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Pennsylvania Transportation Institute

Vehicle Systems & Safety Program

Next Steps in Quality Control and Harmonization of Friction Measurements on Highways and Runways

FUNCTIONAL AND PRACTICAL FRICTION MEASUREMETNS BUT **HOW**

The ultimate question is:

- Is there a way in which we can get a reliable friction reading for functional characteristic measurements ??

ROADMAP

- Scientific and operational consolidations of harmonization
  - Review present FMD taking into account elements effecting friction readings
  - Assess the anticipated results of current R&D activities and indentify still existing knowledge gaps
  - Assess the feasibility for harmonization based on the investigation of above points
  - Develop proposals for harmonization table / methods
- Investigation for alternative methods to evaluate surface friction characteristics and proposal of the most feasible methods standards
  - Conduct a survey of current technologies in use for friction characteristics measurement
  - Make a review on a global scale of other methods for texture measurements e.g. use of laser, stereo photography, digital image processing
- Define a stepwise procedure and guidelines for harmonization of measurement device
  - Establish conditions for friction characteristics measuring device qualification testing complying with ASTM, ISO, CEN FAA FHWA ICAO standards taking into account all parameters: surfaces, speeds, depth of water film, temperature/weather conditions and required practical test implementation conditions, e.g. number of measurement, accuracy, consistence of results
  - Review technical criteria for measuring device compliance
  - Review acceptable methods, accuracy and consistency of implementing harmonization procedures in relation with ASTM, ISO, FHWA, FAA, CEN and ICAO standards
  - Propose the establishment of a reference equipment database taking into account factors like type of equipment, type and location of surface, type of tire, inflation pressure, test speeds, and weather conditions during tests,
  - Assess the need to issue specific AGENCY specifications (i.e. FHWA, AASHTO, FAA) in this field
  - Develop proposals for harmonization methods

We will discuss
Highlighted part

Basic Problem #1

Why is harmonization of FMDs so difficult?

FACTS AND OBSERVATIONS

Devices are very different

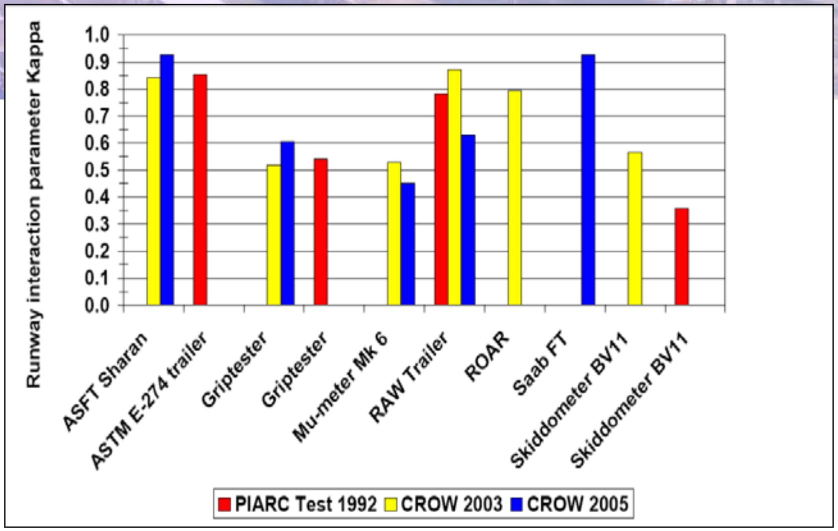
Harmonization trials tried to compensate for all the differences by two constants and did not set any requirements for acceptance

FACTS AND OBSERVATIONS

Poor device repeatability and device family reproducibility <u>prohibits</u> adequate harmonization

Harmonization trials tried to compensate for all the variation in one device and they used one device from a device family to represent the whole device family

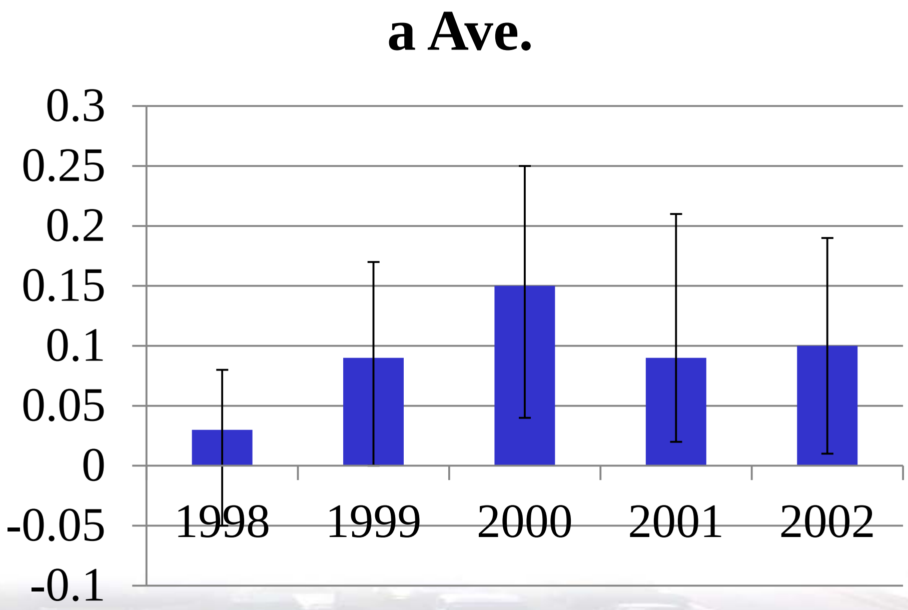
FACTS AND OBSERVATIONS



Consistency of the Kappa Runway Interaction Parameter in ESDU Model, CROW, 2006

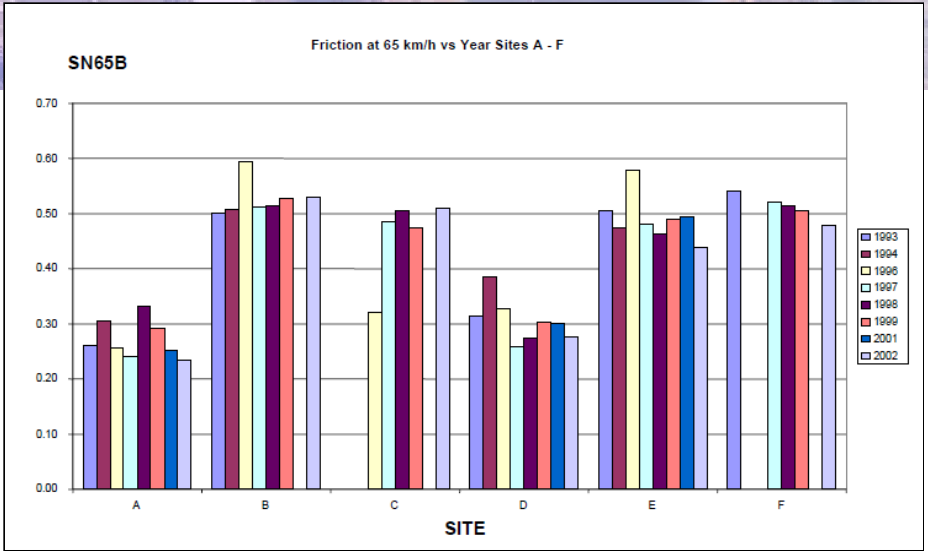
Harmonization trials came up with different constants each year

Devices are changing by time



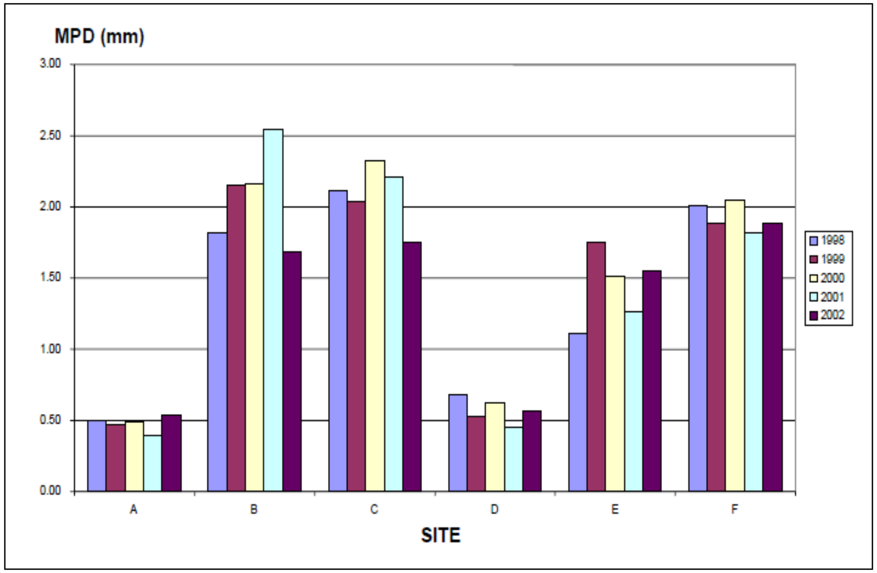
Variation over Time for the “a” Constants in the IFI Model

FACTS AND OBSERVATIONS



Wallop NASA Site Surface Friction Changes over 8 Years as Measured by the VADOT E0274 Trailer

Surfaces are changing by time



Wallop NASA Site Surface Texture Changes over 8 Years as Measured by the CT Meter

Harmonization trials could not distinguish between the changes in the surface and the device

ARE THERE OTHER FACTORS ?

- Difference in measuring principles
  (locked wheel, side force, continuous fixed slip etc.)
- Differences within device family
  (slip ratio, wheel angle, lock rate, **tire type** etc.)
- Watering systems
- Others?

Attempts

	Scenario =>	#0	#1	#2	#3a	#3b	#4	#5	#6	#7	#8a	#8b	#9	#10	#11	#12	#13
F-model	$F = F_0 \cdot e^{-S/S_0}$	×	×	×	×	×	×	×	×	×	×	×				×	×
	$F = F_0 \cdot e^{-(S/S_0)^\alpha}$												×	×	×		
S_0-model	$S_0 = 57 + 56 \cdot MPD$	×	×														
	$S_0 = a \cdot MPD^b$ (1)			×	×	×	×	×	×	×	×	×	×	×	×		×
	Actual S_0-value from *F(S)*															×	
EFI-model	$EFI = A + B \cdot F_{30}$	×	×	×	×	×	×										
	$EFI = B \cdot F_{30}$							×	×	×	×	×	×	×	×	×	×
Calibration method	$<< EFI >>= \alpha + \beta \cdot EFI$	×	×	×	×	×											
	$EFI = \alpha' + \beta' \cdot << EFI >>$						×										
	$<< EFI >>= \beta \cdot EFI$							×	×	×	×	×	×	×	×	×	
	$<< EFI >>= \beta \cdot < EFI >$																×
Statistical tests	$F > 0.01$	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	$S_0 > 0$	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	$\sigma_r(F) < 0.04$	×	×														
	$\sigma_{EFI} > 0.07$	×															
	$R_F^2 > 0.5$			×			×	×	×	×	×	×	×	×	×	×	×
	$R_{EFI}^2 > 0.5$			×	×	×	×										
	$CV_{EFI} >$				10%	5%	10%										
	"k-test" (0,5%)			×													
	"h-test" (0,5%)			×													
Discarded devices									F05	F05 F15	F05 F15 SFC	BFC (2)	F05	F05 F15	F05 F15	F05 F15	F05 F15

(1) With weighting . (2) F05 and F15 were also discarded here since they are of *BFC*-type

FEHRL, 2006

ARE THERE OTHER PROBLEMS?

- **Conformance of design** of the device family (according to claimed standards)
- **Quality of individual devices** ({lack of} maintenance, usage, repairs etc.)
- **Quality of calibration** (static vs. dynamic calibration)
- **Certified, knowledgeable operators** ({lack of} operator training, certification)

IS THERE ANY OTHER WAY ? Alternative solutions

1. Theoretical approach – macro-, micro-texture, and viscoelastic properties
   No efficient way to measure micro-texture
2. Criteria-based approach on the pavement texture and its geometrical properties – **Early Stages**
3. Cross Pollination from other industries – **Presently not Probable**

TWO POSSIBLE APPROCHES

#2 #3, need further observation and validation

LONG TERM: HIGH RISK, 15-20 YEARS

WHAT ARE OUR OPTIONS??

FORGET ABOUT FRICTION MEASURMENT

OR

MAKE IT WORK

OUR OBJECTIVES

- Is it possible with the given state-of-the-art to harmonize FMDs?
- How can it be done?

PROBLEM DEFINITION & POSSIBLE SOLUTION

1. Devices are very different

1. Use models that adequately describe the device differences in harmonization process
2. Improve models that are not adequate or scrap them
3. If no model exists, develop and **enforce** strict **standardized technical specifications**

PROBLEM DEFINITION & POSSIBLE SOLUTION

2. **Poor device repeatability and device family reproducibility prohibit adequate harmonization**

- Develop **strict standards** and enforce **conformity**
- Develop and enforce **UNIFORM calibration of device components**
- Develop and enforce strict requirement for **BOTH static and dynamic calibration regularly**

PROBLEM DEFINITION & POSSIBLE SOLUTION

3. Devices are changing by time

- Find a reference device that is time stable, economic, repeatable and reproducible
- Check all reference devices regularly to check time stability
- Develop and **enforce** strict requirement for time stability

PROBLEM DEFINITION & POSSIBLE SOLUTION

4. **Surfaces are changing by time, including reference surfaces too**

- Design **small, laboratory-kept reference surface panels** that are time stable, economical, repeatable and reproducible (**use with small portable high quality reference device**)

PROBLEM DEFINITION & POSSIBLE SOLUTION

5. Issues with calibration/harmonization process

- Develop or choose a harmonization procedure that accounts for the device differences using adequate models
- Develop and **enforce** strict quality requirements for the harmonization testing
- Develop and **enforce** strict plan for the frequency of the execution of this harmonization testing

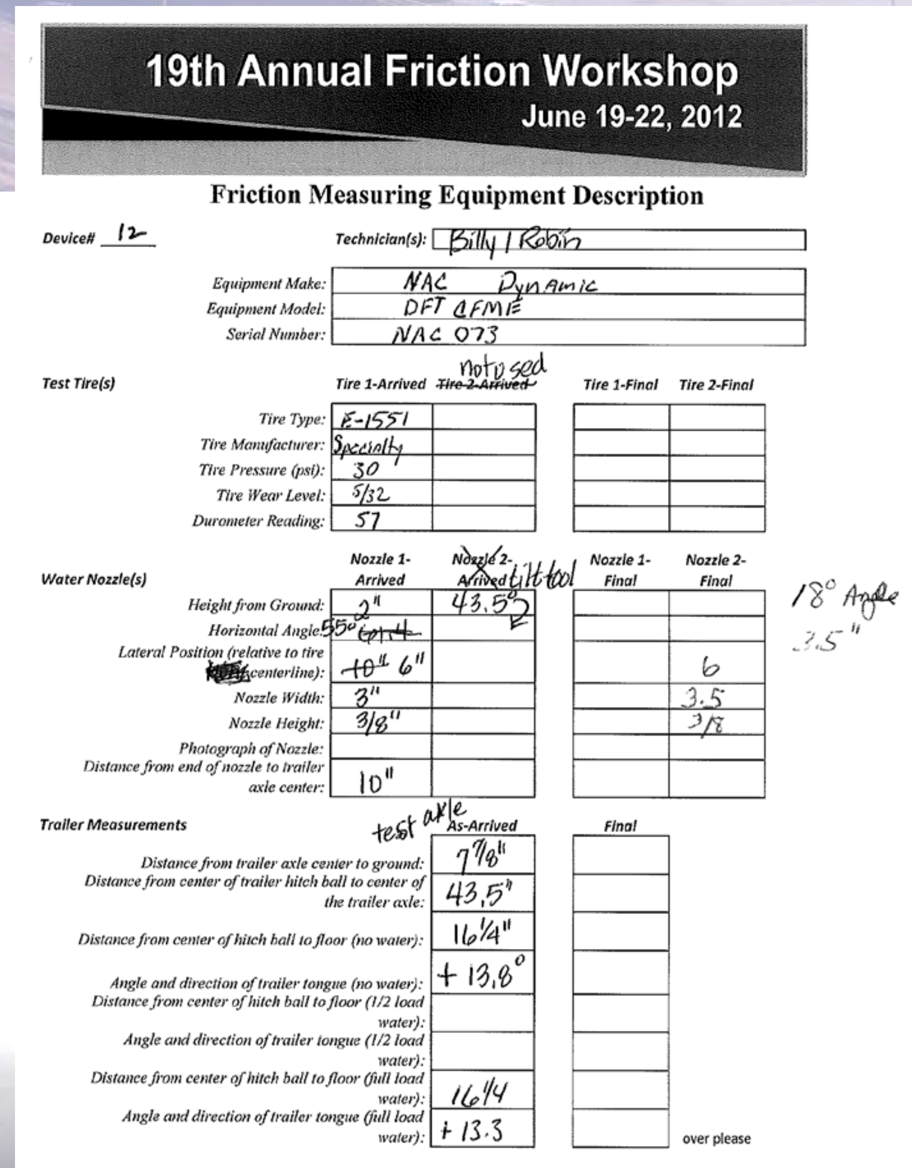
PROBLEM DEFINITION & POSSIBLE SOLUTION

6. **Procedural and operational problems (field calibration, and operations)**

- Develop **uniform requirements for operator training** and **regularly train and certify operators** (at the same time dynamic calibration takes place)

Trials at PSU begin to counter all problems defined

1. **Determine Conformity to applicable standard**



19th Annual Friction Workshop
June 19-22, 2012

Friction Measuring Equipment Description

Device# 12 Technician(s): Billy / Robin

Equipment Make:	NAC Dynamic
Equipment Model:	DFT & FME
Serial Number:	NAC 073

Test Tire(s)

	Tire 1-Arrived	~~Tire 2-Arrived~~ not used	Tire 1-Final	Tire 2-Final
Tire Type:	E-1551			
Tire Manufacturer:	Specialty			
Tire Pressure (psi):	30			
Tire Wear Level:	5/32			
Durometer Reading:	57			

Water Nozzle(s)

	Nozzle 1-Arrived	~~Nozzle 2-Arrived~~ tilt tool	Nozzle 1-Final	Nozzle 2-Final
Height from Ground:	2"	43.5° 2		
Horizontal Angle:	55° ~~@ 1/4~~			
Lateral Position (relative to tire centerline):	~~10"~~ 6"			6
Nozzle Width:	3"			3.5
Nozzle Height:	3/8"			3/8
Photograph of Nozzle:				
Distance from end of nozzle to trailer axle center:	10"			

18° Angle
3.5"

Trailer Measurements

	test axle As-Arrived	Final
Distance from trailer axle center to ground:	7 7/8"	
Distance from center of trailer hitch ball to center of the trailer axle:	43.5"	
Distance from center of hitch ball to floor (no water):	16 1/4"	
Angle and direction of trailer tongue (no water):	+ 13.8°	
Distance from center of hitch ball to floor (1/2 load water):		
Angle and direction of trailer tongue (1/2 load water):		
Distance from center of hitch ball to floor (full load water):	16 1/4	
Angle and direction of trailer tongue (full load water):	+ 13.3	

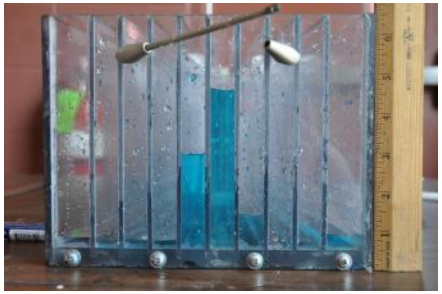
over please

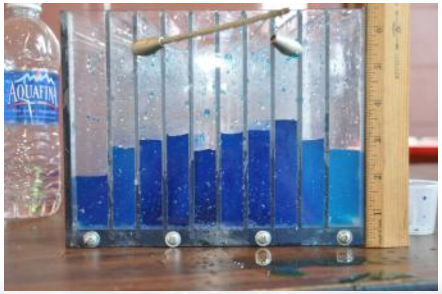
Trials at PSU begin to counter all problems defined

2. **Used UNIFORM calibration procedure**

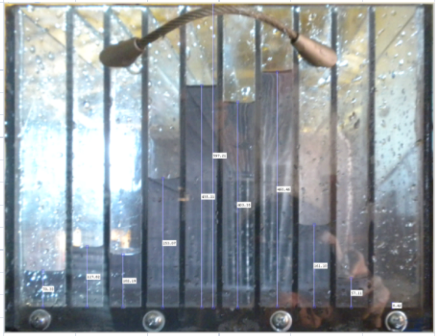
Trials at PSU begin to counter all problems defined

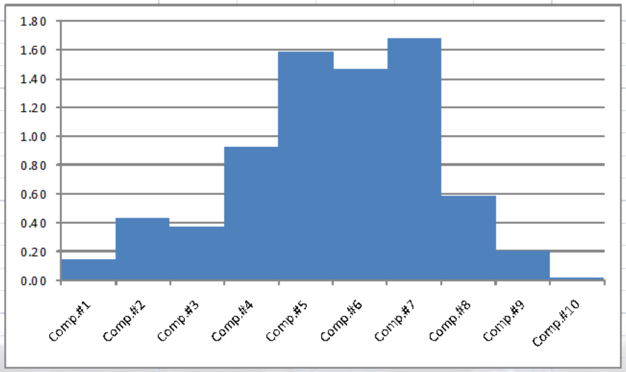
3. Calibration of Individual Components





	Set W Depth:	0.5 mm				
	Speed=	704 in/s		Time=	2.4	
	cal=	99.535 Pixels/in				
MuMeter 1.2.JPG		Water Height [pixels]	Water Height [in]	Volume [in^3]	Film Thickness [in]	Film Thickness [mm]
MuMeter 1.2.JPG	Comp.#1	70.33	0.71	9.15	0.0058	0.15
MuMeter 1.2.JPG	Comp.#2	117.82	1.18	7.15	0.0169	0.43
MuMeter 1.2.JPG	Comp.#3	102.19	1.03	6.20	0.0147	0.37
MuMeter 1.2.JPG	Comp.#4	253.07	2.54	15.36	0.0364	0.92
MuMeter 1.2.JPG	Comp.#5	435.21	4.37	26.42	0.0626	1.59
MuMeter 1.2.JPG	Comp.#6	403.35	4.05	24.49	0.0580	1.47
MuMeter 1.2.JPG	Comp.#7	460.46	4.63	27.96	0.0662	1.68
MuMeter 1.2.JPG	Comp.#8	161.10	1.62	9.78	0.0232	0.59
MuMeter 1.2.JPG	Comp.#9	57.11	0.57	3.47	0.0082	0.21
MuMeter 1.2.JPG	Comp.#10	8.42	0.08	1.10	0.0007	0.02
			Actual:	131.08 in^3		
			Theoretical:	128.88 in^4		





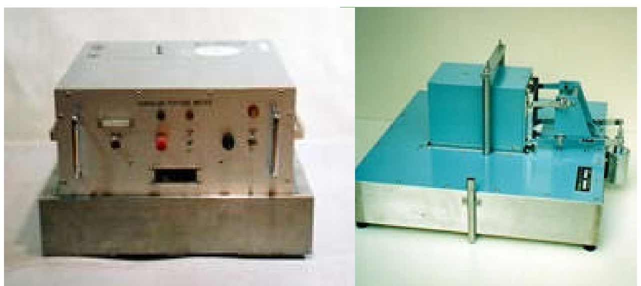
Trials at PSU begin to counter all problems defined

4. Calibration of ACTUAL SLIP %, SLIP ANGLE

Trials at PSU begin to counter all problems defined

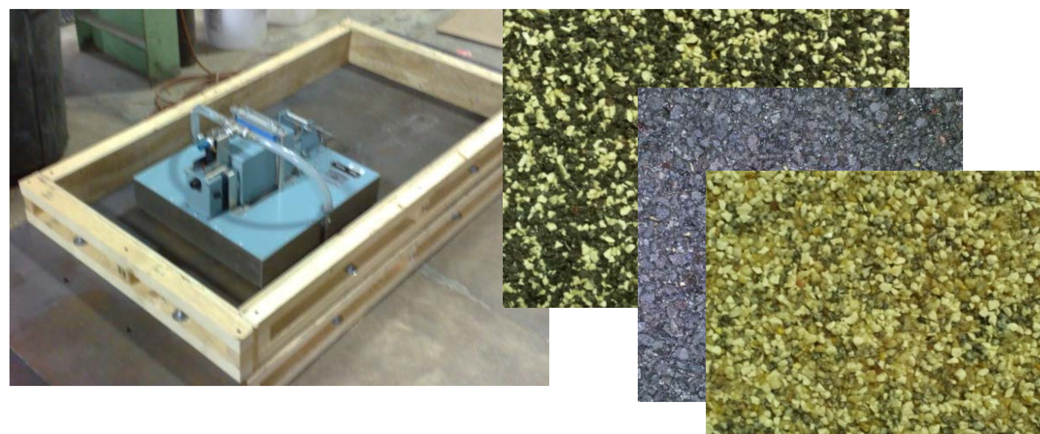
5. **Used Reference Devices**

CTMeter DFTester



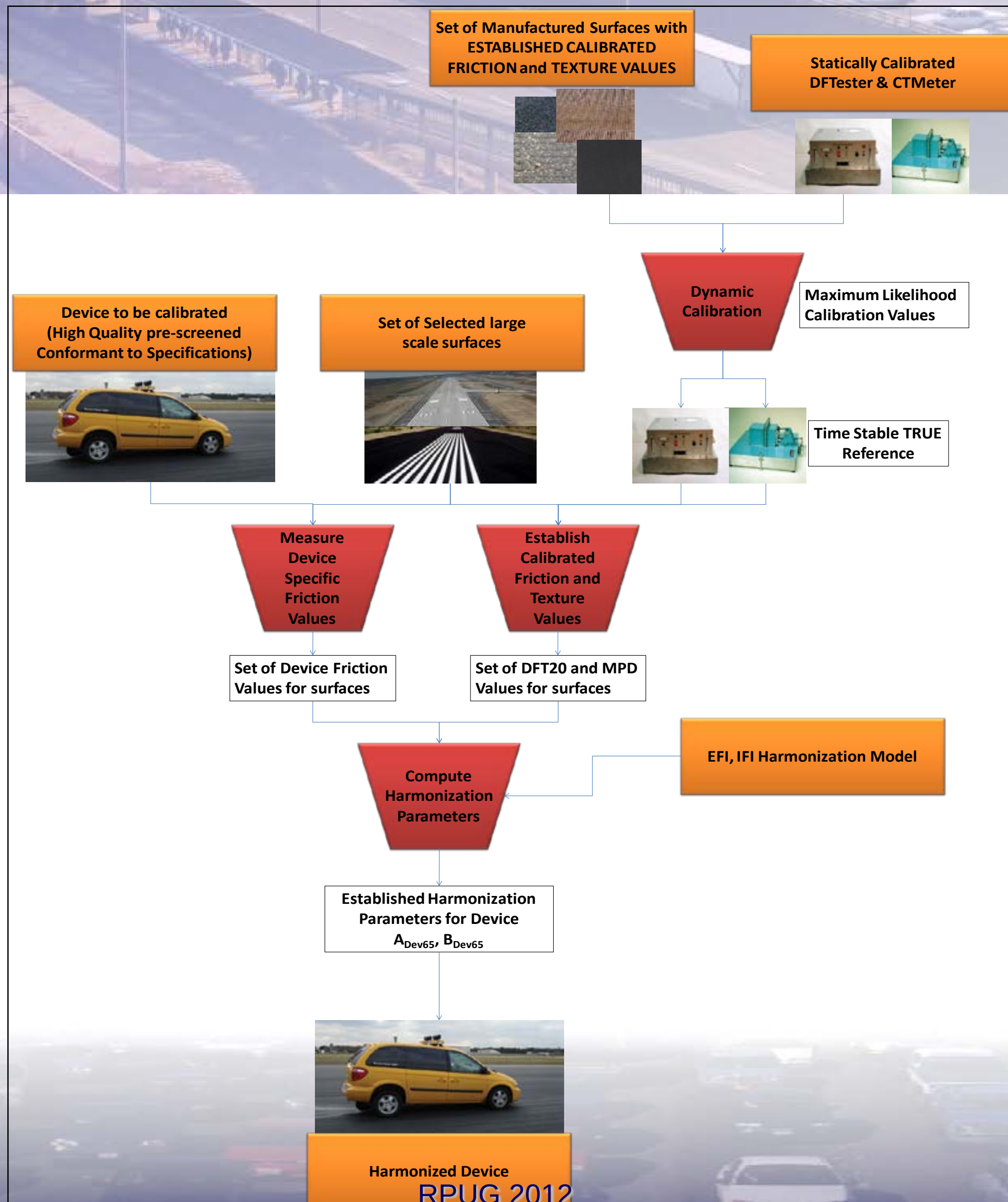
Time Stable
VERY HIGH
Reputability and Reproducibility
(studies in New Zealand, Florida, PSU)

6. **Used small, laboratory-kept reference surface panels**

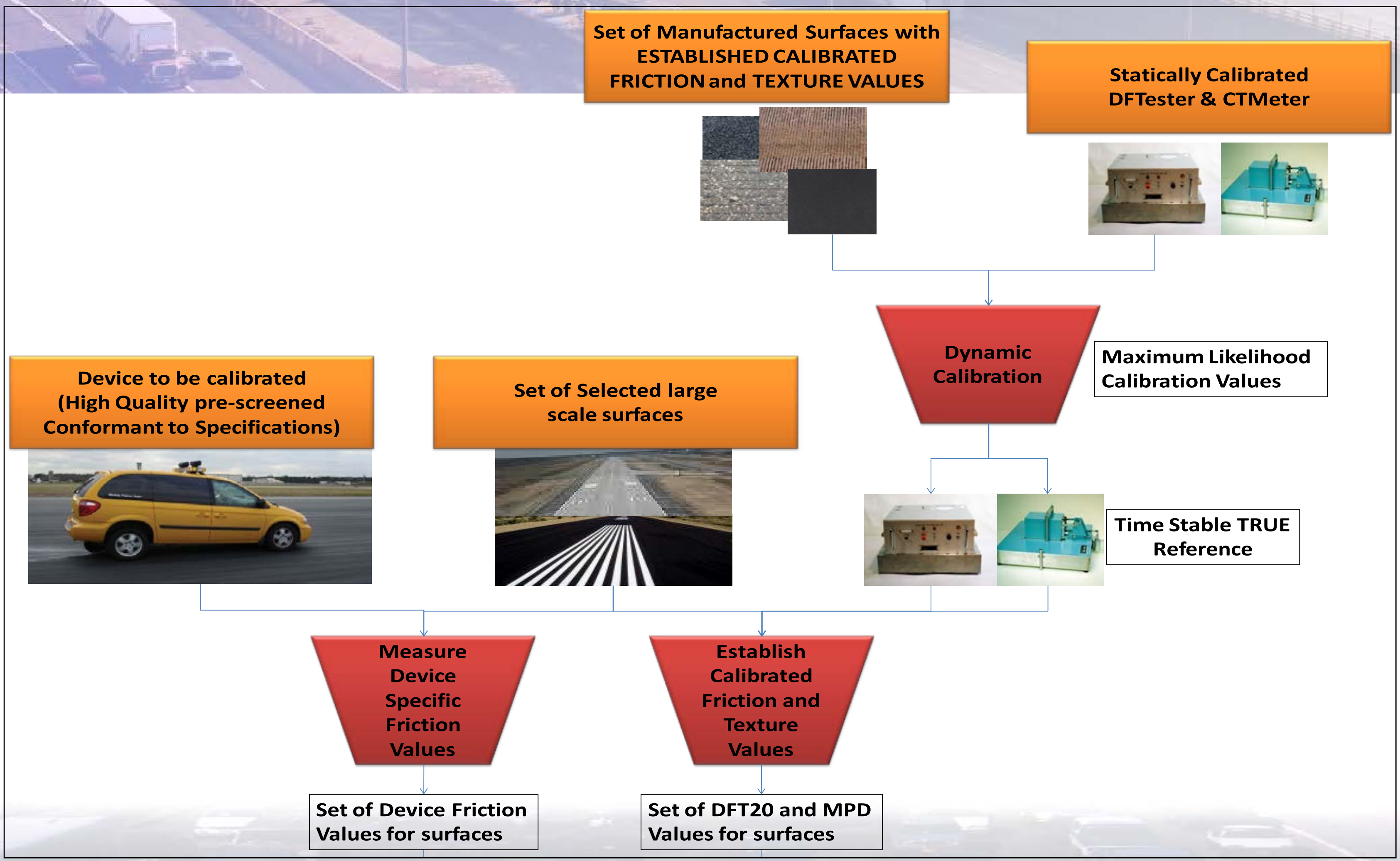


Statically and dynamically calibrated the DF tester and CT meter

THE HARMONIZATION PROCEDURE



THE HARMONIZATION PROCEDURE



THE HARMONIZATION PROCEDURE

Measure Device Specific Friction Values

Establish Calibrated Friction and Texture Values

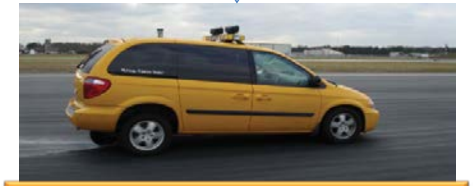
Set of Device Friction Values for surfaces

Set of DFT20 and MPD Values for surfaces

Compute Harmonization Parameters

EFI, IFI Harmonization Model

Established Harmonization Parameters for Device A_{Dev65}, B_{Dev65}



Harmonized Device

Operator Training and Certification

Operator Training

Quality Trainers

Certified Operators

Technical advantages

- Eliminates problems stemming from time instability
- Ensures that harmonized FMDs will deliver low variability and precise measurements
  - ✓ Helps FMD manufacturers maintain high-quality equipment
- Ensures higher standardization among the different friction measurement principles and devices
  - ✓ Delivers a higher quality and fidelity harmonization process

Practical advantages

- Proposed small and portable measurement devices are
  - ✓ Maintained in ideal laboratory environment
  - ✓ Calibrated in ideal laboratory environment
    - Using high-quality, small-scale surfaces
  - ✓ Transported easily
  - ✓ Operated at the selected large-scale field test sites easily and efficiently

Economic advantages

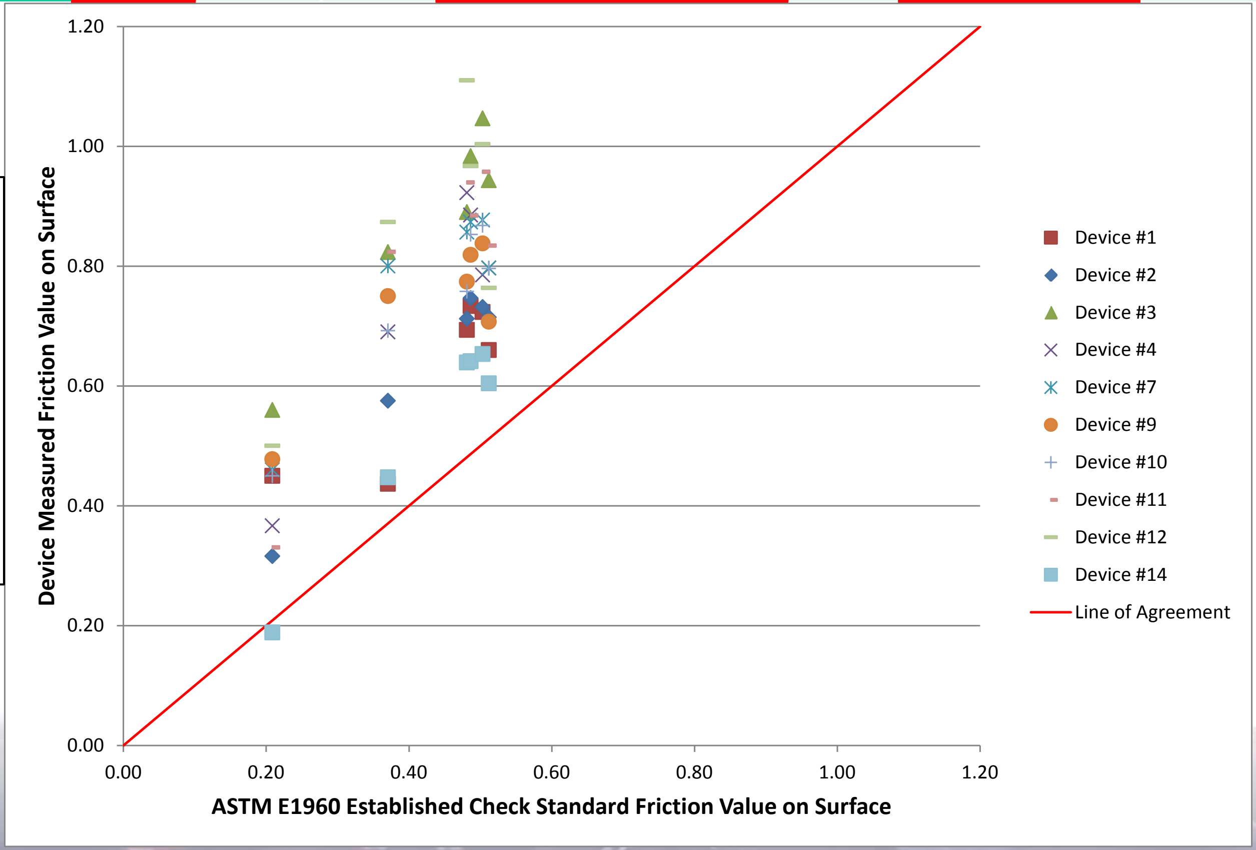
- Proposed small and portable devices are
  - ✓ relatively inexpensive compared to full size FMDs
  - ✓ inexpensive to ship from location to location
- Proposed calibration surfaces are very inexpensive to produce compared to large scale surfaces

360 Degree Approach

Preliminary Results
2012 PSU Friction Workshop

	Dev#1	Dev#2	Dev#3	Dev#4	Dev#5	Dev#6	Dev#7	Dev#8	Dev#9	Dev#10
Device:	#1	#2	#3	#4	#7	#9	#10	#11	#12	#14
Gain (a)	0.75	0.70	0.66	0.55	0.69	0.79	0.74	0.47	0.43	0.64
Offset (b)	-0.03	-0.02	-0.15	0.02	-0.11	-0.15	-0.12	0.05	0.05	0.09
R^2	0.74	0.98	0.92	0.87	0.85	0.76	0.93	0.86	0.62	0.97

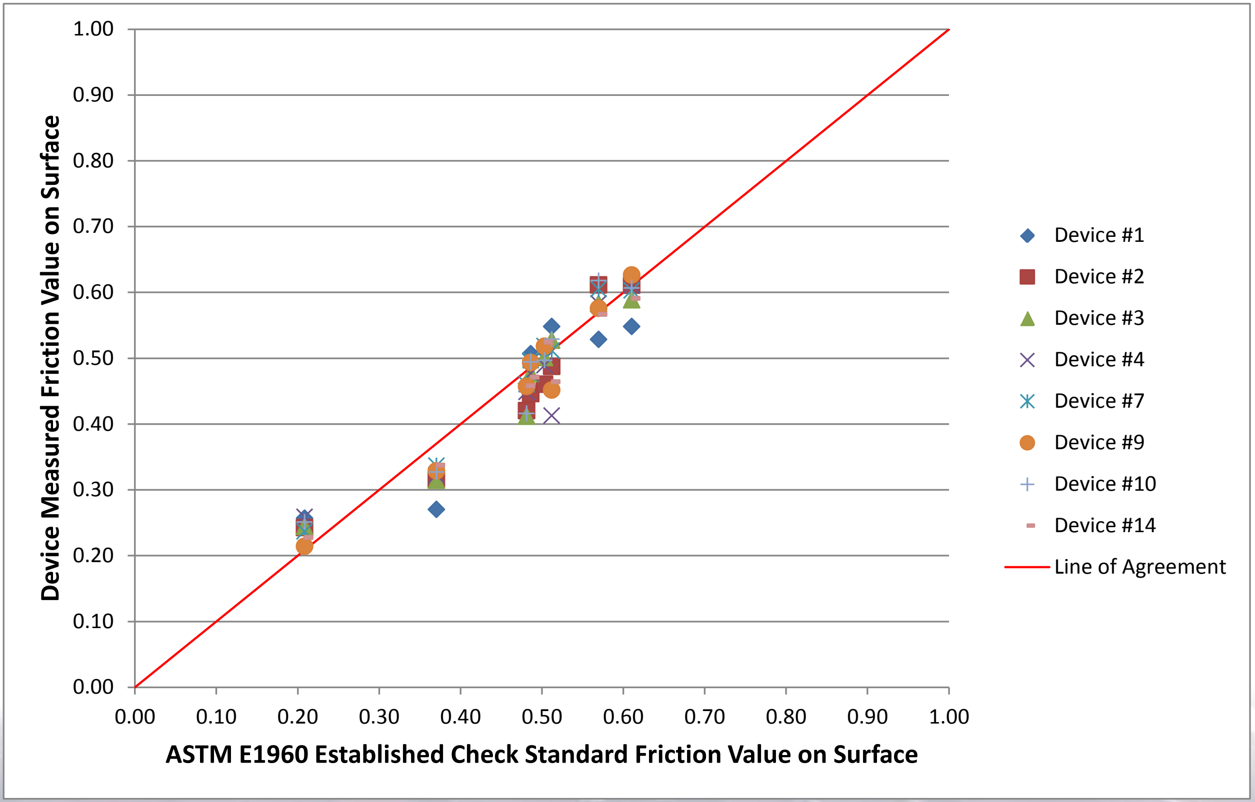
BEFORE quality control, training, and static and dynamic calibration



Preliminary Results
2012 PSU Friction Workshop

	Dev#1	Dev#2	Dev#3	Dev#4	Dev#5	Dev#6	Dev#7	Dev#8
Device:	#1	#2	#3	#4	#7	#9	#10	#14
Gain (a)	0.95	0.93	0.97	0.99	0.97	0.93	0.93	1.03
Offset (b)	0.04	0.05	0.02	0.02	0.01	0.04	0.03	0.00
R^2	0.83	0.91	0.92	0.90	0.97	0.95	0.91	0.96

AFTER quality control, training, and static and dynamic calibration



FINAL CONCLUSION

The ultimate question was:

- **Is there a way we can get a reliable friction reading for functional characteristic measurements ??**

The answer is:

- **YES, a set of procedures, standards, specifications and methodology were identified that could deliver harmonization with high probability.**