Pavement Texturing Updates and State DOT Directions

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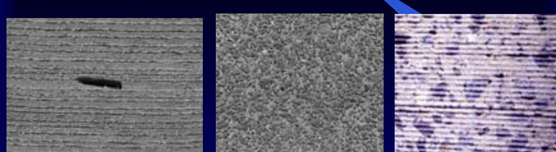
Pavement Surface Characteristics

- Surface characteristics are the key to functional performance
- Functional performance is how the customer rates the pavement
- Major factors are:
  - Safety
  - Condition (Durability)
  - Smoothness
  - Noise

(From R.M. Larson presentation, Dec 2005)

Texture

- Surface texture is an important element of the pavement surface characteristics



- Pavement texture affects wet-weather ride (safety), splash and spray tendencies (safety), and tire/pavement noise (comfort)

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Why is Texture Important?

- Safety problems
  - Worldwide, more than one million deaths and 50 million injuries annually
  - In the US, 40,000+ deaths and 3 million injuries annually
  - Resulting traffic delays and economic impacts
    - User costs and general economic costs
    - $231 billion per year (est.)
  - 10 to 20 percent of highway crashes can be prevented (with large reductions in deaths and serious injuries) by having adequate surface texture!

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Why is this an issue?

- If existing trends continue, the equivalent of every man, woman, and child in 24 States and Washington, DC will be killed or injured by 2010!
  - 33 million victims
  - $2 trillion economic costs

(From R.M. Larson presentation, Dec 2005)

Why is Texture Important?

- Noise problem
  - Exterior traffic noise (primarily tire/pavement) is becoming the No. 1 environmental concern in urban areas
  - The current use of noise walls to address the problem is not the most cost effective solution
  - Interior noise/tire whine is also a major concern

Noise & Safety aspects of texture must be considered together!

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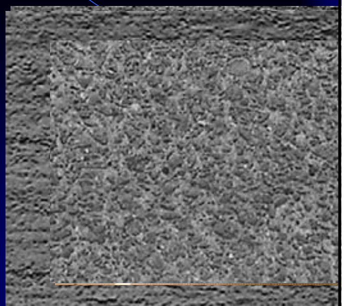
Texturing Methods

- Transverse tine
- Longitudinal tine
- Turf drag
- Burlap drag
- Diamond grinding
- Longitudinal grooving
- Exposed aggregate



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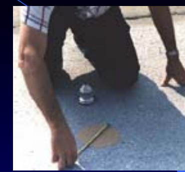
Texture Measurement

- Mean Texture Depth – sand patch (ASTM E 965)
  - 1 mm MTD typically required/specified



- Mean Profile Depth – profile based
- ROSAN

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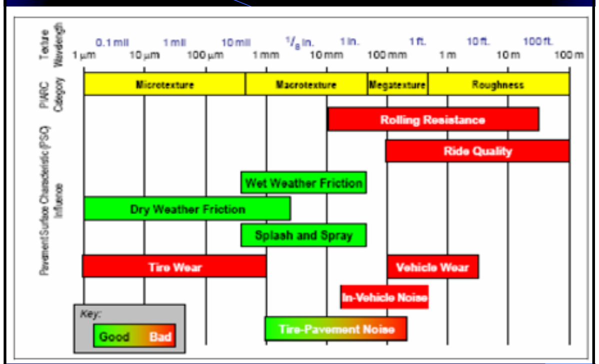
MACROTEXTURE IS THE KEY!!



•Tire Pavement Characteristics Influenced by Categories of Texture
Courtesy of Ulf Sandberg VTI Tire Road Reference Manual

How Can User Concerns Be Addressed?

- Incentives/Disincentives for friction, noise AND ride
- Performance-related or end result specifications
- Warranty specifications
- Improved method specs
- Others? Provide surfaces to meet design stopping distances – mix design

(From R.M. Larson presentation, Dec 2005)

What is Noise, How is it Controlled, and How Does it Affect Our Lives

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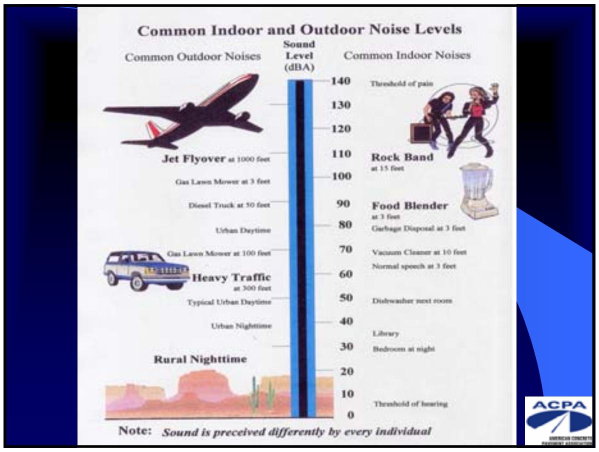
NOISE IS UNWANTED SOUND:
Musically, noise to one may be music to another!

But, on highways, noise is noise to all!


Common Indoor and Outdoor Noise Levels
Common Outdoor Noises
Sound Level (dBA)
Common Indoor Noises
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Threshold of pain
Jet Flyover at 1000 feet
Rock Band at 15 feet
Food Blender at 3 feet
Garbage Disposal at 3 feet
Heavy Traffic at 300 feet
Rural Nighttime
Note: Sound is preceived differently by every individual
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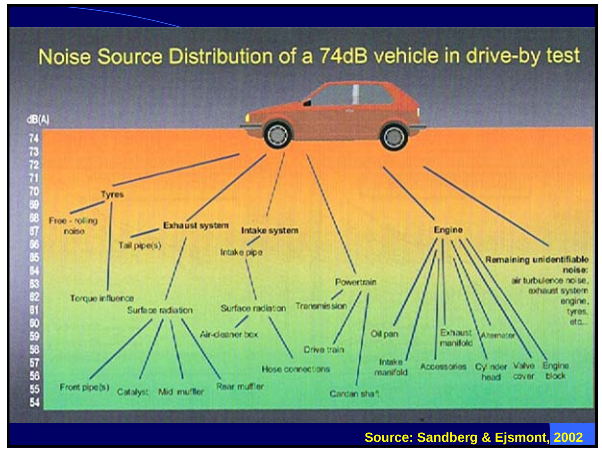
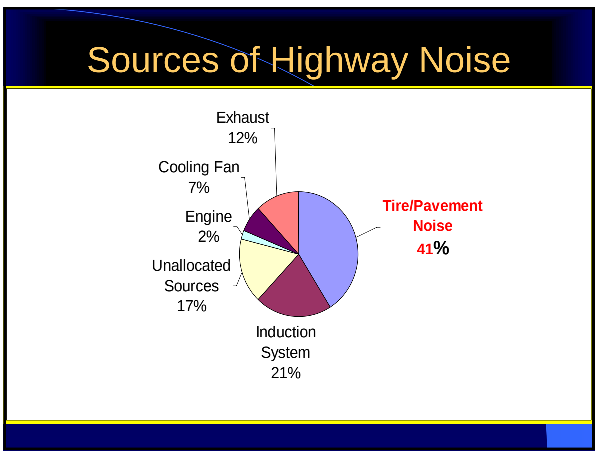
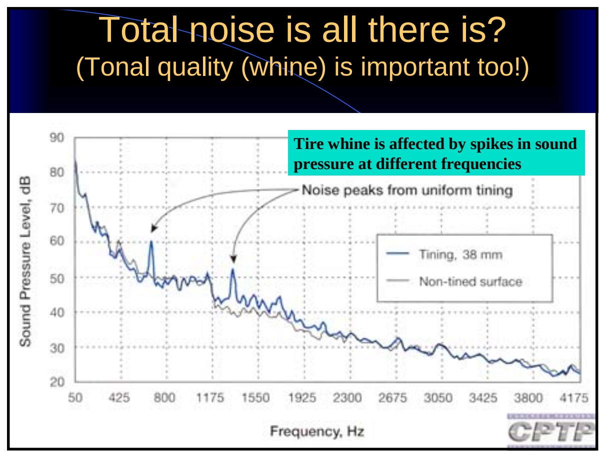

Noise Source Distribution of a 74dB vehicle in drive-by test
dB(A)
Tyres
Free - rolling noise
Exhaust system
Intake system
Engine
Tail pipe(s)
Intake pipe
Remaining unidentifiable noise
Torque influence
Surface radiation
Powertrain
Transmission
Air-cleaner box
Oil pan
Drive train
Front pipe(s)
Catalyst
Mid muffler
Rear muffler
Hose connections
Cardan shaft
Intake manifold
Accessories
Cylinder head
Valve cover
Engine block
Source: Sandberg & Ejsmont, 2002


Sources of Highway Noise
Exhaust 12%
Cooling Fan 7%
Engine 2%
Unallocated Sources 17%
Induction System 21%
Tire/Pavement Noise 41%


Total noise is all there is?
(Tonal quality (whine) is important too!)
Tire whine is affected by spikes in sound pressure at different frequencies
Noise peaks from uniform tining
Tining, 38 mm
Non-tined surface
Sound Pressure Level, dB
90
80
70
60
50
40
30
20
50
425
800
1175
1550
1925
2300
2675
3050
3425
3800
4175
Frequency, Hz
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Doubling Traffic adds 3dBA
65 Decibels
68 Decibels
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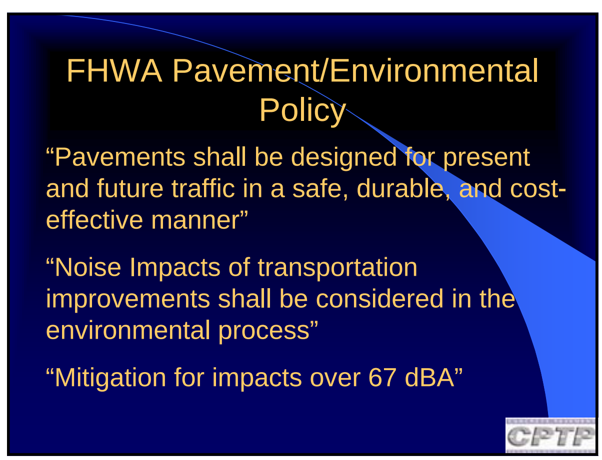
FHWA Pavement/Environmental Policy
"Pavements shall be designed for present and future traffic in a durable, and cost-effective manner"
"Noise Impacts of transportation improvements shall be considered in the environmental process"
"Mitigation for impacts over 67 dBA"
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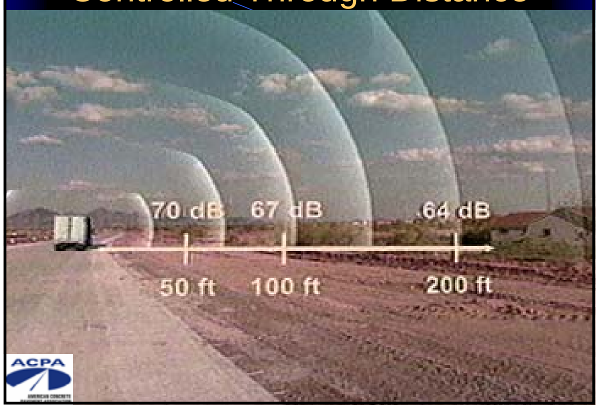
CFR– Title 23: Highways – Part 772 Procedure for Abatement of Highway Traffic & Construction Noise

- Residential noise abatement criterion of 67 dBA
  - Threshold value that triggers noise study and *consideration* of noise abatement
  - Only peak noise levels considered (not nighttime)
- Every reasonable effort to be made to obtain substantial noise reductions
- If severe noise impacts remain at residential areas (>75 dBA or increase >30 dBA), then, consider measures beyond sound walls
- Views of impacted residents will be considered in selecting noise abatement procedures

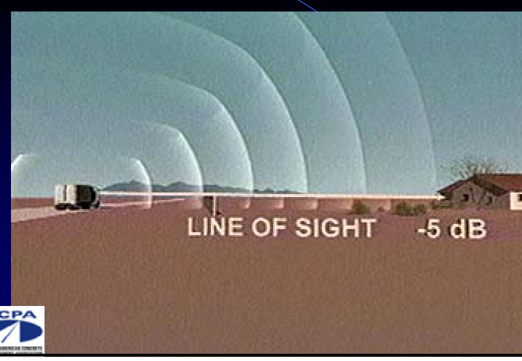
How Is Noise Controlled

- At the Source
  - Reduce vehicle and tire/pavement emissions
- Through Distance
  - 3 dBA reduction for doubling of distance
    - e.g., if 25ft = 70dBA, the 50ft = 67dBA, 100 ft = 64 dBA
- Use Obstructions
  - Berms, Walls, etc.

Controlled Through Distance



Controlled Through Obstructions 1 dBA for each 2 ft of Wall Above

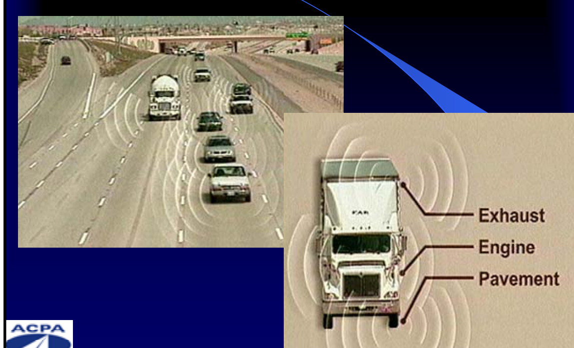


Noise Reduction Techniques

- Distance – not always possible/practical
- Noise Walls (not cost-effective)
- Current focus on reduction of noise at the source
  - Reduce megatexture (50-100 mm)
  - Reduce air displacement (macrotexture)
  - Increase impedance (porosity)

ALTERING MACROTEXTURE IS KEY TO CONTROLLING NOISE GENERATED BY TIRE/PAVEMENT INTERACTION!!

Sounds Control At the Source



Impact of Sound Reduction at the Source on Noise Wall Height and Cost

- A decrease of 2 dBA means a reduction of five feet in wall height or about $528,000/mile of wall
  - (assumes an average wall cost of $20/sf)

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Ways of Measuring Sound

Wayside (Far Field)

Close Proximity (Near Field)

Sound Intensity (Near Field)

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In Summary

- Noise Should be Controlled at the Source – Surface Texture DOES Matter!
- Noise Should be Managed (Just Like Friction, Roughness, Rutting, and Cracking)

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Why is Friction Important?

SAFETY!!!

- Texture/Friction is a Surrogate for Safety
- Texture/Friction is a Major Road User Concern

FHWA Pavement Policy:

FHWA Technical Advisory T 5040.36
"Surface Texture for Asphalt and Concrete Pavements", June 17, 2005

"*tire/surface noise should be considered* when specifying pavement and bridge surfaces"

BUT

"safety considerations are paramount"

Friction Measurement

- Friction Number (ASTM E274)
  - Ribbed tire (E 501)
  - Smooth (E 524)
- International Friction Index (IFI) (ASTM E1960)
  - Incorporates friction testing & macro-texture
- Minimum Values (?? – no one wants to take a stand on this)

Locked Wheel Tester (US)

Fixed Slip Tester (Non-US & airports)

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Incorporating Safety into Pavement Management

- Incorporate safety triggers into decision trees
- Use investigatory levels as triggers to verify if poor texture/friction is contributing to high crash rate
- Requires upper management to set performance targets

Surface Texture Needs

Safe, Durable and Cost-Effective

- Quiet
- Need for
  - Microtexture for low-speed friction
  - Macrotexture for wet-weather friction
- Durable – long-term service
- Cost-effective – life cycle cost benefits

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Colorado I-70 (1979)

- 25-mm uniform transverse tining
- Transverse turf drag
- Var. spacing transverse tining ← Best friction, but noisy!
- 13-mm uniform transverse tining + LTD ←
- Var. spacing transverse sawcuts + LTD
- 25-mm uniform transverse tining + LTD
- 19-mm long. grooving + LTD ←
- Longitudinal turf drag (LTD) ← Lowest noise levels …
- 19-mm long. tining + LTD ← Lower noise with good friction – best overall!

Colorado DOT Data

(25 ft from center of travel lane)

Texture Type	Noise Level, dBA	Skid No.
PCCP – Longitudinally Tined	75	43
3/8 in. SMA	74	52
PCCP – Transverse Tined	82	44
PCCP – ¼ in. Ground	76	48

Report: CDOT-R1-R-2001-9

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Wisconsin, 1994

Asphalt Pavements:

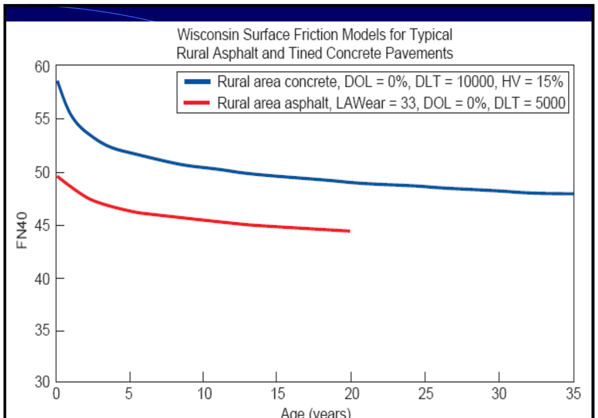
FN = 41.4 – 0.00075 DOLOMITE²
– 1.45 ln (LAVP) + 0.245 LAWEAR

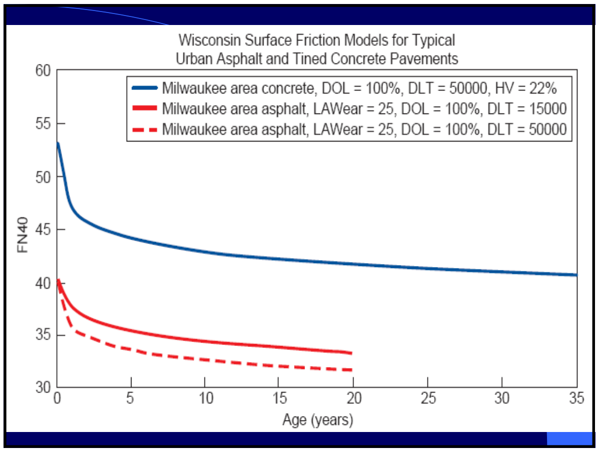
$$FN = 41.4 - 0.00075\,DOLOMITE^2 - 1.45\ln(LAVP) + 0.245\,LAWEAR$$

Tined Concrete Pavements:

$$\ln(FN) = 3.99 - 0.0419\ln(LAVP) - 0.000129\,DOLOMITE + 0.00474\,HV$$

FN = Friction Number at 40 mph
LAVP = Lane Accumulated Vehicle Passes, millions
LAWEAR = Los Angeles Wear (measure of resistance to abrasion, %)
HV = Heavy Vehicles in Design Lane as % of Lane ADT
DOLOMITE = Percent of Dolomite Aggregate in Mix





Speed Gradient Values
(Wisconsin, 1994)

- [FN(40) – FN(50)]/10
  - Good results <0.40
- Tined PCC and SMA were best (SG~0.25)
- Other asphalt ≥ 0.40
- Shallow turf drag worst (SG~0.59)

Wisconsin, 2000

- 57 test sites in six states
  - Included 10 new construction sections with different textures in Wisconsin
  - All sites 3 – 7 years old
- Measurements
  - Noise (interior, exterior, ranking)
  - Texture (ROSAN, sand patch)
  - Friction (ASTM 274, smooth tire
  - Smoothness (IRI)

Wisconsin, 2000

Pavement Type/Texture	Lmax (dBA)	Leq (dBA)	ROSAN (OWP) MPD (mm)	ROSAN (OWP) ETD (mm)	Sand Patch (mm)
Asphalt (SHRP)	80.0	65.6	0.238	0.173	0.447
Asphalt (SMA)	81.1	67.2	0.480	0.682	1.045
PCC - Uniform Transverse Tining	83.8	68.9	0.688	0.733	0.578
PCC - Random Transverse Tining	84.5	68.9	0.561	0.852	0.860
PCC - Skewed Tining	83.2	68.0	0.467	0.654	0.770
PCC - Longitudinal Tining	81.8	68.3	0.780	1.319	0.810

Wisconsin, 2000

Pavement Type/Texture	ROSAN (OWP) MPD (mm)	ROSAN (OWP) ETD (mm)	Sand Patch (mm)	FN40(S)	FN50(S)	Friction Gradient
Asphalt (SHRP)	0.238	0.173	0.447	23.9	18.8	0.51
Asphalt (SMA)	0.480	0.682	1.045	32.2	28.7	0.35
PCC - Uniform Transverse Tining	0.688	0.733	0.578	44.8	44.5	0.34
PCC - Random Transverse Tining	0.561	0.852	0.860	53.4	47.4	0.59
PCC - Skewed Tining	0.467	0.654	0.770	53.7	47.5	0.62
PCC - Longitudinal Tining	0.780	1.319	0.810	54.4	47.6	0.68

Wisconsin, 2000
Expected Noise Reductions

Pavement Type/Texture	Sound Reduction from Transversely Tined PCC (dBA) Interior (Leq)	Sound Reduction from Transversely Tined PCC (dBA) Exterior (Lmax)
Randomly-spaced transversely tined	<1	1 – 3
Randomly-spaced skewed (1:6, left ahead) tining	1.5 - 2	4
Longitudinally tined	2	4 – 7
Open-textured asphalt concrete	2 - 3	5

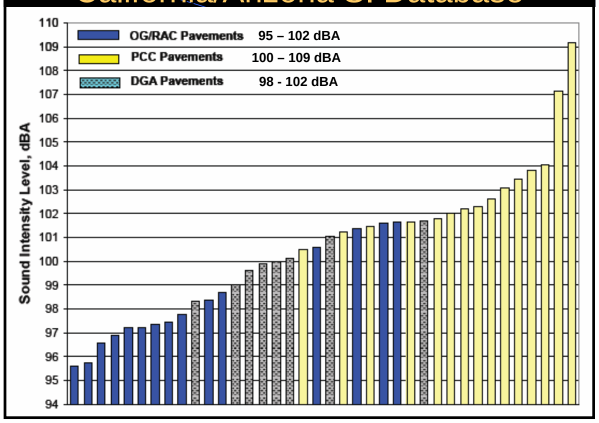
Wisconsin, 2000 Conclusions

- Wide, deep transverse tining is noisiest
- Deep tining results in wide marks at surface
- Noise for longintudinal tining is not sensitive to tining depth
  - Depth increase 50 – 250%, little or no noise increase
- Diamond grinding of transverse tining can reduce tire-pavement noise by up to 3 dBA

Recommendation: If noise concerns are strong, consider longitudinal tining (19mm spacing) for low noise, good friction

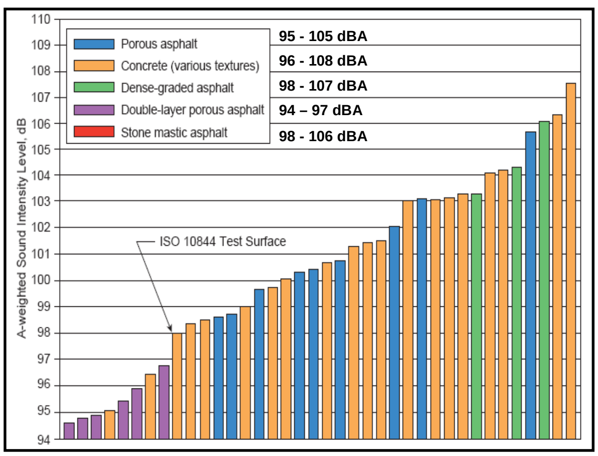
California/Arizona Database

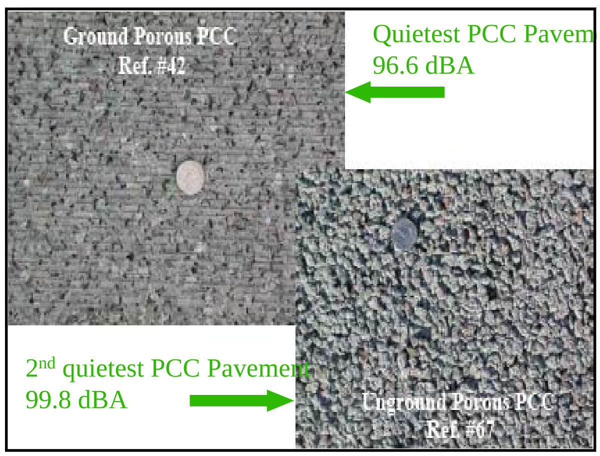
California/Arizona SI Database

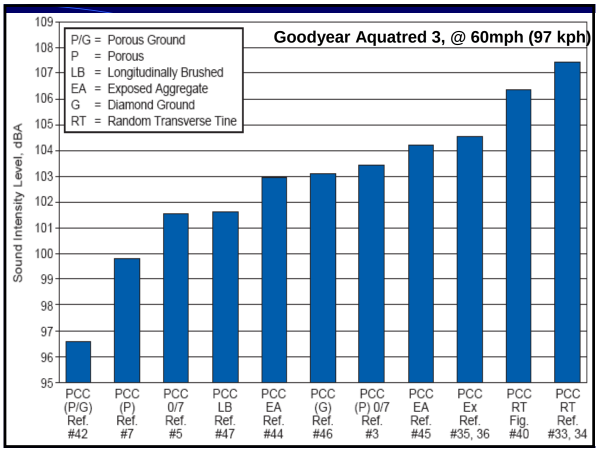


Noise Intensity Testing in Europe (NITE)

- California DOT and US FHWA funded
- Perform SI measures in Europe (66 test sections using same equipment used to compile California/Arizona database)
  - Measure SI of "quiet" pavements
  - Measure SI of typical pavements
  - Relate to U.S. measures using same equipment





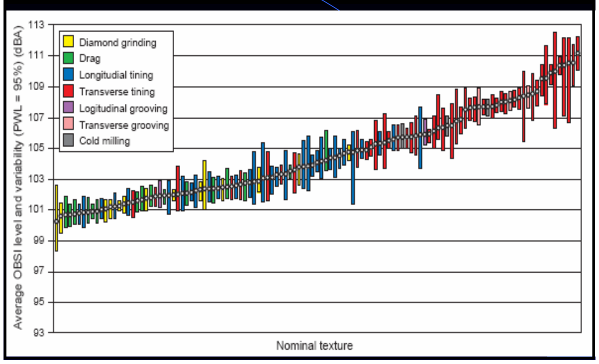


NITE Study Conclusions

- Porous PCC has potential to provide similar tire-pavement noise levels as "quiet" AC, and may be more desirable in some cases.
- Fine exposed aggregate surfaces produced SI levels similar to diamond grinding
- Both of these types of construction should be investigated for application in U.S.

- NITE study pavements 1 – 2 dBA quieter than CA/AZ pavements
- Ranges of SI values (highest – lowest) were similar in US and Europe

Iowa State University CTRE – 2006
(all PCC pavements)



THE MINNESOTA STORY
CONCRETE PAVEMENT SURFACE FINISHING

- Prior to 1976 – Wet Burlap or Carpet Drag
- 1976 – Astro Turf Texturing Plus Tining with 1" Random Effective Spacing
- 1983 – Astro Turf Texturing Plus Tining with 1-1/2" Random Effective Spacing > 35 MPH
- 1995 – Astro Turf Texturing Plus Tining with 5/8"-1" Random Effective Spacing > 35 MPH
- 1998-99 Moratorium on Tining to Mitigate Noise on All Concrete Pavement

- 1999- Turf (or Broom) Drag with Minimum Texture of 0.8 mm
- 2001- Turf (or Broom) Drag with Minimum Texture of 1.0 mm
- 2003 - MN Studies Influence Of texture on Ride Quality
- 2007- Pooled Fund Studies TPF 5-134 TPF 5-163 Initiated

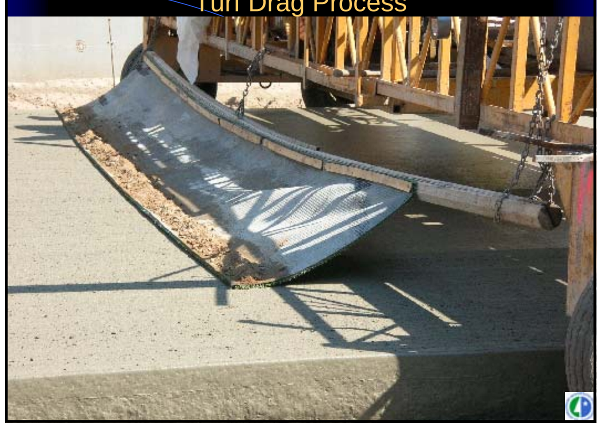
Source: Izevbekhai, TRB 2008

Current Concrete Paving Textures

– Different ways of achieving texture
- Longitudinal Astroturf drag
- Longitudinal Broom finish
- Corrective/ Innovative Diamond Grinding

Source: Izevbekhai, TRB 2008

Turf Drag Process



MnDOT Turf Drag Texture

Photo courtesy Doug Schwartz, MnDOT

2001 Texture Requirement Change

- Prior to 2001, ETD (min) = 0.8 mm
  - Observed range: 0.97 – 1.68 mm
  - Avg: 1.3 mm
  - BUT … avg loss after 1-2 winters = 0.3 mm
- 2001 – present, ETD (min) = 1.0 mm
  - Observed range: 0.84 – 1.89 mm
- Pavements generally meet or exceed present minimums.

Source: Izevbekhai, TRB 2008

Durable, long-lasting turf texture requires high-quality concrete!

- W/C Spec (incentives)
- Well-graded Aggregate (incentives)
- Additional incentives for Initial Ride Quality, Aggregate Quality
- These mix design changes affect other design/construction parameters (e.g., strength, cement demand, use of dowel baskets/DBIs, etc.)

Water-Cementitious Ratio Requirement and Incentive

Water-Cementitious	Incentive/Disincentive ($/c.y.)
0.35 or less	+$4.00
0.36	+$3.00
0.37	+$2.00
0.38	+$1.25
0.39	+$0.50
0.40	+$0.00
0.41	-$0.50
0.42	-$1.25
0.43	-$2.00
0.44	-$3.00
0.45 or more	Concrete Engr's Rec.

No mix with w/c > 0.40 shall knowingly be placed.

Optional Incentive for Well-Graded Aggregate

Sieve Sizes	% Retained ($2.00/c.y.)	% Retained ($0.50/c.y.)
2-inch	0	0
1.5-inch	≤ 8	≤ 7
1.0-inch	8 – 18	7 – 18
¾-inch	8 – 18	7 – 18
½-inch	8 – 18	7 – 18
3/8-inch	8 – 18	7 – 18
#4	8 – 18	7 – 18
#8	8 – 18	7 – 18
#16	8 – 18	7 – 18
#30	8 – 18	7 – 18
#50	≤ 18	≤ 18
#100	≤ 8	≤ 7
#200	≤ 1.6	≤ 1.6

DATA ANALYSIS

Data Analysis Independent Of Traffic Exposure
- Annual wet weather accident count from 1994 to 2004
- Annual Total accident count from 1994 to 2004

Data Considering Traffic Exposure
- Annual Wet Weather Crash rates from 1994 to 2004
- Annual Total Crashes from 1994 to 2004

Summary Of MN Wet Weather Accident Counts

WWA COUNTS	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TH 21 Jordan	3	3	4	4	2		4	4	2	1	3
TH 35, RP 13to27	5	2	6	3	4	2	3	6	6	5	6
TH 35, RP 68 to79	5	6	7	10	10	7	6	5	14	5	26
TH 35W, RP 9 to11	16	10	10	10	8	5	13	5	4	8	12
TH 35W, RP 35to41	1	3	7	3	5	5	9	1	1	2	2
TH90, RP 222to235	2	2	3	4	5	2	4	0	2	1	2
TH 90, RP 166to174	1	0	2	0	0	0	3	0	0	3	2
TH 94, RP 115 to 128	3	1	0	3	3	4	0	1	1	3	0
TH 94, RP 2 1 to 27	1	2	1	2	0	1	0	1	5	0	2
TH 94, 38 to 51	1	2	1	4	0	0	1	3	0	1	1
TH 169, RP 96 to 102	5	3	2	3	8	7	10	6	8	2	5
TH 7, RP 142 to 151	4	6	2	2	2	1	2	4	0	1	2
TH 100, RP 8 to 13	36	41	28	31	30	34	39	43	32	15	18
TH 169, RP 88 to 90	3	2	1	4	2	2	3	1	1	1	2

Source: Izevbekhai, TRB 2008

Summary Of MN Total Accident Counts

TOTAL ACCIDENTS	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TH 21 Jordan	20	28	27	28	21	33	32	39	35	30	19
TH 35, RP 13to27	48	17	59	75	41	58	57	107	48	50	55
TH 35, RP 68 to79	33	55	96	82	61	66	71	68	104	93	141
TH 35W, RP 9 to11	53	52	41	44	42	52	57	36	32	42	64
TH 35W, RP 35to41	34	27	40	32	31	47	56	39	50	55	48
TH90, RP 222to235	17	11	36	27	27	25	28	41	19	33	37
TH 90, RP 166to174	15	8	21	16	11	14	22	14	9	13	19
TH 94, RP 115 to 128	25	34	42	45	37	37	28	48	41	31	33
TH 94, RP 2 1 to 27	14	9	12	29	10	10	10	18	13	12	15
TH 94, 38 to 51	13	29	17	48	10	14	19	21	18	28	27
TH 169, RP 96 to 102	32	31	24	22	36	37	57	35	35	28	35
TH 7, RP 142 to 151	22	31	27	29	26	14	17	28	17	26	14
TH 100, RP 8 to 13	169	187	196	174	161	161	208	205	187	136	110
TH 169, RP 88 to 90	11	6	2	6	10	8	13	7	7	6	18

Source: Izevbekhai, TRB 2008

Summary Of MN Wet Weather Accidents – Percentage of All Accidents

WWA FRACTION	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TH 21 Jordan	0.15	0.11	0.15	0.14	0.1	0.03	0.13	0.1	0.06	0.03	0.16
TH 35, RP 13to27	0.1	0.12	0.1	0.04	0.1	0.03	0.05	0.06	0.13	0.1	0.11
TH 35, RP 68to79	0.15	0.11	0.07	0.12	0.16	0.11	0.08	0.07	0.13	0.05	0.18
TH 35W, RP 9 to11	0.3	0.19	0.24	0.23	0.19	0.1	0.23	0.14	0.13	0.19	0.19
TH 35W, RP 35to41	0.03	0.11	0.18	0.09	0.16	0.11	0.16	0.03	0.02	0.04	0.04
TH90, RP 222to235	0.12	0.18	0.08	0.15	0.19	0.08	0.14	0	0.11	0.03	0.05
TH 90, RP 166to174	0.07	0	0.1	0	0	0	0.14	0	0	0.23	0.11
TH 94, RP 115 to 128	0.12	0.03	0	0.07	0.08	0.11	0	0.02	0.02	0.1	0
TH 94, RP 2 1 to 27	0.07	0.22	0.08	0.07	0	0.1	0	0.06	0.38	0	0.13
TH 94, 38 to 51	0.08	0.07	0.06	0.08	0	0	0.05	0.14	0	0.04	0.04
TH 169, RP 96 to 102	0.16	0.1	0.08	0.14	0.22	0.19	0.18	0.17	0.23	0.07	0.14
TH 7, RP 142 to 151	0.18	0.19	0.07	0.07	0.08	0.07	0.12	0.14	0	0.04	0.14
TH 100, RP 8 to 13	0.21	0.22	0.14	0.18	0.19	0.21	0.19	0.21	0.17	0.11	0.16
TH 169, RP 88 to 90	0.27	0.33	0.5	0.67	0.2	0.25	0.23	0.14	0.14	0.17	0.11

Source: Izevbekhai, TRB 2008

Computation of Crash Rates

Crash rates were computed as follows :

- Rate per million entering vehicles R = N (1million)/Y (ADT) (S) (365)
  - N is number of crashes and Y is the number of Years S is segment length
- For critical rates, Rc = Ra +K (Ra/M)0.5 + 0.5/m
  - Where Rc is Critical Crash Rate . This was not considered in this report
  - Ra is system wide Crash Rate by intersection or Highway type
  - M is vehicle exposure during study period
  - K is constant factor depending on level of confidence
    - At 99.5% , K =2.576
    - At 95% Confidence, K =1.645
    - At 90% confidence, K = 1.282
- Crash rates analyzed to normalize traffic volume before and after.
- Crash rates preferred to accident count data
  - Crash rates include volume of vehicular traffic entering the segment and segment length in addition to the actual accident counts.

Overall Crash Rates in MN Test Sections

CRASH RATES IN TEST SECTIONS

Route	YEAR 1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
MNTH 21	4.9	3.3	1.8	2.3	1.6	1.8	3.1	2.7	2.1	0.8	1.0	1.3
ISTH 35	0.8	0.3	0.8	1.1	0.6	0.8	0.7	1.2	0.8	0.8	0.6	0.7
ISTH 35	0.3	0.5	0.9	0.8	0.6	0.6	0.6	0.5	0.7	0.7	0.9	0.5
ISTH 35W	2.0	2.3	1.7	1.6	1.2	1.5	1.4	0.9	1.0	1.2	1.5	1.2
ISTH 35W	0.5	0.4	0.6	0.5	0.4	0.6	0.7	0.5	0.6	0.7	0.5	0.5
ISTH 90	0.4	0.3	0.6	0.5	0.5	0.4	0.5	0.6	0.3	0.5	0.6	0.5
ISTH 90	0.8	0.2	0.7	0.7	0.5	0.6	0.8	0.6	0.3	0.5	0.7	0.4
ISTH 94	0.5	0.6	0.6	0.7	0.6	0.5	0.4	0.7	0.5	0.4	0.4	0.6
ISTH 94	0.8	0.3	0.5	1.2	0.4	0.3	0.3	0.8	0.5	0.4	0.5	1.2
ISTH 94	0.3	0.7	0.4	1.2	0.2	0.3	0.4	0.4	0.4	0.6	0.5	0.6
USTH 169	0.9	0.9	0.7	0.8	0.9	0.9	1.2	0.7	0.8	0.8	0.6	0.5
USTH 169	1.4	0.7	0.2	0.7	1.1	0.8	1.3	0.7	0.8	0.7	1.8	0.7
MNTH 7	2.0	2.4	1.7	1.5	1.6	0.7	1.3	1.5	1.1	1.3	1.3	1.2
MNTH 100	1.6	1.6	1.8	1.2	1.3	1.3	1.7	1.6	1.5	1.1	0.7	0.6

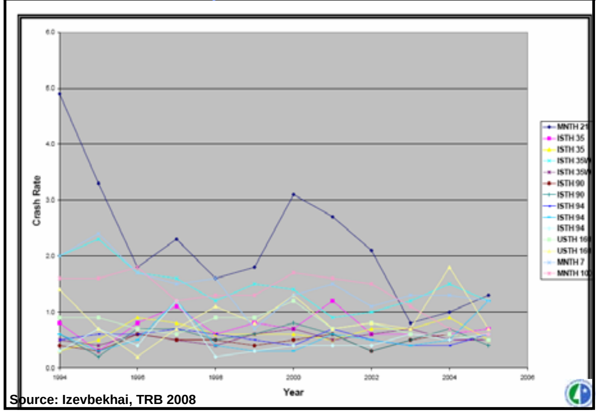
Source: Izevbekhai, TRB 2008

MN Wet Weather Crash Rates (% of Total)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
MNTH 21	0.188	0.364	0.000	0.250	0.000	0.125	0.083	0.000	0.200	0.000	0.200	0.286
ISTH 35	0.091	0.130	0.111	0.059	0.188	0.077	0.063	0.069	0.153	0.102	0.115	0.107
ISTH 35	0.147	0.109	0.073	0.129	0.164	0.104	0.088	0.068	0.128	0.052	0.179	0.128
ISTH 35W	0.304	0.289	0.254	0.230	0.226	0.133	0.205	0.171	0.167	0.156	0.188	0.168
ISTH 35W	0.031	0.111	0.158	0.065	0.138	0.106	0.127	0.026	0.041	0.036	0.043	0.174
ISTH 90	0.111	0.154	0.083	0.129	0.185	0.077	0.138	0.000	0.100	0.030	0.053	0.118
ISTH 90	0.105	0.000	0.100	0.050	0.071	0.000	0.080	0.000	0.000	0.167	0.087	0.000
ISTH 94	0.107	0.029	0.000	0.065	0.128	0.103	0.000	0.019	0.024	0.097	0.000	0.077
ISTH 94	0.077	0.250	0.083	0.069	0.000	0.100	0.000	0.056	0.385	0.000	0.133	0.079
ISTH 94	0.077	0.065	0.053	0.073	0.000	0.000	0.043	0.120	0.000	0.033	0.063	0.079
USTH 169	0.152	0.121	0.077	0.136	0.214	0.171	0.169	0.171	0.200	0.129	0.121	0.071
USTH 169	0.250	0.333	0.500	0.667	0.182	0.250	0.231	0.143	0.125	0.143	0.158	0.000
MNTH 7	0.162	0.244	0.162	0.121	0.194	0.118	0.067	0.108	0.037	0.061	0.133	0.172
MNTH 100	0.204	0.196	0.157	0.187	0.211	0.174	0.179	0.223	0.158	0.097	0.151	0.212

Source: Izevbekhai, TRB 2008

Chronological Trend of Crash Rates in Wet Weather



STATISTICAL ANALYSIS

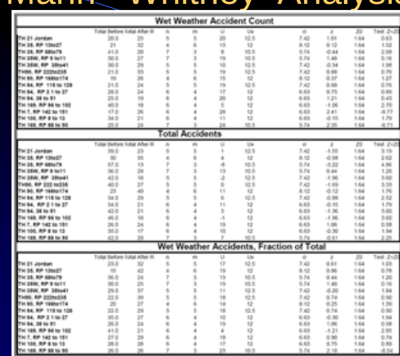
Objective:
- Compare Wet weather Accident data in previous texturing to Data in current texturing
- Performance evaluation of current texturing according to 2005 FHWA Texture Advisory
- Evaluate adequacy of current texturing

Strategy:
- Comparative Descriptive Statistics
- Mann-Whitney Z-test
- X^2 (Chi-Squared) Test

Descriptive Statistics For Wet Weather Accident Data

Test Section Statistics	WWA Count		Total Accident Count		WWA Fraction of Total Acc.	
TH 21	Before	After	Before	After	Before	After
Mean	3.20	2.80	24.80	31.00	0.13	0.10
Standard Deviation	0.84	1.30	3.96	7.52	0.03	0.05
169, RP 88 to 90						
Mean	2.43	1.33	8.00	10.33	0.35	0.14
Standard Deviation	0.98	0.58	3.70	6.66	0.17	0.03
TH 35, RP 13 to 27						
Mean	4.00	4.67	49.75	62.50	0.09	0.08
Standard Deviation	1.83	1.75	24.49	22.15	0.03	0.04
35, RP 68 to 79						
Mean	7.29	15.00	66.29	112.67	0.12	0.12
Standard Deviation	1.98	10.54	20.06	25.15	0.03	0.07
35W, RP 35 to 41						
Mean	3.80	3.00	32.80	49.60	0.11	0.06
Standard Deviation	2.28	3.39	4.76	6.80	0.06	0.06
35W, RP 9 to 11						
Mean	10.29	8.00	48.71	46.00	0.21	0.17
Standard Deviation	3.50	4.00	6.26	16.37	0.06	0.04
35W, RP 35 to 41						
Mean	3.80	3.00	32.80	49.60	0.11	0.06
Standard Deviation	2.28	3.39	4.76	6.80	0.06	0.06
90, RP 166 to 174						
Mean	0.75	1.33	15.00	15.17	0.04	0.08
Standard Deviation	0.96	1.51	5.35	4.62	0.05	0.10
94, RP 115 to 128						
Mean	2.00	1.00	36.60	36.20	0.06	0.03
Standard Deviation	1.41	1.22	7.77	8.17	0.05	0.04
94, RP21 to 27						
Mean	1.17	2.00	14.00	14.50	0.09	0.1

Mann –Whitney Analysis



Wet weather accident rates before and after current texturing practices are similar.

MnDOT CONCLUSIONS

- In the sections tested and analyzed, neither the wet weather accident counts nor the crash rates increased with current texturing practices (95 % confidence level).
- Crash rates in the test sections studied retained the same distribution before and after current texturing.
- On Minnesota pavements with current turf drag texture designs, 10.3% of all accidents occur in wet weather. This is lower than the National average of 20%.

Best Practice Examples

TX DOT Wet Weather Accident Reduction Program (WWARP)-May 1999

- 100% macro texture PMS survey
- Friction tests on 25% of 70,000 miles annually (50% of I-state system)
- 50 mi/hr Locked Wheel Test with smooth tire (concurrent macro texture)
- Texture data estimates friction every 0.1 mile to $\pm$ 6 friction numbers (FN)
  - Data added to PMS

Texas Texture and Friction Research

Estimated benefits for a 10-year period:

- Surface Texture Measurement System
  - 12 lives saved
  - 1100 accidents prevented
  - $5,922,000 saved
- Micro-Deval Aggregate Test: $1,495,000
- Alt. Polish Value and Soundness Specs:
  - 60 lives saved
  - 8060 accidents prevented

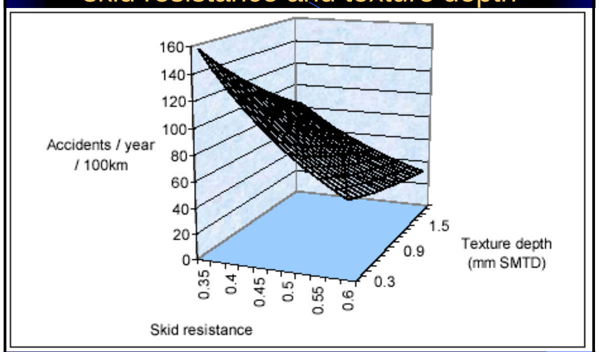
Estimated savings - $30-40 million

Best Practice Example United Kingdom

- Formal Skid Resistance Policy - Started late 1980's – 15 years documented experience
- Have related texture and friction to accidents
- Defined site categories and investigatory levels (Monitor annually)
- Have approved products list – HAPAS
- Conducted 10,000 Road Safety Audits last year

In 2004, U.K. has achieved 28% of 40% 10-year accident reduction goal – It Works!

Accidents versus skid resistance and texture depth



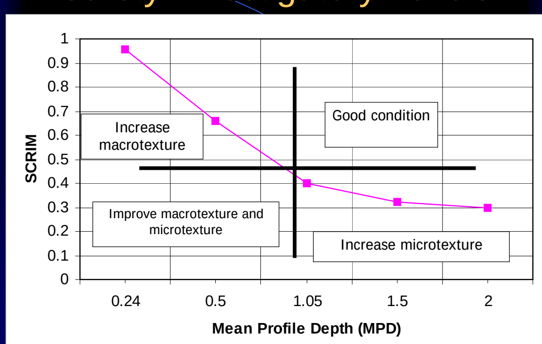
Ref: Viner, Sinhal, and Parry, SURF 2004

United Kingdom Policy Site Categories vs. Investigatory Levels

Revised 2004 – 15 years experience

Site category and definition		Investigatory level at 50km/h							
		0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65
A	Motorway class								
B	Dual carriageway non-event								
C	Single carriageway non-event								
Q	Approaches to and across minor and major junctions, approaches to roundabouts								
K	Approaches to pedestrian crossings and other high risk situations								
R	Roundabout								
G1	Gradient 5 to 10% longer than 50m								
G2	Gradient >10% longer than 50m								
S1	Bend radius <500m – dual carriageway								
S2	Bend radius <500m – single carriageway								

Safety Investigatory Levels



From Tighe et al. 2000

NCHRP 10-69 – Texturing of Concrete Pavements

- Looking at alternatives to tining
- Focusing on durability, safety, and noise
- Initiated by States with texture-durability issues
- Include construction of experimental sections
- Includes overlay options
- Expected completion in Apr 2008

Concrete Paving Texturing Recommendations and Guidelines

- Microtexture
  - 25% silica sand
  - Turf drag or burlap drag
- Macrotexture for high-speed facility (for reduced noise)
  - Texture depth
- Highly durable coarse aggregate

CPTP

PCCP Texture Guidelines

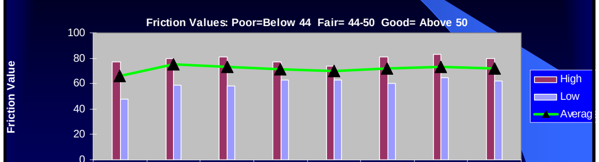
- Tining
  - 3 mm width
  - 3 mm depth
  - ~~Random transverse spacing~~
    - ~~10/14/16/11/10/13/15/16/11/10/21/13/10 mm~~
    - ~~32/19/22/25/35/22/22/22/22/25/35/13/38 mm~~
  - 19 mm longitudinal
- Diamond grinding (?)
- Under 50 mph - burlap drag

Also, separate tining & curing operations

CPTP

AZ - K. J. Law Friction Tester

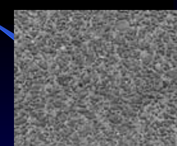
S202 West Friction/Special Test for Longitudinal & Transverse Tining (500' each @40mph)



	T	T	T	T	L	L	L	L
High	77	80	81	77	74	81	83	80
Low	48	59	58	63	63	60	65	62
Average	66	75	73	71	70	72	73	72

L=Longitudinal Tining T=Transverse Tining

PCCP Texturing Guidelines



- Other Methods
  - MN Turf Drag (with mix mods)
  - Exposed aggregate
  - Plastic brushing
  - Better engineered surfaces
- Acceptable only if safety performance documented
  - Wet-weather accident history
  - Friction test results
    - Smooth tire
    - International Friction Index (IFI)

CPTP

Immediate Practical Recommendations

- Use longitudinal tining for new construction (as per Colorado, Wisconsin and some other States)
  - Separate curing & tining operations
- Implement MnDOT Turf Drag or Longitudinal Brushing only as part of a System Approach that includes mix design modifications to ensure texture durability
- Consider grinding or longitudinal grooving for existing pavements

Other Conclusions/Recommendations

- Important to measure both macrotexture and friction (microtexture)
- Friction must be measured with a blank or smooth tire
- IFI Approach (Concurrent macrotexture [laser] and Friction [skid trailer]) reduces testing in half and gets better data
- Improved data collection, storage, analysis makes large reductions in deaths and serious injuries possible within 5 years

In Summary

- Surface Type Does Matter-Noise Should be Controlled at the Source
- Noise Should be Managed Just Like Friction, Roughness, Rutting, and Cracking
- We're at the Beginning of a Journey
- People Do Care How They Live-It's a Quality of Life Issue!!!

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- Dr. Rob Rasmussen, Transtec, USA
- *Many other authors, practitioners and researchers ….*

Thank You!

Any Questions?

MnDOT Std Coarse Aggregate Incentives

- Class A (Granite, Quartzite, etc.) - $1.00/c.y.
- Class B (Carbonates):

Absorption, %	Pay Change per fraction
<1.00	+$1.00/c.y.
1.01 – 1.45	+$0.50/c.y.
1.46 – 1.76	0
1.77 – 1.85	-$1.00/c.y.
>1.86	Engineer's Rec

- Class C (Gravel):

Carbonate Content, %	Pay Change per fraction
<15.0	+$1.00/c.y.
15.1 – 24.0	+$0.50/c.y.
24.1 – 31.0	0
31.1 – 35.0	-$1.00/c.y.
>35.0	Engineer's Rec

- Class R (Recycled): Not considered

MnDOT Spec. Coarse Aggregate Incentives

- Class A (Granite, Quartzite, etc.) - $1.90/c.y.
- Class B (Carbonates):

Absorption, %	Pay Change per fraction
<1.00	+$1.90/c.y.
1.01 – 1.20	+$1.15/c.y.
1.21 – 1.40	0
1.41 – 1.60	-$1.50/c.y.
1.61 – 1.85	-$2.70/c.y.
>1.86	Engineer's Rec

- Class C (Gravel):

Carbonate Content, %	Pay Change per fraction
<10.0	+$1.90/c.y.
10.1 – 14.0	+$1.15/c.y.
14.1 – 20.0	0
20.1 – 25.0	-$1.50/c.y.
25.1 – 35.0	-$2.70/c.y.
>35.0	Engineer's Rec

- Class R (Recycled): Not considered