Mitigating Sand Patch Test Variability Using Laser Technology

Yorguo El Hachem, Sareh Kouchaki, Dr. Jorge Prozzi

The University of Texas at Austin

Sponsored by TxDOT and US DOT

Outline

- Sand Patch Test (ASTM E965)
- Variability in Sand Patch Test
- ANOVA
  - Experiment 1
  - Experiment 2
  - Experiment 3
- 3D Laser Scanner
- Conclusion

Section 1

Texture Characterization Technique, Sand Patch Test ASTM E965

ANalysis **O**f **VA**riance

Sand Patch Test (ASTM E965)

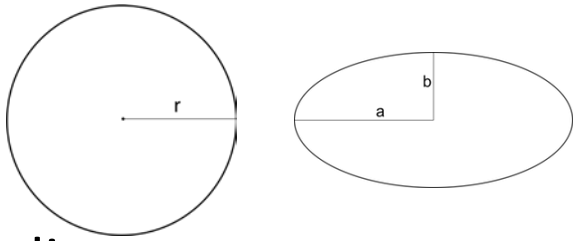
- Material and Equipment used:
  - Ottawa sand
  - Volumetric beaker
  - Wind Screen
  - Brushes and vacuum cleaner
  - Flat disk spreader
  - Ruler
  - Chalk
  - Paper and pen

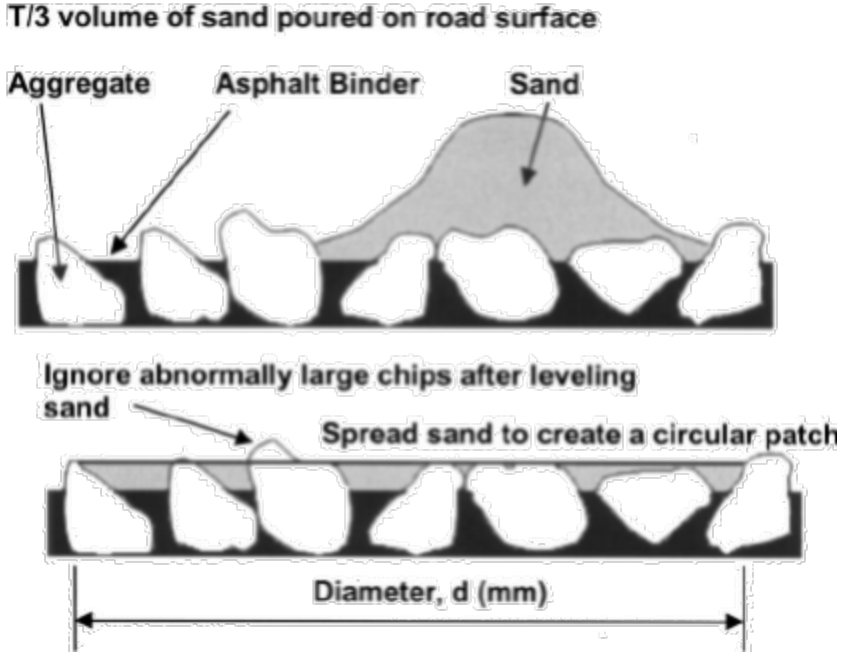
- Test Method:
  - Select test area
    - Dry
    - Homogeneous
    - No localized features
  - Clean area
  - Measure 25 mL sand [25,000 mm^3]
  - Pour and circularly spread sand
  - Record 4 diameter measurements

$$MTD = \frac{4V}{\pi . D_{avg}^2}$$

Variability in Sand Patch Test

- Presence of cracks or porous surfaces
- Volume measurement (Tapping the side of a container or its bottom)
  - How consistent is the measured volume with the spread volume
- Uneven spread of the Ottawa Sand
- Ability to form a circle vs. ellipse
  - $A_{circle} = \pi r^2$ vs. $A_{ellipse} = \pi . a . b$
    if $r = 15 \rightarrow \mathbf{A = 706.8}$
    if $a = 16$ and $b = 14 \rightarrow \mathbf{A = 703.7}$
- Loss of material
- Accuracy of measurement of the diameter
- Rotating 45° for each measurement
- Cleaning the floor and presence of dust
- Remaining in the same area





ANOVA

- ANOVA stands for "**AN**alysis **O**f **VA**riance"
- Statistical tool
- Determines significant differences between two or more sample means of the populations
- Assesses the effects of various independent factor
- Figures out how much of the total variance comes from:
  - The variance between the groups
  - The variance within the groups

ANOVA of Sand Patch Test

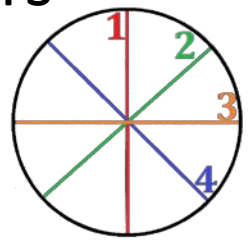
$$MTD = \frac{4V}{\pi . D_{avg}^2}$$

- How does it apply?
  - Site variability
  - Surface variability
  - Operator variability

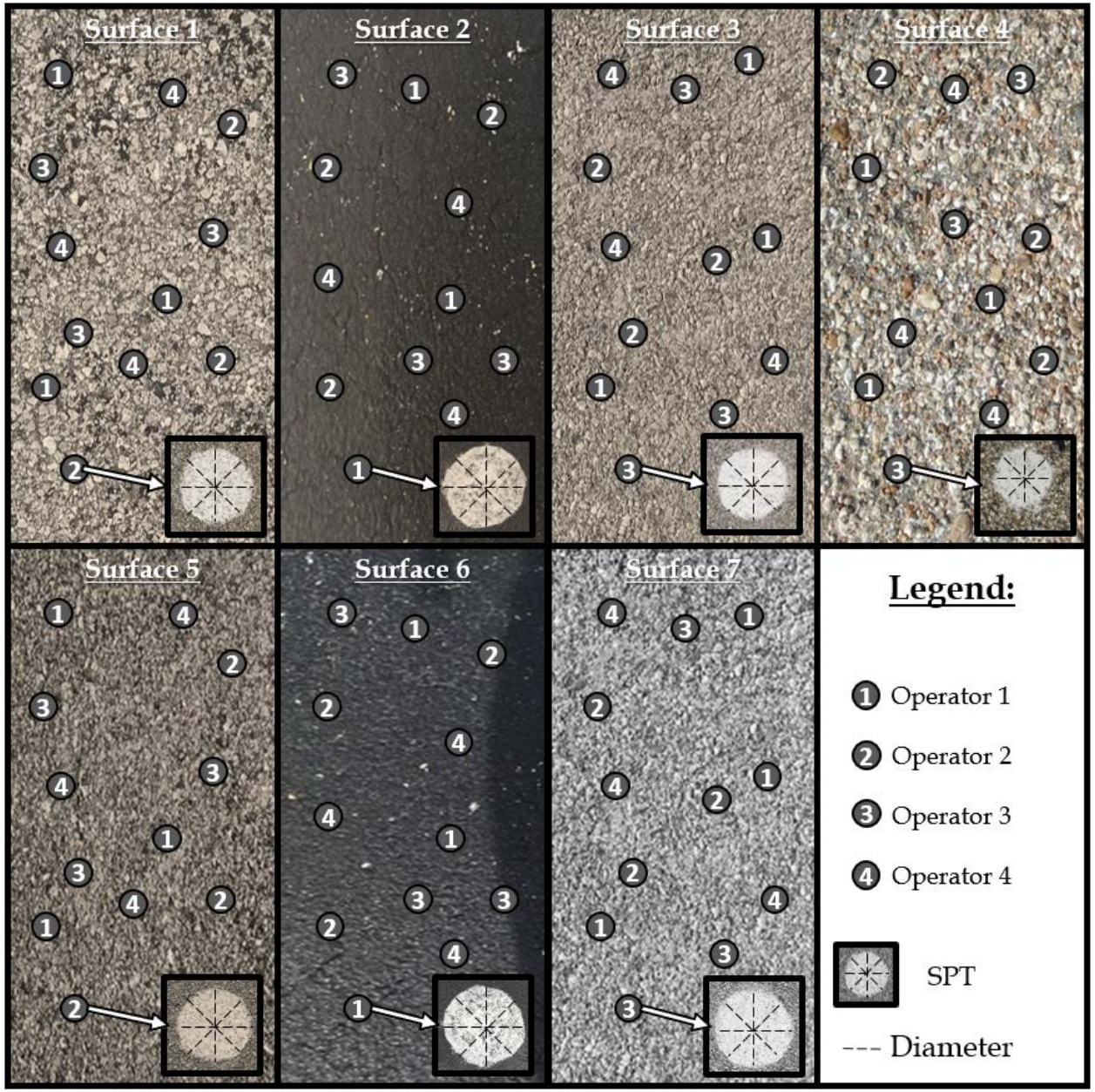
- Need to find out how much of total variance is:
  - Between groups
  - Within group

Experiment 1

- 7 different site surfaces
- 4 different operators
- 3 Distinct trial locations
  - 84 Locations
- 4 diameters



- **<u>Recipe for Variability</u>**
  - 84 SPT's



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Results of Sand Patch Tests

$$D_{AVG} = \frac{\sum D_{Measured}}{4}$$

$$MTD = \frac{4V}{\pi . D_{avg}^2}$$

O/S	Surface 1 MTD (mm)	Surface 2 MTD (mm)	Surface 3 MTD (mm)	Surface 4 MTD (mm)	Surface 5 MTD (mm)	Surface 6 MTD (mm)	Surface 7 MTD (mm)
Operator #1 Average MTD (3 SPT's)	0.93	0.51	1.07	2.45	0.84	0.58	1.82
Operator #2 Average MTD (3 SPT's)	0.91	0.53	1.05	2.31	0.73	0.59	1.59
Operator #3 Average MTD (3 SPT's)	0.94	0.51	1.08	2.72	0.76	0.53	1.67
Operator #4 Average MTD (3 SPT's)	0.88	0.47	1.02	2.16	0.69	0.55	1.67
Overall Average	0.92	0.51	1.06	2.41	0.76	0.56	1.69
Standard Deviation	0.05	0.04	0.07	0.30	0.12	0.06	0.16
Coefficient of Variation	5%	7%	7%	12%	16%	10%	9%

Variability Between Site Sections

One Way ANOVA: Surface			
Surfaces	**# Diameters**	**Average (mm)**	**Variance**
Surface 1	48	186.6	26.2
Surface 2	48	251.6	92.8
Surface 3	48	173.9	36.4
Surface 4	48	115.5	49.1
Surface 5	48	206.7	247.9
Surface 6	48	238.8	204.1
Surface 7	48	137.6	37.8
ANOVA			
Statistical Parameter	**F-Value**	**P-value**	**F crit**
Results	1,208	**1.06E-220**	2.13

Discussion

One Way ANOVA: Surface			
Surfaces	**# Diameters**	**Average (mm)**	**Variance**
Surface 1	48	186.6	26.2
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ANOVA			
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Results	1,208	**1.06E-220**	2.13

- Differentiate between surfaces?
- Statistical Parameters
  - $\alpha = 0.05$ *is the chance of wrongly concluding that there is a difference between two groups when in reality there no such difference*
  - $\mathrm{F-Value} = \dfrac{\text{variance between sample means}}{\text{variance within the sample}}$
- P-value < α & High F-value
  - Reject null hypothesis (means of all the surfaces' diameters are the same)
    - At least one surface diameter mean which is significantly different from the rest
  - Variance between section surface means is much higher than the variance within the surfaces themselves.
- Conclusion: The selected section has a major effect on the measured diameter from the SPT. It can differentiate between different sections.

Variability within a Pavement Surface

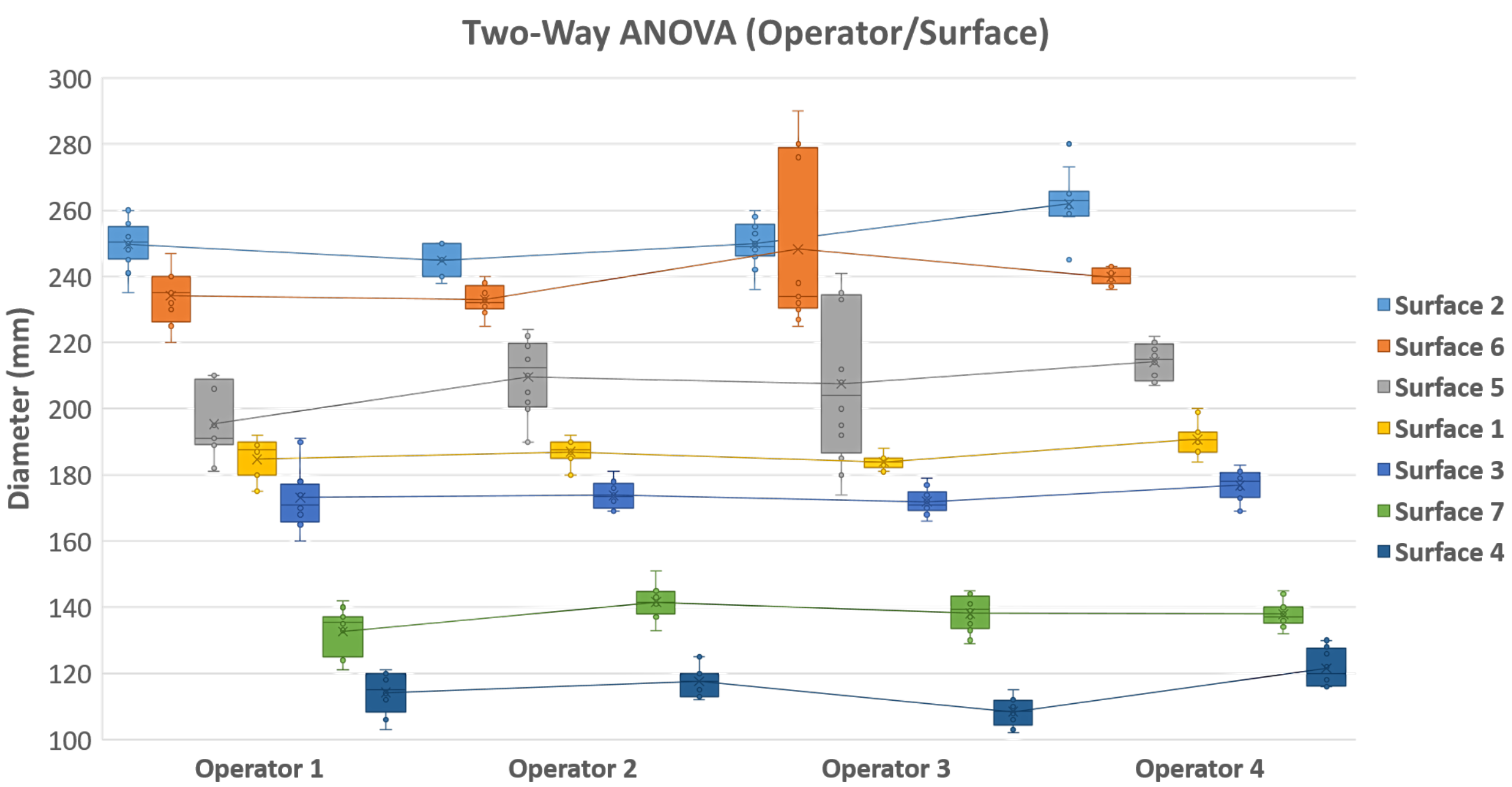
One Way ANOVA – Independent Factor: Operators in Surface			
One Way ANOVA: Operators within Surface 1			
Operators	**# Diameters**	**Average (mm)**	**Variance**
Operator 1	12	184.8	38.0
Operator 2	12	187.0	15.3
Operator 3	12	183.9	3.9
Operator 4	12	190.8	24.4
ANOVA			
Statistical Parameter	**F**	**P-value**	**F crit**
Result	5.49	0.003	2.82
…			
Surface 2 … Surface 6			
…			

One Way ANOVA: Operators within Surface 7			
Operators	**# Diameters**	**Average**	**Variance**
Operator 1	12	132.7	49.3
Operator 2	12	141.6	22.6
Operator 3	12	138.2	30.2
Operator 4	12	137.9	15.2
ANOVA			
Statistical Parameter	**F**	**P-value**	**F crit**
Result	5.54	0.003	2.82
ANOVA (Average of 7 Surfaces)			
Statistical Parameter	**F**	**P-value**	**F crit**
Result	6.36	0.001	2.82

Discussion

- P-value < α
  - At least one diameter mean is significantly different from the rest and non-homogeneity exists within the surface.
- If the bias generated by the operator is insignificant, one can conclude that the pavement texture within the surface is not homogeneous.

One Way ANOVA – Independent Factor: Operators in Surface			
One Way ANOVA: Operators within Surface 1			
Operators	**# Diameters**	**Average (mm)**	**Variance**
Operator 1	12	184.8	38.0
Operator 2	12	187.0	15.3
Operator 3	12	183.9	3.9
Operator 4	12	190.8	24.4
ANOVA			
Variation Source	**F**	**P-value**	**F crit**
Between Groups	5.49	0.003	2.82
…			
Surface 2 … Surface 6			
…			
One Way ANOVA: Operators within Surface 7			
Operators	**# Diameters**	**Average**	**Variance**
Operator 1	12	132.7	49.3
Operator 2	12	141.6	22.6
Operator 3	12	138.2	30.2
Operator 4	12	137.9	15.2
ANOVA			
Variation Source	**F**	**P-value**	**F crit**
Between Groups	5.54	0.003	2.82
Within Groups			
Total			
ANOVA (Average of 7 Surfaces)			
Variation Source	**F**	**P-value**	**F crit**
Total	6.36	0.001	2.82



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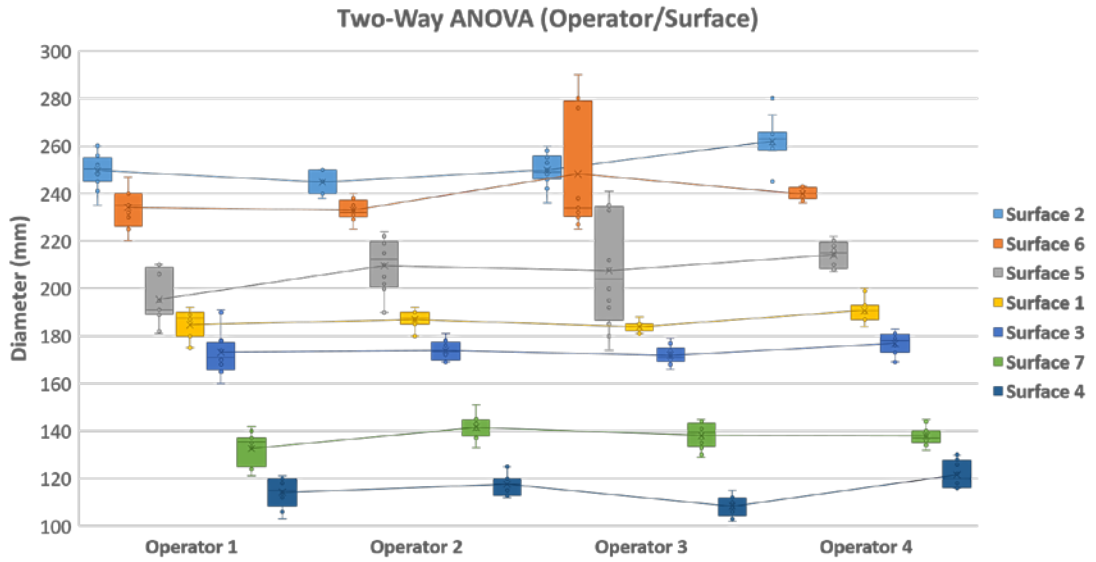
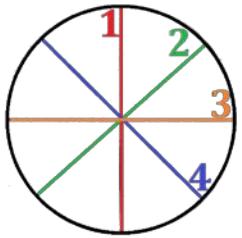
Discussion

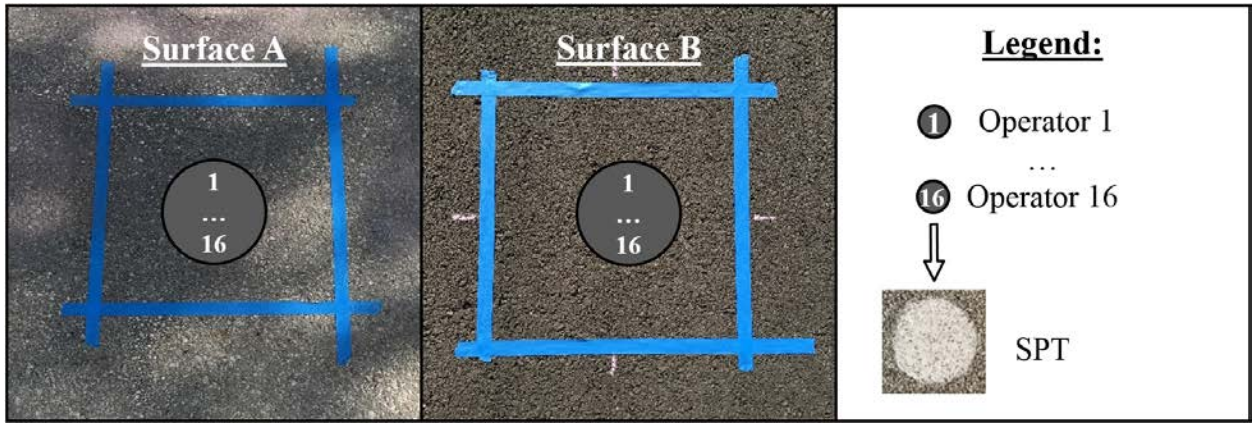
- Curves should be parallel and horizontal (if surfaces were perfectly homogenous and operator variability did not exist)
- Surface non-homogeneity and/or inherent operator differences.



Experiment 2

- 2 different site surfaces
- 16 different operators
- 1 Fixed trial location per surface
- 4 diameters



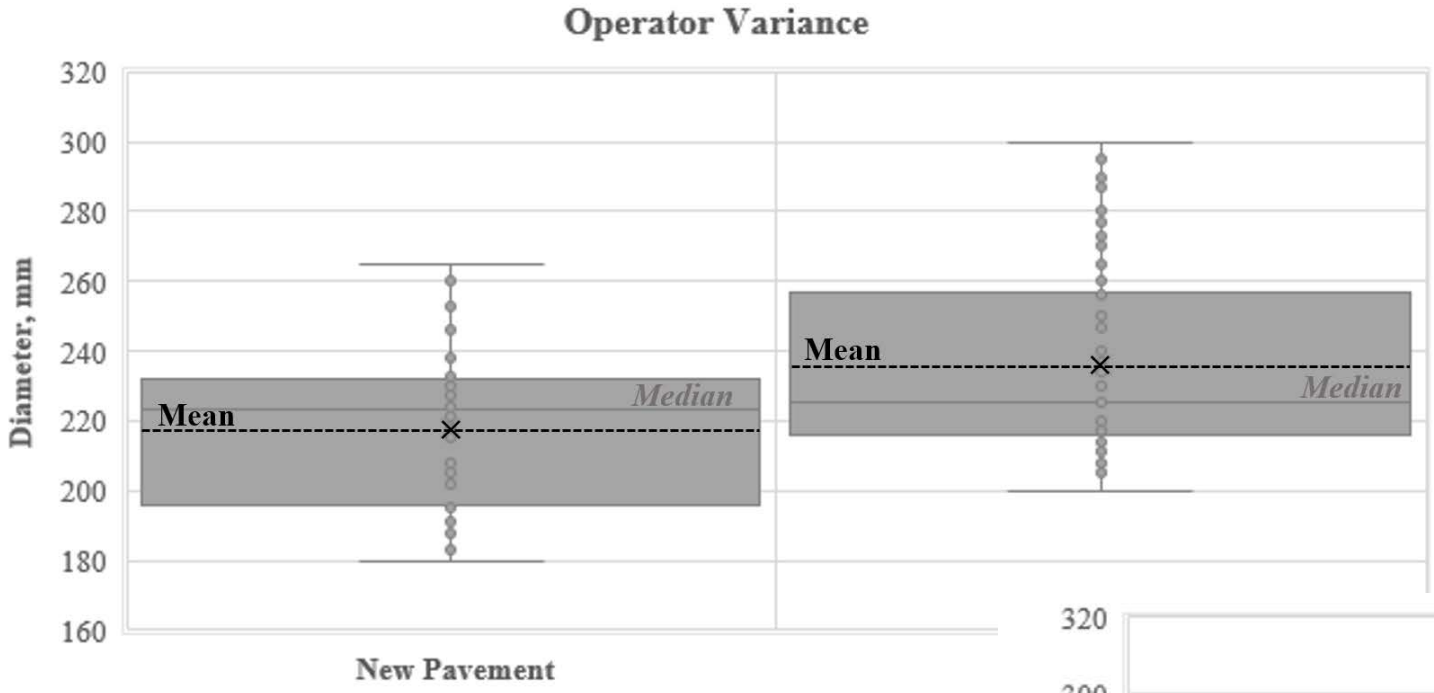


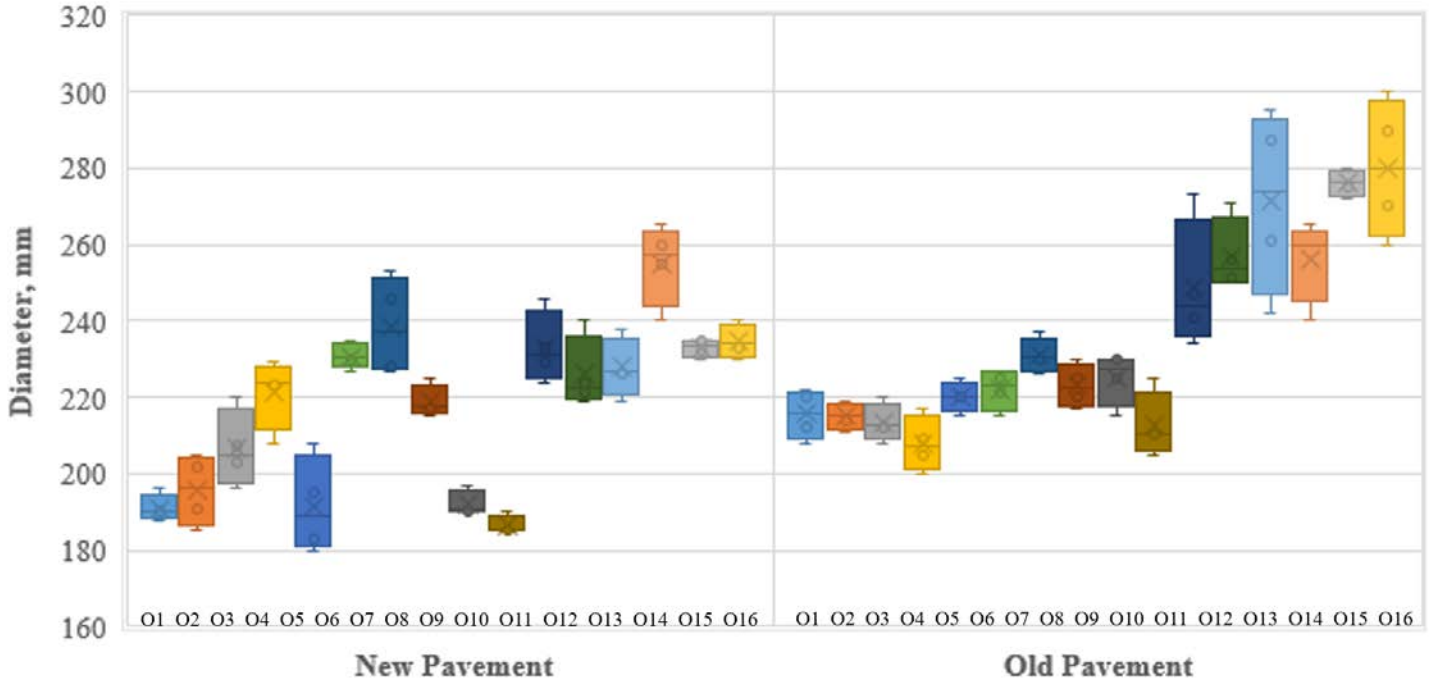
- **<u>Limiting Surface Variability</u>**
- Focusing on Operator variability
  - 32 SPT's

Variability between Operators, Reproducibility

One Way ANOVA – Independent Factor: Operators			
Surface A: New Pavement			
Operators	Diameters	Average	Variance
Operator 1	4	191.0	12.0
Operator 2	4	195.8	87.6
Operator 3	4	206.5	101.7
Operator 4	4	221.3	84.3
Operator 5	4	191.5	163.0
Operator 6	4	230.8	10.9
Operator 7	4	238.5	169.7
Operator 8	4	218.8	18.9
Operator 9	4	192.0	11.3
Operator 10	4	186.3	6.3
Operator 11	4	233.0	88.7
Operator 12	4	226.0	91.3
Operator 13	4	227.8	61.6
Operator 14	4	255.0	116.7
Operator 15	4	233.0	6.0
Operator 16	4	234.5	17.7
ANOVA			
Statistical Parameter	F	P-value	F crit
Result	26.82	2.9 E-18	1.88

One Way ANOVA – Independent Factor: Operators			
Surface B: Old Pavement			
Operators	Diameters	Average	Variance
Operator 1	4	215.5	43.7
Operator 2	4	215.0	11.3
Operator 3	4	213.3	24.9
Operator 4	4	207.8	51.6
Operator 5	4	220.0	16.7
Operator 6	4	222.0	28.0
Operator 7	4	231.0	20.7
Operator 8	4	223.0	32.7
Operator 9	4	225.0	50.0
Operator 10	4	212.5	75.0
Operator 11	4	248.8	289.6
Operator 12	4	257.0	94.0
Operator 13	4	271.3	590.9
Operator 14	4	256.3	122.9
Operator 15	4	276.0	11.3
Operator 16	4	280.0	333.3
ANOVA			
Statistical Parameter	F	P-value	F crit
Result	22.06	1.6E-16	1.88





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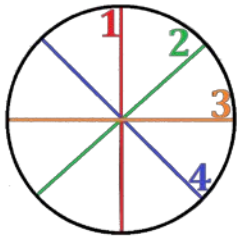
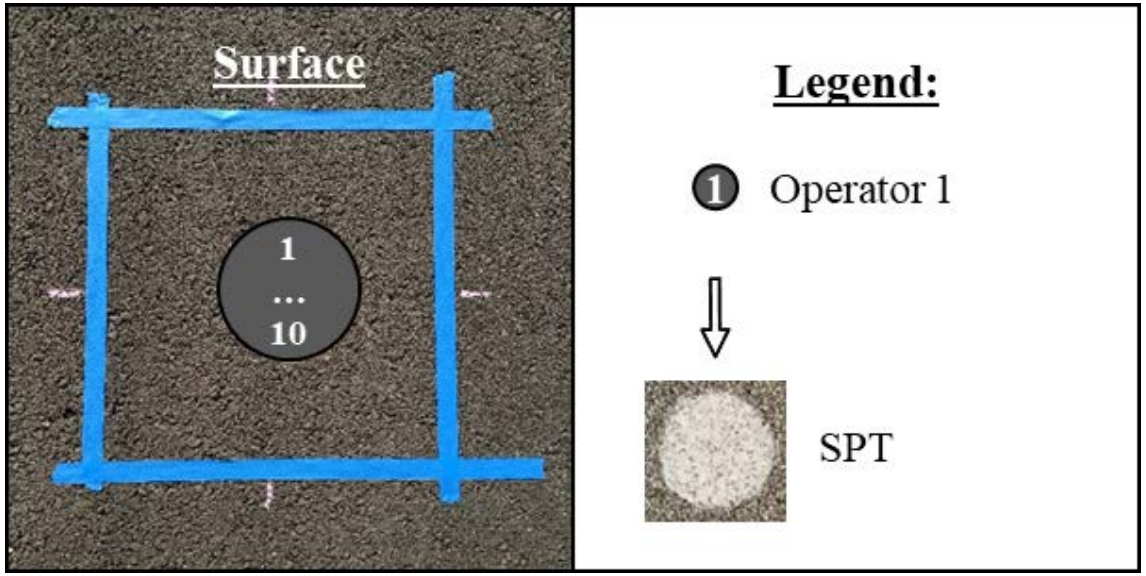
Discussion

- P-value < α
  - Reject null hypothesis that means of all the operators' diameters are same
  - Conclude that there exists at least one operator diameter mean which is significantly different from the rest
- High F-Value
  - Variance between operators > variance within the sample operators
    - Reproducibility of the SPT is much lower than its repeatability.
- Conclude that the SPT is generally subjective and highly depends on the perception of the operator.

Experiment 3

- 1 different site surfaces
- 1 operators
- 1 Fixed trial location per surface
  - 10 Trials
- 4 diameters





- **<u>Limiting Surface Variability</u>**
- Focusing on one Operator variability
  - 10 SPT's

Single Operator Variability, Repeatability

One Way ANOVA: Surface			
Surfaces	**# Diameters**	**Average D (mm)**	**Variance**
SPT1	4	207.75	8.92
SPT2	4	215.00	6.67
SPT3	4	199.00	6.67
SPT4	4	212.75	8.92
SPT5	4	221.00	6.67
SPT6	4	229.00	6.67
SPT7	4	217.75	9.58
SPT8	4	202.75	11.58
SPT9	4	214.00	6.67
SPT10	4	224.50	11.67
ANOVA			
Statistical Parameter	**F**	**P-value**	**F crit**
Result	41.81	1.5E-14	2.21

Discussion

- P-value < α
  - Reject null hypothesis that mean diameters of all the SPTs are the same
  - Conclude that there exists at least one test trial significantly different from the rest.
  - This demonstrates that the repeatability of the SPT is low.
- SPT is a relatively subjective test that highly depends on the perception of the operator during one specific trial and independent of other trials.

One Way ANOVA: Surface			
Surfaces	**# Diameters**	**Average D (mm)**	**Variance**
SPT1	4	207.75	8.92
SPT2	4	215.00	6.67
SPT3	4	199.00	6.67
SPT4	4	212.75	8.92
SPT5	4	221.00	6.67
SPT6	4	229.00	6.67
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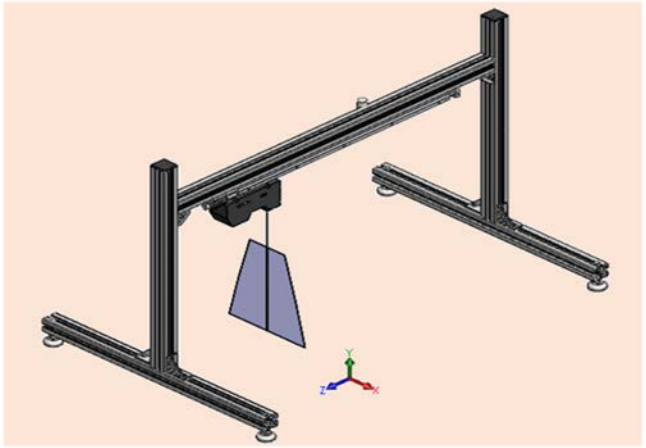
ANOVA			
Statistical Parameter	**F**	**P-value**	**F crit**
Result	41.81	1.5E-14	2.21

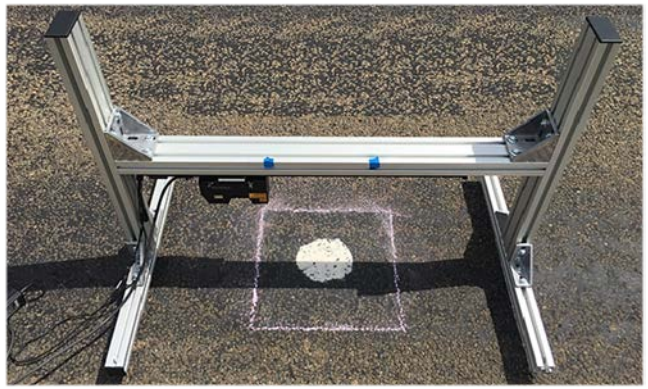
Section 2

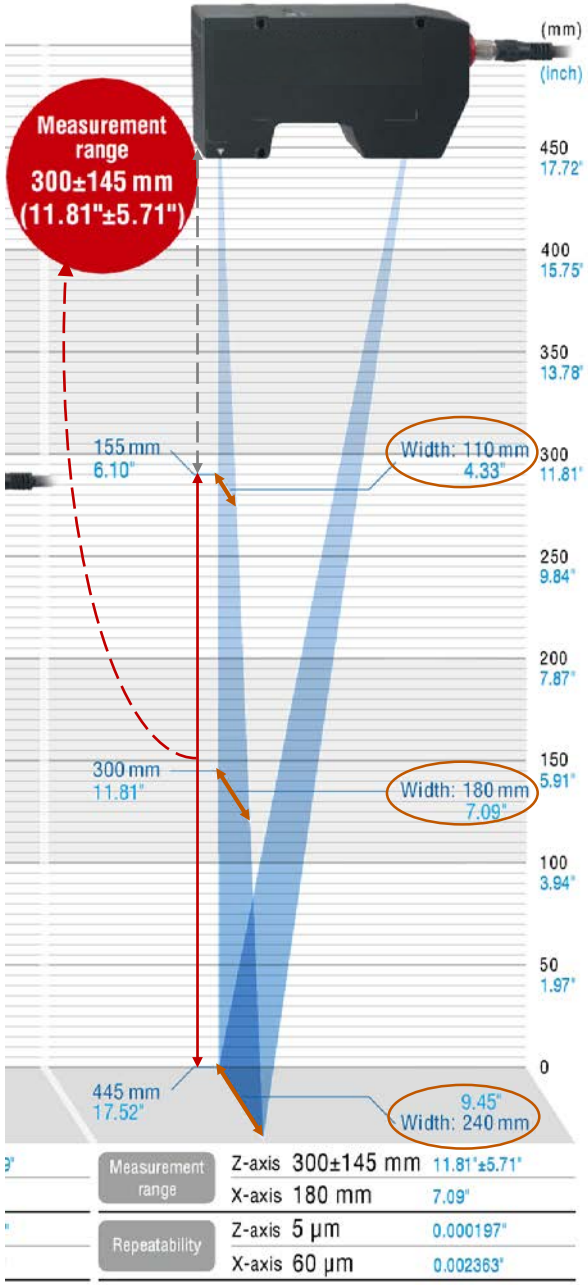
Mitigation

3D Line Laser Scanner

3D Laser Scanner







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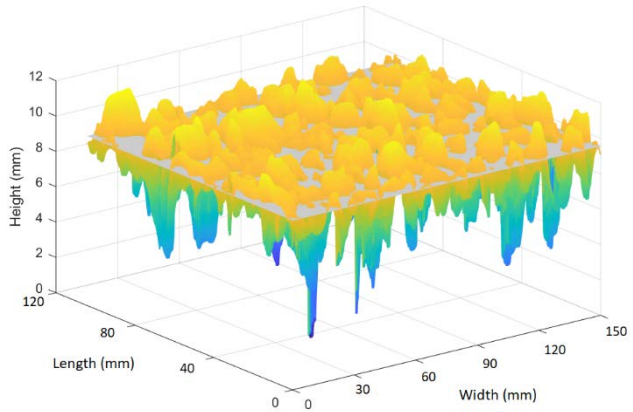
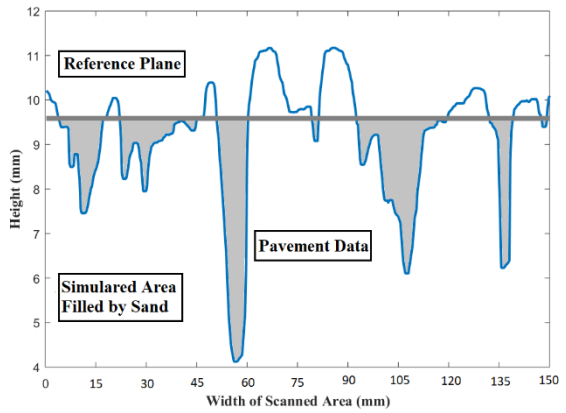
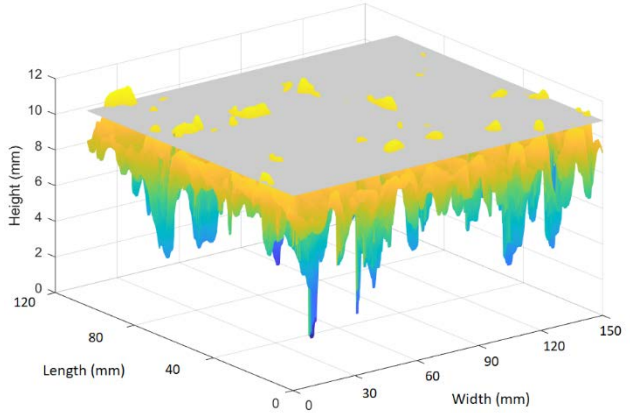
Reference Plane

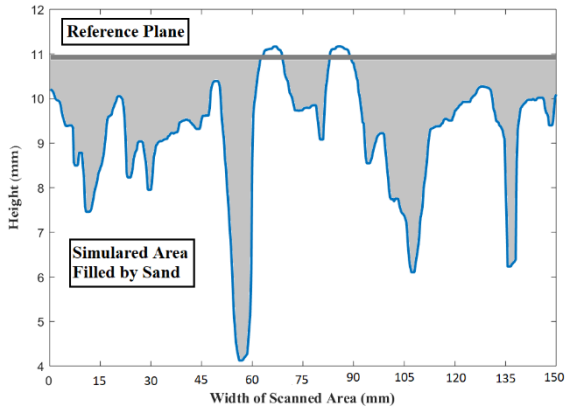
50th Percentile



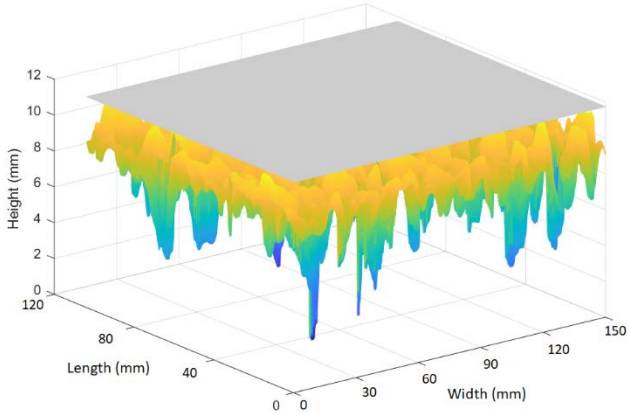


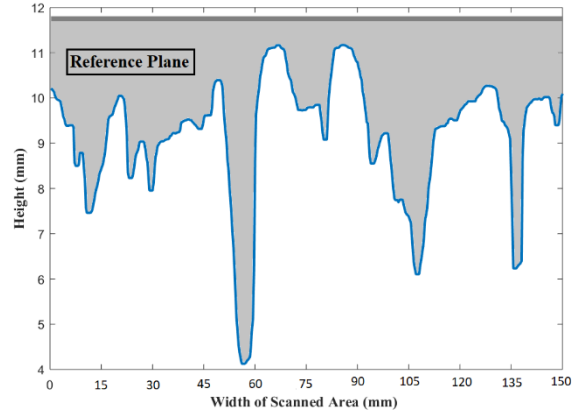
97th Percentile





100th Percentile





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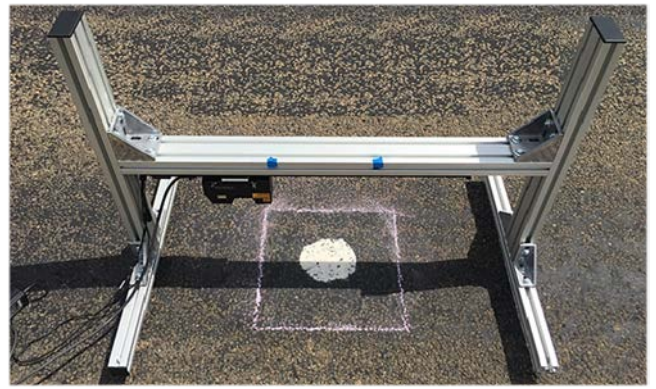
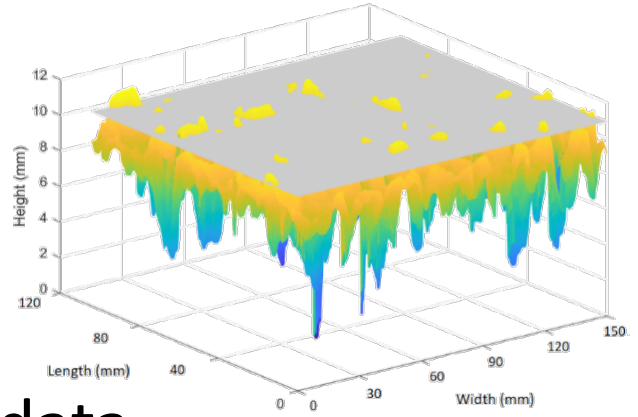
Test Results

Test Location	FM 1626		RM 12		FM 1431		IH 20		SH 36		SH 195		US 84		US 181	
Test Sections	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
SPT MTD	0.75	0.73	0.47	0.47	1.24	1.34	2.33	2.29	2.04	2.09	1.60	1.78	1.18	1.24	1.36	1.33
BPN	27.00	36.75	64.29	68.33	32.20	36.00	44.20	41.60	35.00	33.80	40.29	39.90	36.60	35.00	55.50	43.00
Percentiles	Model MTD Results															
50%	0.53	0.56	0.29	0.29	1.10	1.13	1.31	1.08	1.42	1.42	1.13	1.17	0.30	0.36	0.91	0.94
52%	0.53	0.56	0.29	0.29	1.10	1.12	1.33	1.11	1.43	1.43	1.13	1.17	0.31	0.37	0.91	0.95
54%	0.53	0.56	0.29	0.29	1.11	1.12	1.35	1.14	1.44	1.45	1.13	1.17	0.31	0.38	0.91	0.95
56%	0.53	0.56	0.29	0.29	1.11	1.12	1.37	1.18	1.46	1.47	1.12	1.17	0.32	0.40	0.91	0.95
58%	0.53	0.56	0.29	0.29	1.12	1.12	1.39	1.21	1.47	1.49	1.12	1.17	0.33	0.41	0.91	0.95
60%	0.53	0.56	0.29	0.29	1.12	1.13	1.42	1.24	1.48	1.51	1.12	1.18	0.33	0.43	0.91	0.95
62%	0.53	0.56	0.29	0.29	1.12	1.13	1.45	1.28	1.49	1.53	1.13	1.18	0.34	0.44	0.91	0.96
64%	0.53	0.56	0.29	0.29	1.13	1.14	1.48	1.31	1.50	1.55	1.13	1.19	0.35	0.46	0.91	0.96
66%	0.53	0.56	0.29	0.29	1.13	1.14	1.51	1.35	1.51	1.58	1.13	1.20	0.36	0.48	0.92	0.96
68%	0.53	0.56	0.30	0.30	1.13	1.14	1.55	1.39	1.52	1.61	1.14	1.20	0.37	0.49	0.92	0.97
70%	0.53	0.57	0.30	0.30	1.14	1.15	1.58	1.42	1.53	1.64	1.15	1.21	0.39	0.51	0.92	0.97
72%	0.53	0.57	0.30	0.30	1.15	1.15	1.62	1.47	1.55	1.67	1.16	1.22	0.40	0.53	0.93	0.98
74%	0.53	0.57	0.31	0.30	1.16	1.16	1.66	1.52	1.56	1.70	1.17	1.23	0.42	0.54	0.94	0.99
76%	0.54	0.58	0.31	0.31	1.18	1.17	1.71	1.56	1.58	1.74	1.18	1.24	0.45	0.56	0.95	1.00
78%	0.54	0.58	0.31	0.31	1.19	1.18	1.76	1.61	1.60	1.79	1.19	1.24	0.47	0.59	0.97	1.01
80%	0.55	0.59	0.32	0.32	1.21	1.19	1.81	1.65	1.62	1.85	1.21	1.26	0.50	0.61	0.98	1.02
82%	0.55	0.59	0.32	0.32	1.22	1.21	1.87	1.70	1.64	1.91	1.23	1.27	0.54	0.64	1.00	1.04
84%	0.56	0.60	0.33	0.33	1.24	1.23	1.94	1.75	1.67	1.97	1.26	1.29	0.58	0.68	1.02	1.06
86%	0.57	0.61	0.34	0.33	1.27	1.25	2.00	1.81	1.71	2.05	1.29	1.31	0.63	0.73	1.04	1.08
88%	0.58	0.62	0.35	0.34	1.30	1.28	2.10	1.87	1.75	2.15	1.32	1.33	0.69	0.78	1.07	1.10
90%	0.59	0.64	0.36	0.35	1.34	1.31	2.21	1.94	1.80	2.25	1.37	1.37	0.75	0.85	1.11	1.13
92%	0.61	0.66	0.37	0.37	1.40	1.34	2.35	2.04	1.86	2.37	1.42	1.41	0.82	0.94	1.15	1.17
94%	0.63	0.68	0.39	0.38	1.47	1.39	2.51	2.16	1.94	2.52	1.49	1.46	0.93	1.07	1.21	1.22
96%	0.66	0.71	0.41	0.41	1.56	1.46	2.72	2.37	2.07	2.71	1.59	1.54	1.06	1.23	1.29	1.28
98%	0.71	0.77	0.46	0.45	1.73	1.58	2.99	2.73	2.28	3.07	1.78	1.66	1.27	1.50	1.43	1.38
100%	1.27	1.46	1.08	2.54	2.54	2.31	4.04	4.35	3.43	4.40	2.44	2.28	2.22	2.84	3.04	2.02



- Highlighted value: computer-obtained MTD closest to sand patch test.
- 12/16 sections, plane between the 96th & 99th percentile.
- Results in the four other sections are all above the 84th percentile.
- Variability: inherent subjectivity and variability of the sand patch test procedure.

3D Laser Scanner Prototype



- A reference plane at the 97th percentile of the surface data
  - Most likely plane
  - Captures the sand patch test
  - Provides an adequate estimate of the MTD.
- In the developing step areas of 3D Laser and SPT are equal
- The whole scanned surface can be used to provide a better estimate of the MTD.
  - More data points, more efficient surface texture estimates

Repeatability

- Measuring one area 5 times using both methods

No. of Tests	Prototype Results	Sand Patch Test Results
1	0.6304	0.7483
2	0.6305	0.7000
3	0.6303	0.7724
4	0.6300	0.7322
5	0.6301	0.6232
Comparing Results		
Standard deviation	0.0002	0.0578
Coefficient of variation (%)	0.0329	8.0781
Range	0.0005	0.1492

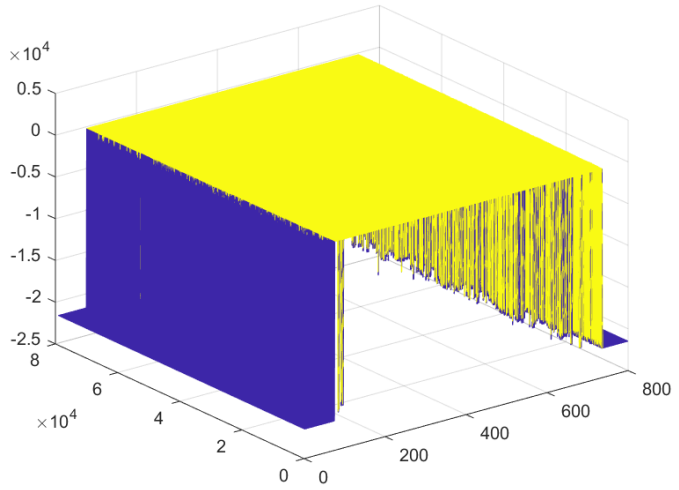
- The developed 3D Laser Prototype provides better repeatability

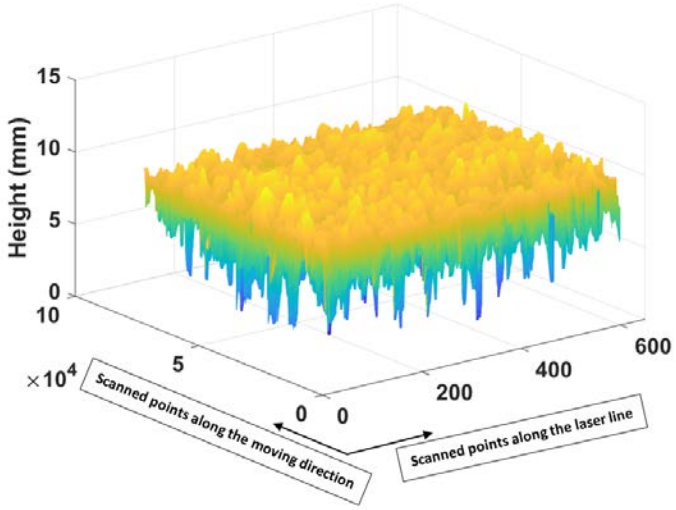
Conclusion

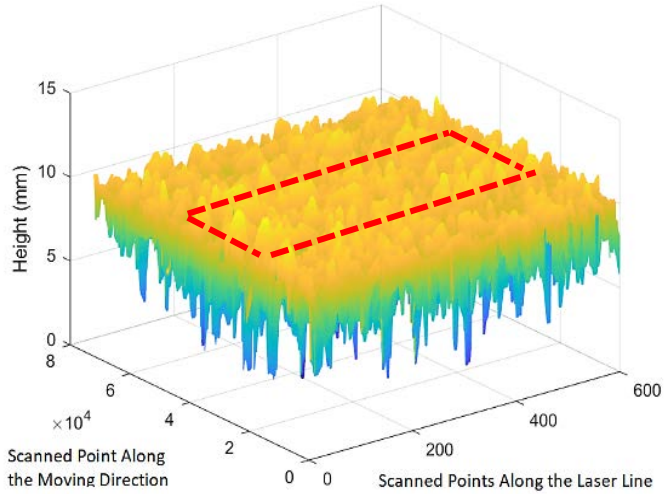
- Need for accurate measurements of pavement macrotexture to assess
  - Potential skid problems
  - Road **safety**
- SPT common & inexpensive
  - Has low reliability
  - Subjective: based on user perception
- 3D Laser scanner prototype
  - Highly reliable & repeatable
  - Unbiased: Eliminated user perception from test method
  - Larger & continuous sections can be assessed

Thank You

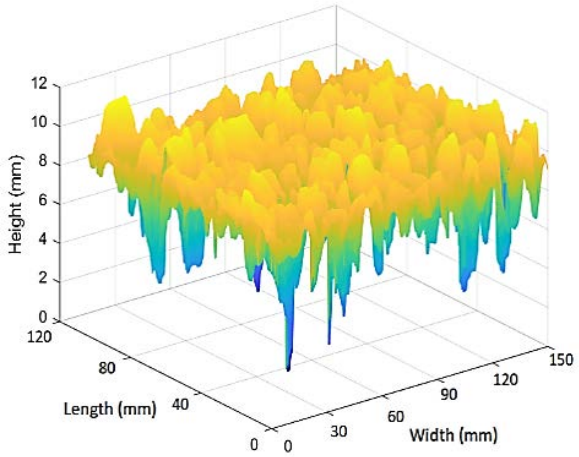
MTD Using 3D Laser Scanner Algorithm







- Filtering scanned data from NAN's (Not a Number)
  - Uncollected laser scan
- Median filtering outliers
- Mean filtering dead points
- Removing slope



RPUG Road Profile Users' Group

ANOVA

- ANOVA tests the non-specific null hypothesis that all population means for all conditions are equal.

$$\mu_X = \mu_Y = \mu_Z = \cdots$$

- When the hypothesis is rejected
  - At least 1 of the population means is different from at least 1 other mean
- When the hypothesis is accepted,
  - The population means are equal with a confidence defined by an F-Statistic
- The independent factors are the variables designated by the experimenter as a potential source of variance.
  - *SPT experimental factors:* **Operators, site surfaces, trials (replicates)**

One-Way ANOVA

Estimate of the variance	
Mean square error (MSE)	**Mean square between (MSB)**
Differences within the group	Differences between the groups
Estimates σ^2 regardless of whether the null hypothesis is true	Estimates σ^2 only if the null hypothesis is true
$$MSE = \frac{\sum_{i=1}^{n} \sigma^2{}_i}{n}$$ where i is a distinct group of the n groups within an independent factor	$$MSB = k_{(\text{elements per group})} \times \sigma^2_{\{\mu_1, \mu_2, \ldots \mu_n\}}$$ where k is the number of elements in a group, and μ is the mean of a group

$$F = \frac{\textbf{Variance between sample means}}{\textbf{Variance within the sample}} = \frac{\textbf{MSB}}{\textbf{MSE}}$$