Comparison of Friction Measurements in the US between the SCRIM99 and the E274 Locked-wheel Skid Testers

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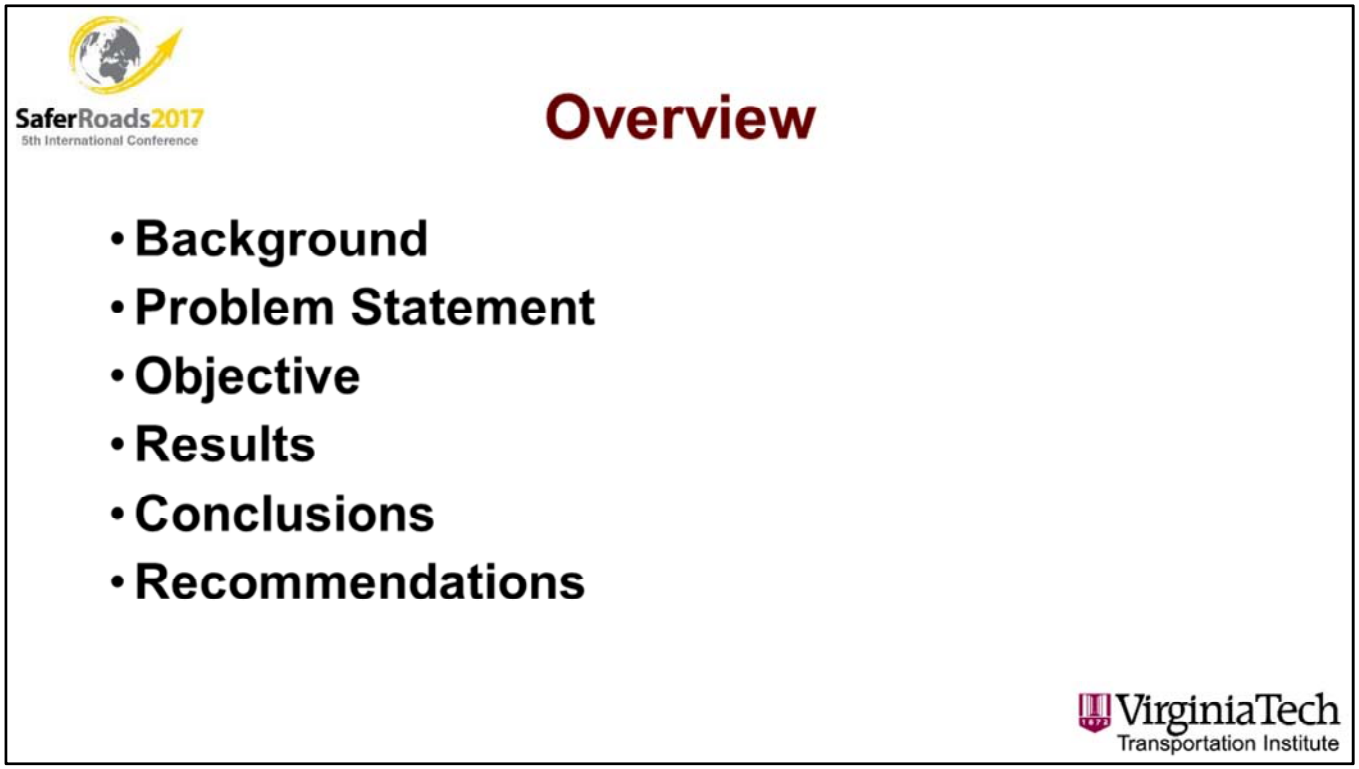
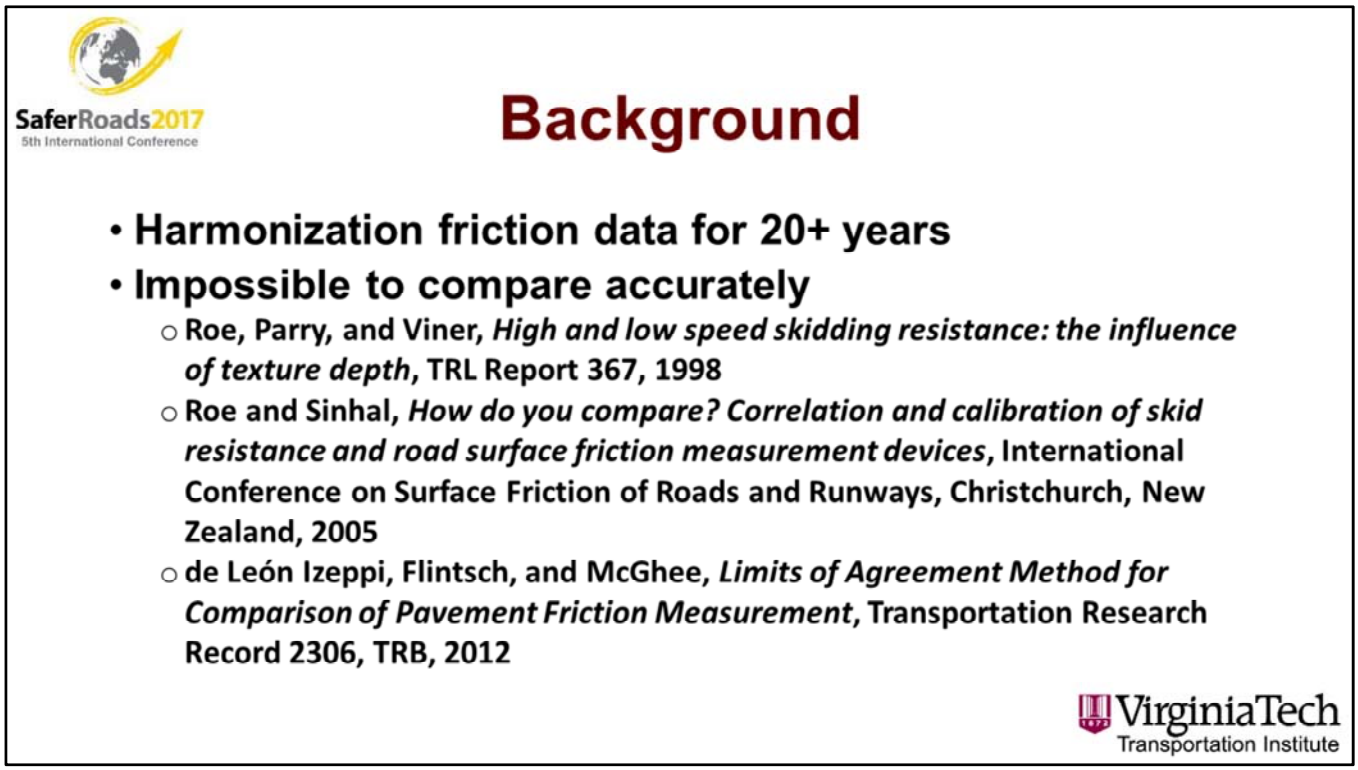
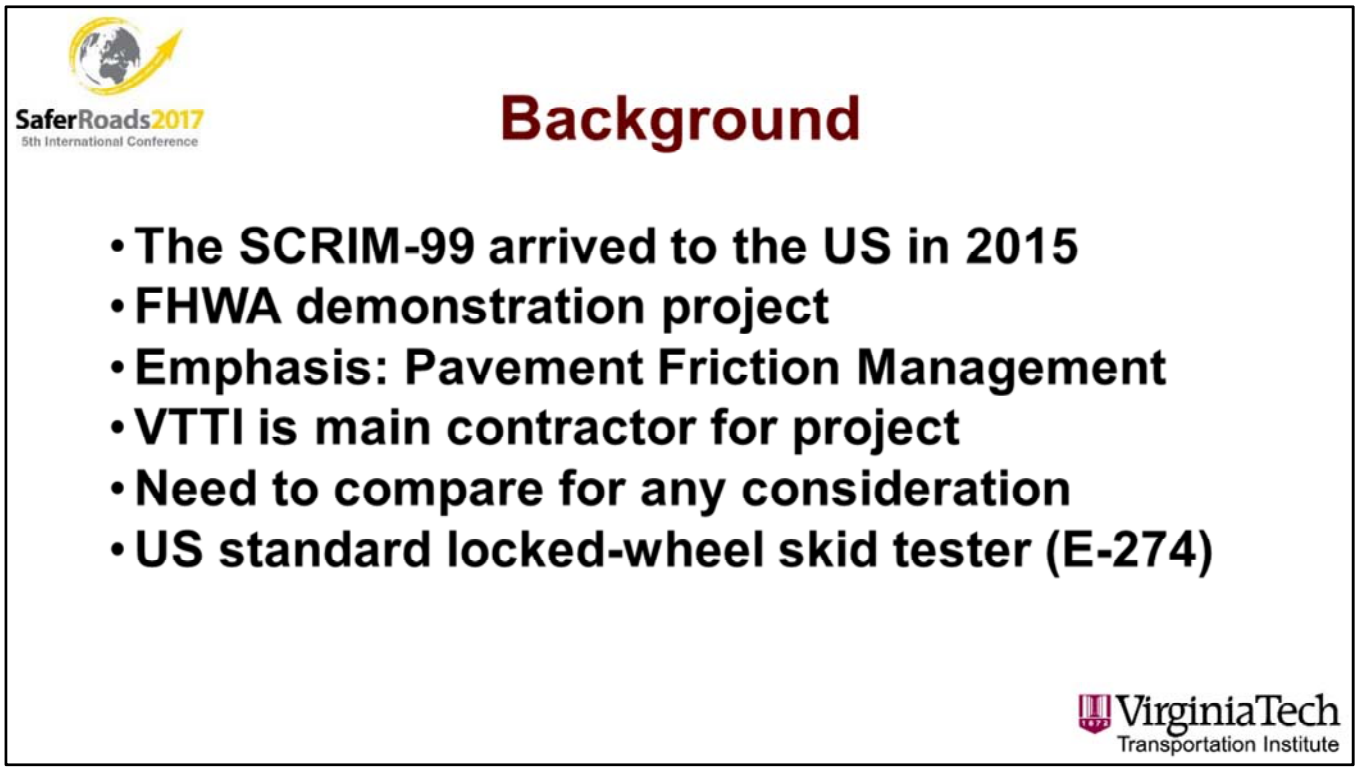
I am very glad to be in Auckland participating in this the most supreme of all friction related conferences in the World. I am hoping we can have it next in the US and that by 2020 there will be more SCRIMS there.



This is the outline of my presentation.



Harmonization of Friction Devices has been a request for Santa Claus for a very long time and I am afraid that it will continue to be there for a long time. Several papers come to mind but these are just some of the ones that I think are important in this context.



Our SCRIM, which has been denominated SCRIM-99 by WDM arrived to the US in June 2015 after anxiously waiting for almost 5 years for the purchase to happen. The Virginia Tech Transportation Institute is the main contractor for the project with FHWA. Because in the US it is the first SCRIM to arrive to the country and because there are really no other CFME that are being utilized to do road friction measurements, it was imperative that comparisons be made with these.

SCRIM-99

- Friction
- Macrotexture
- IMU + GPS
  - Grade
  - Cross-slope
  - Curvature
- Video (front)
- Water tank for 2,200 gallons (8400 liters)
- 150 miles (241 km) of Continuous Data per tank

SCRIM-99 was designed for the US. It has the capacity to do 150 miles per tank and the hope is that this will allow 300 miles of survey to be done in the future in one day (500 km.)

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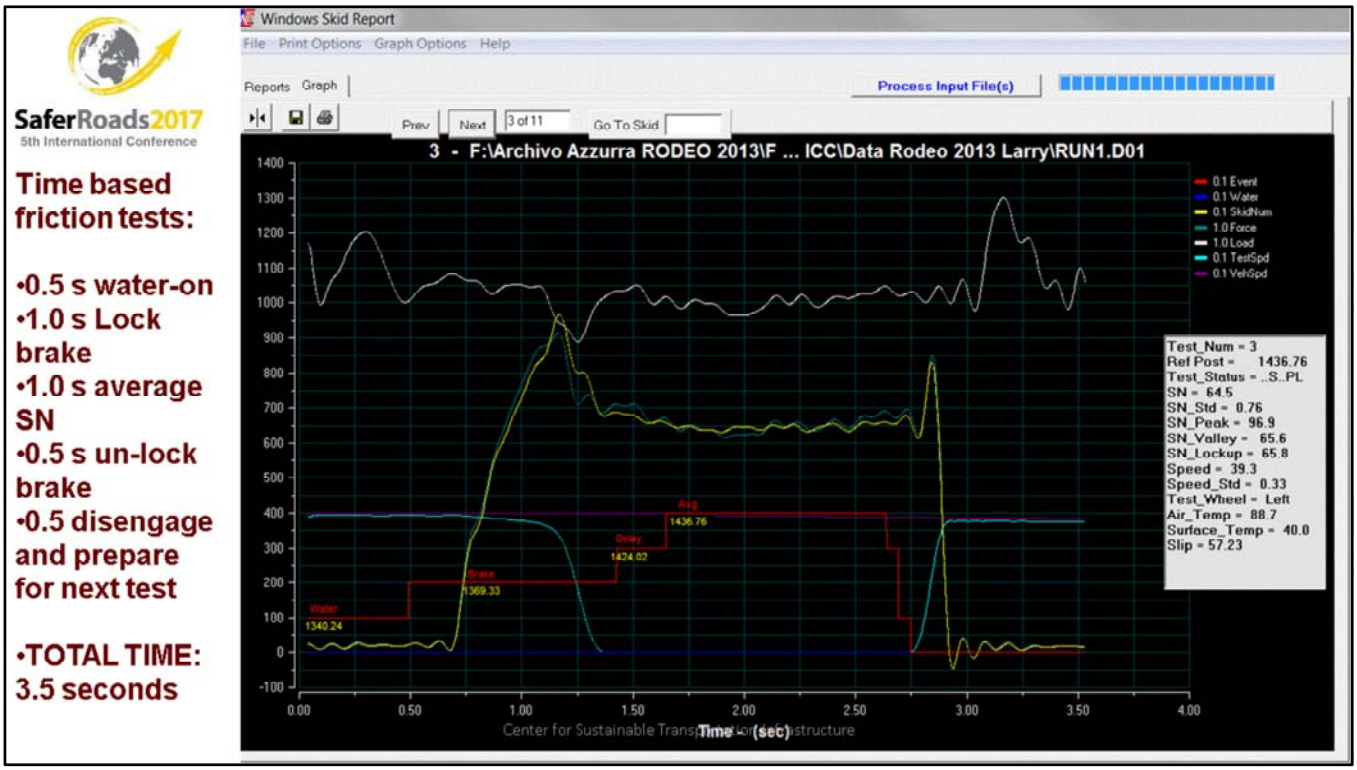
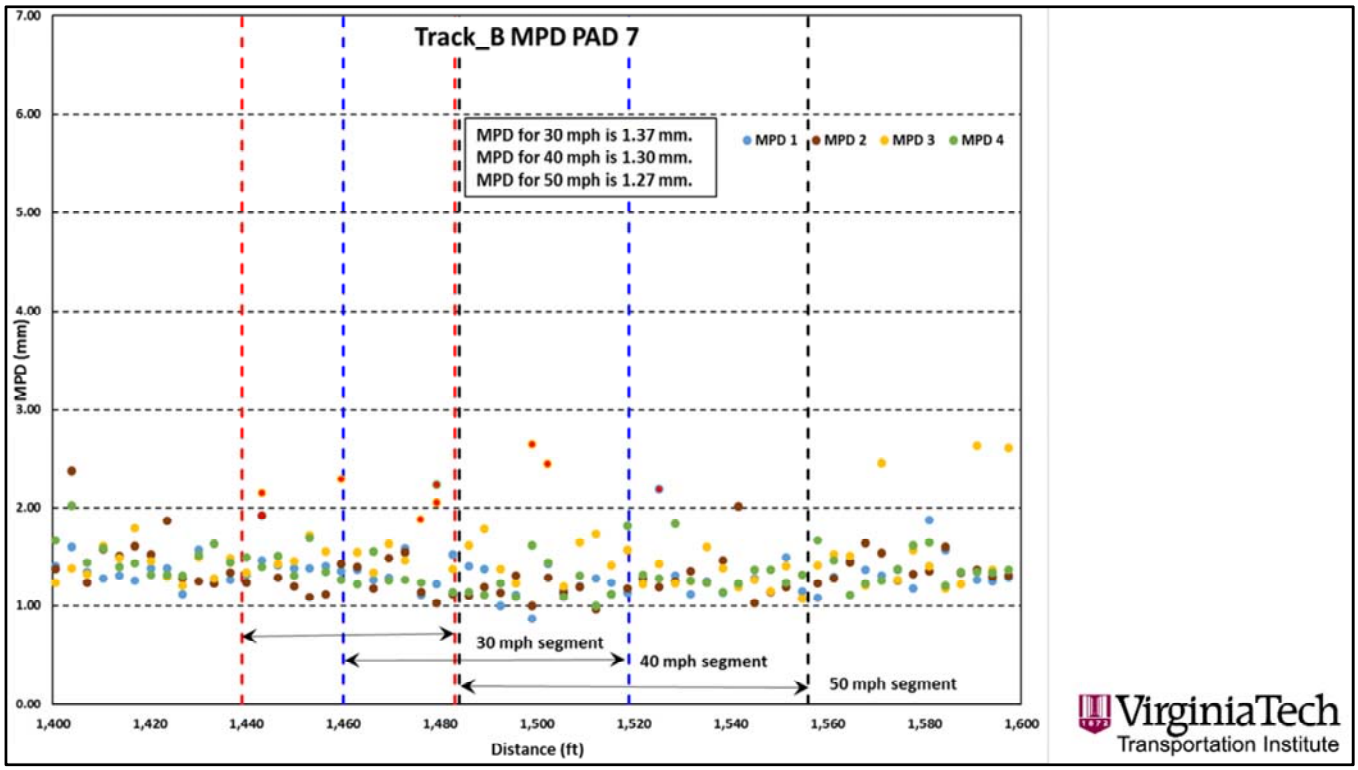
E-274
Locked-wheel skid tester

Two tires:
-Ribbed "micro"
-Smooth "macro"

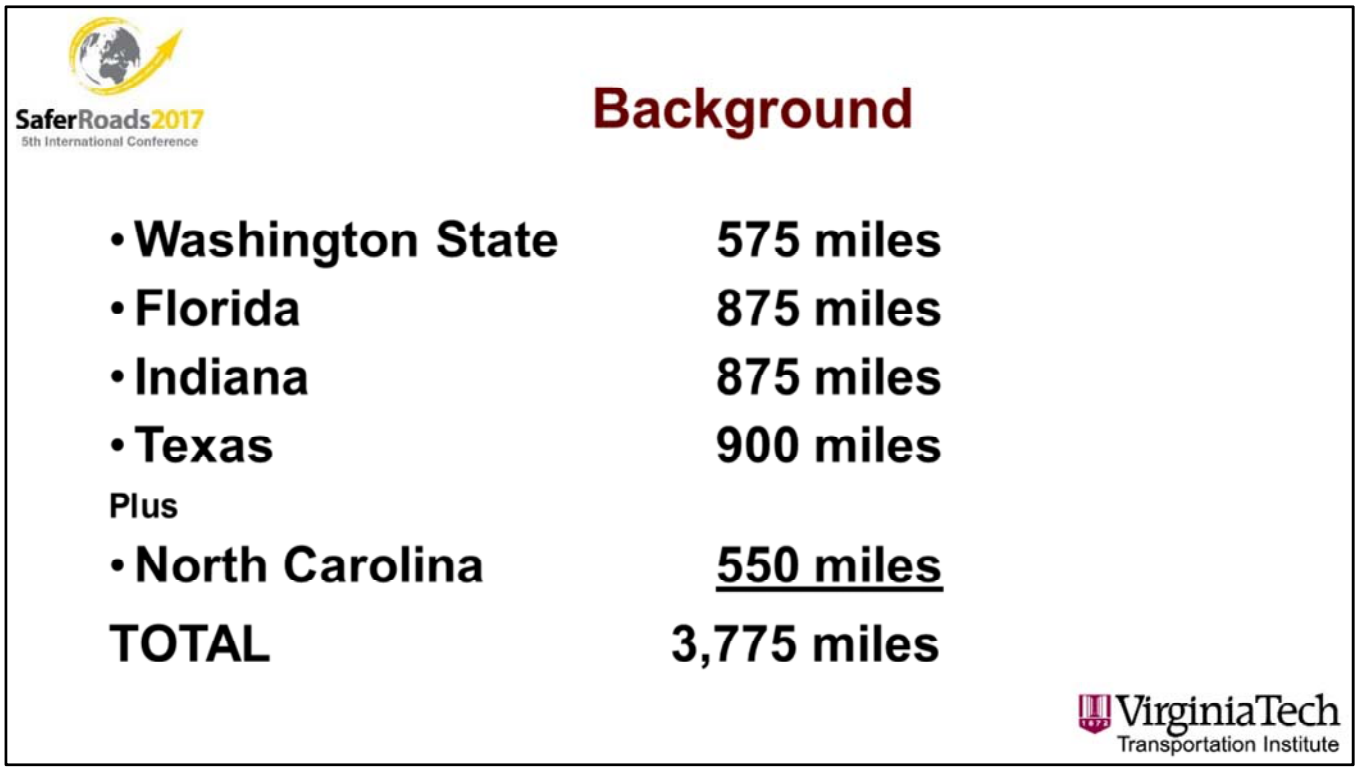
This is the ASTM E-274 Locked-wheel skid tester used in 49 of the 50 states in the US for friction measurements. As indicated by its name, the mechanism locks the tire and drags it for every measurement, thus limiting the distance where the measurements are made.



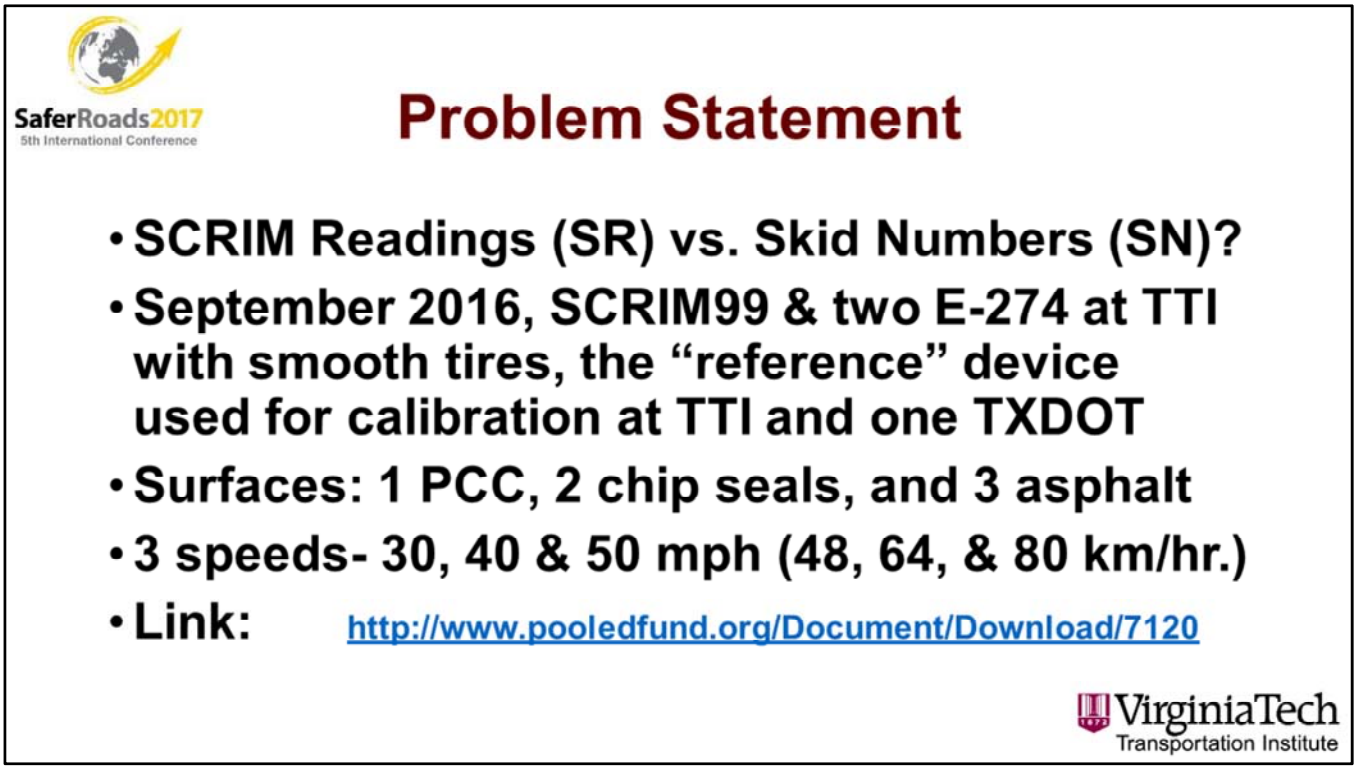
Indicated is the whole cycle of measurement.



Because it is a time based measurement, the distances that it measured in each of the pads was different for each measurement. As can be seen, the surfaces varied, having some overlap between the first and the second speeds and the second and the third speeds, but almost none between the first and the third speeds.



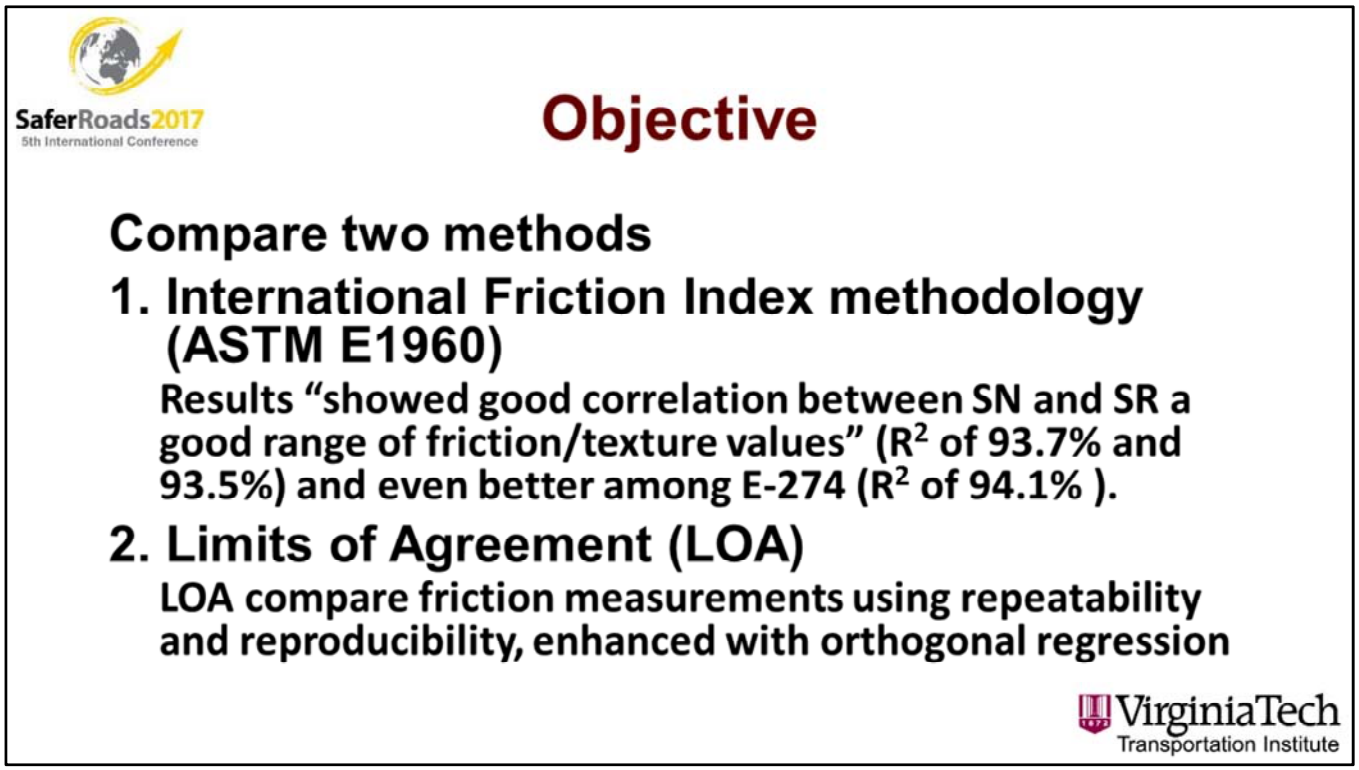
To date, this is the total number of miles that were surveyed in 2016 by the SCRIM-99. We are still processing, analyzing, and making the reports for all these miles of data. The North Carolina project is not a part of the original FHWA project, and vey interestingly it will produce a complete comparison with locked wheel skid testers with both tires, a Grip Tester, and the SCRIM-99.



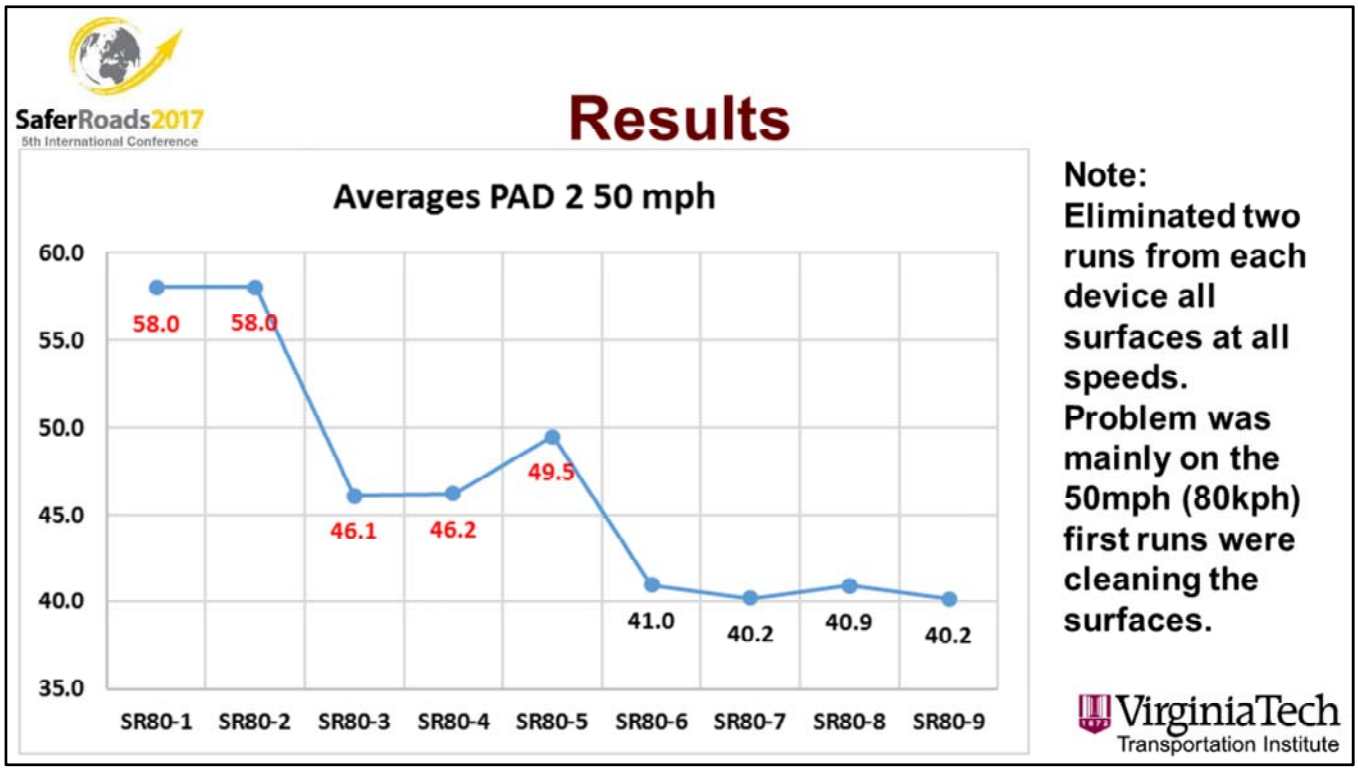
So the task at hand is to determine how to SCRIM Readings compare with Skid Numbers. A report on the original comparison made by the Texas Transportation Institute is available at the link.

These are some of the researchers and personnel that helped making this comparison a reality. The site of the track is in College Station, Texas at an old air force base used by TTI for several projects.

Pictures of some of the surfaces tested.

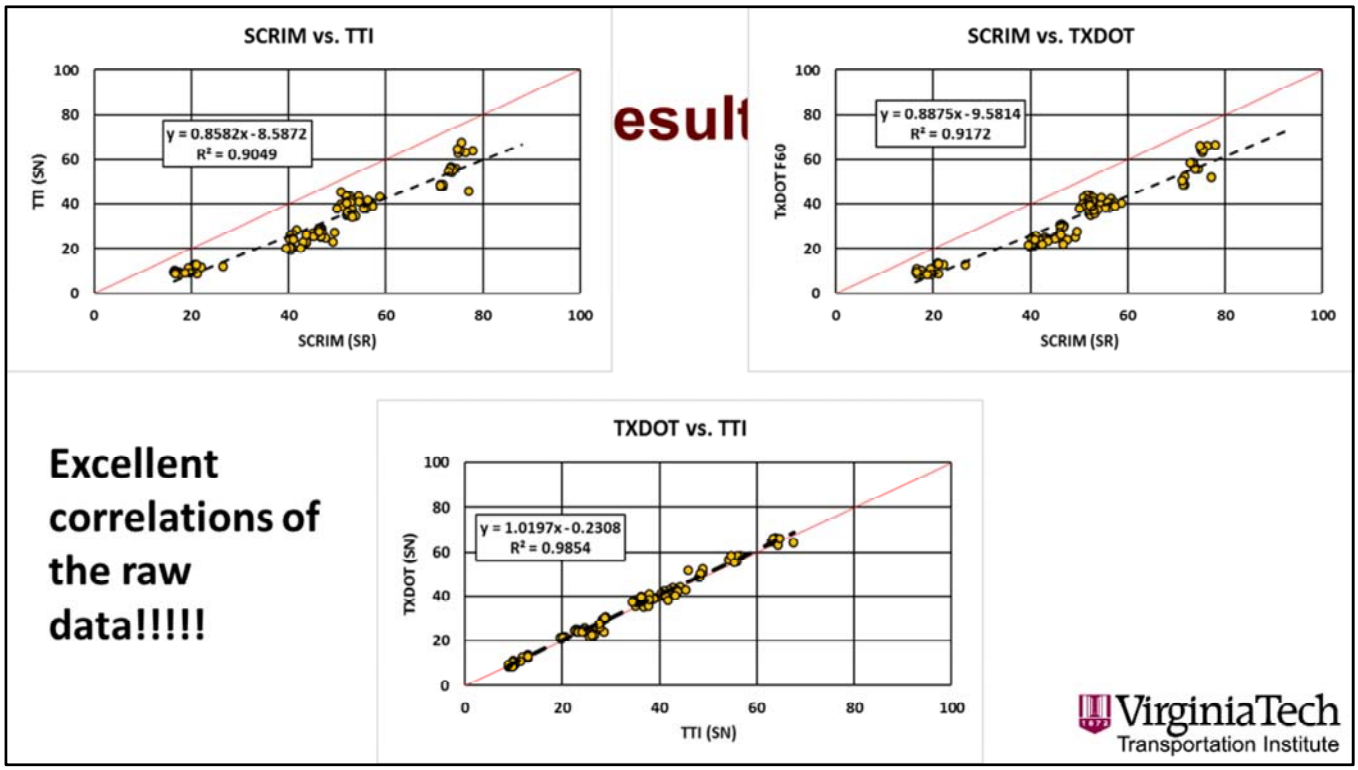


A review between two different methods to compare the friction measurements will be performed. The second method is the one we are endorsing.



This part of Texas suffered from intensive rains that flooded the tracks in the middle of June. Unfortunately this was not detected and the first set of passes on them was spend “washing” them. Several results should not have been used, but to equalize everything we decided to do the review without the first two runs in the set of eight that were taken.

After the testing it is obvious were all the dust had gone.



The raw data had excellent correlations, so maybe it would have been better to stop there? However, correlations are not very good indicators of agreement as it will be shown later on.

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Results

IFI Method originated in PIARC experiment 1994-95

- **"Speed gradient"** $Sp = 14.2 + 89.7MPD$ **(CT Meter)**
- ***"Golden Value"*** $F60 = 0.081 + 0.732xDFT_{20}\ exp\left(\frac{-40}{S_p}\right)$
- **Determine IFI calibration coefficients for each device by plotting FRS60 vs. "Golden" F60, where,**
- $FR60 = \boldsymbol{FRS_i} exp\left[\left(\frac{S-60}{S_p}\right)\right]$ *S = slip speed of device*

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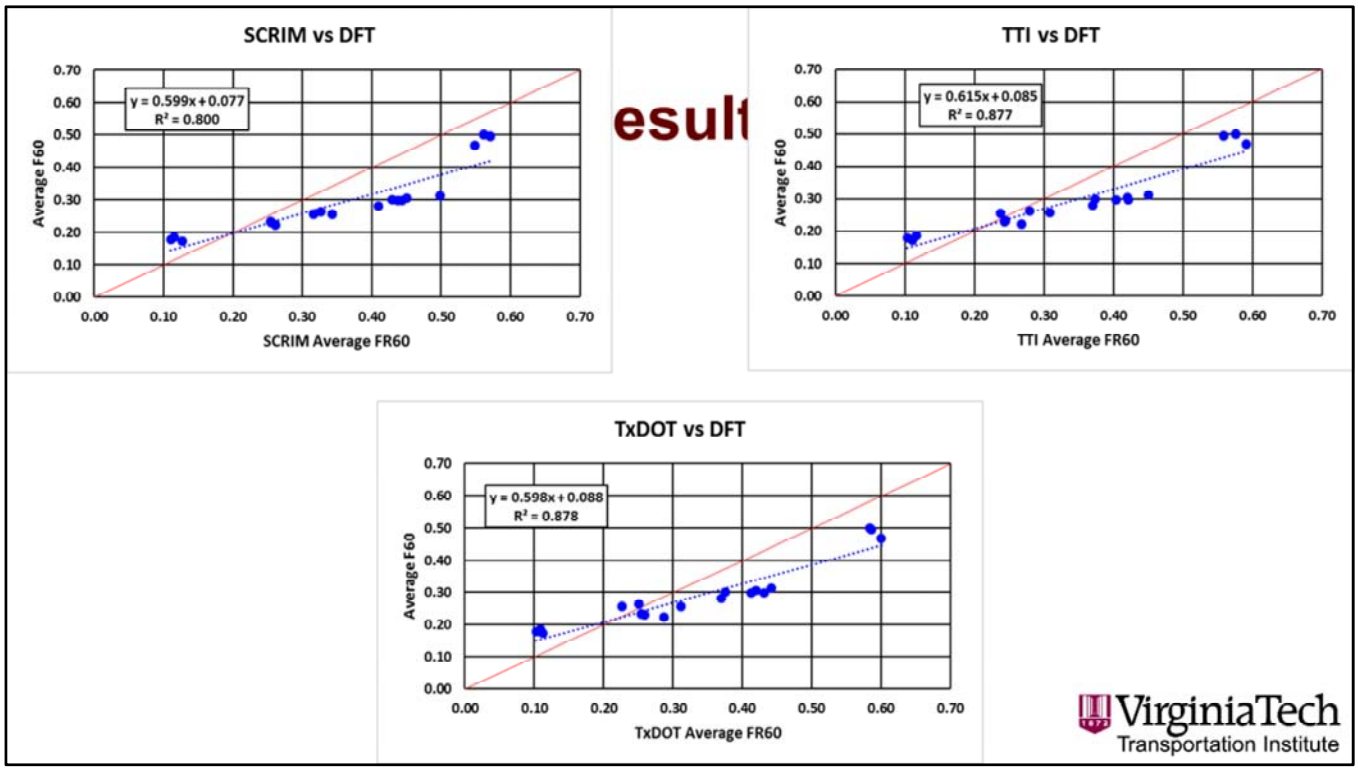
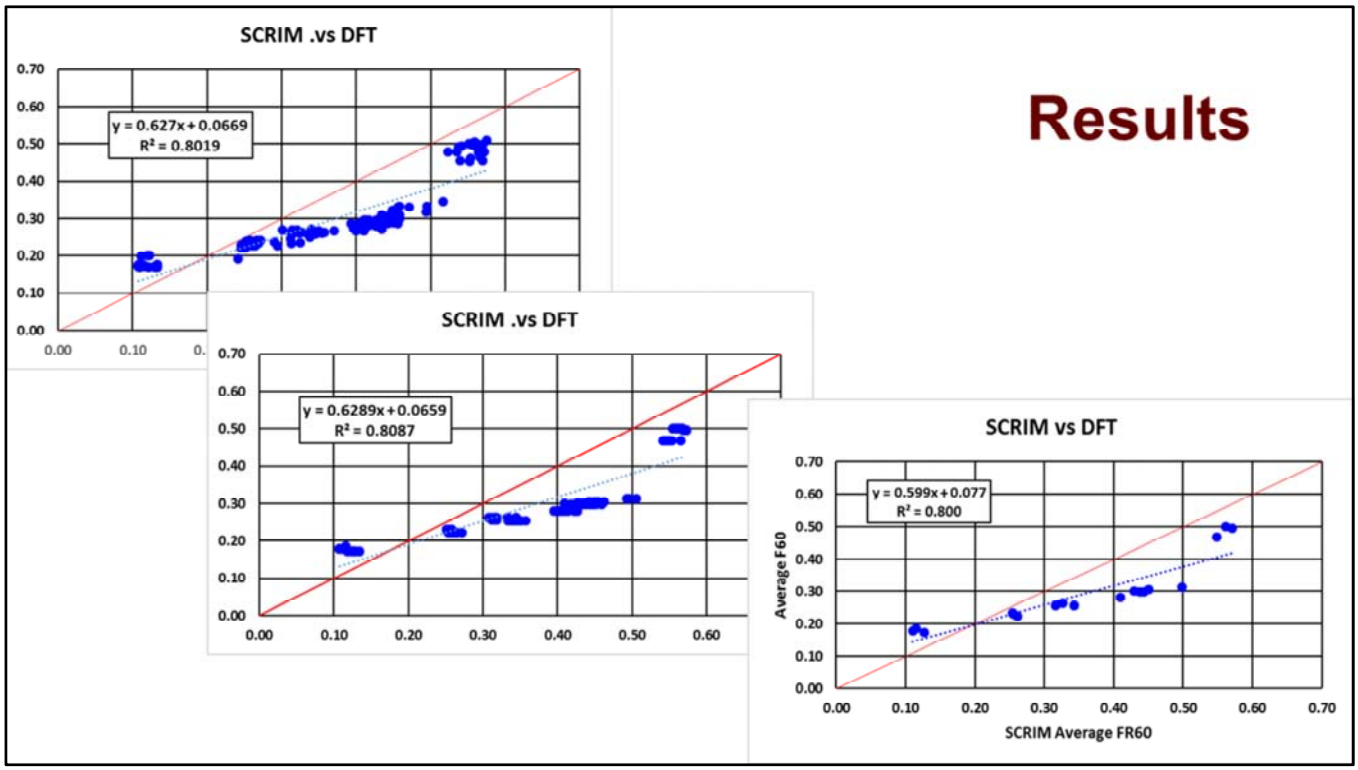
Equations and background on the IFI method used by TTI to do the comparison.



Initial correlations to obtain the A and B coefficients to transform the FR60 values for the devices into their “calibrated” values. The golden values are represented in the y-axis and the FR60 values for all three devices are in the x-axis.



These three plots show the “transformation” process with the IFI to understand how the process flattens all the data with a lot of variability to an average value.

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Results

- **The calibration constants are then determined with the correlation and substituted as the A and B in:**
- $F60 = A + BxFR60$
- **With this equation, compute F60 values for each device and compare them with each other to obtain their correlation.**

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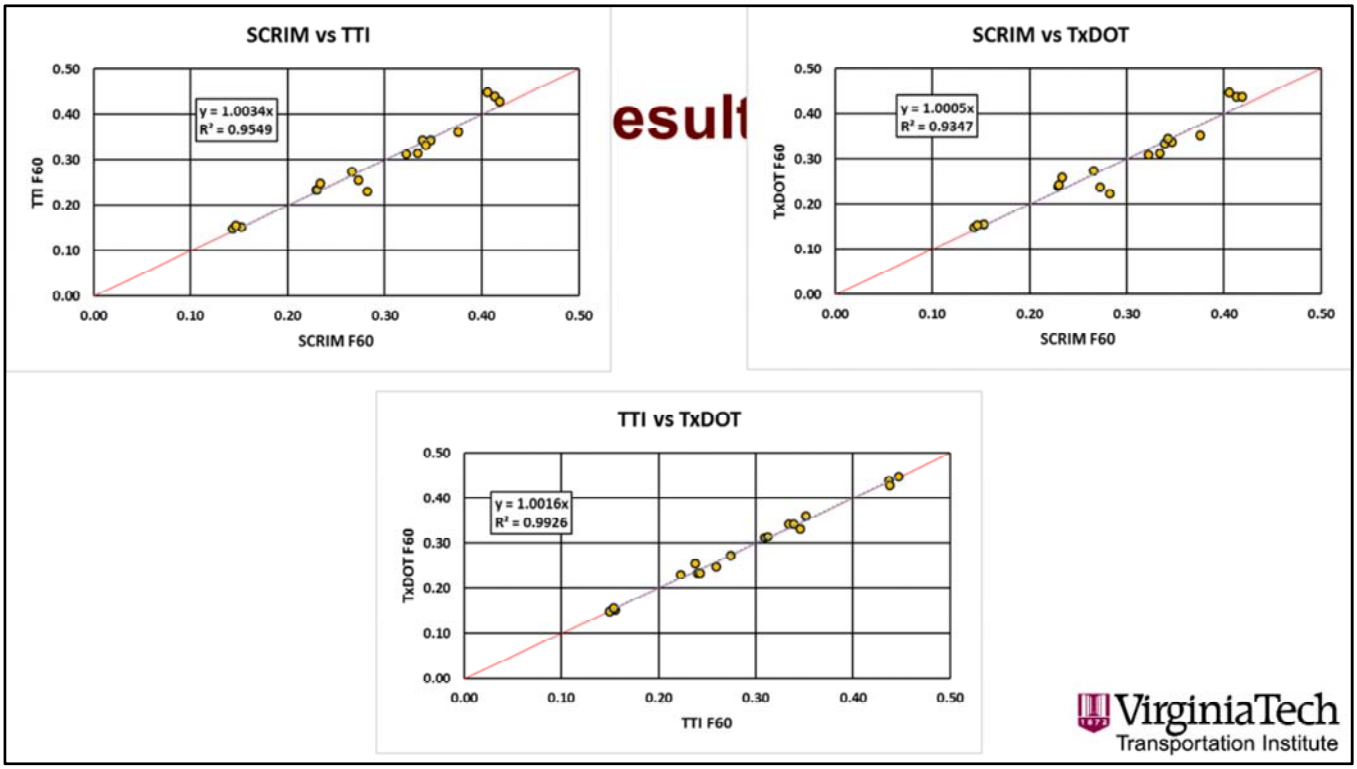
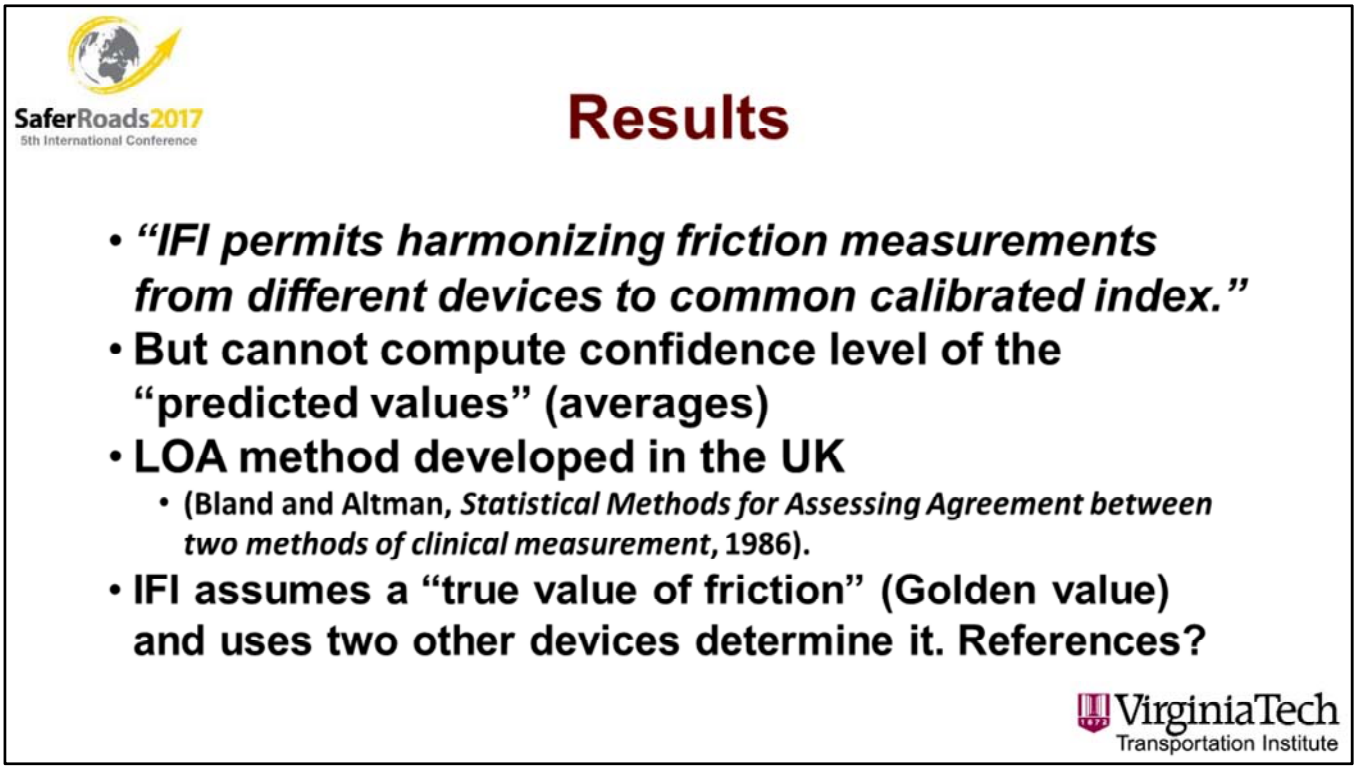
After the A and B constants have been determined, the calibrated friction values for the three devices were obtained and compared to each other, again by their R^2.



Results of the correlations with intercepts = zero.



Supposed benefits of the IFI method and origin of the LOA method.

Can anyone really say that the DFT is the almighty friction device for all the devices? Why?

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Results

- **What is agreement? "the 'closeness' between readings"**
- **Agree sufficiently to make them interchangeable?**
- **LOA three components:**
  - **Two are indicative of the variability of each device (1 and 2)**
  - **And one captures the effect of their interaction on "*m*" runs each**
- $s_{c=} \sqrt{s_D^2 + (f_1)s_1^2 + (f_2)s_2^2}, f_1 = \left(1 - \frac{1}{m_1}\right), f_2 = \left(1 - \frac{1}{m_2}\right)$

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What we are trying to obtain is a comparison of the agreement for the devices that could ease someone's mind if they were trying to decide to interchange them. This is of course caused by the historical results that most DOTs have with all their data, and that is why it is so hard to change them.
However, the same can be said about almost anything. Do you remember Window 3.0? The old IBM PC with two drives for 5 ¼" floppy disks? And the sun is still coming out every morning…

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Results

- **Repeatability of each device is equal to r_i =**

$$r_i = 1.96\ x\ \sqrt{2}s_i = 2.77\sqrt{s_i^2}$$

- **Reproducibility or LOA is also computed for a 95% Confidence Interval**

$$LOA = 1.96 s_c$$

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The LOA method uses the well known and trusted repeatability and reproducibility concepts that are scientifically determined and what's more utilize the variability and the errors in measurement of the friction devices, not get rid of them by averaging results to make comparisons.

Results

LOA SCRIM-TXDOT

TXDOT Sites	PAD	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	TXDC Aver
1	Pad1-30	29.9	30.2	29.3	31.1	30.0	30.6	30.2
2	Pad2-30	24.4	24.2	24.2	22.0	25.2	25.1	24.2
3	Pad2A-30	12.3	12.8	13.8	12.9	13.2	11.1	12.7
4	Pad5-30	43.9	43.0	44.2	42.7	43.0	42.2	43.2
5	Pad6-30	40.0	39.6	40.2	38.8	38.5	37.9	39.2
6	Pad7-30	64.5	66.5	66.0	63.3	64.2	66.1	65.1
7	Pad1-40	24.6	25.2	24.0	24.3	24.1	24.2	24.4
8	Pad2-40	24.0	25.3	24.5	23.4	22.7	22.7	23.8
9	Pad2A-40	9.8	11.2	9.6	8.8	8.4	10.5	9.7
10	Pad5-40	39.7	40.3	42.8	41.4	42.5	41.3	41.3
11	Pad6-40	37.9	40.0	35.8	35.1	35.8	37.3	37.0
12	Pad7-40	55.8	58.4	56.5	55.5	58.4	58.4	57.2
13	Pad1-50	21.3	21.8	20.8	21.5	21.8	21.5	21.5
14	Pad2-50	27.3	26.2	27.8	26.0	24.9	24.2	26.1
15	Pad2A-50	8.5	8.9	8.6	8.4	8.5	9.7	8.8
16	Pad5-50	40.4	40.9	40.2	38.1	39.0	40.9	39.9
17	Pad6-50	38.4	38.1	38.7	39.5	37.7	37.3	38.3
18	Pad7-50	52.1	48.6	50.8	52.5	48.8	50.4	50.5

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	25156	17	1480	1247	0	1.74
Within Groups	106.8	90	**1.19**			
Total	25263	107				

r=2.77*SQRT MSE WG= **3.02** **Repeatability**

TXDOT

$$s_1^2 = s_{TXDOT}^2 = 1.19$$

$$s_2^2 = s_{SCRIM}^2 = 2.55$$

$$f_1 = f_2 = \left(1 - \frac{1}{m}\right) = 0.833,$$

since $m_1 = m_2 = 6$

LOA SCRIM-TXDOT

SCRIM	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	SCRI Aver
Pad1-30	46.7	46.8	46.2	46.4	46.7	46.0	46.5
Pad2-30	47.0	46.6	47.6	46.6	49.1	45.8	47.1
Pad2A-30	20.5	**26.5**	20.8	22.1	21.1	19.4	21.7
Pad5-30	52.2	54.4	51.6	52.6	50.8	51.9	52.2
Pad6-30	51.7	52.3	50.7	51.1	50.9	50.0	51.1
Pad7-30	77.9	76.3	75.2	75.5	74.8	74.7	75.7
Pad1-40	43.7	42.9	43.1	43.2	43.7	43.0	43.3
Pad2-40	41.6	45.0	45.1	43.6	40.9	40.3	42.7
Pad2A-40	16.4	16.5	16.5	16.8	17.4	17.5	16.9
Pad5-40	54.4	52.1	52.9	52.8	**56.5**	52.0	53.4
Pad6-40	53.0	52.0	52.0	52.4	53.1	52.1	52.4
Pad7-40	74.4	73.4	73.6	73.9	73.3	72.8	73.6
Pad1-50	40.8	42.4	39.9	40.4	40.2	39.5	40.5
Pad2-50	**46.1**	**46.2**	**49.5**	41.0	40.2	40.9	44.0
Pad2A-50	**19.6**	**21.2**	**17.7**	**18.7**	16.7	16.6	18.4
Pad5-50	**58.7**	**57.2**	**56.6**	56.3	57.3	55.9	57.0
Pad6-50	**55.4**	52.7	52.5	52.1	53.8	53.0	53.3
Pad7-50	**77.1**	71.7	71.3	71.7	71.3	71.2	72.4

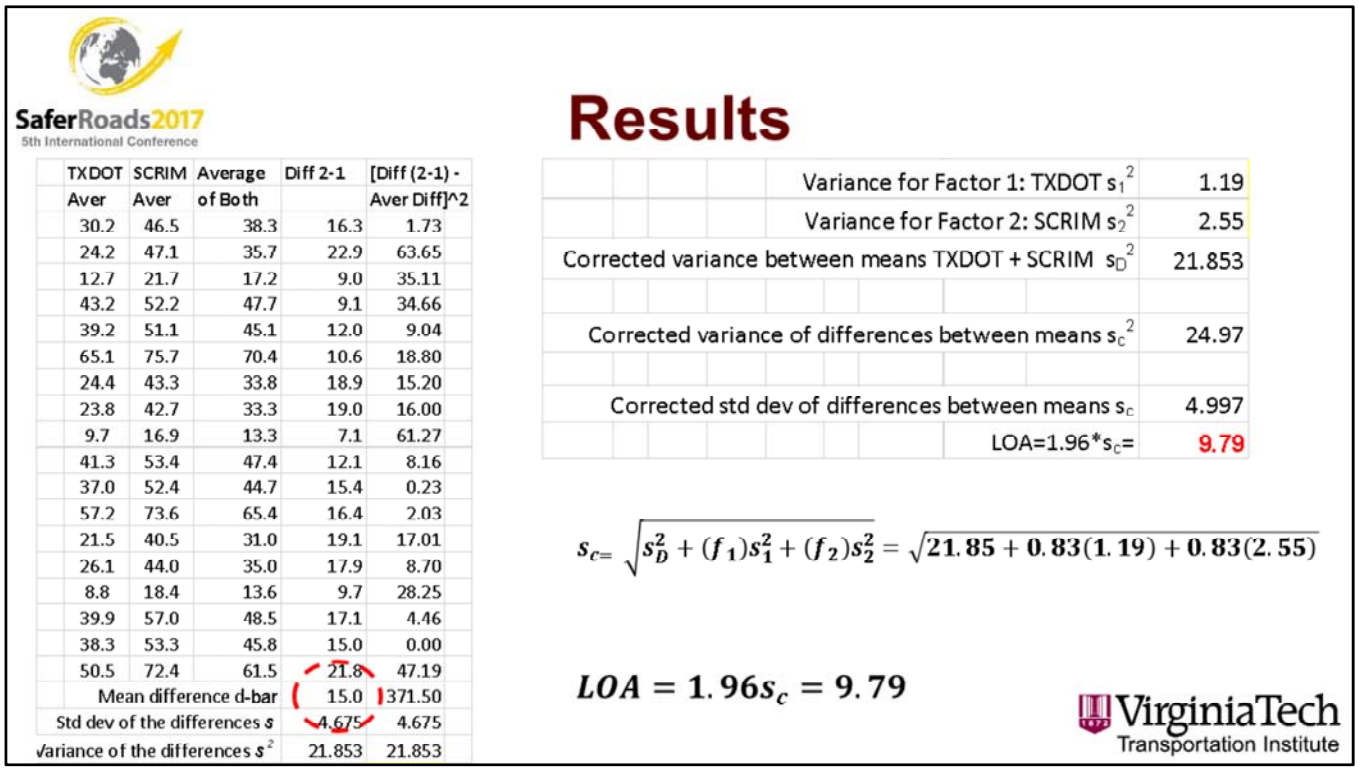
ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	29172	17	1716	672	0	1.74
Within Groups	229.75	90	**2.55**			
Total	29402	107				

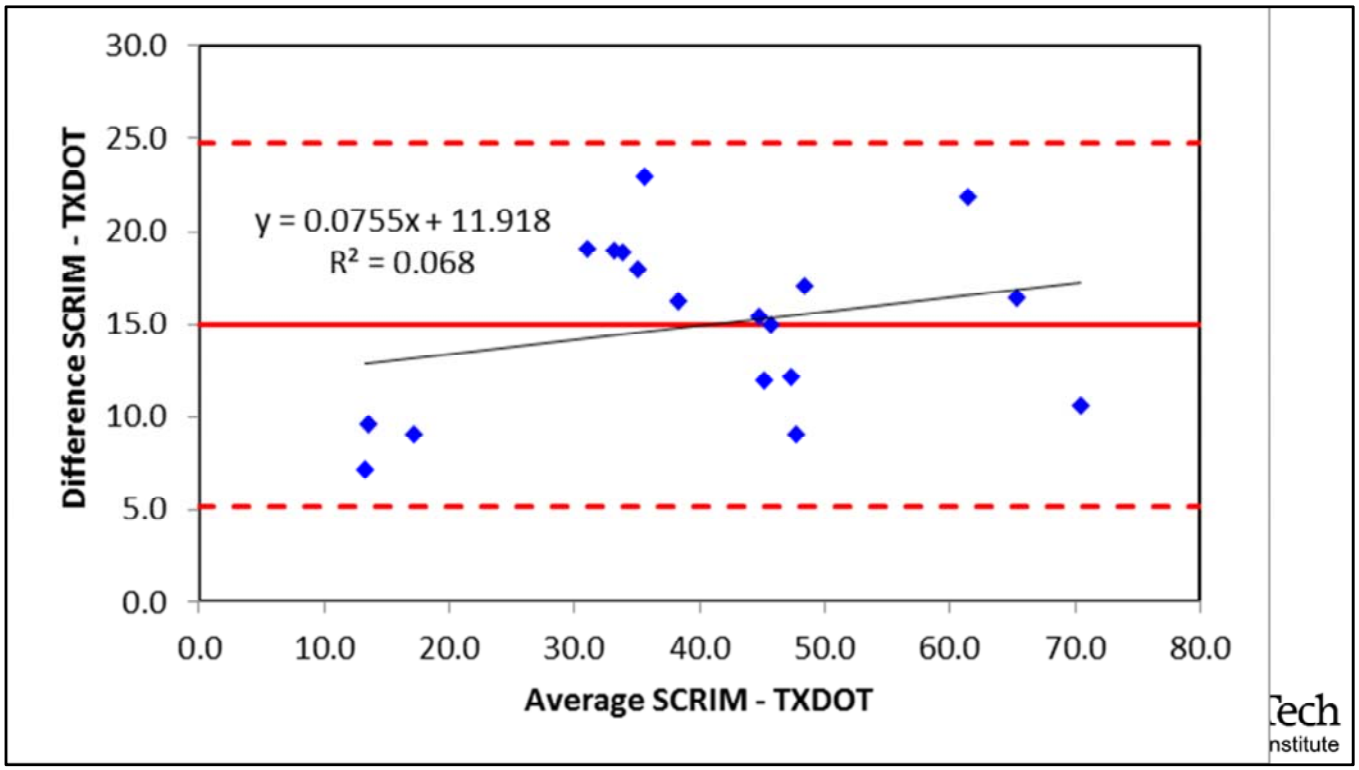
r=2.77*SQRT MSE WG **4.43** **Repeatability**

SCRIM

The first example is between the TXDOT and the SCRIM. The first step is to obtain the variance of the differences between measurements within the same instrument, which is closely related to the repeatability coefficient.

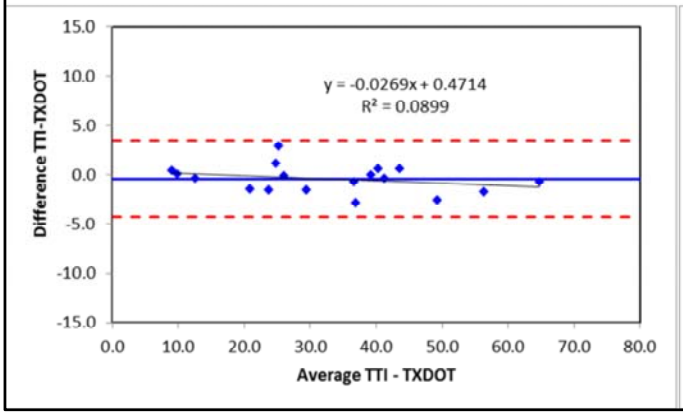


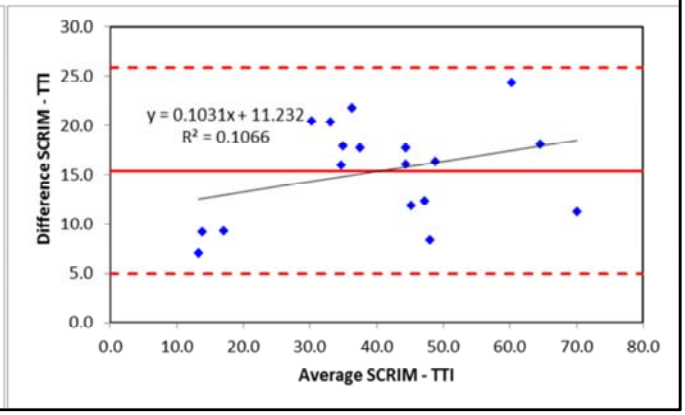
Having the variances for each of the two devices to account for their variability, it is now time to compute the estimate of the variability to account for the interaction between the two devices. This is usually the effect of the things that are different between them and that affect the results of the measurements, such as the tire, slip speed, etc.



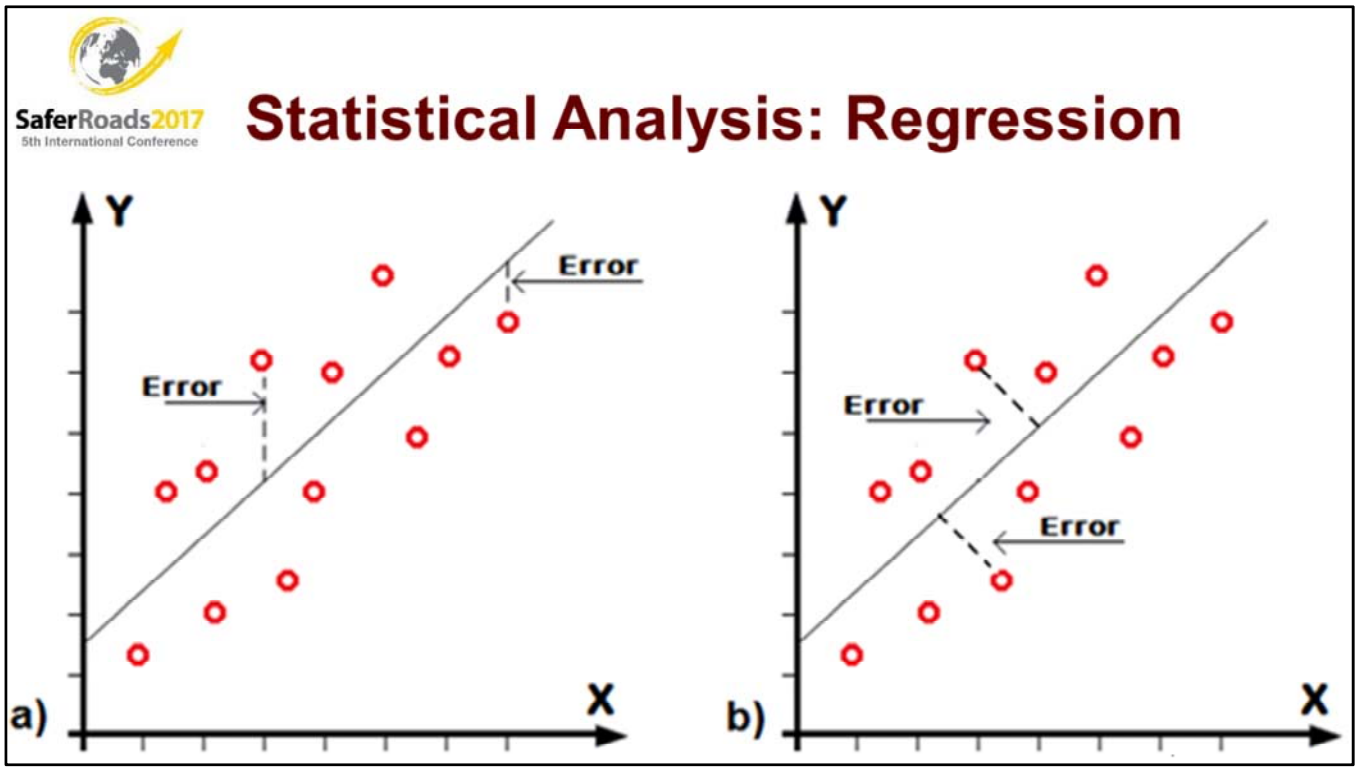
Plotting the averages of the measurements against their differences perfectly illustrates the concept of LOA as the boundaries between which 95% of the measurements will lie. When these boundaries are separated apart very far, the agreement is poor. If they are close then the agreement is good.
However, what is considered too far or close enough is a call that is made by every owner depending on the intended use of the data. Think for example the case of a thermometer; how accurate does it have to be to measure a child's fever? Or the temperature in a swimming pool?

Variance for Factor 1: TTI s_1^2	1.13		Variance for Factor 1: TTI s_1^2	1.13
Variance for Factor 2: TXDOT s_2^2	1.19		Variance for Factor 2: SCRIM s_2^2	2.55
Corrected variance between means TTI+TXDOT s_D^2	1.933	**Results**	Corrected variance between means TTI + SCRIM s_D^2	25.272
Corrected variance of differences between means s_c^2	3.87		Corrected variance of differences between means s_c^2	28.34
Corrected std dev of differences between means s_c	1.966		Corrected std dev of differences between means s_c	5.324
LOA=1.96*s_c=	3.85		LOA=1.96*s_c=	10.43

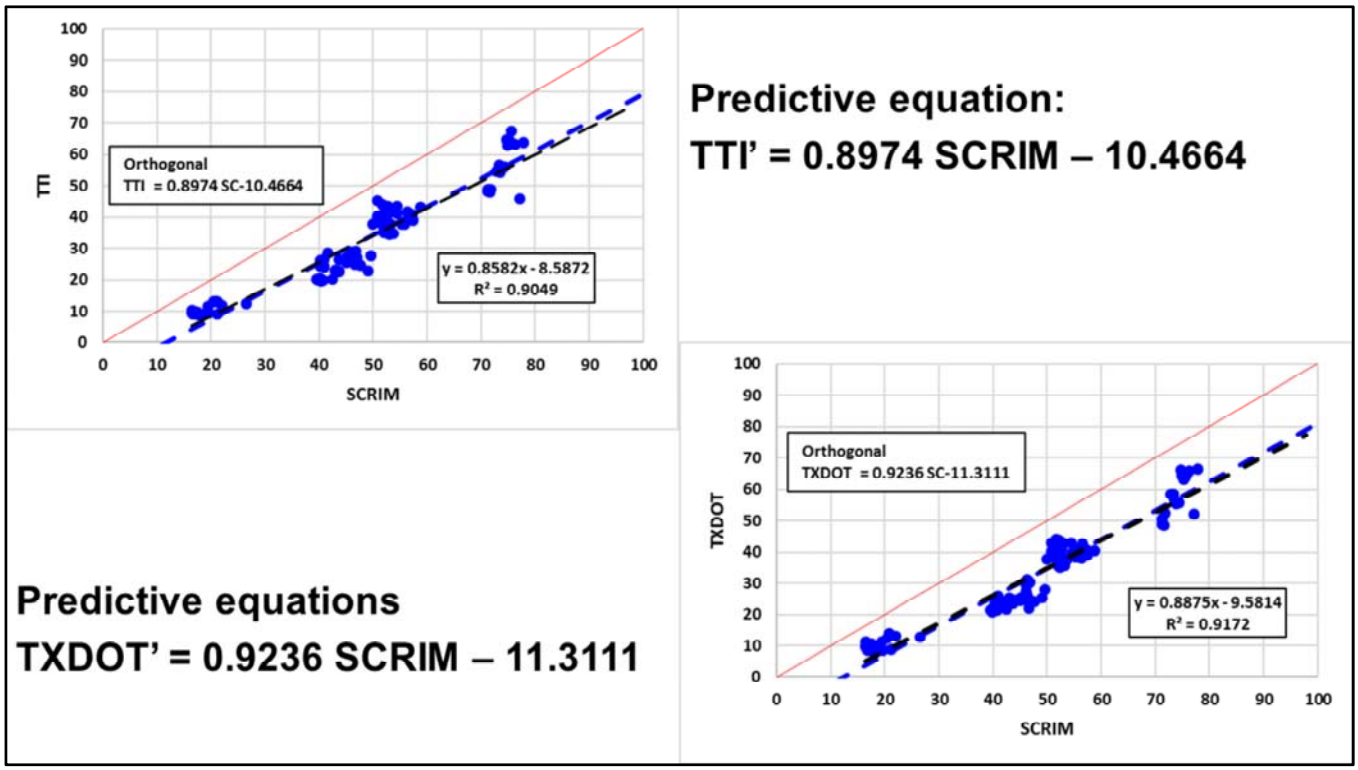




This slide shows the results for the other two comparisons. The limits between the SCRIM and the TTI device are similar to that obtained with the TXDOT device. Notice that because both of the skid testers have the same characteristics, the LOA for them are much closer, as it was to be expected.



This plot shows the advantage of using Orthogonal Regression instead of the common Linear Regression used in the IFI. When the Golden value from the DFT measurements are used in the y-axis, it is implicitly stating that it has no error and all the variations are caused by the variability of the other device.
We know that is not true and it would only be true if it can be proven that it is the reference device. Not very golden…
By using Orthogonal Regression we will get a better relationship between two devices because it assumes that the variances are equal. When these are available, a correction factor will improve the relationship even more and produce improved prediction results.

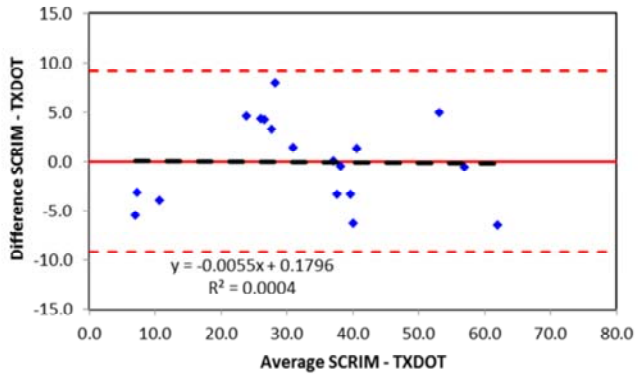


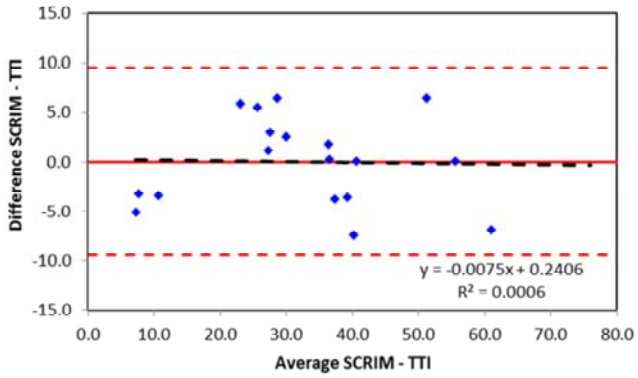
Applying orthogonal regression to the original data, predictive equations can be used to obtain better estimated predictions that can be compared with the actual measured data and new LOA computed to better represent the expected ranges in the variations of the predicted measurements with the other device.

Variance for Factor 1: TXDOT s_1^2	1.19
Variance for Factor 2: SCRIM s_2^2	2.55
Corrected variance between means TXDOT + SCRIM s_D^2	18.845
Corrected variance of differences between means s_c^2	21.96
Corrected std dev of differences between means s_c	4.686
LOA=1.96*s_c=	9.19

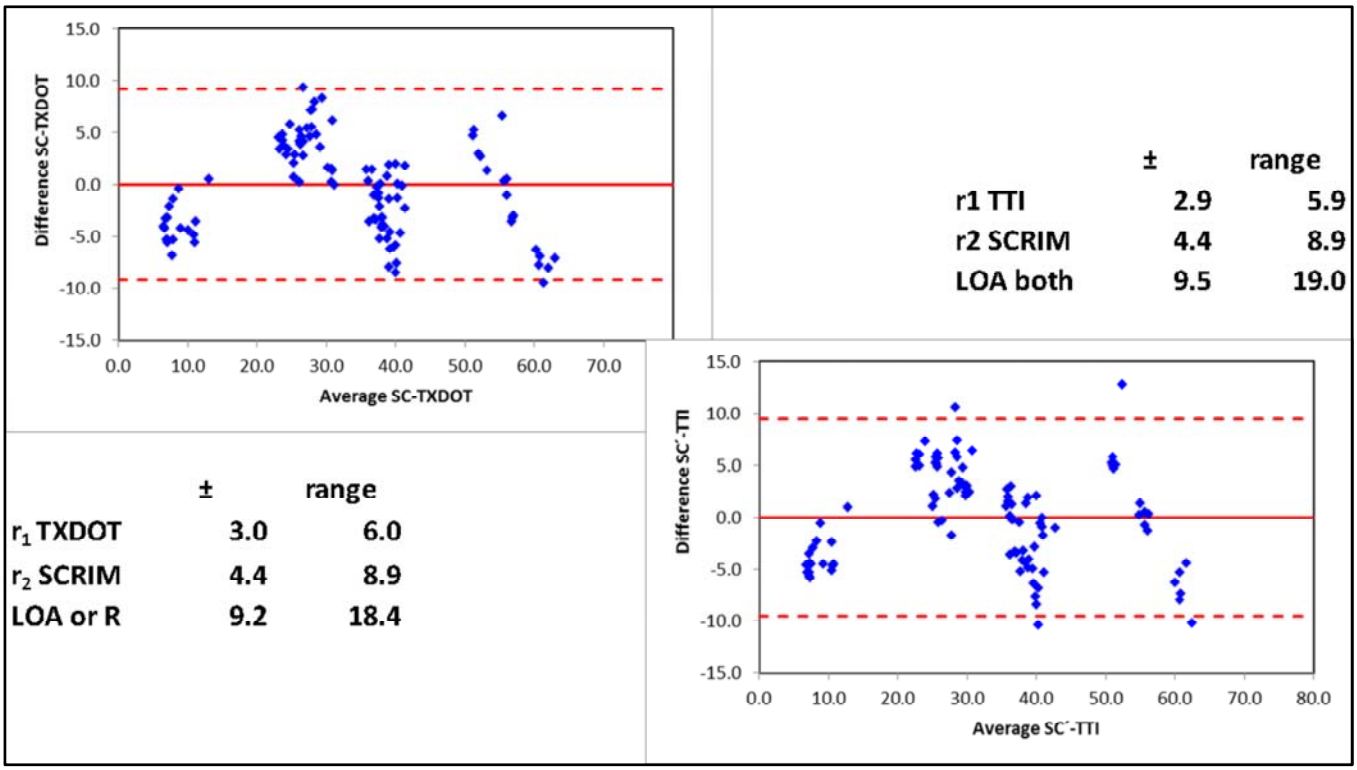
Results

Variance for Factor 1: TTI s_1^2	1.13
Variance for Factor 2: SCRIM s_2^2	2.55
Corrected variance between means TTI + SCRIM s_D^2	20.326
Corrected variance of differences between means s_c^2	23.40
Corrected std dev of differences between means s_c	4.837
LOA=1.96*s_c=	9.48





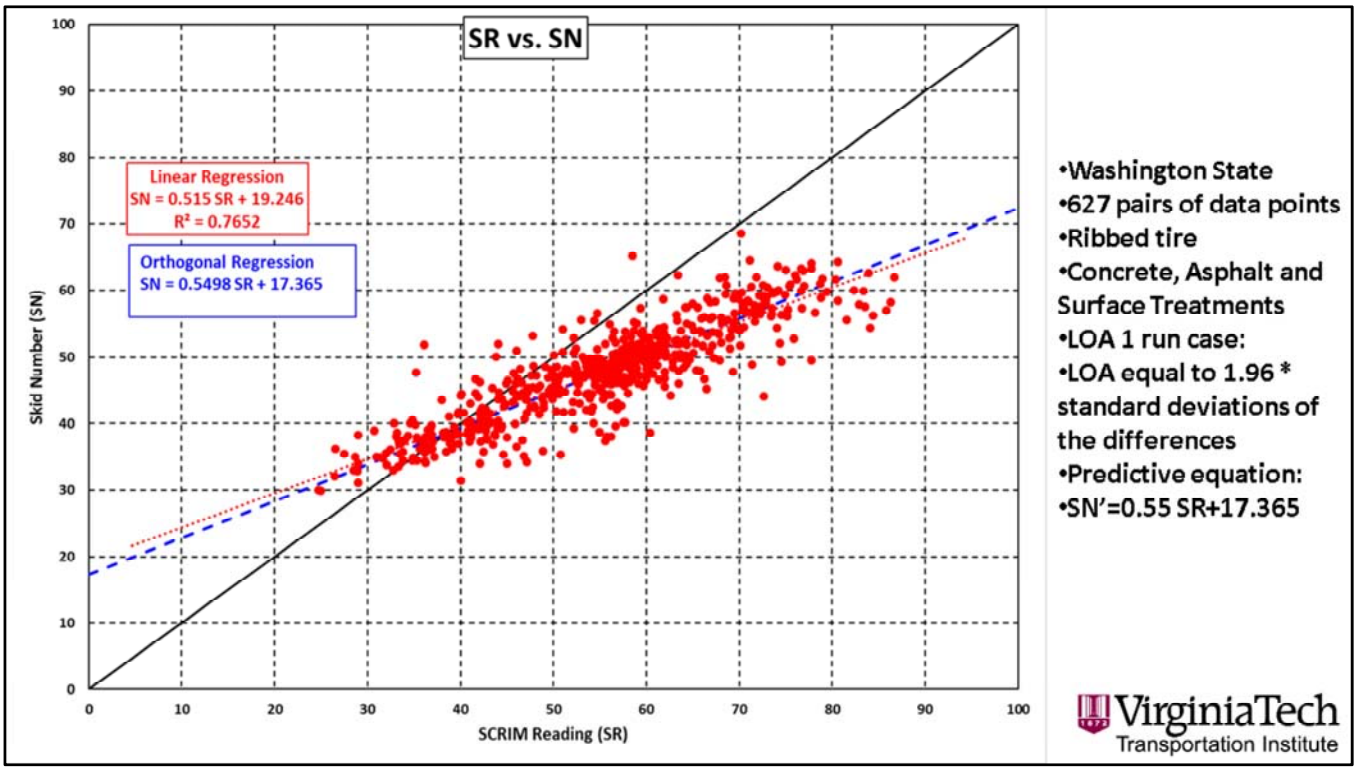
The results show that LOA for both of the SCRIM vs. E-274 devices were improved, not by much but improved. Still the difference in range of values will be decided if the interchange is necessary.



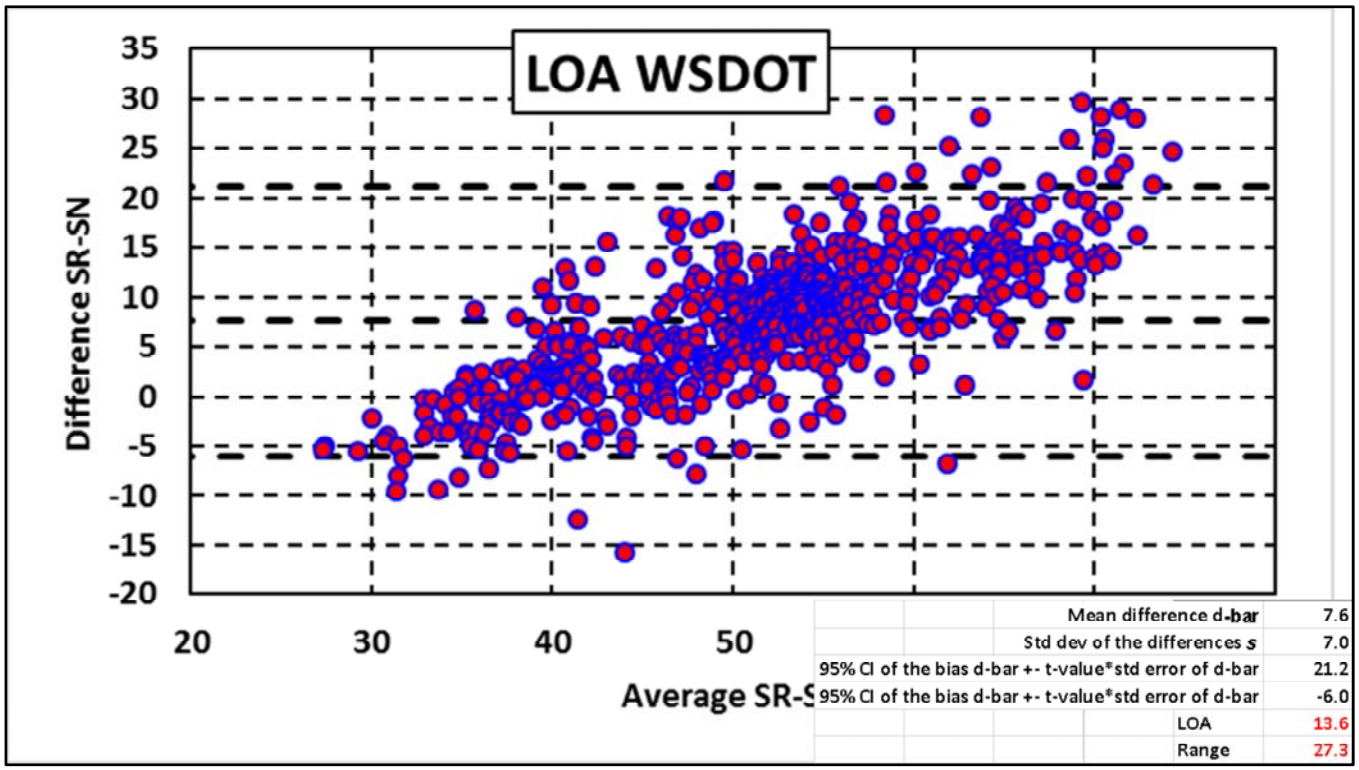
	±	range
r1 TTI	2.9	5.9
r2 SCRIM	4.4	8.9
LOA both	9.5	19.0

	±	range
r_1 TXDOT	3.0	6.0
r_2 SCRIM	4.4	8.9
LOA or R	9.2	18.4

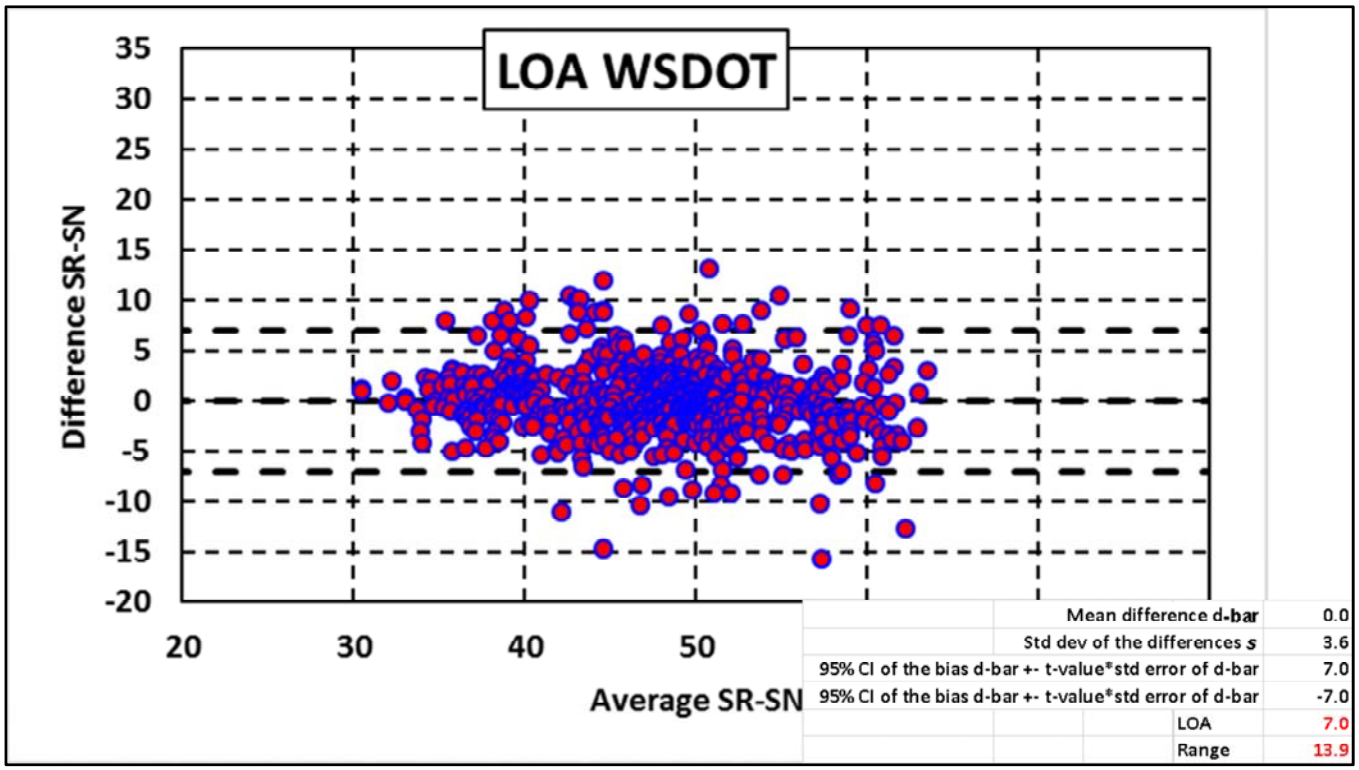
New LOA values for both comparisons.



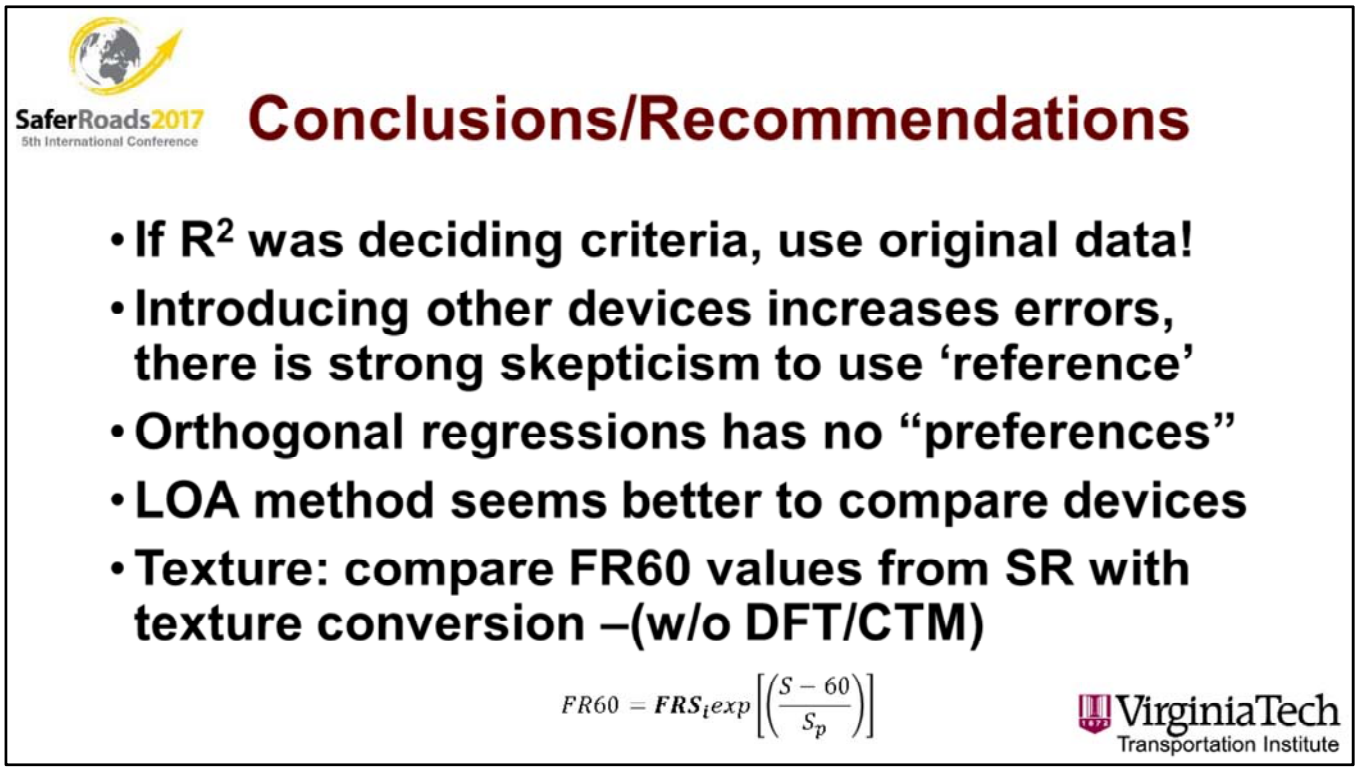
Real life example of the use of LOA with a lot of measurements. In this case, nothing of the variability of the other device is known.



The original data comparison shows that there is a positive slope in the data that can be eliminated with the orthogonal regression so it would be helpful to do it. The range is values is significantly much greater than the data in the TTI comparison.



However, after the modifications, the range of LOA is actually smaller, thus giving more accurate predictions for this device. Notice also that there is no need to use a CT Meter or a DFT to come up with a workable solution.



The conclusions indicate that LOA is a better alternative. Such comparisons cannot be made with a method that flattens the variability of the measurements and predicts averages.
Transforming the values of the friction measurements with the measured values of texture could be an interesting alternative that might reduce the LOA even more, but definitively not using the DFT.

The gray truck is the Volvo Hummer! 12 cylinder.