Implementation of a Pavement Friction Management Program for Virginia DOT

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Outline

- **Introduction**
- **Objectives**
- **Methodology**
- **Example**
- **Conclusions**

Introduction

What is a Pavement Friction Management Program (PFMP)?

It is a systemic approach of reducing skid-related vehicle crashes by maintaining adequate friction properties in a cost-effective manner.

Source:
1. Federal Highway Administration (FHWA). (Updated 2017). https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/friction_management/
2. [Image on right] https://www.kwikbondpolymers.com/products/ppc-hfst-high-friction-surface-treatment/

Introduction

How to implement a Pavement Friction Management Program (PFMP)?

1. **Routine friction testing.**

    - May also include macrotexture and road surface geometry.

2. **Analyze Friction, crash records, and other related data.**

    i. Estimate the effect of friction on crash risk using statistical analysis.
    ii. Establish friction investigatory levels for friction demand categories.
    iii. Identify sites as candidates for surface treatment when friction is below investigatory level.

3. **Employ cost-benefit analyses to choose candidates sites that yield the greatest benefit from friction improvement.**

Introduction: Terminology

What is Friction Demand?

❖**The amount of friction needed to safely maneuver a vehicle:**

1. **Acceleration**
2. **Braking**
3. **Steering**

Introduction: Terminology

What is a Friction Investigatory Level?

- **A threshold that identifies sites where friction is possibly inadequate, which can increase crash risk.**

- **Triggers investigation to determine the cause of the friction deficiency and whether treatment to improve friction is necessary.**

Objective

Demonstrate how to implement a PFMP in VA:

1. Measure continuous friction.
2. Establish friction demand categories and investigatory levels.
3. Perform a cost-benefit analysis.

Methodology

Methodology

Establish Friction Demand Categories. Why?

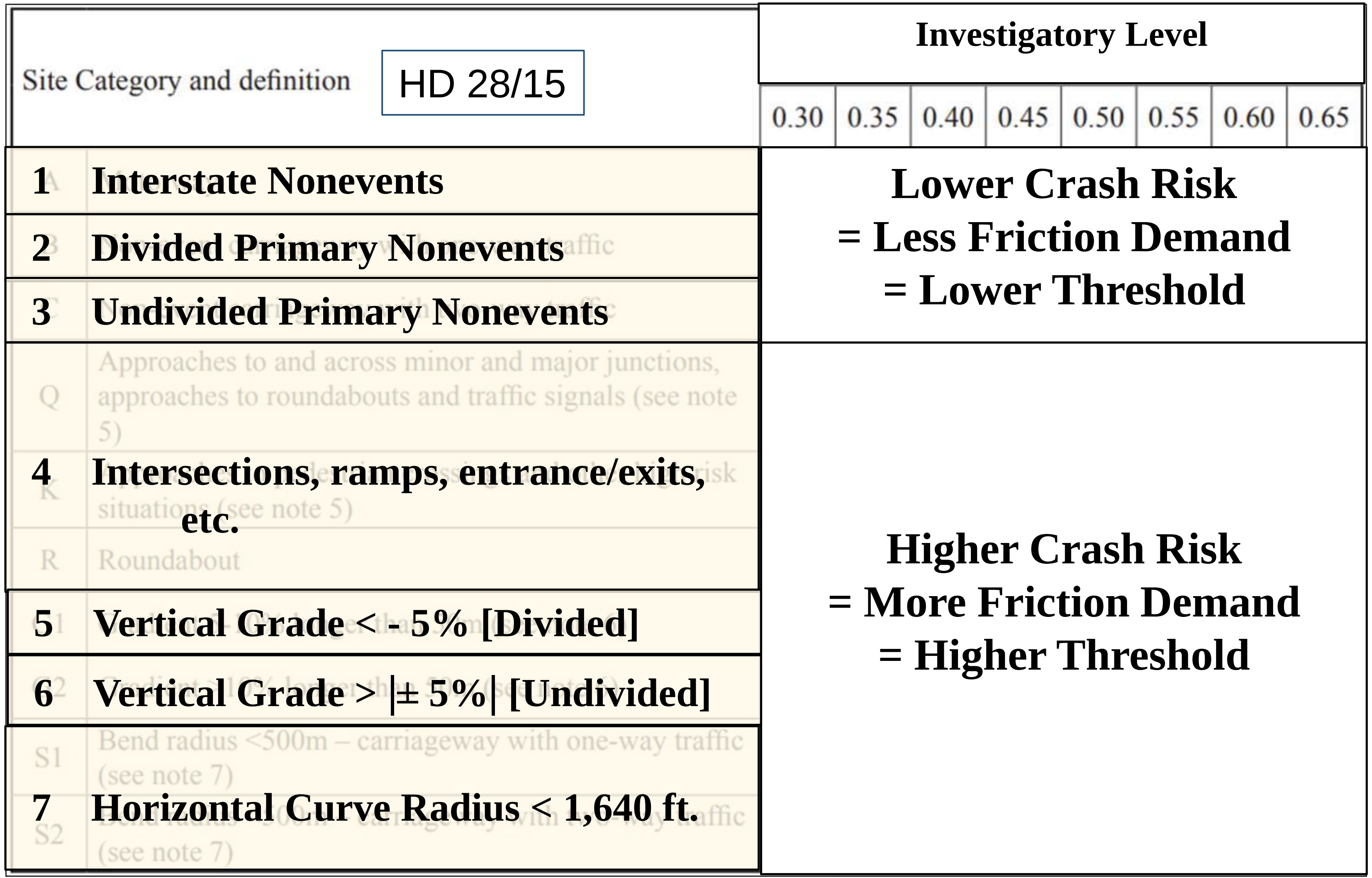
- ❑ **Friction demand is not universal across every section of road.**
  - e.g., NCHRP 37 (1967) & United Kingdom RRL (1957)

- ❑ **Friction Demand depends on Crash Risk, but Crash Risk is not the same everywhere. Some influential factors:**
  - i. Traffic.
  - ii. Road Surface Geometry.
  - iii. Pavement Surface Texture.
  - iv. Vehicle Speed.
  - v. Presence of Intersections, Ramps, Entrance/Exists, etc.

Methodology

Establish Friction Demand Categories. How?

Established logically and systematically based on highway alignment, highway features/environment, and highway traffic characteristic (AASHTO GPF)



	Site Category and definition HD 28/15	Investigatory Level							
		0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65
1	**Interstate Nonevents**	**Lower Crash Risk = Less Friction Demand = Lower Threshold**							
2	**Divided Primary Nonevents**								
3	**Undivided Primary Nonevents**								
Q	Approaches to and across minor and major junctions, approaches to roundabouts and traffic signals (see note 5)	**Higher Crash Risk = More Friction Demand = Higher Threshold**							
4	**Intersections, ramps, entrance/exits, etc.**								
R	Roundabout								
5	**Vertical Grade < - 5% [Divided]**								
6	**Vertical Grade > |± 5%| [Undivided]**								
S1	Bend radius <500m – carriageway with one-way traffic (see note 7)								
7	**Horizontal Curve Radius < 1,640 ft.**								

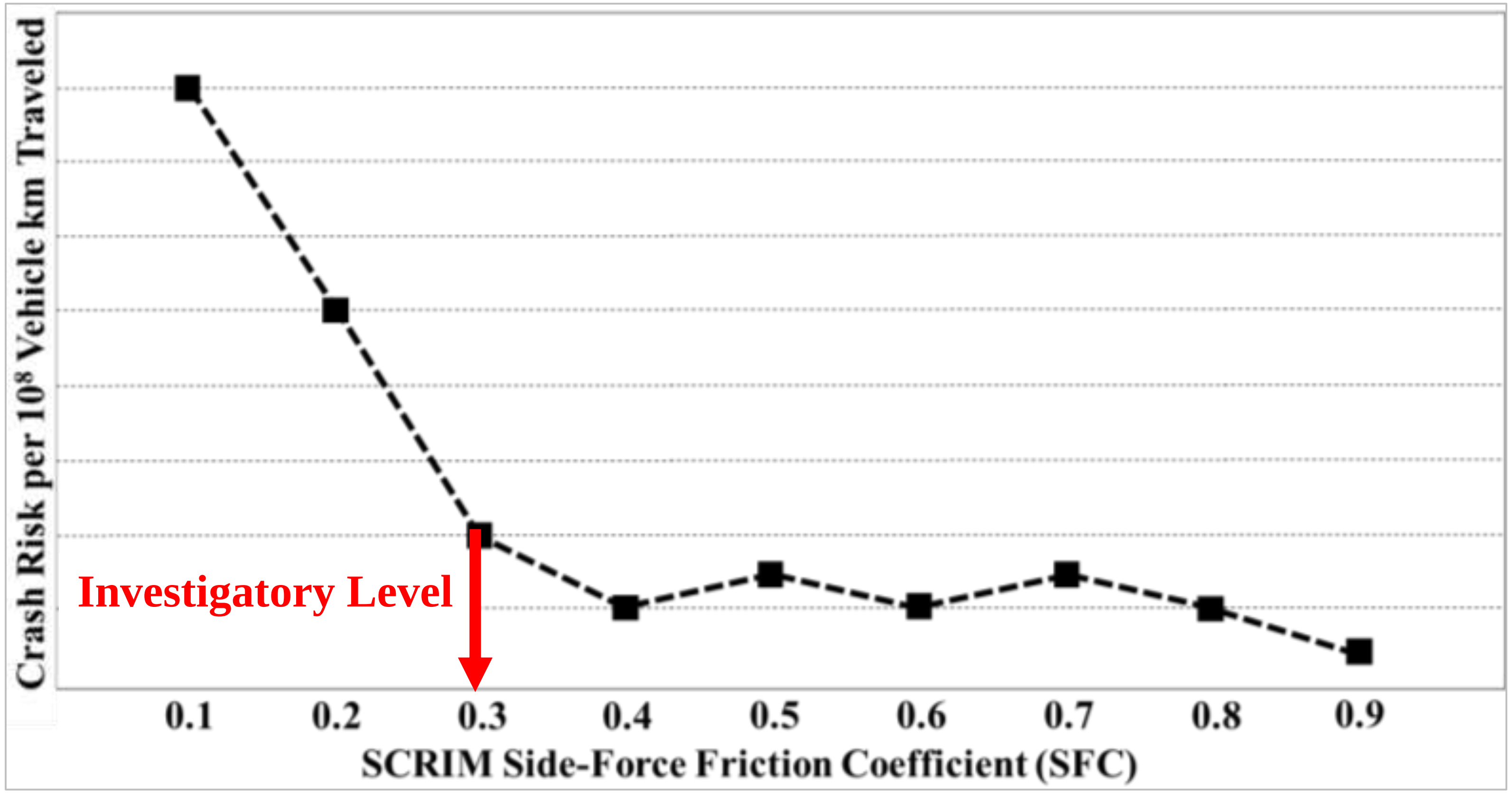
Source: 1. Table Adapted from British Design Manual for Roads and Bridges, Part 1, HD 28/15, Skidding Resistance.
2. AASHTO Guide for Pavement Friction (2009)

Methodology

Establish Investigatory Levels of Friction

- ✓ UK Investigatory Levels
  1. Plot Crash Risk vs. Friction
  2. Investigatory Level is the locations where crash risk starts rapidly increasing with lower friction.

- ✓ Australian Investigatory Levels
  1. Plot Crash Risk vs. Friction
  2. Fit Curve & Equation
  3. Solve for crash risk with existing thresholds.
  4. Choosebackground crash risk
  5. Compute new investigatory levels.



Source: 1. Parry, A.R, and Viner, H.W. (2005). “Accidents and the skidding resistance standard for strategic roads in England.” Report No. TRL622, Transportation Research Laboratory (TRL), Berkshire, United Kingdom.

2. Dias, M., and Choi, Y. (2013). “Development of Safety Related Investigatory Level Guidelines: A Worked Example of Methodology.” AP-T233-13, Austroads Ltd., Sydney, Australia.

Methodology

Estimate Average Expected Crash Risk over a period of time for every section of road based on observed crash data.

- This is done with regression models called safety performance functions (SPFs).

$$SPF_i = e^{\beta_0 + X_i \beta}$$

Where,

SPF_i : Average expected crash count for road segment *i* during study period;
X : Predictors (e.g., traffic, friction, macrotexture, etc.)
β: Regression Coefficients

***SPFs should always includes AADT.**

Source:
1. AASHTO Highway Safety Manual (2010)
2. Srinivasan, R., and Bauer, K. (2013). "Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs." Report No. FHWA-SA-14-005, Federal Highway Administration Office of Safety, Washington, D.C.

Methodology

❖In order to assess benefits of surface treatment in a PFMP, **statistically reliable estimates** of **average expected crash counts** are required.

❖Research has shown that **statistical reliability** is improved by combining observed crash counts and SPF estimates into a weighted average.

Empirical Bayes (EB) Methodology

➢ **2 types of information:**

1. **SPF**
2. **Observed Crash Count, y**

Computation:

$$\mathbf{EB_i = w_i \ast SPF_i + (1 - w_i) \ast y_i}$$

weight parameter: $\mathbf{w_i} = \frac{\mathbf{1}}{\mathbf{1+SPF_i \times \alpha}}$; where α is the **overdispersion parameter** from SPF

Source: Hauer, E., Harwood, D.W., Council, F.M., and Griffith, M.S. (2002). “Estimating Safety by the Empirical Bayes Method: A Tutorial.” *Transportation Research Board*, (1784), 126-131.

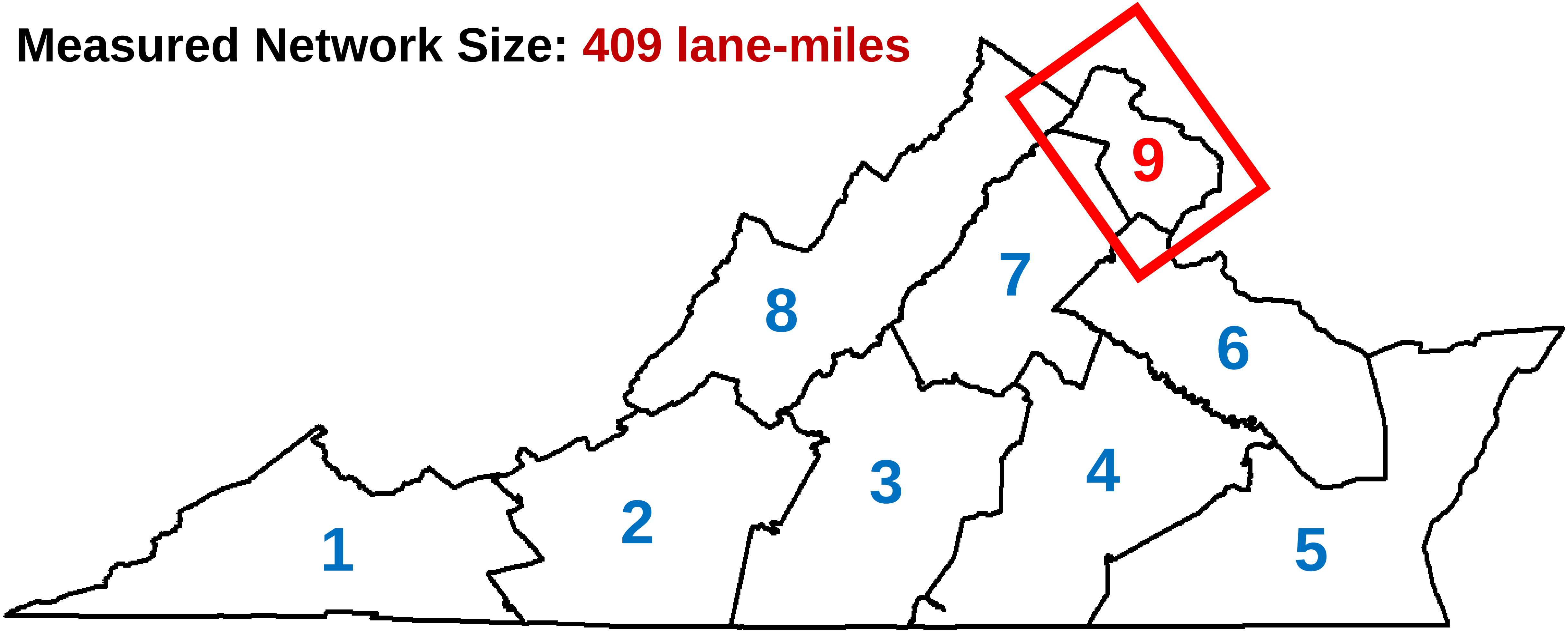
Methodology: Cost-Benefit Analysis

1. Compute Average Cost per Crash for the measured network.
2. Determine Treatment Options and Costs per Lane per 0.1-Mile.
3. Estimate each Treatment’s Improvement to Friction.
4. Identify Sections with Friction Below Investigatory Level.
5. Compute Treatment Costs, Crash Reduction Savings, Total Savings.
6. Treat Sections with [Crash Reduction Savings ÷ Treatment Costs] > 1.0

Example

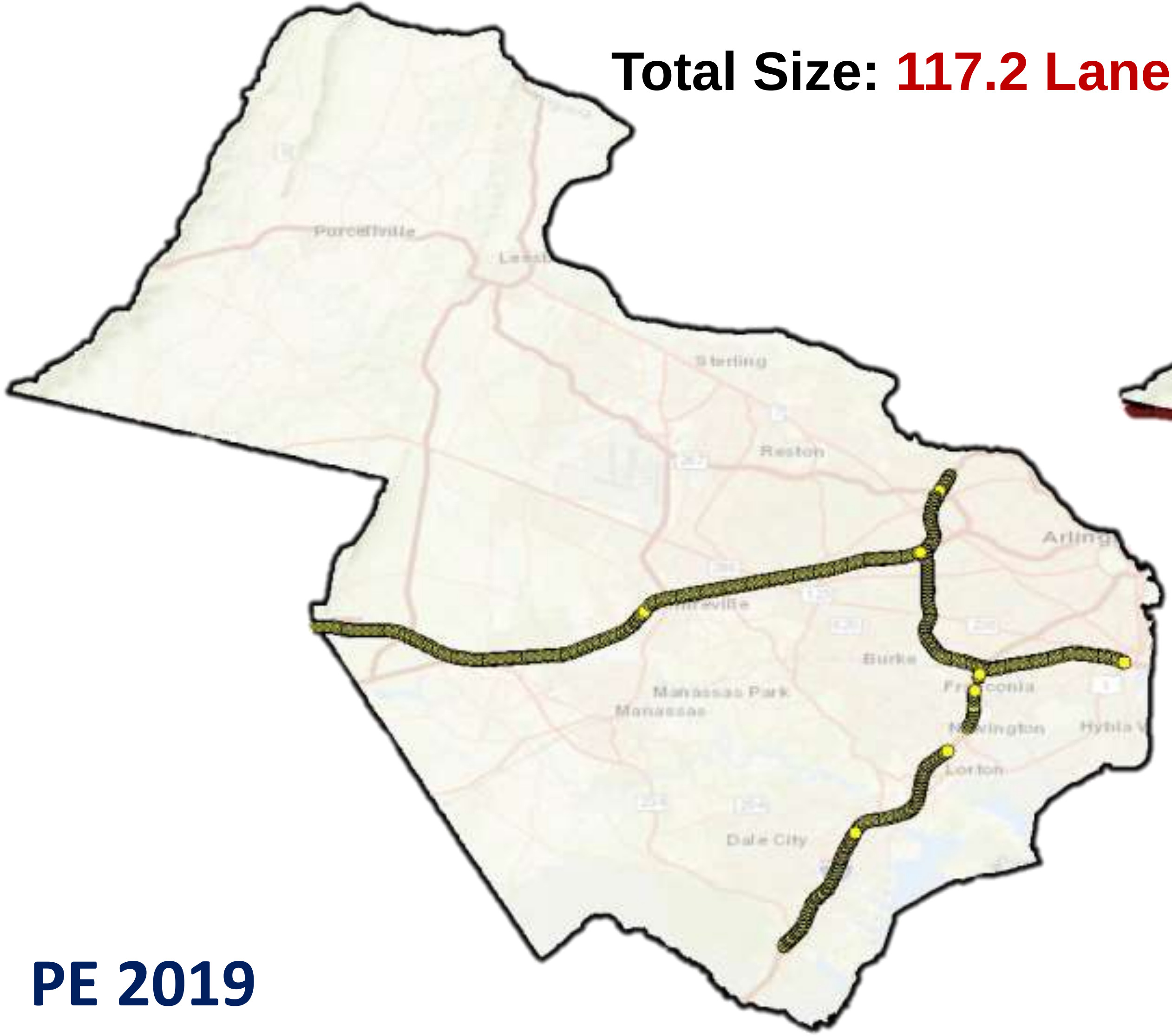
Example: Virginia DOT District 9

- ☐ **Northern Virginia (NOVA)**
- ☐ **Measured Network Size: 409 lane-miles**



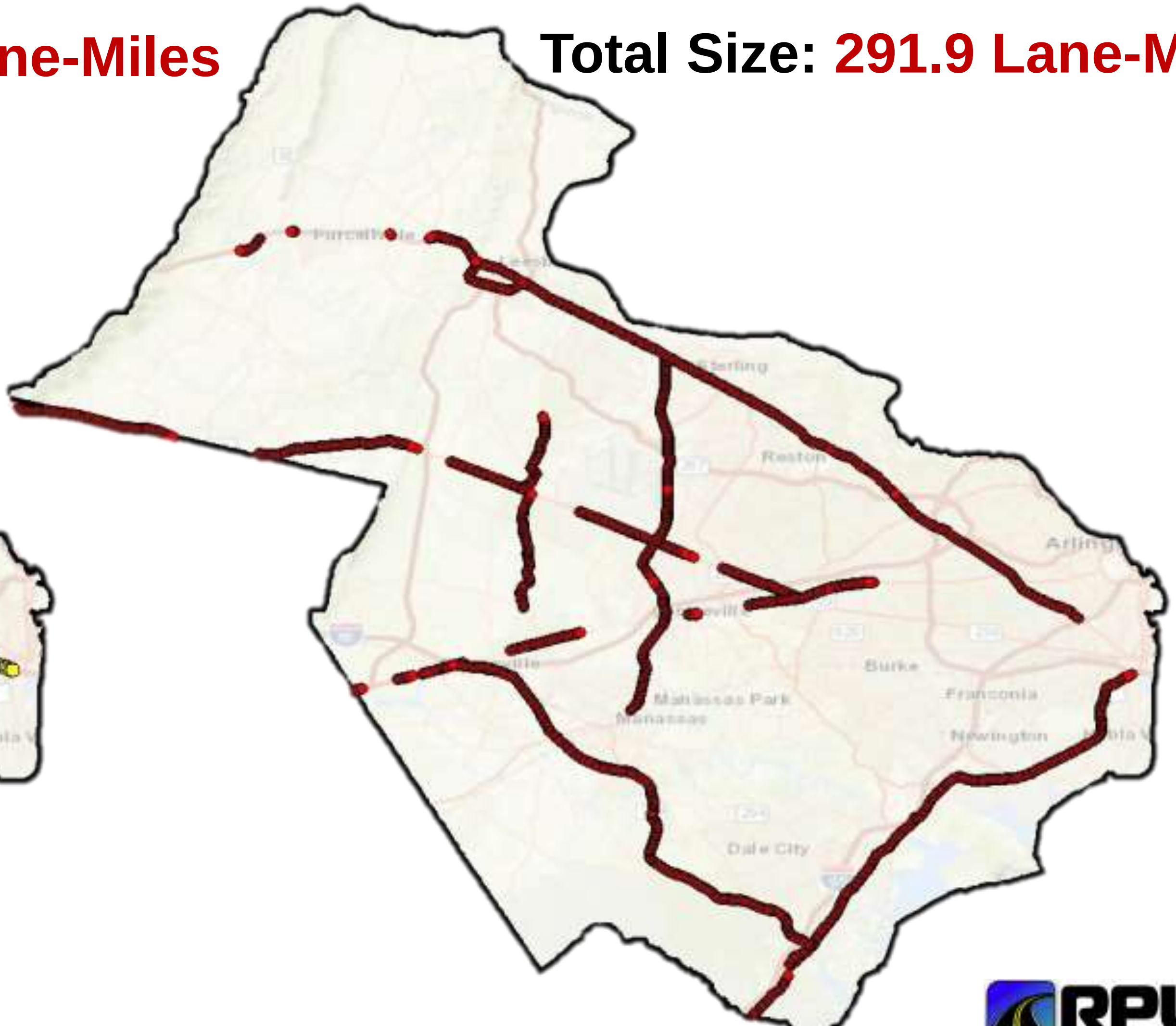
Example: Virginia DOT District 9

Interstate



Total Size: 117.2 Lane-Miles

Primary



Total Size: 291.9 Lane-Miles

Example: Data Collection & Processing

Measure Road Surface Data

➢Data is measured with a <u>Sideway-Force Routine Investigation Machine (SCRIM)</u>

1. Sideway-force Friction [SCRIM Reading (SR)]
2. Macrotexture [Mean Profile Depth (MPD in mm)]
3. Road Surface Geometry
    - ✓ Vertical Grade (%)
    - ✓ Cross-slope (%)
    - ✓ Horizontal Curvature (1/m)
4. Temperature (air, pavement, tire)
5. Global Positioning System (GPS) Coordinates
6. (Synchronized) Dash-cam Video

*All of the data is measured continuously, but **averaged every 10 meters** using processing software.

Example: Data Collection & Procesing

Speed Conversion for the SCRIM Friction Data

In the UK, HD28/15 recommends correcting SCRIM Reading (SR) to 30 mph (50 km/h) [**SR30**]:

- ❑For survey speeds 15 to 53 mph (25 to 85 km/h).

$$\mathbf{SR30} = \mathbf{SR(50)} = \frac{\mathbf{SR(v) * (-0.0152 * v^2 + 4.77 * v + 799)}}{\mathbf{1000}}$$

Where,

v = Survey Speed in km/h

Source: British Design Manual for Roads and Bridges, Part 1, HD 28/15, Skidding Resistance.

Example: Data Collection & Processing

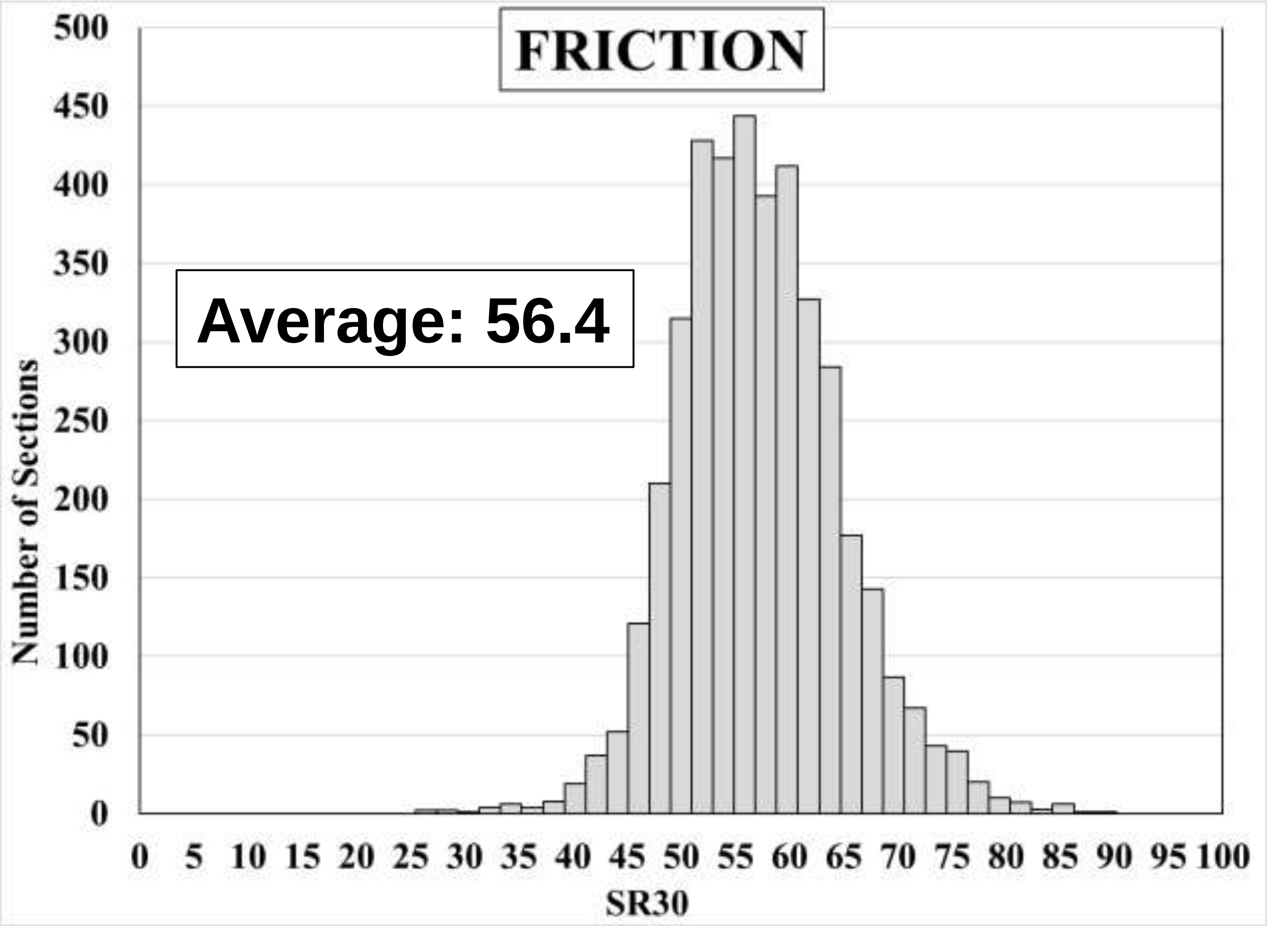
Virginia DOT Data

1. GPS for Mile Post Signs
2. Dry & Wet Pavement Crashes [3-yrs].
3. Average Annual Daily Traffic (AADT).
4. Pavement Maintenance History (3-yrs + Present).
5. GPS or Mile Post Location of Divided Roadway, and Intersections, Ramps, Entrance/Exits, etc.
6. Pavement Surface Type Classification
7. Number of Lanes in each Travel Direction

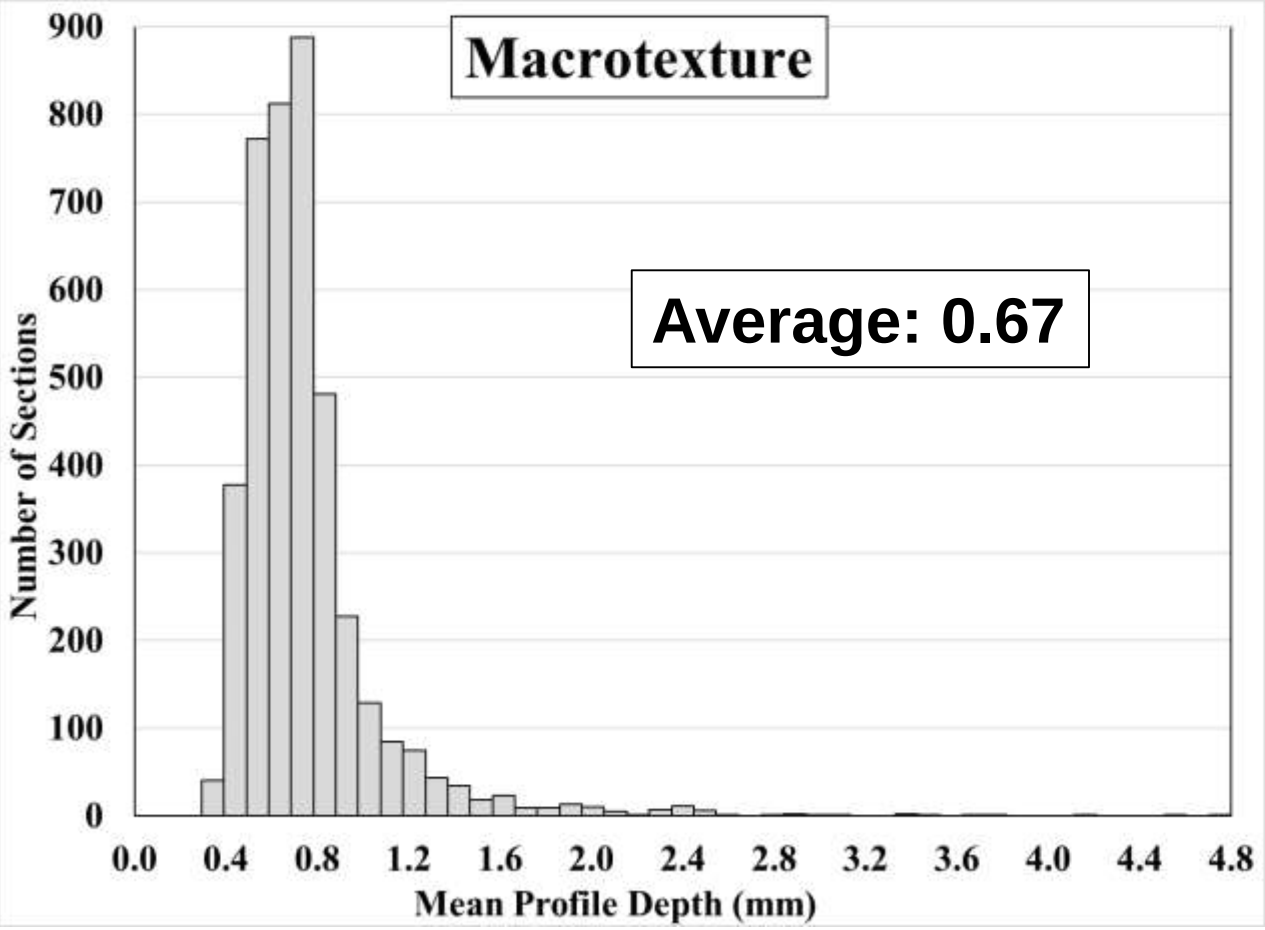
***All of this data is then paired with the measured data every 0.1 mile**

Example: Data Histograms

District 9 Histogram of Friction and Macrotexture



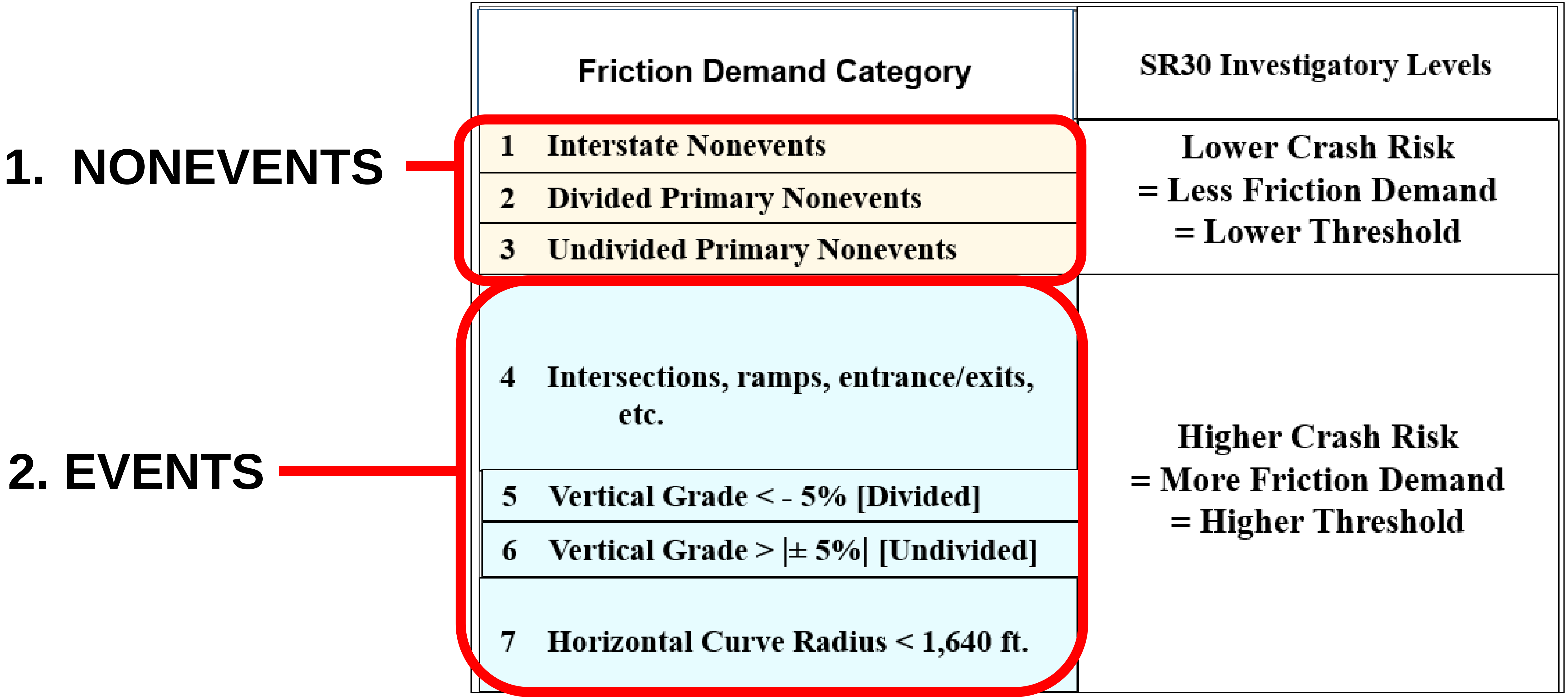
Average: 56.4



Average: 0.67

Example: Friction Demand Categories

2 Primary Categories:



1. NONEVENTS

2. EVENTS

Friction Demand Category	SR30 Investigatory Levels
1 Interstate Nonevents	Lower Crash Risk = Less Friction Demand = Lower Threshold
2 Divided Primary Nonevents	
3 Undivided Primary Nonevents	
4 Intersections, ramps, entrance/exits, etc.	Higher Crash Risk = More Friction Demand = Higher Threshold
5 Vertical Grade < - 5% [Divided]	
6 Vertical Grade > |± 5%| [Undivided]	
7 Horizontal Curve Radius < 1,640 ft.	

Example: Friction Demand Categories

Nonevents

- ✓ Interstate Highway **988 Sections**
- ✓ Divided Primary **1,234 Sections**
- ✓ Undivided Primary **380 Sections**

Total Size: 2,602 0.1-Mile Sections

Example: Friction Demand Categories

Events

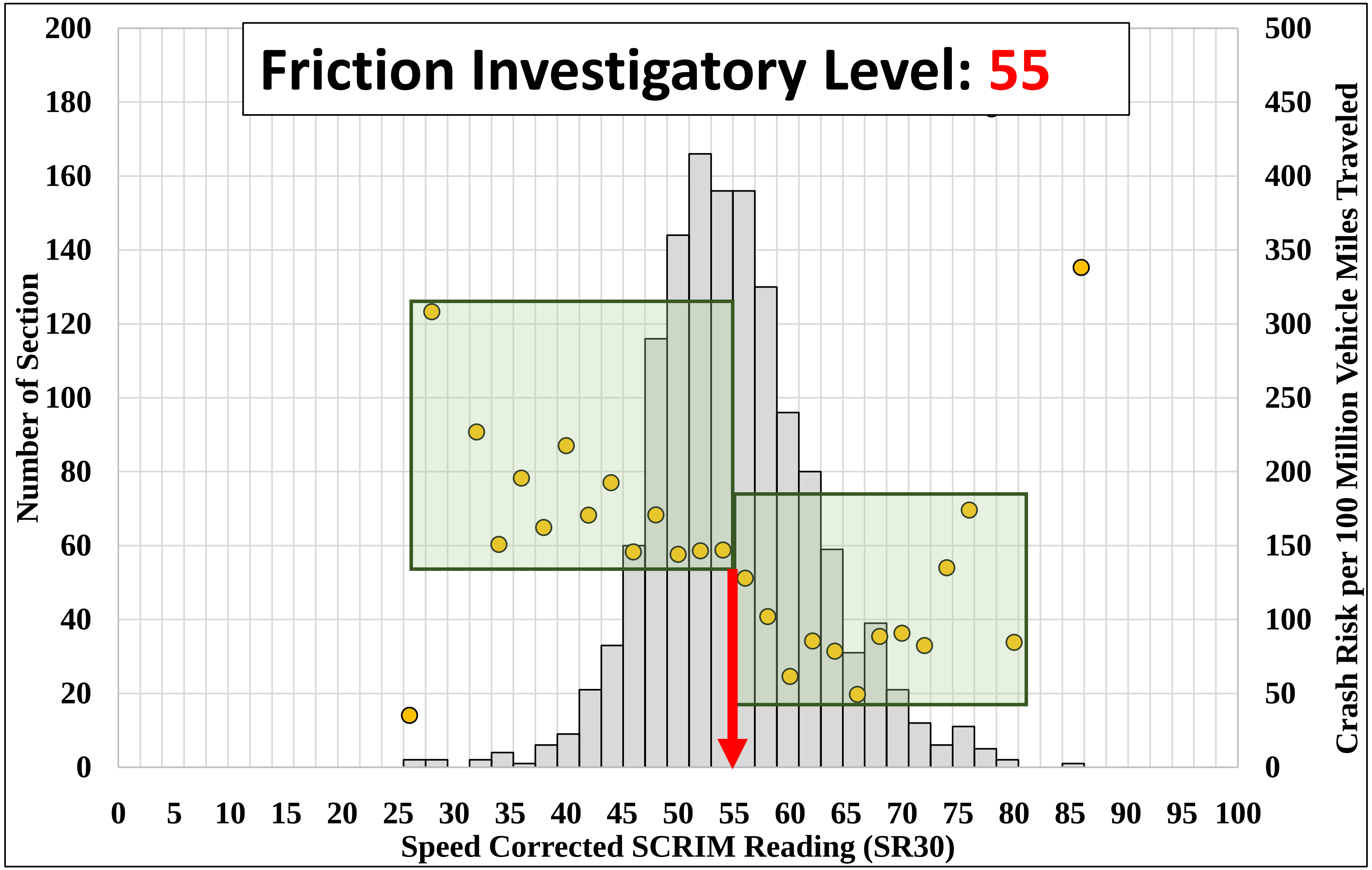
- ✓ Intersections, ramps, entrances/exits, etc. **1,371 Sections**
- ✓ Horizontal Curve Radius < 1,640 feet. **62 Sections**
- ✓ Divided Vertical Gradient < -5%
- ✓ Undivided Vertical Gradient > |±5%|

45 Sections

Total Size: 1,478 0.1-Mile Sections

Example: Investigatory Levels

Events – Intersections, ramps, entrance/exists, etc.



Example: Investigatory Levels

Events

Investigatory Level: 55

Nonevents

Investigatory Level: 50

NOTE:

- Thresholds for FHWA Project
  - **Events: 50 – 60**
  - **Nonevents: 35 – 45**

Example: Safety Performance Function (SPF)

District SPF Model

OVERDISPERSION (α)	**0.795**
LOG-LIKELIHOOD	**-10,444**

Friction Parameter Estimate: -0.038

Model Parameter	Estimate
Intercept [β_0]	**-4.414**
ln(AADT)	**0.756**
Cross-Slope *(%)*	-
Vertical Gradient *(%)*	-
Horizontal Curvature *(1/mile)*	-
Number of Lanes	**0.115**
Divided Road *(1 – Yes; 0 – No)*	**-0.357**
Intersection, Ramp, Entrance/Exit, etc. *(1 – Yes; 0 – No)*	**0.428**
Pavement Surface Type *Asphalt Concrete (AC) = 1; Portland Cement Concrete (PCC) = 0*	**-0.445**
Macrotexture *(Mean Profile Depth [MPD] in mm)*	-
Friction *(Speed Corrected SCRIM Reading [SR30])*	**-0.038**
Route Name *(Indicator Terms: 1 – Yes; 0 – No)*	
I-495	**-0.181**
I-66	**-0.149**
I-95	**0.159**
SC 659	**-0.368**
SR 234	**-0.323**
SR 28	**0.309**
SR 7	**0.601**
US 29	**0.432**
US 50	**-0.060**

Example: Comprehensive Average Cost per Crash

Average Cost per Crash

$3,743,153,454 ÷ 23,236 ≈ $\boxed{\$108{,}600}$


Crash Costs for Highway Safety Analysis

FHWA Safety Program

Injury Level		District 9 Crashes	2016 Comprehensive Unit Costs[1]	District 9 Crash Costs
K	Fatal Injury	62	$11,295,402	$700,314,924
A	Serious Injury	722	$654,967	$472,886,174
B	Moderate Injury	4,403	$198,492	$873,960,276
C	Minor Injury	2,292	$125,562	$287,788,104
O	No Injury	15,757	$11,906	$187,602,842
Total		**23,236**	-	**$3,743,153,454**

Note: [1] The 2016 National Comprehensive Unit Costs for KABCO crashes are from Table 33 in Harmon et al. 2018.

Source: Harmon, T., Bahar, G., and Gross, F. (2018). "Crash Costs for Highway Safety Analysis." Report No. FHWA-SA-17-071, Federal Highway Administration Office of Safety, Washington, D.C.

Example: Treatment Options

- ❑ NOTE: Example for Asphalt Concrete [AC] Surfaces only.

AC Treatment Options:

1. **Hot Mix Asphalt (HMA) Overlay**

   - ➢Cost per Lane per 0.1-Mile: $8,230
   - ➢**SR30 = 65**

2. **High Friction Surface (HFS)**

   - ➢Cost per Lane per 0.1-Mile: $19,000
   - ➢**SR30 = 80**

Example: Estimate Remaining Costs

Sections with Friction below Investigatory Level May Receive Treatment:

1. Treatment Costs: **[Cost / Lane / 0.1-mile] × Lane Count**

2. Compute SPF After Treatment: $\mathbf{SPF_{After}}$

3. Compute EB After Treatment: $\mathbf{EB_{After}} = \dfrac{\mathbf{SPF_{After}}}{\mathbf{SPF_{Before}}} \times \mathbf{EB_{Before}}$

   - ➢Crash Reduction: $\mathbf{EB_{After}} - \mathbf{EB_{Before}}$

   - ➢Crash Reduction Savings: $\mathbf{Crash\ Reduction} \times \mathbf{\$108,600}$

4. Total Savings: $\mathbf{Crash\ Reduction\ Savings} - \mathbf{Treatment\ Costs}$

Example: Final Results for AC Surfaces

Treatment Option	**Potential Crash Reduction**	**Total Savings**
❖HMA Overlay	4,268 (19.4%)	$454.6 Million

❑No High Friction Surface Treatments

Total Savings per Section	0.1-Mile Sections			Predicted Crash Reduction	Total Treatment Costs	Total Savings
	HMA Overlay	HFS	Total			
> $5.0 M	0	0	0	0	$0	$0
> $4.0 M	0	0	0	0	$0	$0
> $3.0 M	1	0	1	35	$32,920	$3,749,152
> $2.0 M	5	0	5	124	$123,450	$13,340,459
> $1.0 M	69	0	69	871	$1,720,070	$92,851,084
> $0.5 M	212	0	212	1,412	$5,036,760	$148,257,339
< $0.5 M	919	0	919	1,827	$1,964,433	$196,403,115
Total	**1,206**	**0**	**1,206**	**4,269**	**$8,877,633**	**$454,601,149**

Conclusions

Based on the findings:

1. **Investigatory levels of friction can be established based on the relationship between crash risk and continuous friction measurements.**
2. **Investigatory levels can be used in a cost-effective method of choosing candidate sections that could benefit most from treatment.**
3. **The benefits of treatment can be assessed using SPF/EB analyses and the estimated improvement to available friction.**
    - ✓Approximately 31% of AC sections would be treated:
        - ➢Only HMA overlays, No HFS.
        - ➢Potential crash reduction of 19.4%.
        - ➢Total potential savings of $454.6M