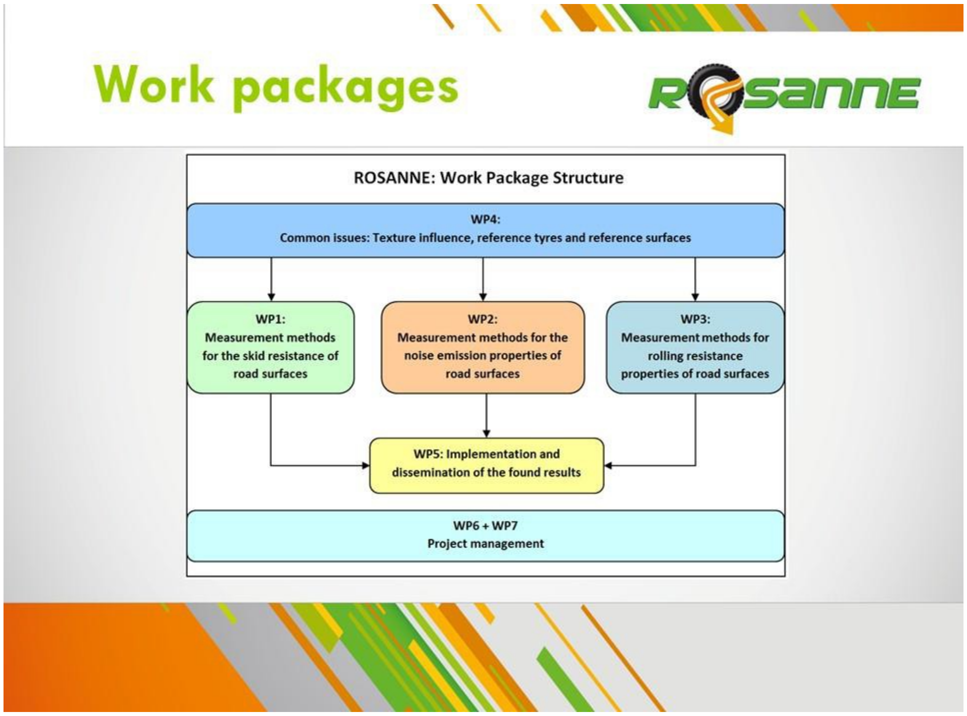


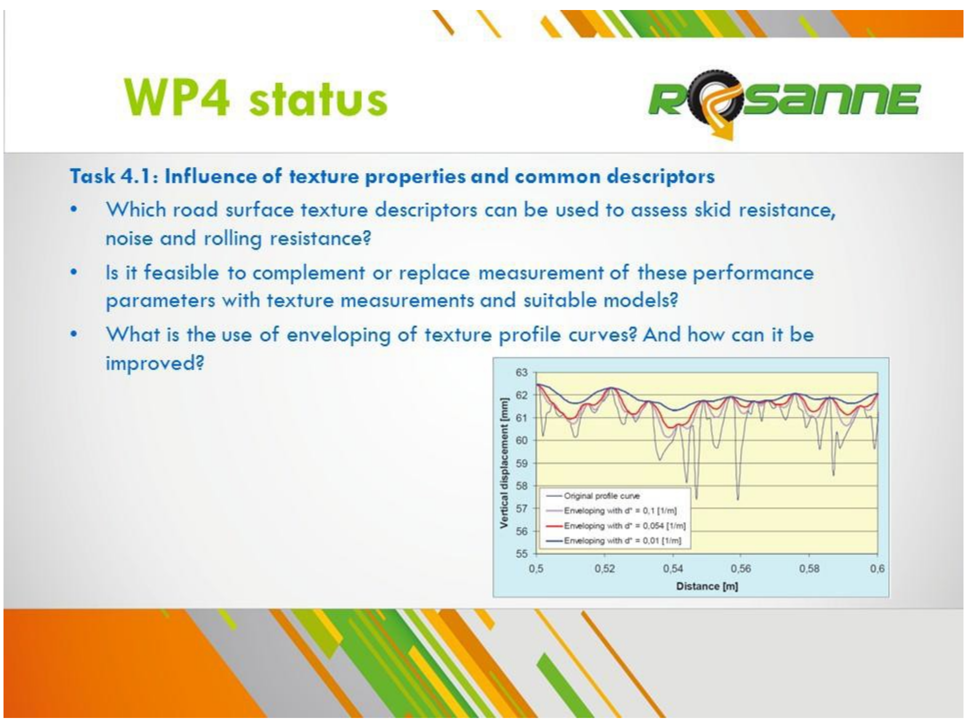
Setting up a platform and organizing workshops–expert working groups (Milestones M1.1, M1.2, M2.1, M3.2, M4.1, M5.5) to network with past, current, and future research activities on skid resistance, rolling resistance, and noise emissions (M5.3 and M5.4). To collect and share existing knowledge about these issues (M5.2) and to raise awareness concerning the safety relevance and greening influence of road surface parameters (Deliverables D5.1, D5.3).

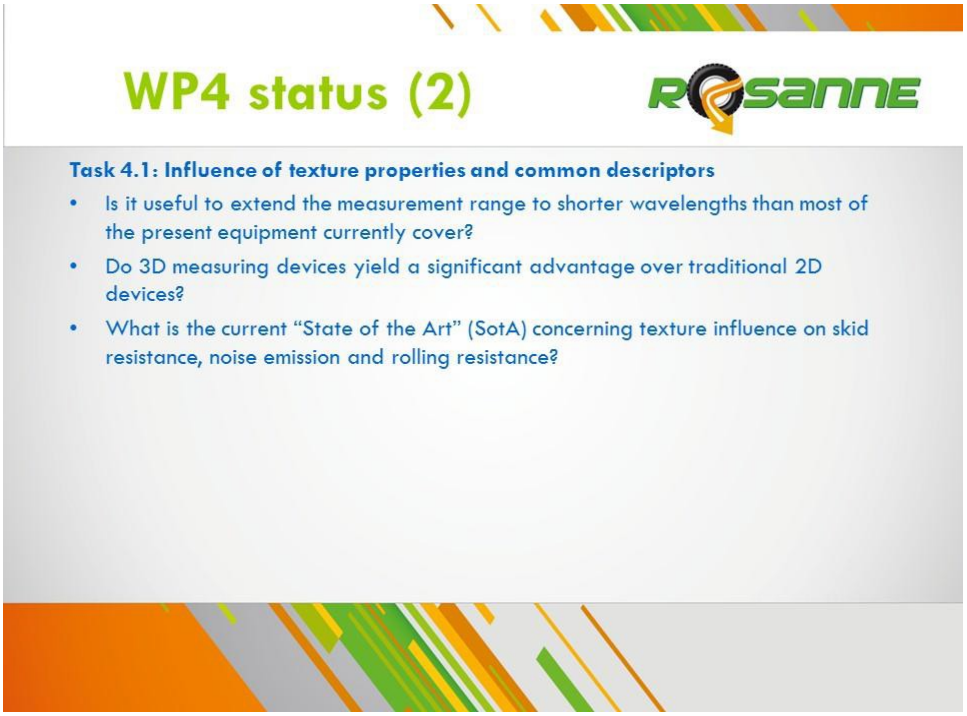
Studying national standards–policies of different European Union and neighboring countries concerning skid resistance, rolling resistance, and noise emissions; to document current practice in European Union countries; and to provide recommendations for a common European policy on skid resistance, rolling resistance, and noise emissions (M1.3).

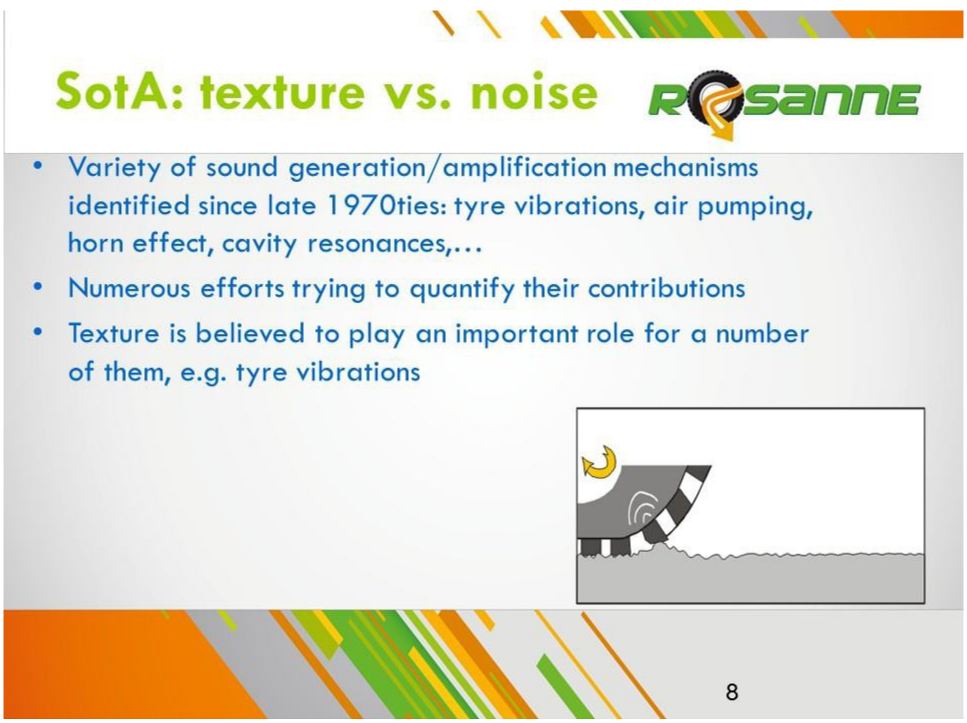
Developing a road map or an implementation plan including specific stages for the short, medium, and longer term (2010, 2015, 2020) towards the final harmonization of skid resistance test methods and reference surfaces based on research work (M2.5).

Creating one or more matrices showing interdependencies and environmental effects of the factors that influencing road surfaces and tires in relation to skid resistance, rolling resistance, and noise emissions. This matrix will allow knowledge gaps to be identified and indicate the need for future research work (M3.1).


Work packages
ROSANNE
ROSANNE: Work Package Structure
WP4:
Common issues: Texture influence, reference tyres and reference surfaces
WP1:
Measurement methods for the skid resistance of road surfaces
WP2:
Measurement methods for the noise emission properties of road surfaces
WP3:
Measurement methods for rolling resistance properties of road surfaces
WP5: Implementation and dissemination of the found results
WP6 + WP7
Project management


WP4 status
ROSANNE
Task 4.1: Influence of texture properties and common descriptors
• Which road surface texture descriptors can be used to assess skid resistance, noise and rolling resistance?
• Is it feasible to complement or replace measurement of these performance parameters with texture measurements and suitable models?
• What is the use of enveloping of texture profile curves? And how can it be improved?
Vertical displacement [mm]
Distance [m]
Original profile curve
Enveloping with d* = 0,1 [1/m]
Enveloping with d* = 0,054 [1/m]
Enveloping with d* = 0,01 [1/m]


WP4 status (2)
ROSANNE
Task 4.1: Influence of texture properties and common descriptors
• Is it useful to extend the measurement range to shorter wavelengths than most of the present equipment currently cover?
• Do 3D measuring devices yield a significant advantage over traditional 2D devices?
• What is the current "State of the Art" (SotA) concerning texture influence on skid resistance, noise emission and rolling resistance?


SotA: texture vs. noise
ROSANNE
• Variety of sound generation/amplification mechanisms identified since late 1970ties: tyre vibrations, air pumping, horn effect, cavity resonances,…
• Numerous efforts trying to quantify their contributions
• Texture is believed to play an important role for a number of them, e.g. tyre vibrations
8

SotA: texture vs. noise

ROSANNE

	Effect	Frequency	Signi-ficance
Mechanical impulses	Impulses given to the tyres by contact between the texture of the road surface and the elements in the tyre tread, leading to tyre vibrations.	Depends on speed, but always lower than 1,250 Hz	+++
	Stick-slip: shocks in the tyre tread elements. Audible in extreme cases as "squealing" in bends.	High: > 1,250 Hz	+
	Stick-snap: adhesion between the tyre tread and the road.	High: > 1,250 Hz	+
Aero-dynamic impulses	Air pumping: compression followed by sudden release of air trapped between the tyres and non-interconnected voids in the road.	High: > 1,250 Hz	++
Sound ampli-fication	Horn effect: successive reflections of a sound wave in the conical area formed by the tyre and the road, which results in amplifying the sound.	1-3 kHz	+ ?
Sound absorption (acoustic)	Interconnected voids in the surface course absorb not only tyre/road contact noise, but also engine noise. This effect is more marked as the road surface is more permeable.	Absorption depends on layer thickness, void content and shape	+++

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SotA: noise models

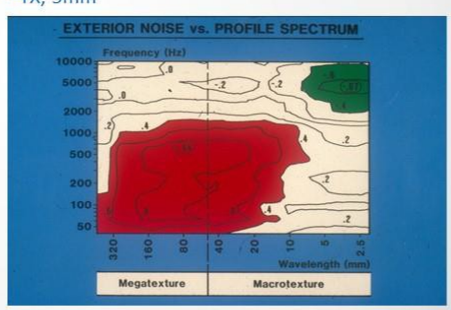
ROSANNE

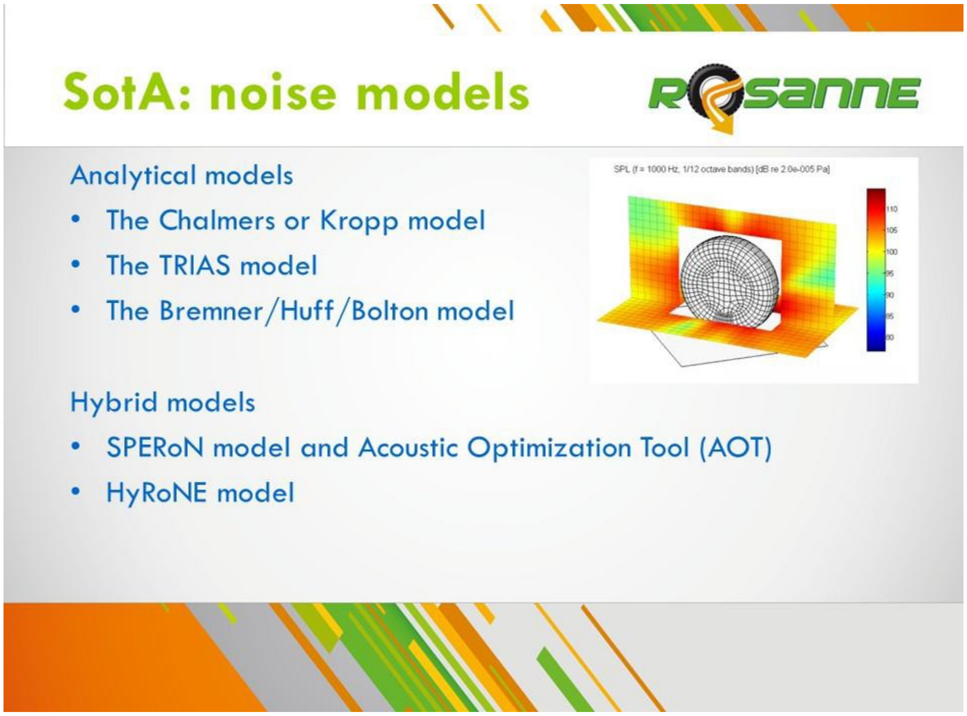
Statistical models

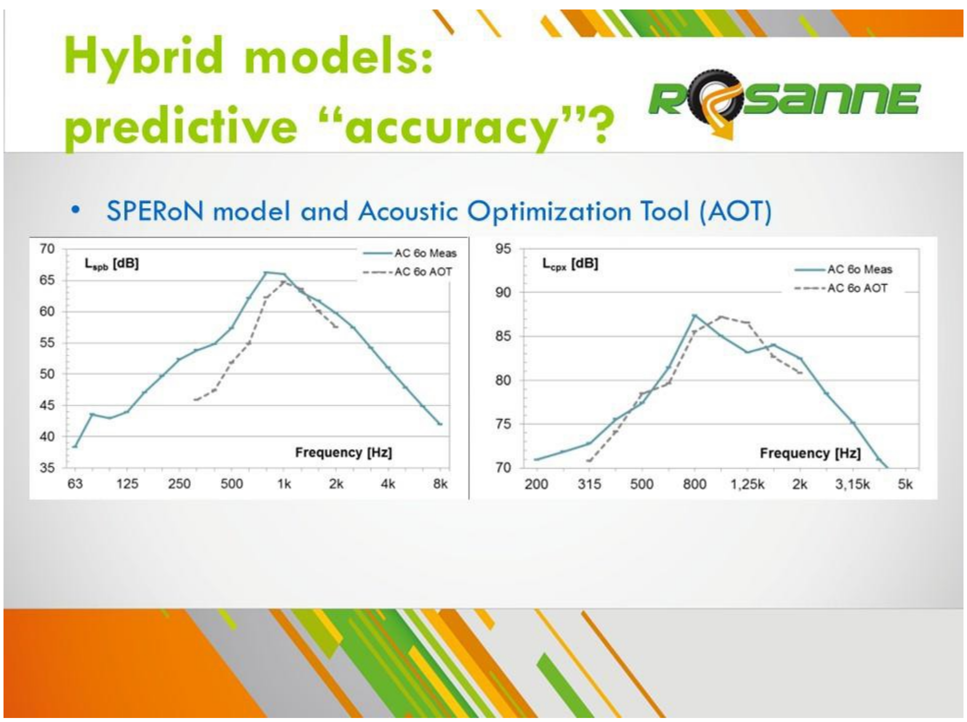
- Sandberg-Descornet model

$$\text{ERNL} = 60 + 0.39\, L_{TX,\,80mm} - 0.13\, L_{TX,\,5mm}$$

- TINO model
- …



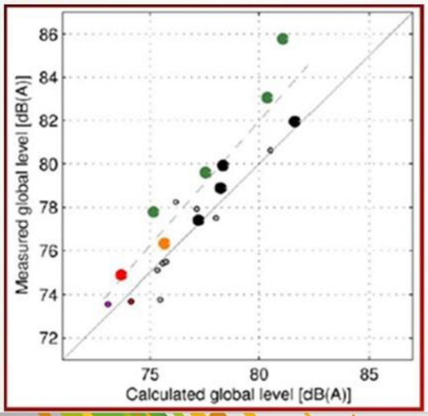

SotA: noise models
ROSANNE
Analytical models
• The Chalmers or Kropp model
• The TRIAS model
• The Bremner/Huff/Bolton model
SPL (f = 1000 Hz, 1/12 octave bands) [dB re 2.0e-005 Pa]
Hybrid models
• SPERoN model and Acoustic Optimization Tool (AOT)
• HyRoNE model


Hybrid models:
predictive "accuracy"?
ROSANNE
• SPERoN model and Acoustic Optimization Tool (AOT)
L_spb [dB]
AC 6o Meas
AC 6o AOT
Frequency [Hz]
70 65 60 55 50 45 40 35
63 125 250 500 1k 2k 4k 8k
L_cpx [dB]
AC 6o Meas
AC 6o AOT
Frequency [Hz]
95 90 85 80 75 70
200 315 500 800 1,25k 2k 3,15k 5k

Hybrid models: predictive power?

ROSANNE

- HyRoNE model



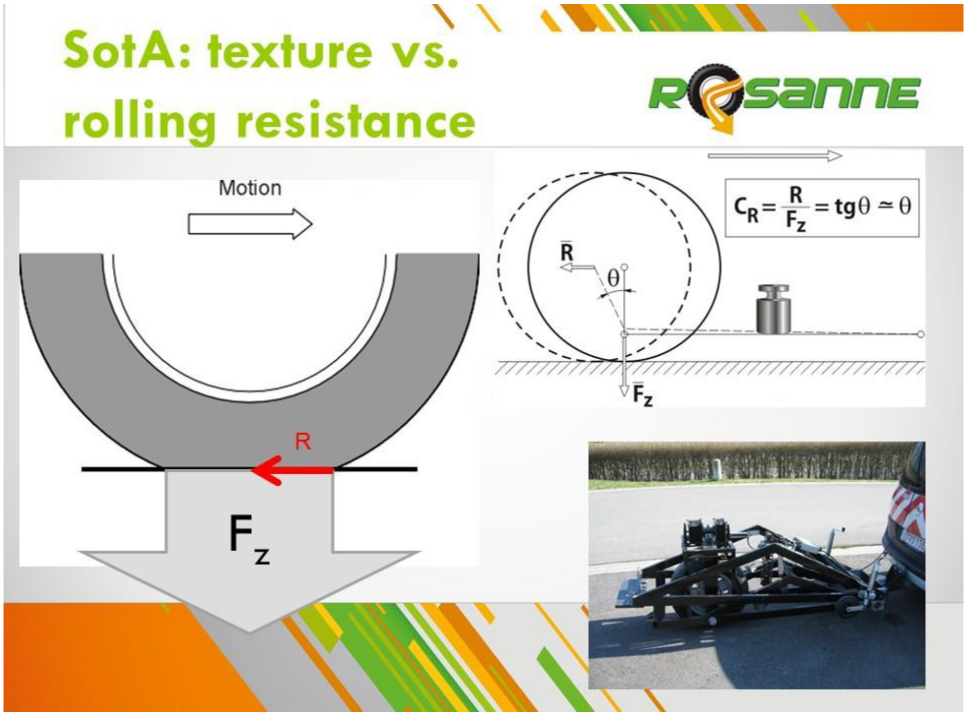
"Noise-from-texture" model

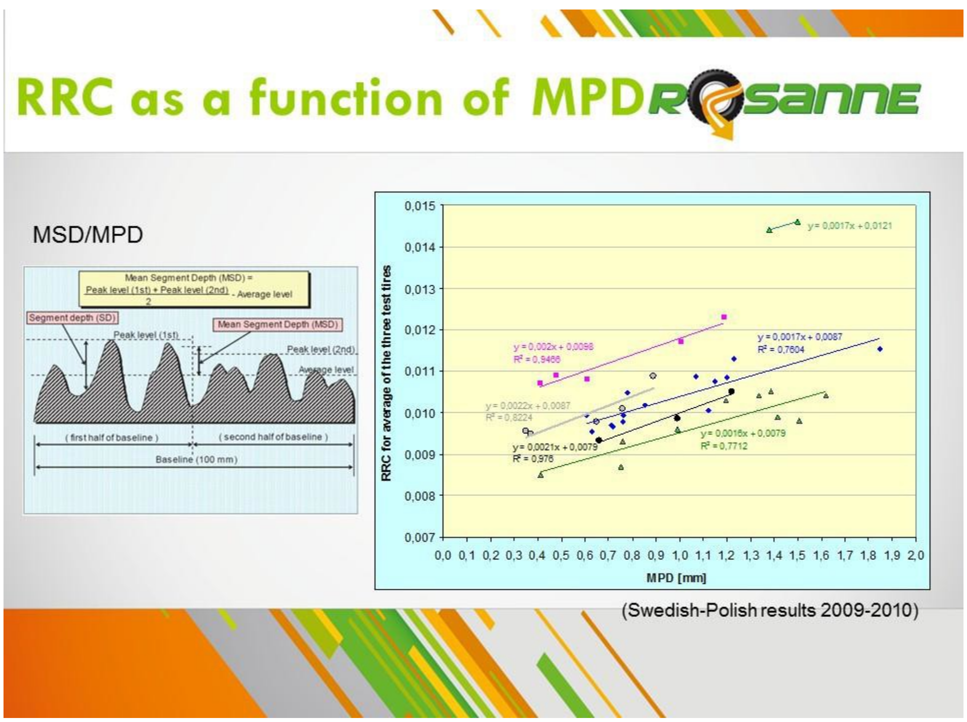
ROSANNE

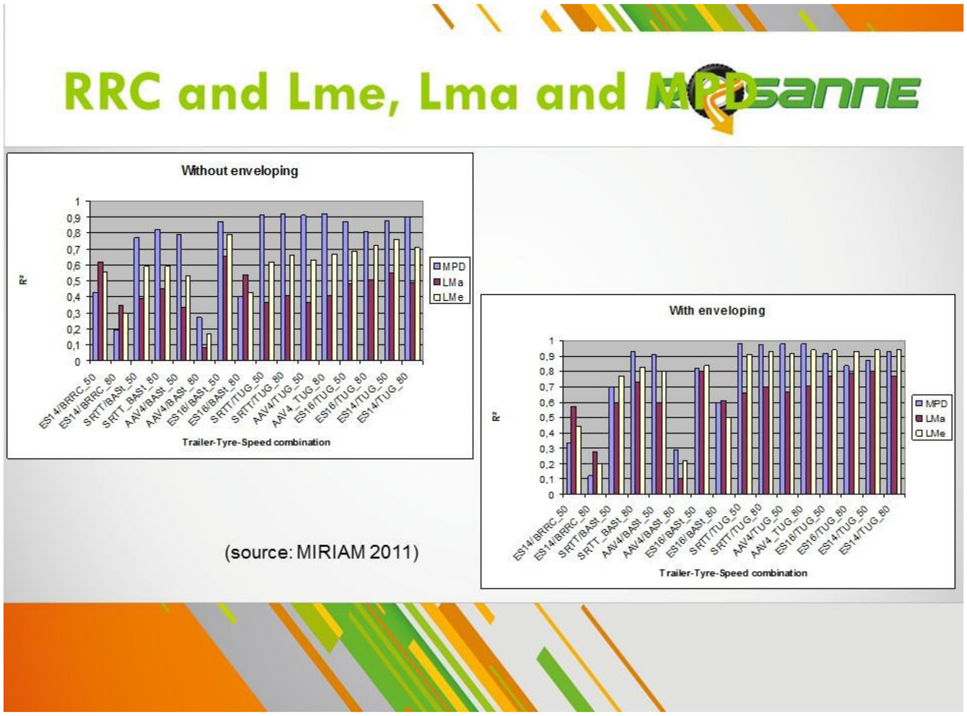
Improvement needed!

…which we will try to provide in ROSANNE:

- Extension of texture range
- Improvement of enveloping procedure
- Enhancing texture data quality
- …


SotA: texture vs. rolling resistance
ROSANNE
Motion
R
F_z
$C_R = \frac{R}{F_z} = tg\theta \simeq \theta$
$\bar{R}$
θ
$\bar{F}_z$


RRC as a function of MPD
ROSANNE
MSD/MPD
Mean Segment Depth (MSD) =
Peak level (1st) + Peak level (2nd) / 2 - Average level
Segment depth (SD)
Mean Segment Depth (MSD)
Peak level (1st)
Peak level (2nd)
Average level
(first half of baseline)
(second half of baseline)
Baseline (100 mm)
y= 0,0017x + 0,0121
y = 0,002x + 0,0098
R² = 0,9466
y = 0,0017x + 0,0087
R² = 0,7604
y = 0,0022x + 0,0087
R² = 0,8224
y= 0,0021x + 0,0079
R² = 0,976
y= 0,0016x + 0,0079
R² = 0,7712
RRC for average of the three test tires
MPD [mm]
0,015
0,014
0,013
0,012
0,011
0,010
0,009
0,008
0,007
0,0 0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 1,0 1,1 1,2 1,3 1,4 1,5 1,6 1,7 1,8 1,9 2,0
(Swedish-Polish results 2009-2010)



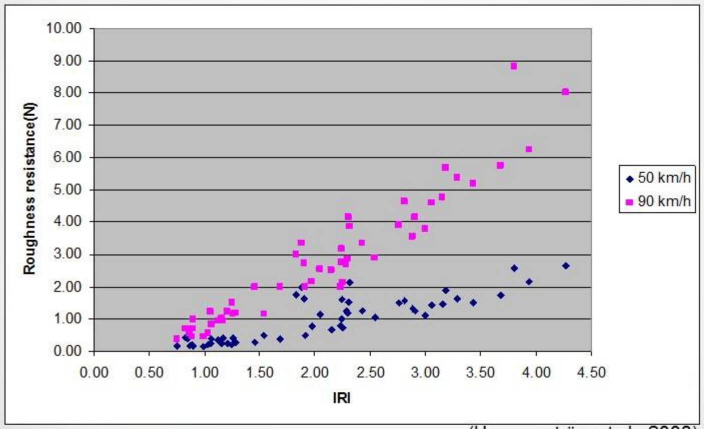
RRC as a function of MPD

ROSANNE

$$RRC = a * MPD + b$$

Source	Year	Value found for slope "a"
BRRC, Belgium	1990	0,0021
New Zealand	1994	0,0022
TUG, Poland (drum)	2011	0,0021
SILENCE	2008	0,002
NordTex	2009-2010	0,0018
VTI, Sweden (coast down)	2011	0,0017
MIRIAM (without enveloping)	2011	0,00174
	average	0,0019
	stdev	0,0002
Minnesota (cannot be true)	2012	0,0004 - 0,0009
The Netherlands (many porous surfaces)	2013	0,00095

RRC and unevenness

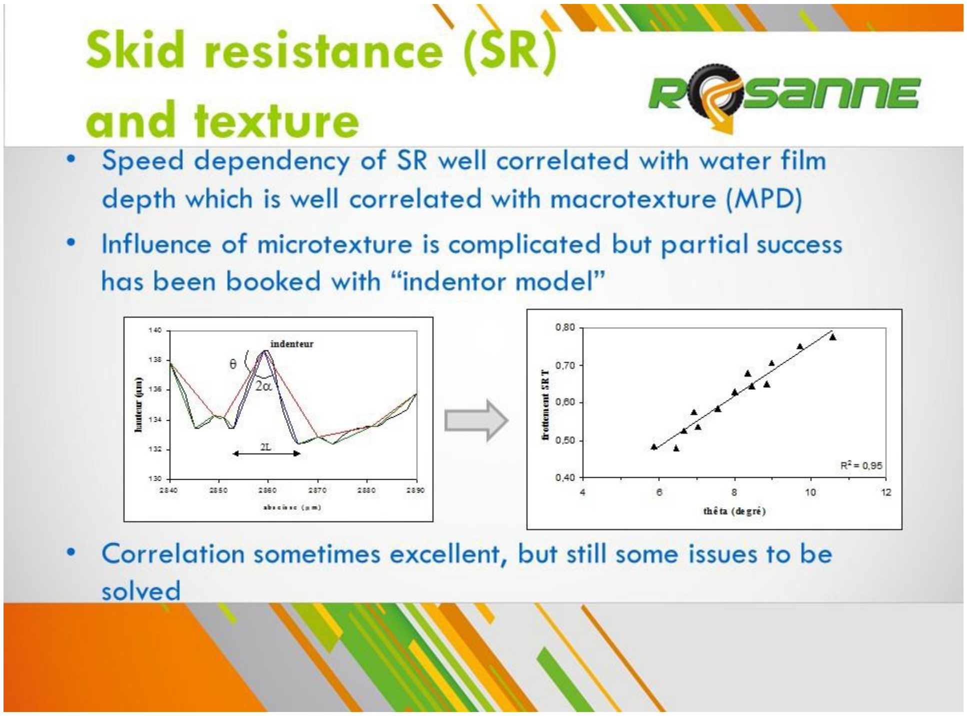


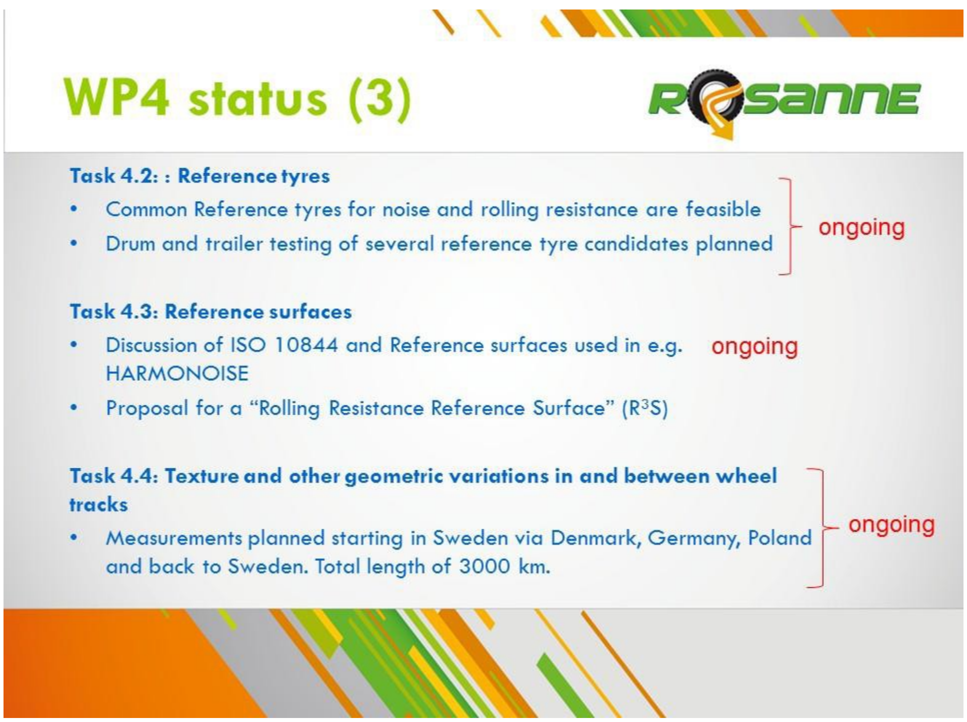
(Hammarström et al., 2008)

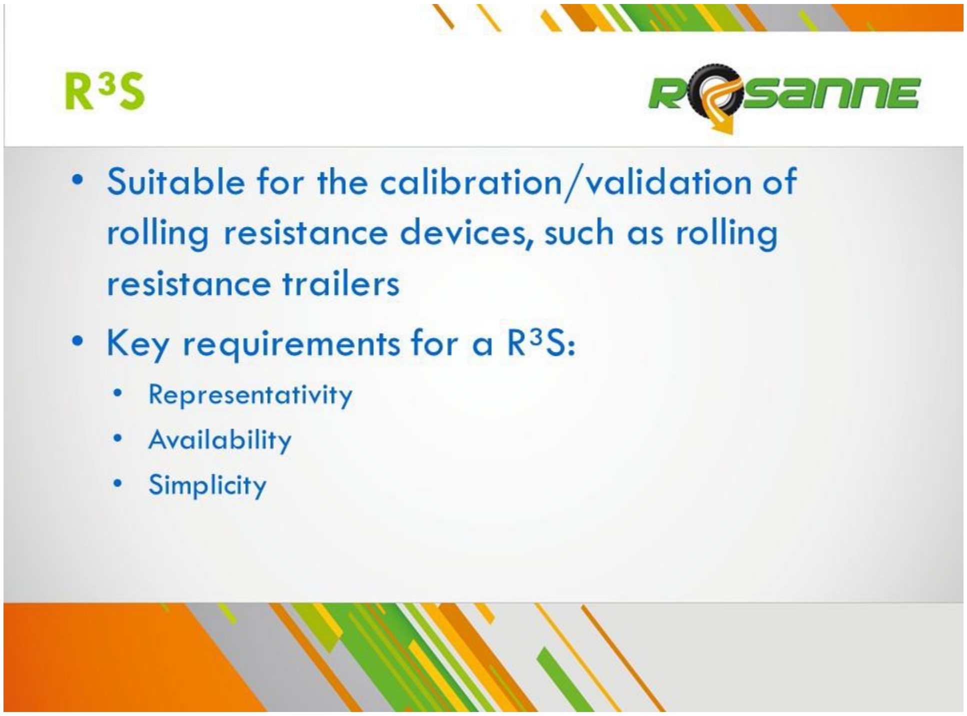
Rolling resistance model

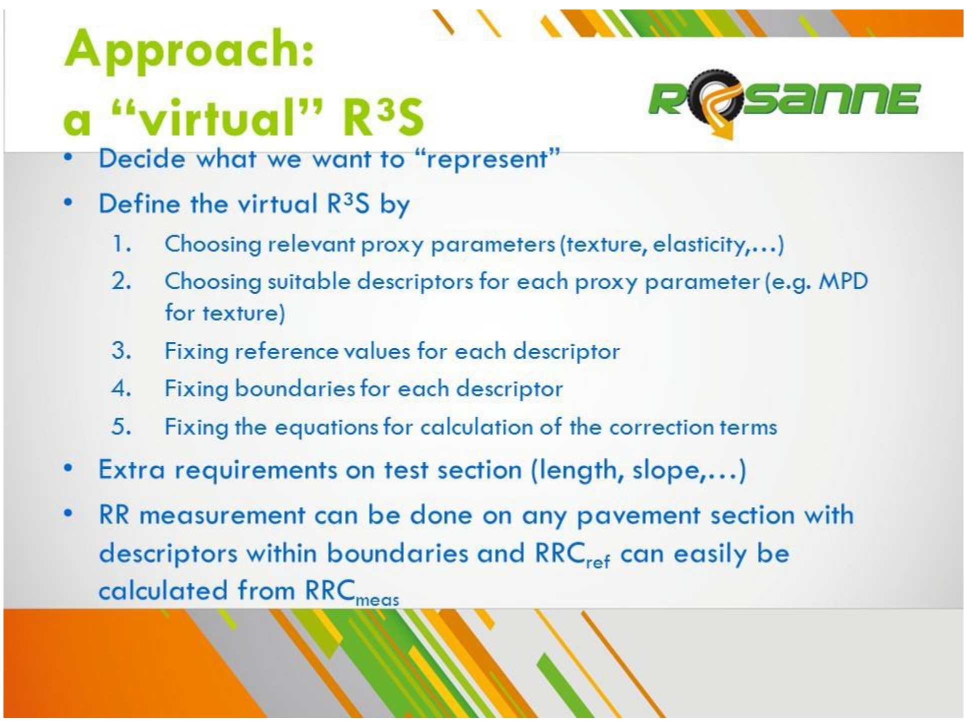
Quite robust and consistent correlations available!

We can proceed…


Skid resistance (SR) and texture
ROSANNE
• Speed dependency of SR well correlated with water film depth which is well correlated with macrotexture (MPD)
• Influence of microtexture is complicated but partial success has been booked with "indentor model"
indenteur
θ
2α
2L
hauteur (µm)
frottement SRT
thêta (degré)
R² = 0,95
• Correlation sometimes excellent, but still some issues to be solved


WP4 status (3)
ROSANNE
Task 4.2: : Reference tyres
• Common Reference tyres for noise and rolling resistance are feasible
• Drum and trailer testing of several reference tyre candidates planned
ongoing
Task 4.3: Reference surfaces
• Discussion of ISO 10844 and Reference surfaces used in e.g. HARMONOISE
ongoing
• Proposal for a "Rolling Resistance Reference Surface" (R³S)
Task 4.4: Texture and other geometric variations in and between wheel tracks
• Measurements planned starting in Sweden via Denmark, Germany, Poland and back to Sweden. Total length of 3000 km.
ongoing


R³S
ROSANNE
Suitable for the calibration/validation of rolling resistance devices, such as rolling resistance trailers
Key requirements for a R³S:
Representativity
Availability
Simplicity


Approach:
a "virtual" R³S
ROSANNE
Decide what we want to "represent"
Define the virtual R³S by
1. Choosing relevant proxy parameters (texture, elasticity,...)
2. Choosing suitable descriptors for each proxy parameter (e.g. MPD for texture)
3. Fixing reference values for each descriptor
4. Fixing boundaries for each descriptor
5. Fixing the equations for calculation of the correction terms
Extra requirements on test section (length, slope,...)
RR measurement can be done on any pavement section with descriptors within boundaries and RRC_{ref} can easily be calculated from RRC_{meas}

Parameter	Value R³S	Acceptable for real test section	Correction
MPD	0.8 mm	[0.6-1.0 mm]	$RRC_{ref} = RRC_{meas} + 0{,}0019 \cdot \Delta MPD$
Skewness	0	[-0,5; +0,5]	0
IRI	0	[0-1.5 mm/m]	0
Rutting (Straight edge)	0	[0-3 mm]	0
Mechanical impedance	∞	AC w.o. elastic material	0
Length	-	[100 m; ∞]	-
Width	-	[3,5 m; ∞]	-
Transversal slope	0 %	[0 %; 3 %]	0
Longitudinal slope	0 %	[0 %; 1 %]	0

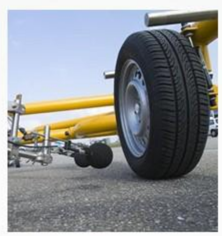
Conclusions

ROSANNE

- Even sophisticated models of today fail to predict noise accurately from texture
- Prediction of rolling resistance appears to work well & we use this to make a proposal for a R^3S
- The relation between skid resistance and texture is complex! Although progress has been booked, there are still some "issues"

ROSANNE

ROSANNE


Contact:
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email: manfred.haider@ait.ac.at
http://www.ait.ac.at

Discussion

There exists a knowledge gap between the highway community and the tire community. Both sides make simple assumptions of the other where complicated intricacies exist.

Efficacy of using smooth and ribbed bias-ply low-durometer rubber tires for friction testing (locked wheel) was raised. It is evident that there are multiple and perhaps conflicting viewpoints ranging from high efficacy as a tool to evaluate a highway surface's micro- and macrotexture contribution to friction to low efficacy given that the modern vehicle fleet is predominately using harder radial tires in conjunction with antilock brake systems.

It was asserted that macrotexture needs to be defined by more than average depth. There are more macrotexture parameters beyond just depth that are currently measureable and quantifiable with today's 2-D and 3-D texture measurement systems which aid in understanding and predicting surface characteristics.

Direct noncontact stationary methods of measuring microtexture in the field are now possible using confocal optical sensors with sub-micro resolution.

Concerning spikes in macrotexture data collection:

- 2-D spikes are predominately due to underexposure of the sensor from insufficient laser illumination; these spikes can be virtually eliminated by increasing the laser power feed ten fold.
- New 3-D texture scanners provide the capability to measure a specific texture point multiple times from varying perspectives–orientations in order to compare measures and eliminate spikes or errors.

Standards are needed to ensure repeatability and reproducibility of macrotexture measurements:

- Sensor specifications:
  - Exposure time (speed dependency),
  - Laser line width or spot size, and
  - Laser power level.
- Filtering specifications—to remove erroneous data or data outside the spectrum of interest without distorting or eliminating what lies within the spectrum of interest.
- Discrimination between 2-D and 3-D systems—the latter has greater stability given the increased quantity of raw data and superiority with respect to anisotropic surfaces

There is much still to learn regarding the role macrotexture plays with respect to anti-icing and deicing chemicals used in winter maintenance. Do varying degrees of macrotexture require varying volumes of chemicals for the same performance?

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Washington, DC 20001