Center for Sustainable Transportation Infrastructure

PAVEMENT FRICTION MANAGEMENT PROGRAMS

Network Level Friction Testing – A tool to reduce crashes

Mid-Atlantic Quality Assurance Workshop

Edgar de León Izeppi

February 12, 2020

Advancing Transportation Through Innovation

TRANSPORTATION INSTITUTE
VIRGINIA TECH.

Center for Sustainable Transportation Infrastructure

Presentation Outline

1) Network Level Friction Testing
2) US – EU comparison
3) E-274 skid tester vs CFME
4) Case 1: CFME vs. E-274
5) Case 2: Low macrotexture
6) Case 3: HFST location
7) Friction Demand
8) Pavement Friction Management

Advancing Transportation Through Innovation

VT TRANSPORTATION INSTITUTE VIRGINIA TECH.

Center for Sustainable Transportation Infrastructure

1. Network Level Friction Testing

Coverage:	**Network Level vs. Hot spots**
Crashes:	**All vs. Wet-only (15%)**
Measurements:	**Full Extent vs. Sample (1%)**
Response:	**Proactive vs. Reactive**

Advancing Transportation Through Innovation

TRANSPORTATION INSTITUTE
VIRGINIA TECH.

No.	State	Crashes	No.	State	Crashes
1	Texas	428,667	27	Mississippi	74,122
2	California	426,228	28	Minnesota	73,498
3	Georgia	318,531	29	Oklahoma	71,218
4	New York	314,974	30	Arkansas	62,808
5	New Jersey	301,233	31	Kansas	61,119
6	Ohio	299,040	32	Iowa	55,488
7	Michigan	293,403	33	Nevada	53,151
8	Illinois	292,437	34	Utah	51,367
9	Florida	235,803	35	New Mexico	46,213
10	North Carolina	209,695	36	Rhode Island	41,788
11	Indiana	189,983	37	Oregon	41,271
12	Louisiana	155,857	38	West Virginia	39,906
13	Tennessee	155,099	39	Nebraska	34,664
14	Missouri	153,015	40	New Hampshire	33,265
15	Massachusett	136,384	41	Maine	33,118
16	Kentucky	126,237	42	Idaho	22,992
17	Alabama	123,503	43	Montana	21,971
18	Wisconsin	121,736	44	North Dakota	17,686
19	Pennsylvania	121,298	45	South Dakota	16,994
20	Virginia	116,742	46	DC	16,841
21	Washington	110,070	47	Delaware	16,723
22	South Carolina	106,864	48	Wyoming	15,507
23	Arizona	106,767	49	Alaska	12,890
24	Colorado	105,000	50	Vermont	12,640
25	Connecticut	103,719	51	Hawaii	10,000
26	Maryland	96,391		Total US	6,085,916

1. Network Level Friction Testing

25 states > 100,000 crashes
35 states > 50,000 crashes
43 states > 20,000 crashes

2009 motor vehicle Police-reported traffic crashes by State (Table 5-3)
Source: The Economic and Societal Impact of Motor Vehicle Crashes, NHTSA, 2010

Center for Sustainable Transportation Infrastructure

1. Network Friction Testing

State	% Miles owned	% Ln-mi owned					
DE	84.0	85.2					
DC	90.7	90.9					
MD	16.0	20.9					
NJ	6.0	10.1					
PA	32.9	35.1					
VA	78.3	78.3					
WV	88.6	88.6					

Advancing Transportation Through Innovation

Center for Sustainable Transportation Infrastructure

1. Network Friction Testing

State	% Miles owned	% Ln-mi owned	Fatality (2017)	Rank			
DE	84.0	85.2	119	44			
DC	90.7	90.9	31	51			
MD	16.0	20.9	550	26			
NJ	6.0	10.1	624	23			
PA	32.9	35.1	1,137	7			
VA	78.3	78.3	839	17			
WV	88.6	88.6	303	35			

Advancing Transportation Through Innovation

Center for Sustainable Transportation Infrastructure

1. Network Friction Testing

State	% Miles owned	% Ln-mi owned	Fatality (2017)	Rank	Fat Rate 100 MVMT	Rank	
DE	84.0	85.2	119	44	1.14	27	
DC	90.7	90.9	31	51	0.83	46	
MD	16.0	20.9	550	26	0.92	42	
NJ	6.0	10.1	624	23	0.81	47	
PA	32.9	35.1	1,137	7	1.12	30	
VA	78.3	78.3	839	17	0.98	39	
WV	88.6	88.6	303	35	1.59	4	

Advancing Transportation Through Innovation

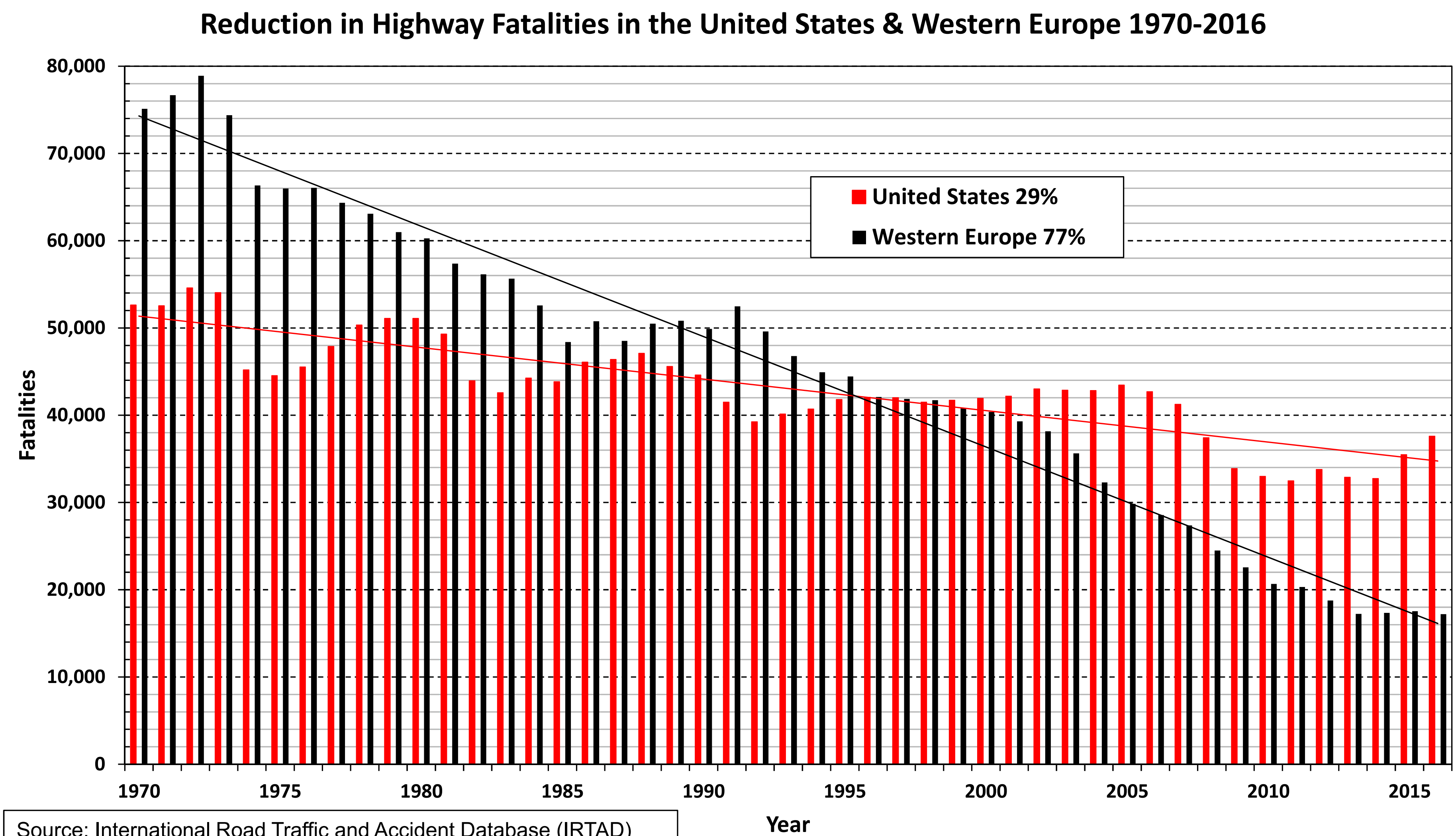
Center for Sustainable Transportation Infrastructure

1. Network Friction Testing

State	% Miles owned	% Ln-mi owned	Fatality (2017)	Rank	Fat Rate 100 MVMT	Rank	Comp Cost in $MM
DE	84.0	85.2	119	44	1.14	27	131
DC	90.7	90.9	31	51	0.83	46	34
MD	16.0	20.9	550	26	0.92	42	605
NJ	6.0	10.1	624	23	0.81	47	686
PA	32.9	35.1	1,137	7	1.12	30	1,251
VA	78.3	78.3	839	17	0.98	39	923
WV	88.6	88.6	303	35	1.59	4	333

Advancing Transportation Through Innovation

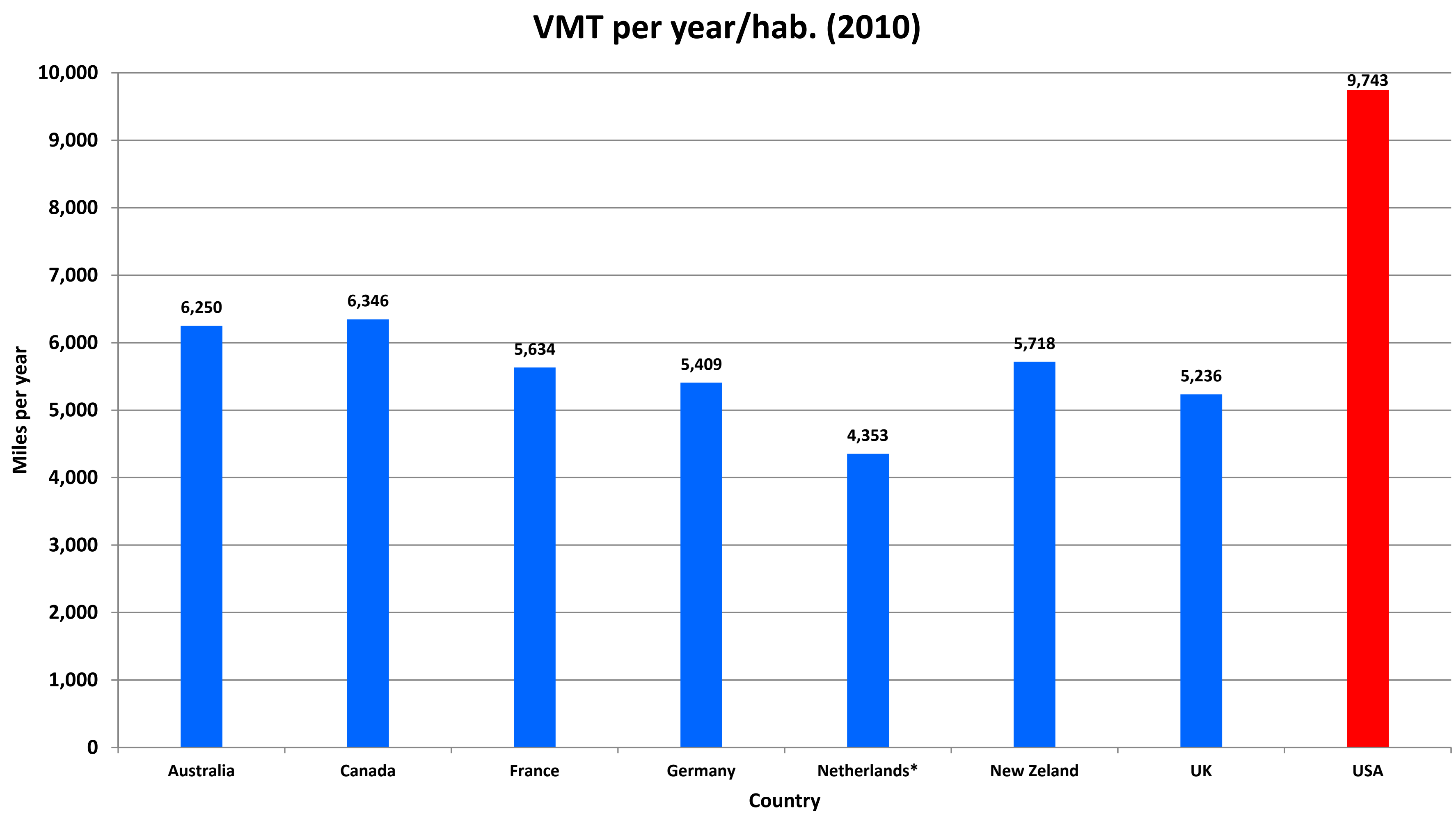
Center for Sustainable Transportation Infrastructure



Source: International Road Traffic and Accident Database (IRTAD)

Advancing Transportation Through Innovation

Center for Sustainable Transportation Infrastructure



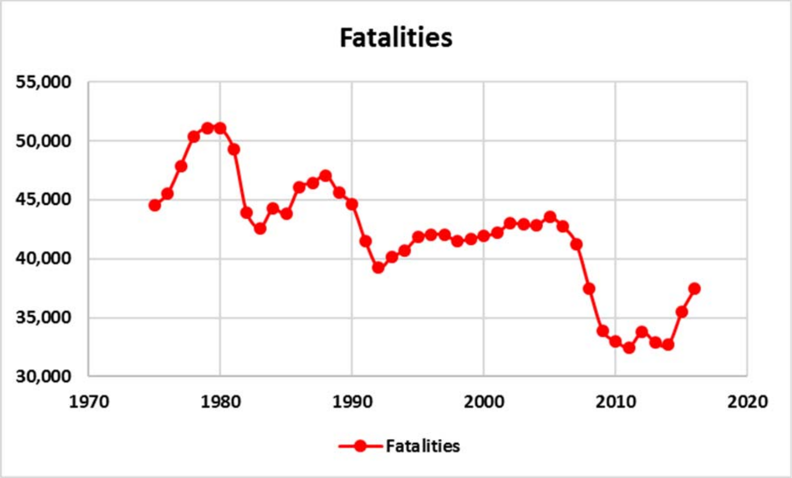
Advancing Transportation Through Innovation

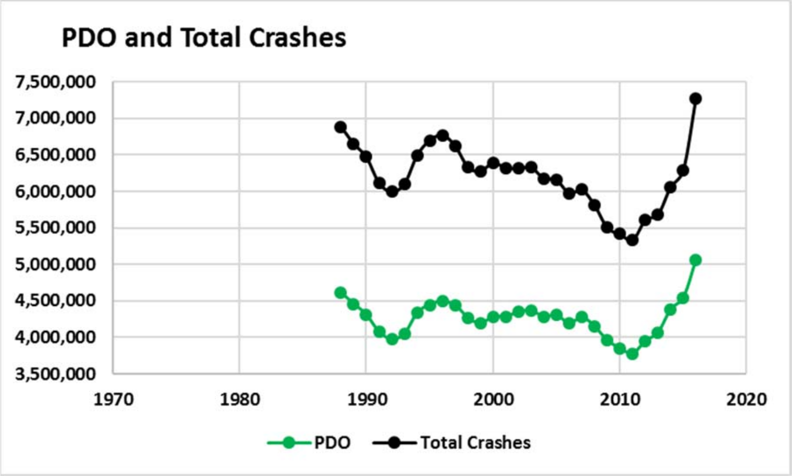
Source: International Road Traffic and Accident Database (IRTAD)

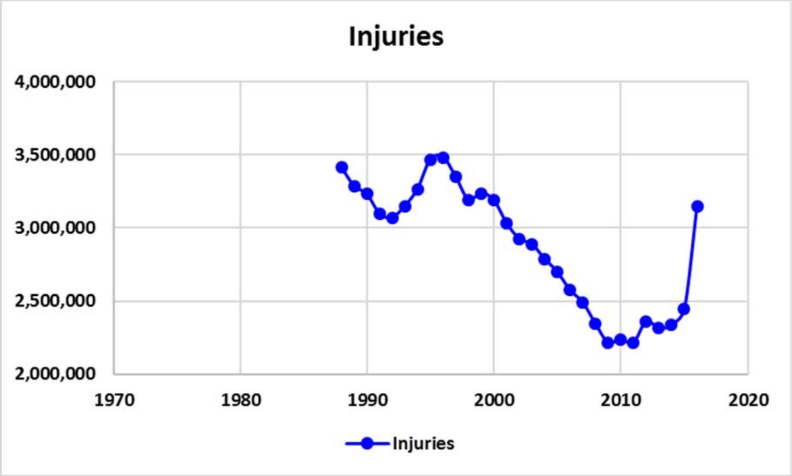
TRANSPORTATION INSTITUTE VIRGINIA TECH.

Center for Sustainable Transportation Infrastructure

US Safety Performance







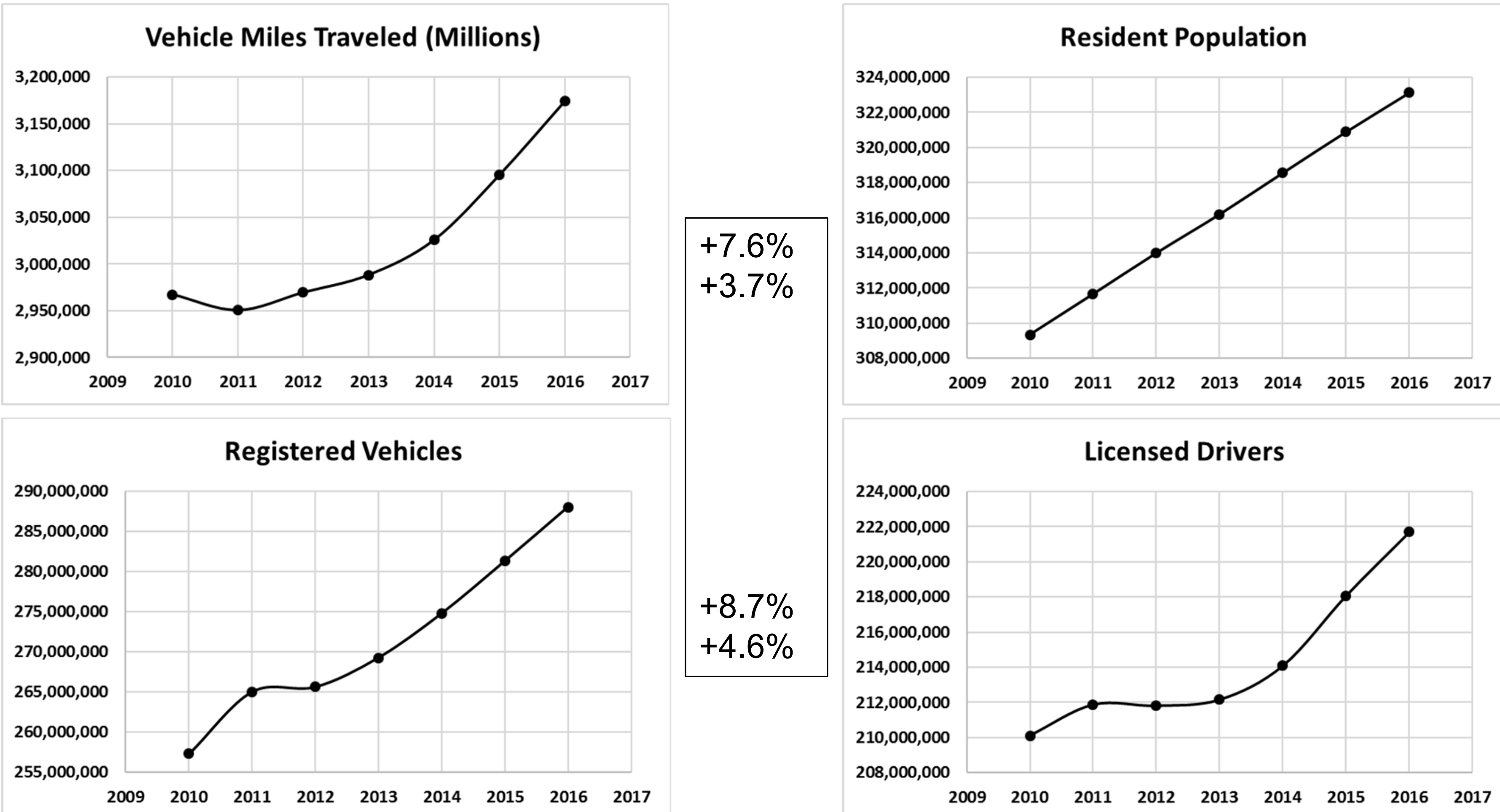
From 2011 to 2016:

- ✓ **Fatalities up 16%**
- ✓ **Injuries up 42%**
- ✓ **PDO crashes up 34%**
- ✓ **Total crashes up 36%**

Advancing Transportation Through Innovation

Center for Sustainable Transportation Infrastructure

Other Statistics (not as high)



Advancing Transportation Through Innovation

Center for Sustainable Transportation Infrastructure

"Principles" of Pavement Friction

1. Only Wet Crashes are related to friction
2. You should only investigate friction related sites with a certain % of wet/dry crash ratios
3. Changing the friction (macro/micro) of a pavement will only reduce wet crashes

Advancing Transportation Through Innovation

VT TRANSPORTATION INSTITUTE VIRGINIA TECH.

Center for Sustainable Transportation Infrastructure

Kentucky HFST Program Crash Reductions

June 2015

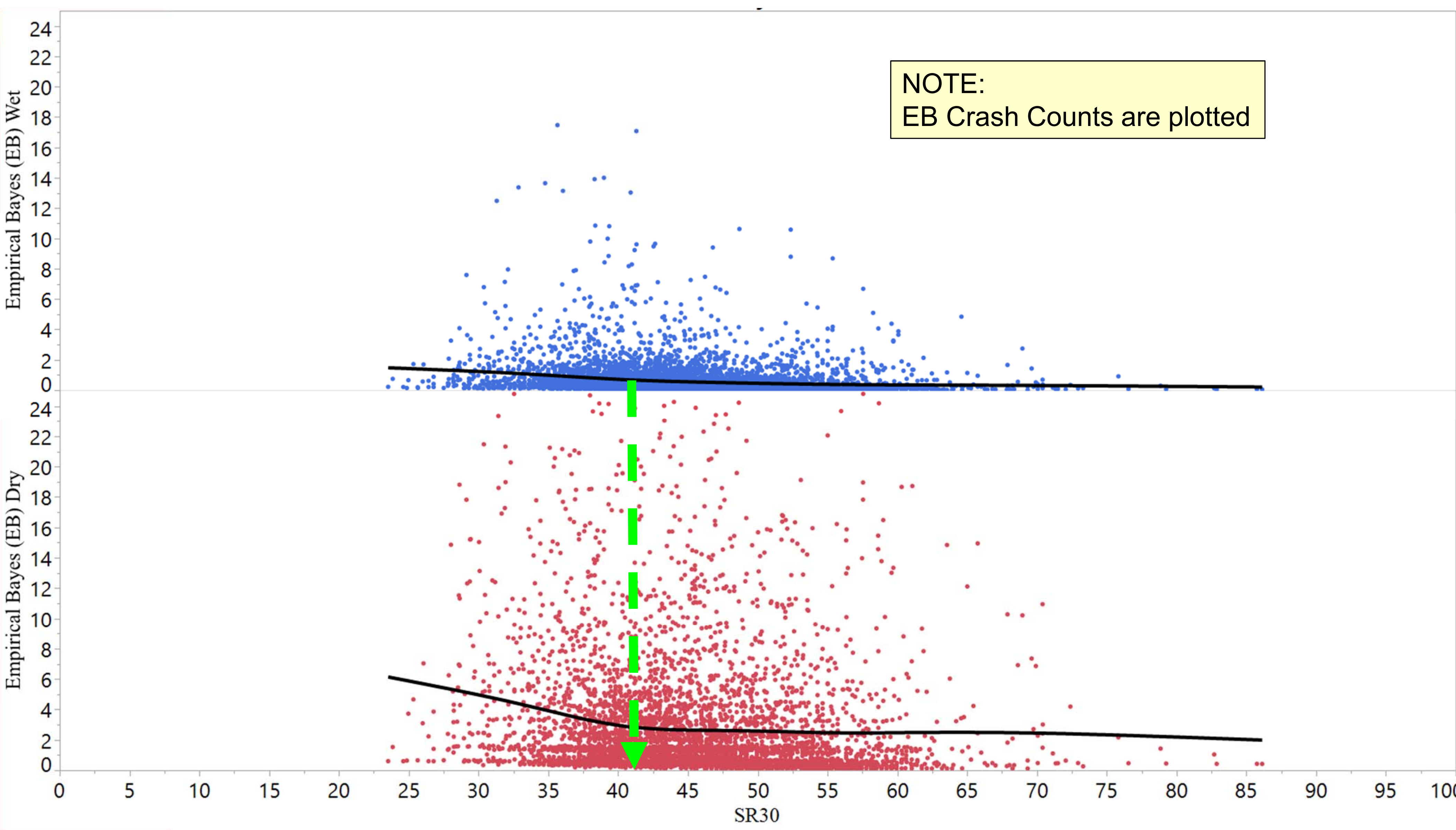
Annual	ALL	RAMPS	CURVES
Wet Avg.	90%	90%	84%
Dry Avg.	**77%**	**78%**	**80%**
Total Avg.	87%	89%	82%

After the installation of HFST, the number of **dry weather** reduction in crashes was also very significant.

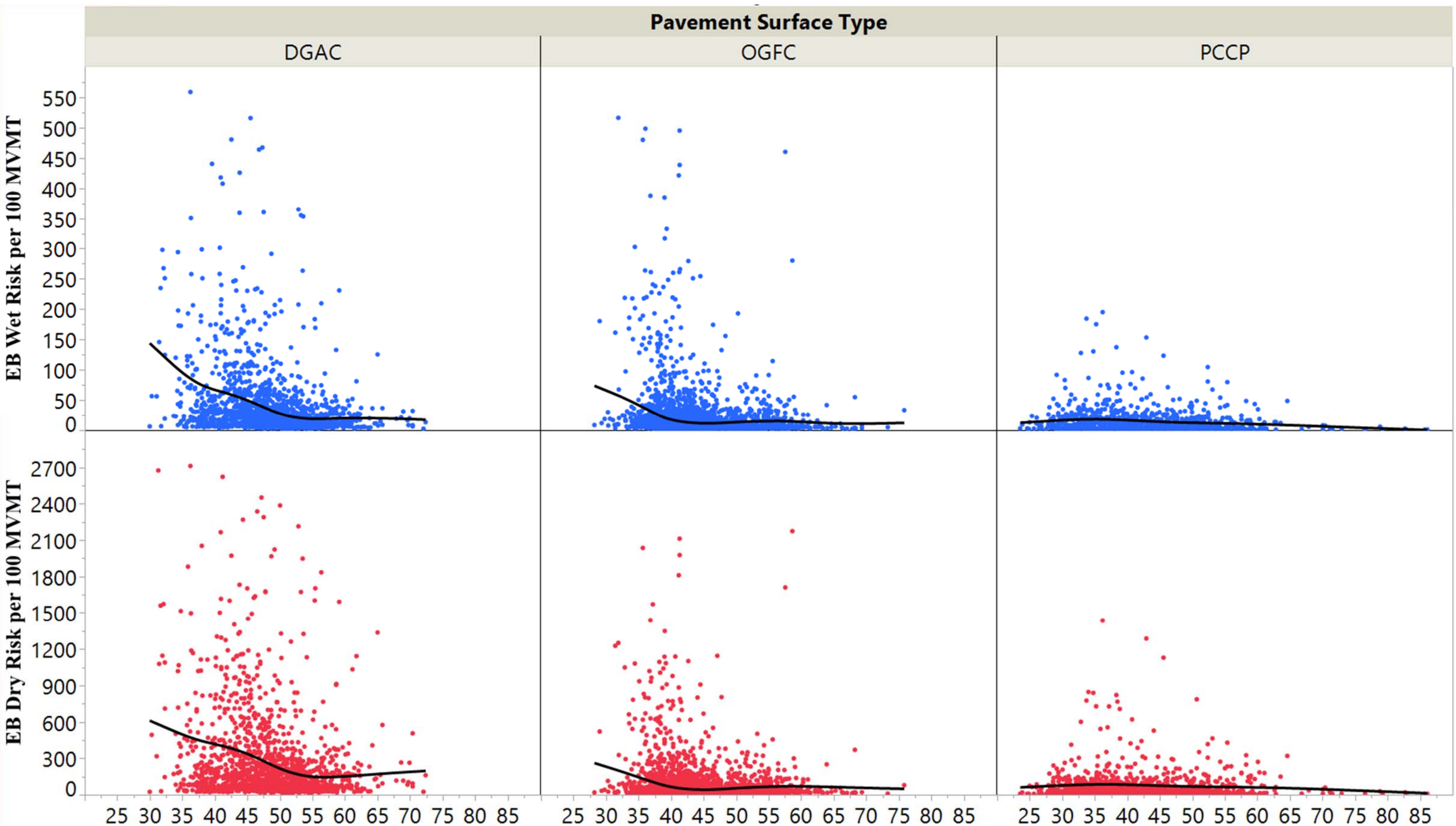
Advancing Transportation Through Innovation

Center for
Sustainable
Transportation
Infrastructure

Myth:
Friction does not improve dry weather crashes skid



NOTE:
EB Crash Counts are plotted
Empirical Bayes (EB) Wet
Empirical Bayes (EB) Dry
SR30


Pavement Surface Type
DGAC
OGFC
PCCP
EB Wet Risk per 100 MVMT
EB Dry Risk per 100 MVMT
0
50
100
150
200
250
300
350
400
450
500
550
0
300
600
900
1200
1500
1800
2100
2400
2700
25 30 35 40 45 50 55 60 65 70 75 80 85
25 30 35 40 45 50 55 60 65 70 75 80 85
25 30 35 40 45 50 55 60 65 70 75 80 85

3. E-274 vs CFME

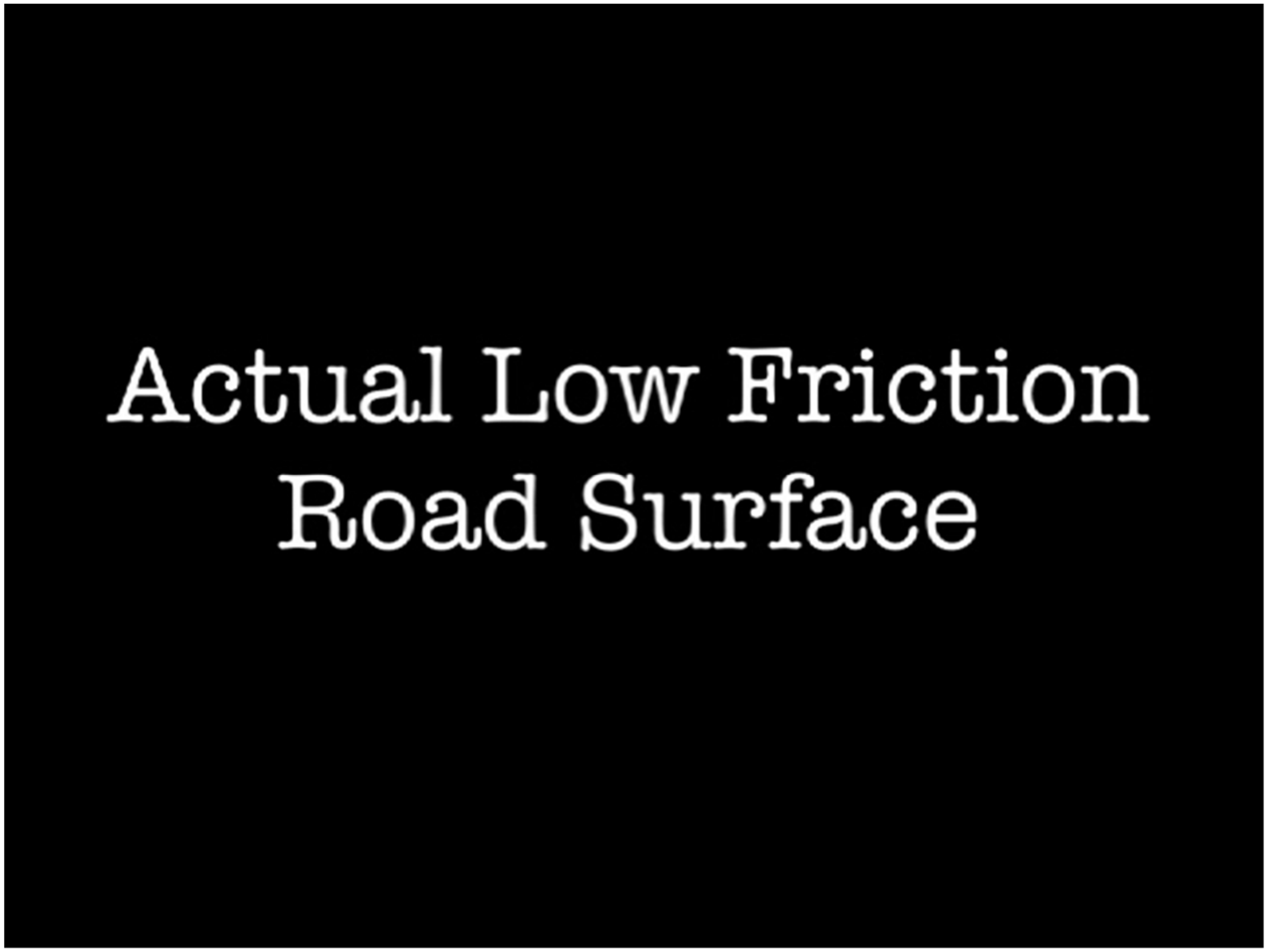
49/50 States use the locked-wheel skid trailer E274 to measure friction to try to do Network (multiyear cycle) Wet Accident Reduction Program (WARP).

Limitations:

- **Locked-wheel cannot do curves, ramps, etc.**
- **Cannot do continuous (@1.0 miles = 1%)**
- **Macrotexture possible, not common**
- **Water ± 2 gal/test @40 mph,**
  - **300 gallon tank, 150 tests, 15 miles**
  - **600 gallon tank, 300 tests, 30 miles**

Center for Sustainable Transportation Infrastructure

3. E-274 vs CFME



3. E-274 vs CFME

Center for Sustainable Transportation Infrastructure

3. E-274 vs CFME

Advancing Transportation Through Innovation

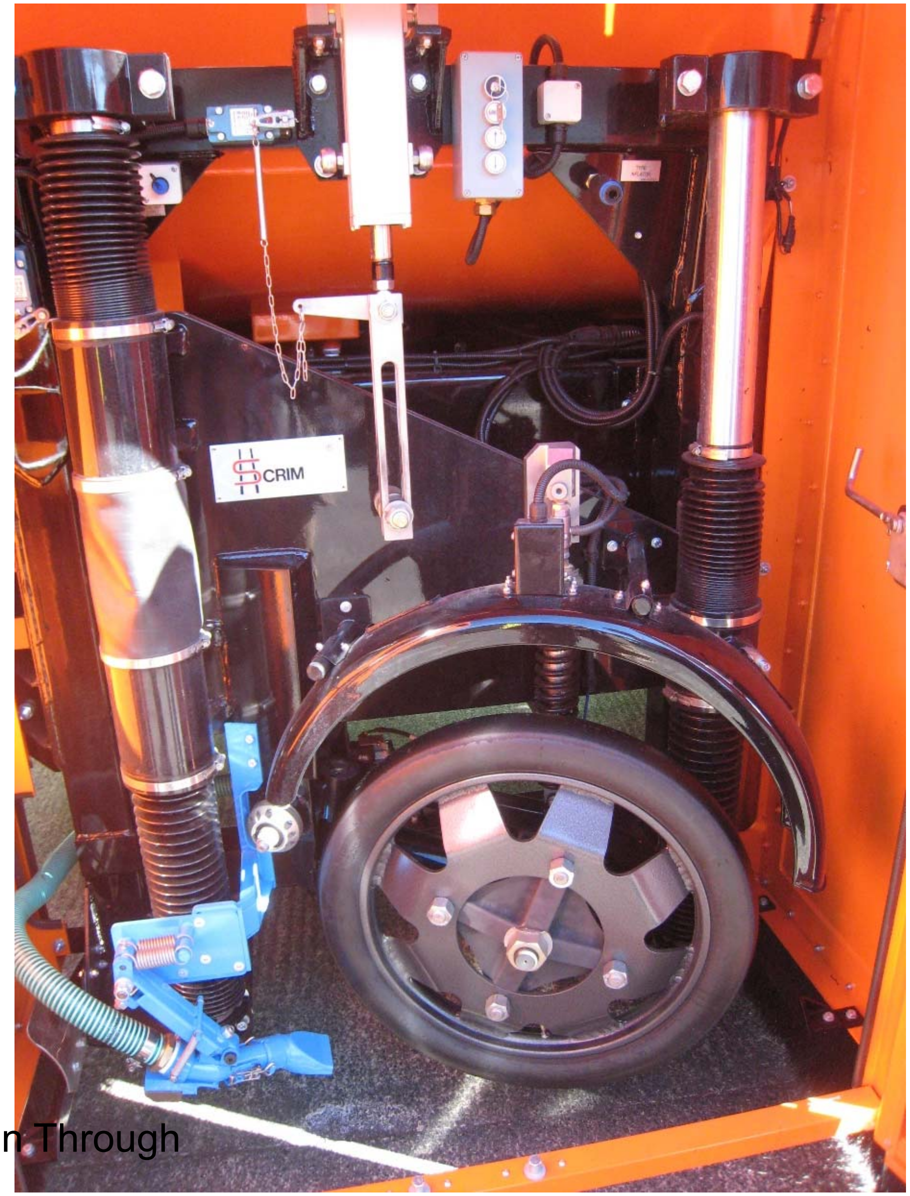
VT TRANSPORTATION INSTITUTE VIRGINIA TECH.

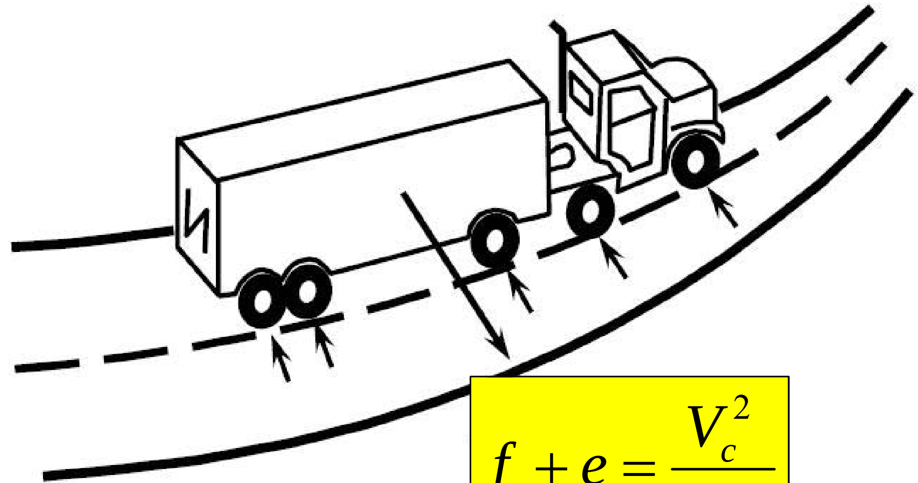
SCRIM

- ✓Friction
- ✓Macrotexture
- ✓IMU + GPS
- ✓Video (front)
- ✓2,200 gallons water tank = 150 miles of continuous data collection per tank

SCRIM

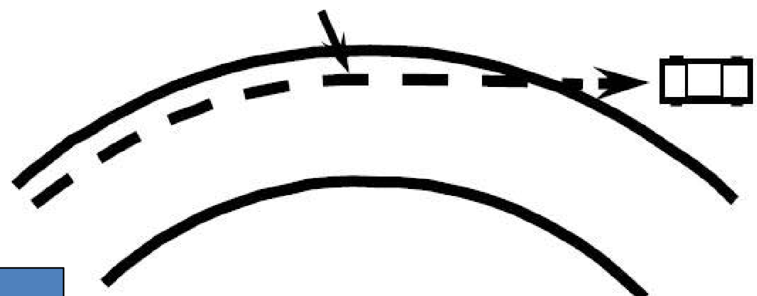
- **Friction**
  - Dynamic vertical load system
  - Dynamic water flow control
  - 20° skew angle (34% slip speed)
  - Operating speed of 15 – 55 mph
- **Macrotexture**
  - 64 kHz laser system
- **GPS coordinates**
- **Geometrics**
  - Vertical grade
  - Cross-slope
  - Horizontal curvature





$$f + e = \frac{V_c^2}{15R}$$

Figure 28. Lateral forces that act on a vehicle as it travels along a curve.



AASHTO Guide for Pavement Friction, p.62

Figure 29. Lateral sliding.

Changes in cross-section in curves

Guide for Pavement Friction, p.62

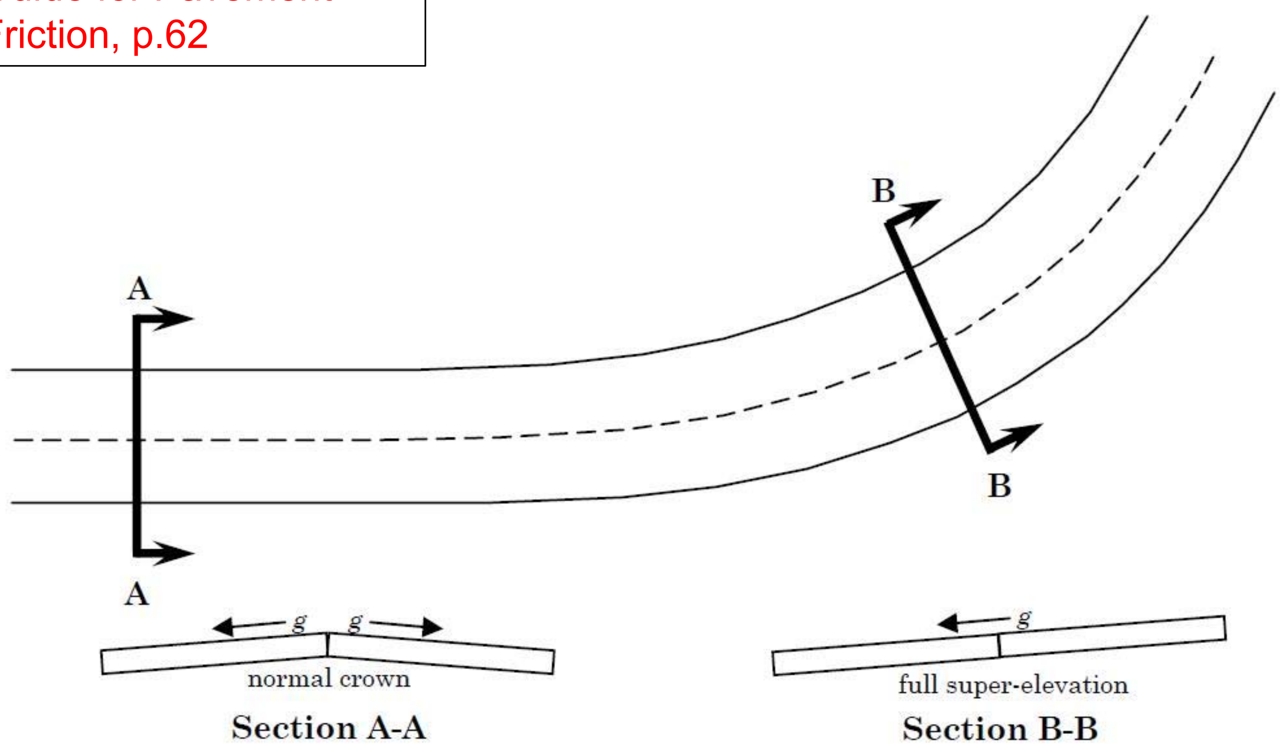


Figure 27. Change in highway cross-section as the horizontal alignment transitions from a tangent to a curve.

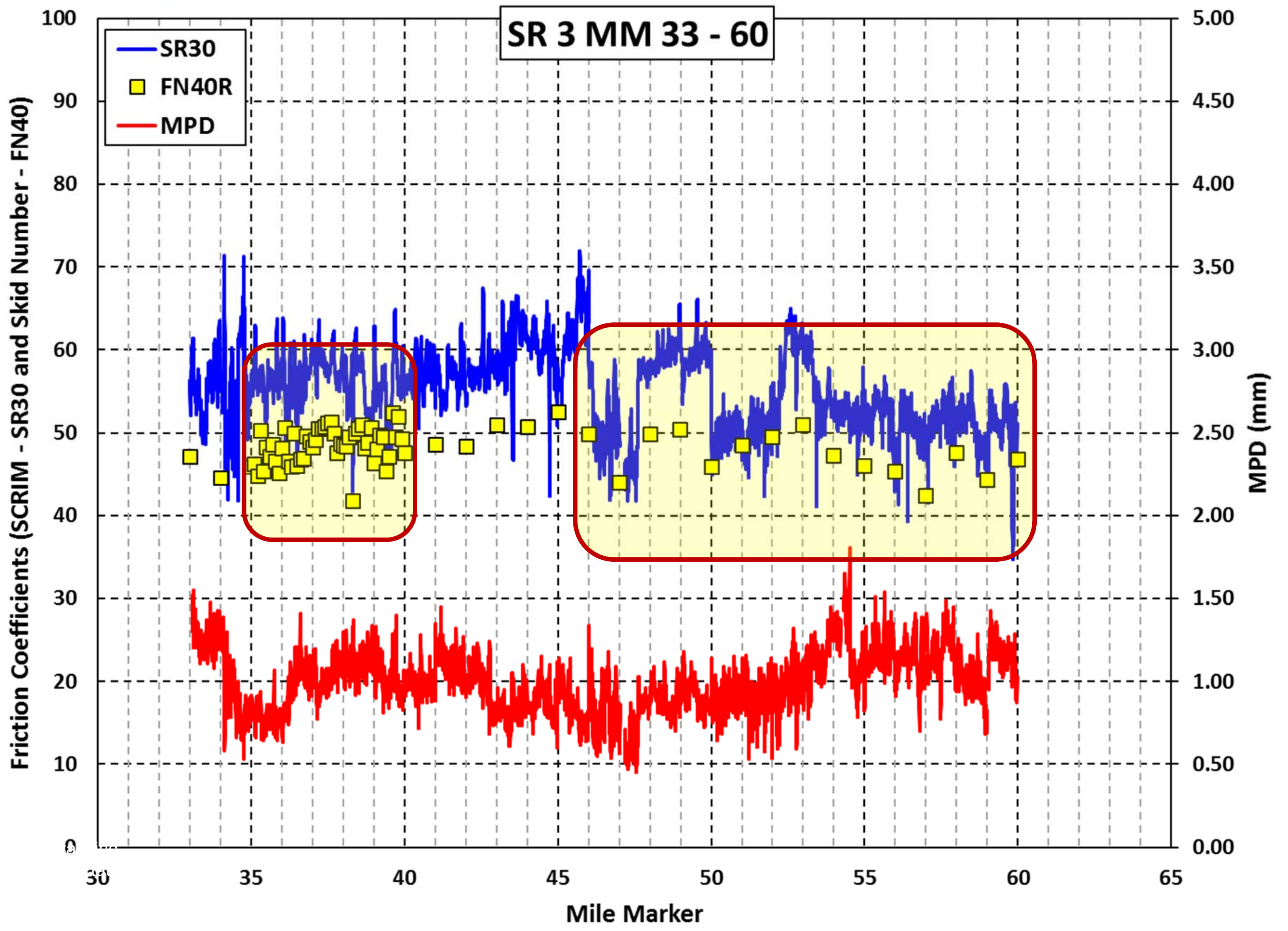
Center for Sustainable Transportation Infrastructure

4. Importance of Continuous Measurements

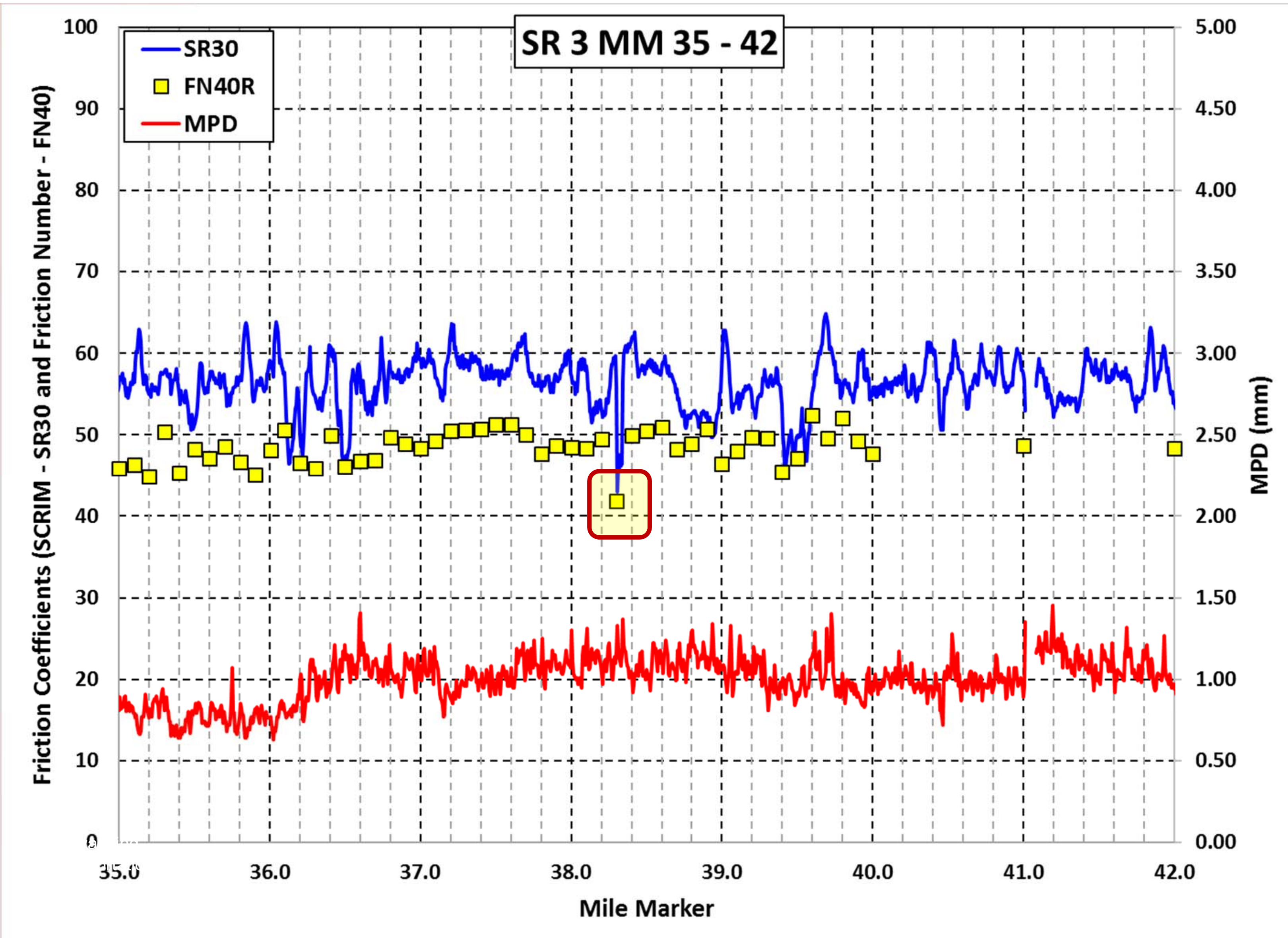
- ✓State Route 3 (MM 59.8)
- ✓Comparison CFME and texture data collection with 1.0 mile friction
- ✓Experimentation of LWST at 0.1 mile

Advancing Transportation Through Innovation

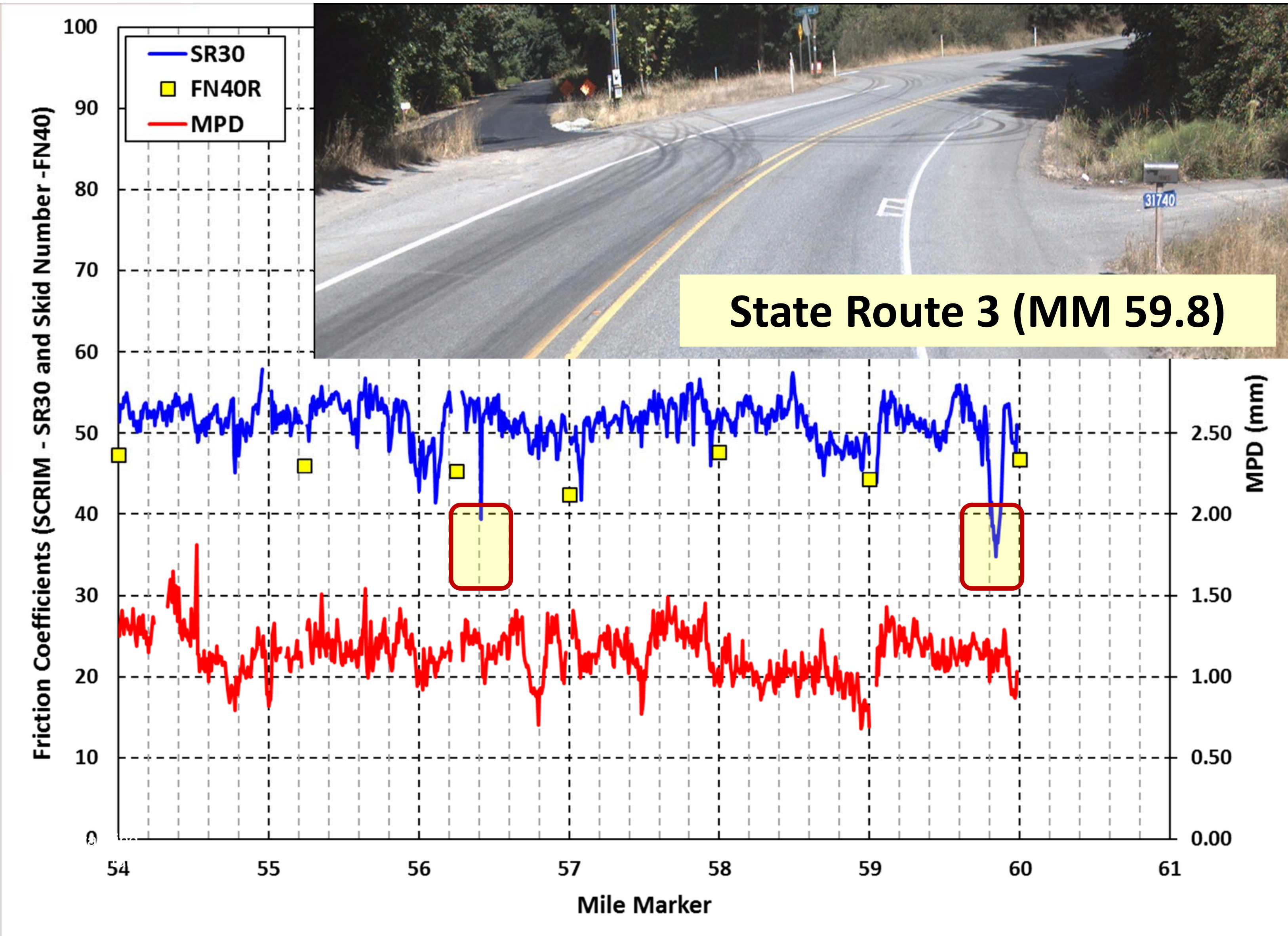
TRANSPORTATION INSTITUTE VIRGINIA TECH.

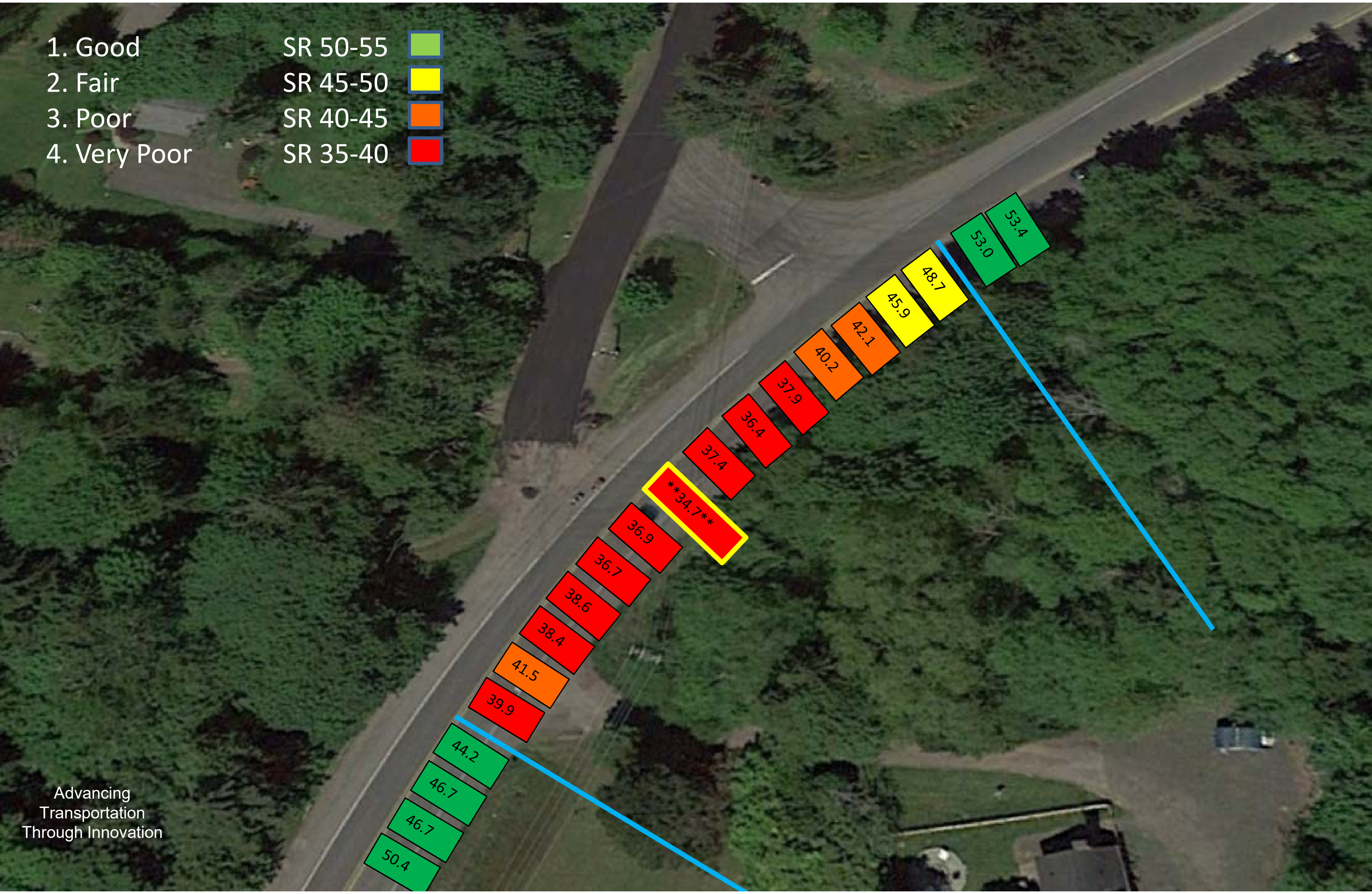


TRANSPORTATION INSTITUTE
VIRGINIA TECH.

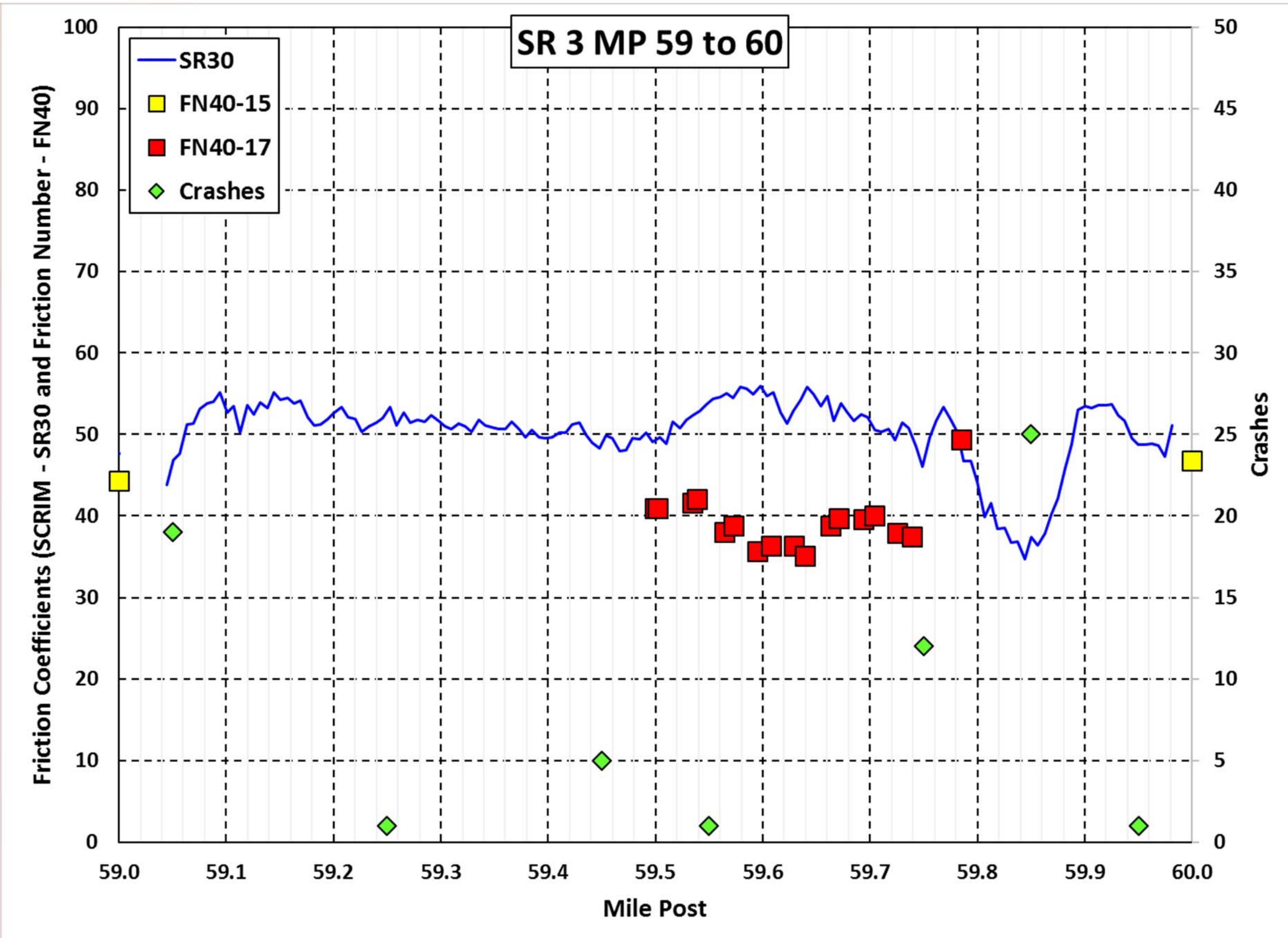


TRANSPORTATION INSTITUTE
VIRGINIA TECH.


State Route 3 (MM 59.8)
SR30
FN40R
MPD
31740
Friction Coefficients (SCRIM - SR30 and Skid Number -FN40)
MPD (mm)
Mile Marker
100
90
80
70
60
50
40
30
20
10
0
2.50
2.00
1.50
1.00
0.50
0.00
54
55
56
57
58
59
60
61



TATION INSTITUTE



TRANSPORTATION INSTITUTE
VIRGINIA TECH.

Center for
Sustainable
Transportation
Infrastructure

5. CASE 2 – Low Macrotexture

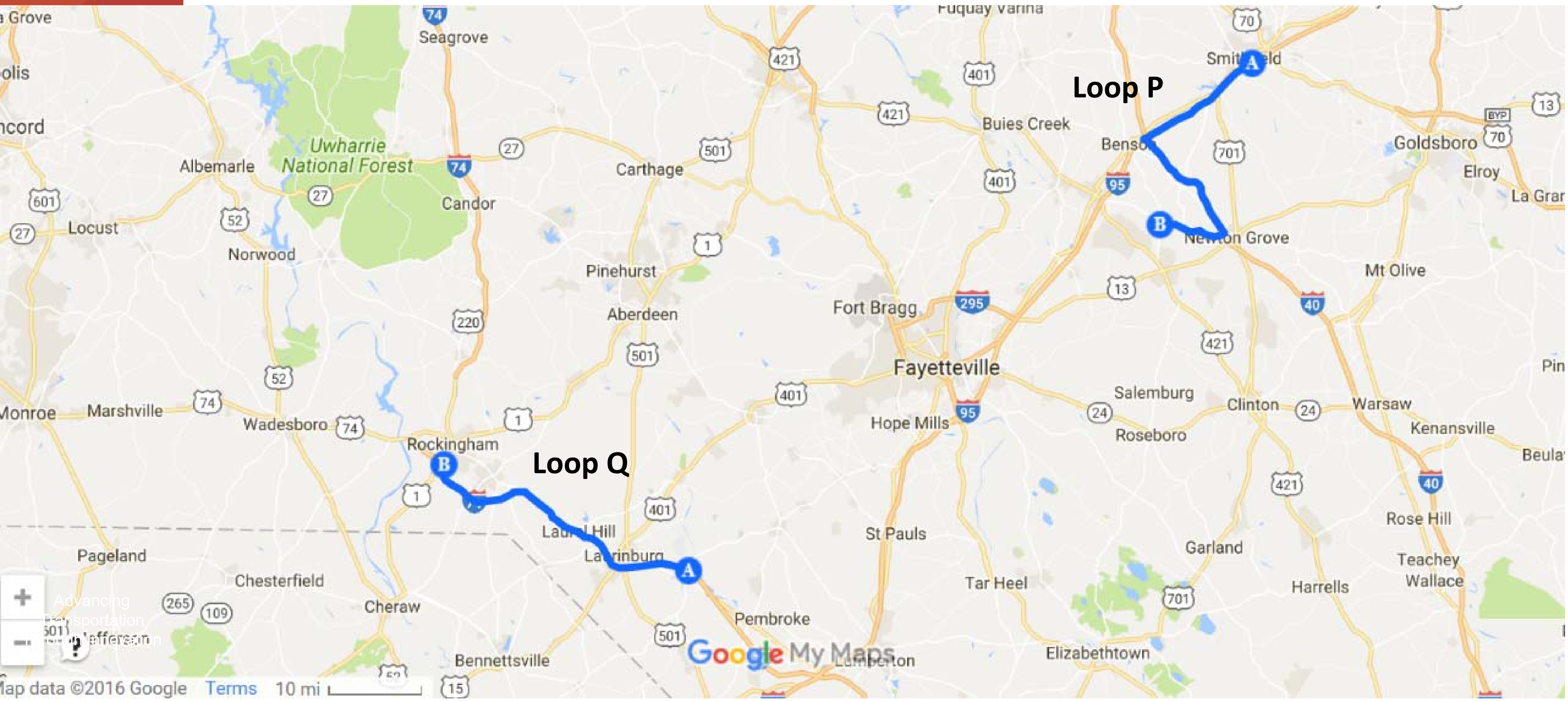
- ✓Interstate Loop Q
- ✓Friction and Texture

Advancing
Transportation
Through Innovation

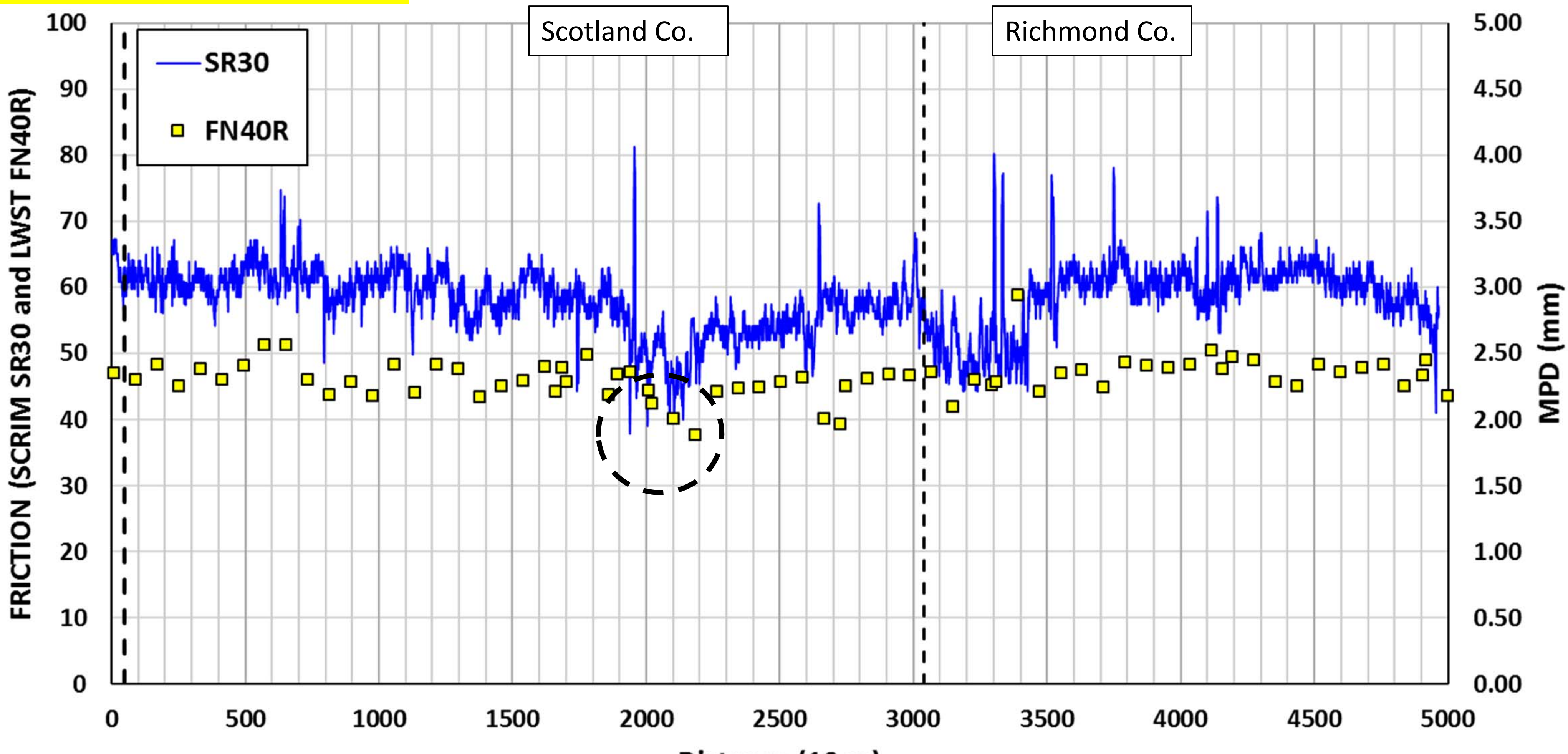
TRANSPORTATION INSTITUTE
VIRGINIA TECH.

Center for Sustainable Transportation Infrastructure

5. Case 2 – Low Macrotexture

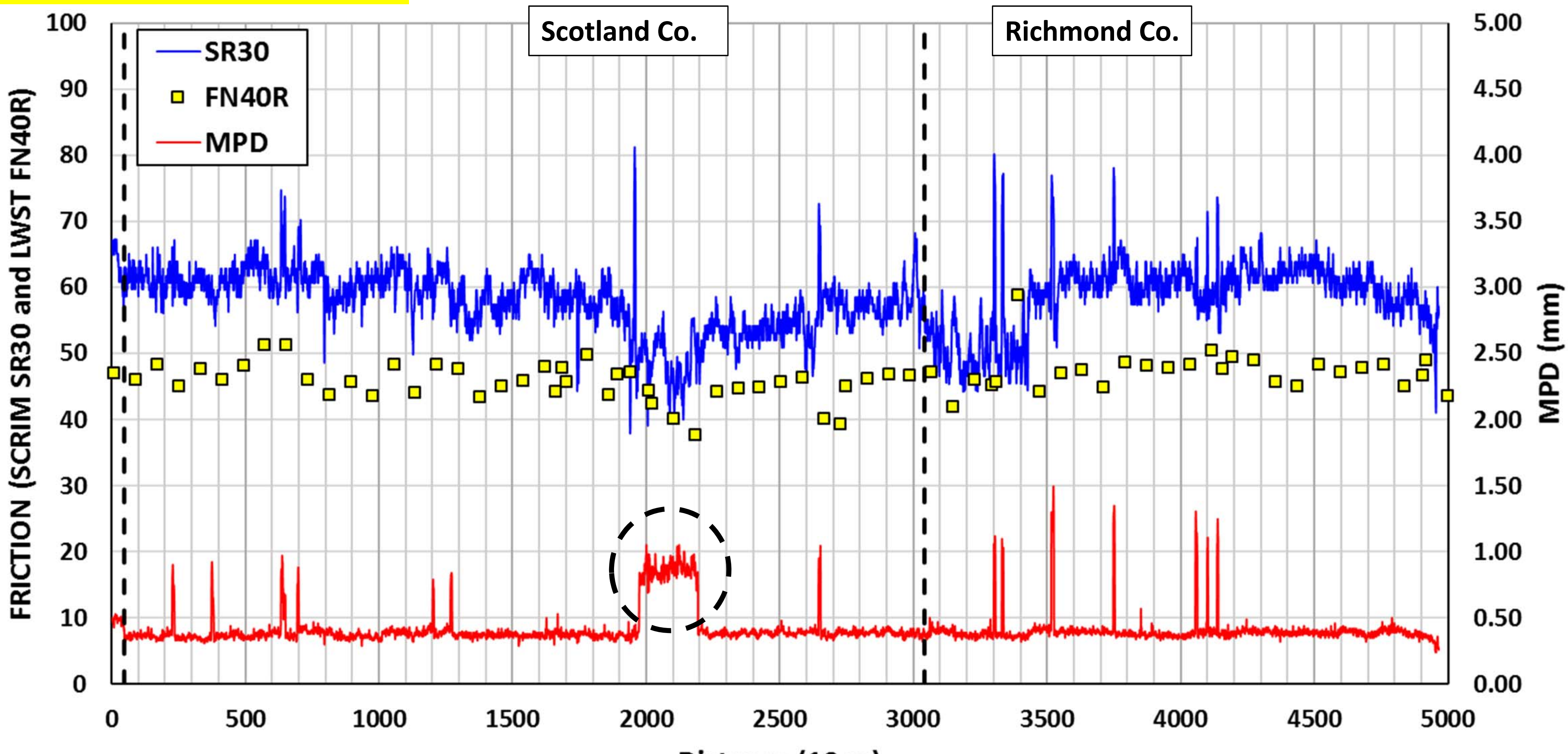


LOOP Q



Advancing Transportation Through Innovation

LOOP Q

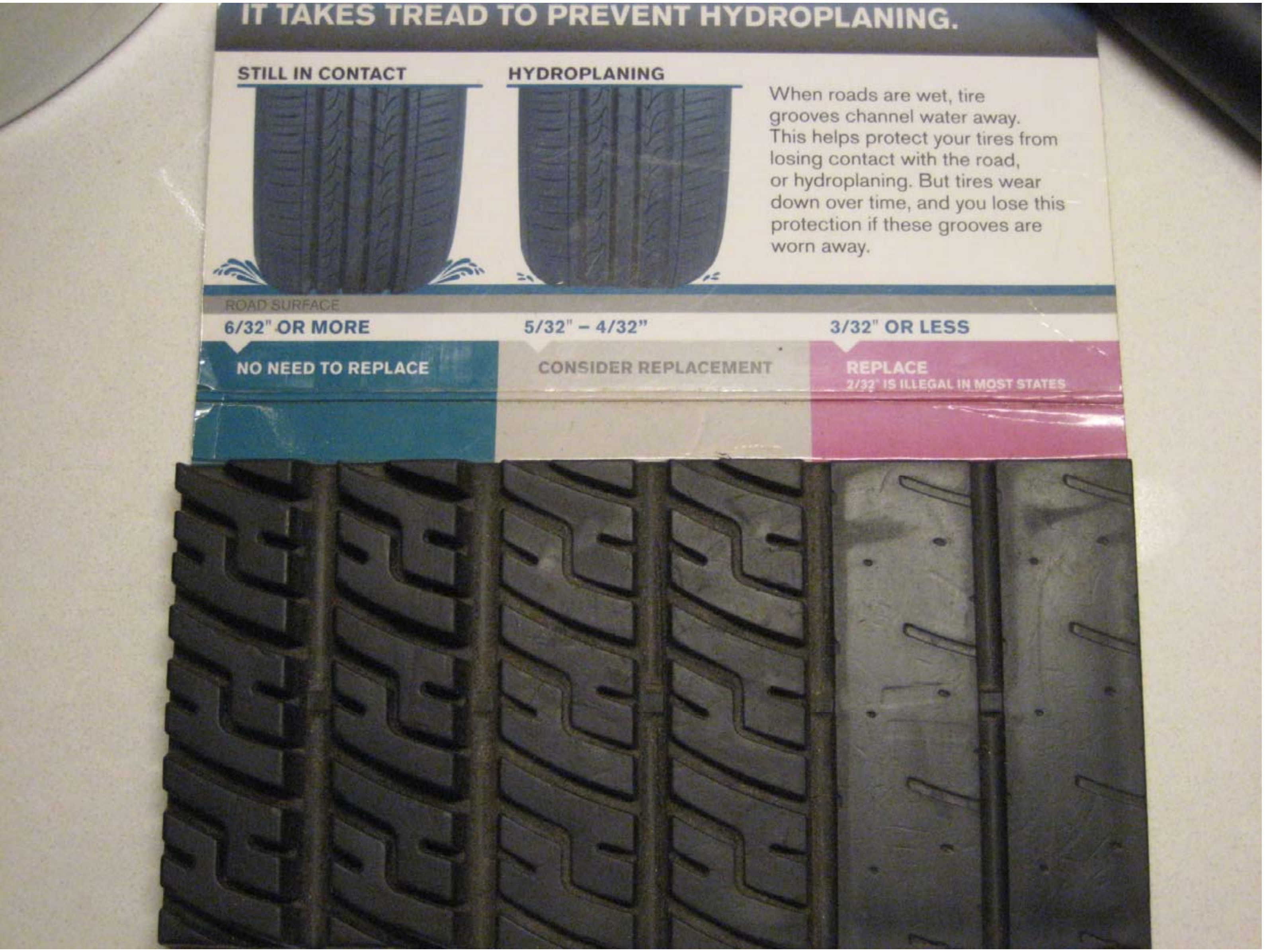


Advancing Transportation Through Innovation

LOOP Q

OLD and newer DGAC

Advancing
Transportation
Through Innovation



0.4 mm =
15.7 mil =
0.01575 inch

2/32 inch =
0.0625 inch =
62.5 mil =
1.6 mm

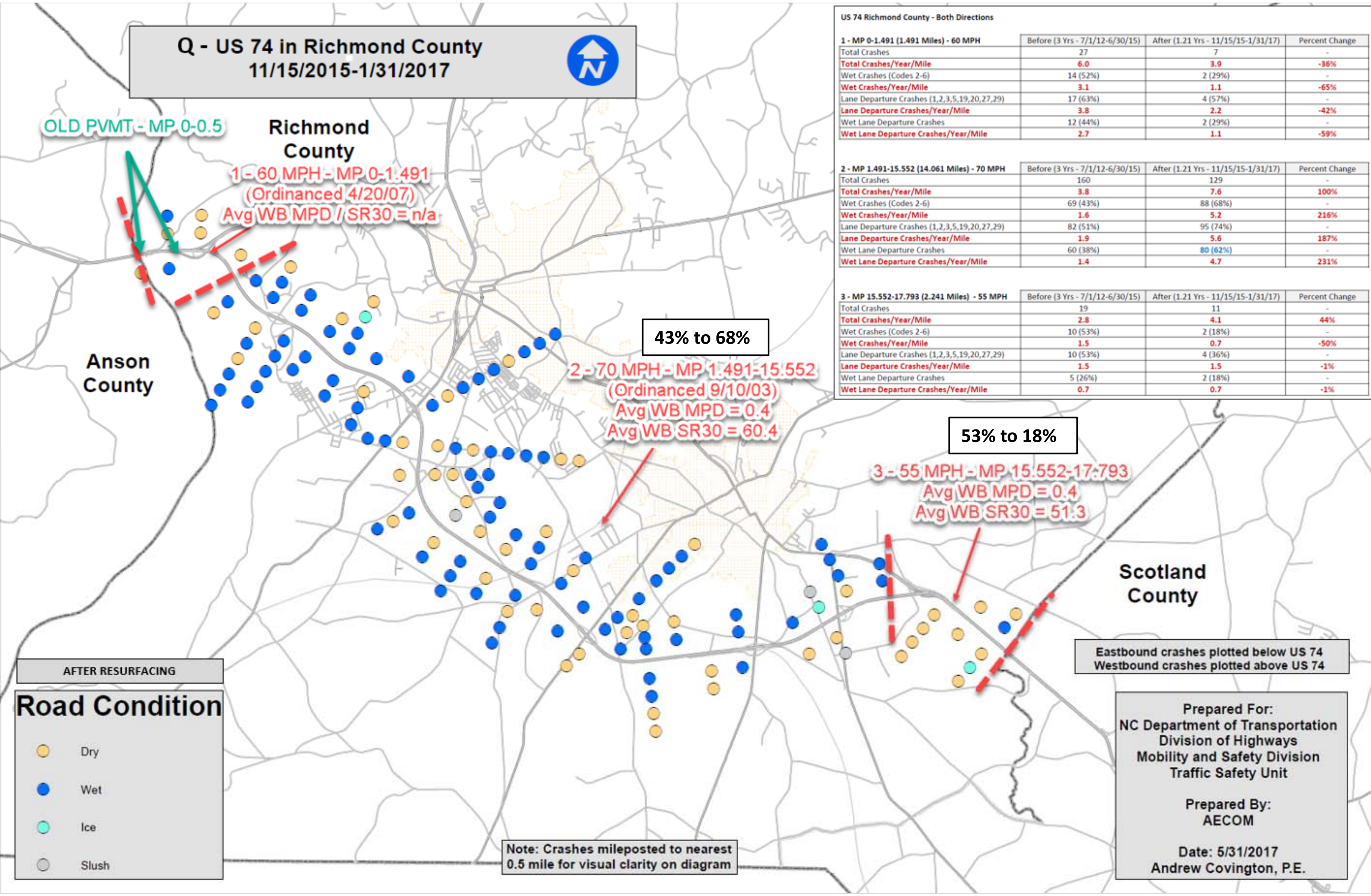
TRANSPORTATION INSTITUTE
VIRGINIA TECH.

NORTH CAROLINA
Department of Transportation

Research Project 2017-02

Preliminary Crash Data

Shawn A. Troy, PE

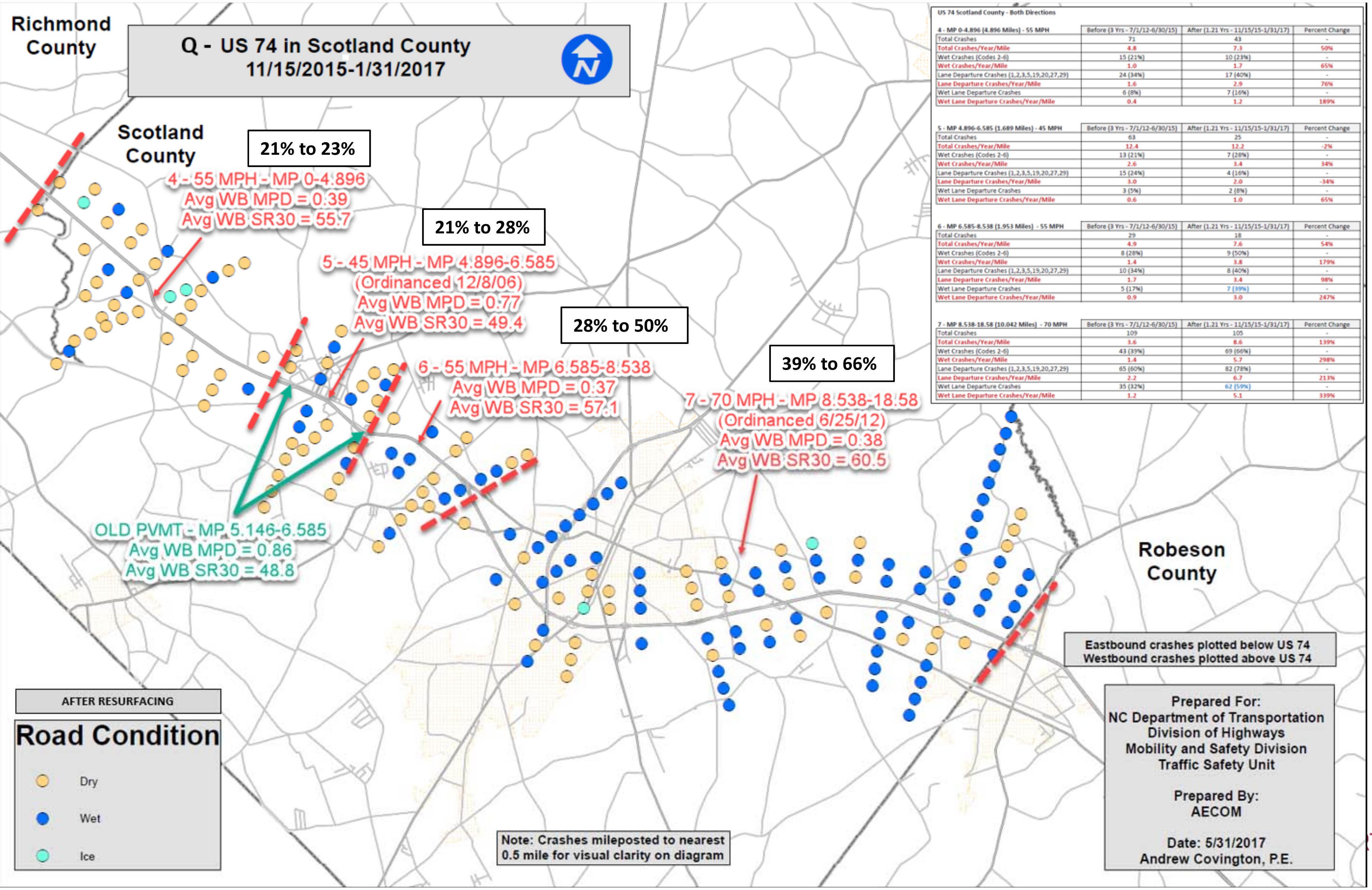


US 74 Richmond County - Both Directions

1 - MP 0-1.491 (1.491 Miles) - 60 MPH	Before (3 Yrs - 7/1/12-6/30/15)	After (1.21 Yrs - 11/15/15-1/31/17)	Percent Change
Total Crashes	27	7	-
Total Crashes/Year/Mile	6.0	3.9	-36%
Wet Crashes (Codes 2-6)	14 (52%)	2 (29%)	-
Wet Crashes/Year/Mile	3.1	1.1	-65%
Lane Departure Crashes (1,2,3,5,19,20,27,29)	17 (63%)	4 (57%)	-
Lane Departure Crashes/Year/Mile	3.8	2.2	-42%
Wet Lane Departure Crashes	12 (44%)	2 (29%)	-
Wet Lane Departure Crashes/Year/Mile	2.7	1.1	-59%

2 - MP 1.491-15.552 (14.061 Miles) - 70 MPH	Before (3 Yrs - 7/1/12-6/30/15)	After (1.21 Yrs - 11/15/15-1/31/17)	Percent Change
Total Crashes	160	129	-
Total Crashes/Year/Mile	3.8	7.6	100%
Wet Crashes (Codes 2-6)	69 (43%)	88 (68%)	-
Wet Crashes/Year/Mile	1.6	5.2	216%
Lane Departure Crashes (1,2,3,5,19,20,27,29)	82 (51%)	95 (74%)	-
Lane Departure Crashes/Year/Mile	1.9	5.6	187%
Wet Lane Departure Crashes	60 (38%)	80 (62%)	-
Wet Lane Departure Crashes/Year/Mile	1.4	4.7	231%

3 - MP 15.552-17.793 (2.241 Miles) - 55 MPH	Before (3 Yrs - 7/1/12-6/30/15)	After (1.21 Yrs - 11/15/15-1/31/17)	Percent Change
Total Crashes	19	11	-
Total Crashes/Year/Mile	2.8	4.1	44%
Wet Crashes (Codes 2-6)	10 (53%)	2 (18%)	-
Wet Crashes/Year/Mile	1.5	0.7	-50%
Lane Departure Crashes (1,2,3,5,19,20,27,29)	10 (53%)	4 (36%)	-
Lane Departure Crashes/Year/Mile	1.5	1.5	-1%
Wet Lane Departure Crashes	5 (26%)	2 (18%)	-
Wet Lane Departure Crashes/Year/Mile	0.7	0.7	-1%



US 74 Scotland County - Both Directions

4 - MP 0-4.896 (4.896 Miles) - 55 MPH	Before (3 Yrs - 7/1/12-6/30/15)	After (1.21 Yrs - 11/15/15-1/31/17)	Percent Change
Total Crashes	71	43	-
Total Crashes/Year/Mile	4.8	7.3	50%
Wet Crashes (Codes 2-6)	15 (21%)	10 (23%)	-
Wet Crashes/Year/Mile	1.0	1.7	65%
Lane Departure Crashes (1,2,3,5,19,20,27,29)	24 (34%)	17 (40%)	-
Lane Departure Crashes/Year/Mile	1.6	2.9	76%
Wet Lane Departure Crashes	6 (8%)	7 (16%)	-
Wet Lane Departure Crashes/Year/Mile	0.4	1.2	189%

5 - MP 4.896-6.585 (1.689 Miles) - 45 MPH	Before (3 Yrs - 7/1/12-6/30/15)	After (1.21 Yrs - 11/15/15-1/31/17)	Percent Change
Total Crashes	63	25	-
Total Crashes/Year/Mile	12.4	12.2	-2%
Wet Crashes (Codes 2-6)	13 (21%)	7 (28%)	-
Wet Crashes/Year/Mile	2.6	3.4	34%
Lane Departure Crashes (1,2,3,5,19,20,27,29)	15 (24%)	4 (16%)	-
Lane Departure Crashes/Year/Mile	3.0	2.0	-34%
Wet Lane Departure Crashes	3 (5%)	2 (8%)	-
Wet Lane Departure Crashes/Year/Mile	0.6	1.0	65%

6 - MP 6.585-8.538 (1.953 Miles) - 55 MPH	Before (3 Yrs - 7/1/12-6/30/15)	After (1.21 Yrs - 11/15/15-1/31/17)	Percent Change
Total Crashes	29	18	-
Total Crashes/Year/Mile	4.9	7.6	54%
Wet Crashes (Codes 2-6)	8 (28%)	9 (50%)	-
Wet Crashes/Year/Mile	1.4	3.8	179%
Lane Departure Crashes (1,2,3,5,19,20,27,29)	10 (34%)	8 (40%)	-
Lane Departure Crashes/Year/Mile	1.7	3.4	98%
Wet Lane Departure Crashes	5 (17%)	7 (39%)	-
Wet Lane Departure Crashes/Year/Mile	0.9	3.0	247%

7 - MP 8.538-18.58 (10.042 Miles) - 70 MPH	Before (3 Yrs - 7/1/12-6/30/15)	After (1.21 Yrs - 11/15/15-1/31/17)	Percent Change
Total Crashes	109	105	-
Total Crashes/Year/Mile	3.6	8.6	139%
Wet Crashes (Codes 2-6)	43 (39%)	69 (66%)	-
Wet Crashes/Year/Mile	1.4	5.7	298%
Lane Departure Crashes (1,2,3,5,19,20,27,29)	65 (60%)	82 (78%)	-
Lane Departure Crashes/Year/Mile	2.2	6.7	213%
Wet Lane Departure Crashes	35 (32%)	62 (59%)	-
Wet Lane Departure Crashes/Year/Mile	1.2	5.1	339%

Center for Sustainable Transportation Infrastructure

Advancing Transportation Through Innovation

Route Summary

- **Section 3, 4, and 6 – 55 MPH**
  - **9.09 Miles** (years before – 3.00, years after – 1.21) ADT = 15,000-18,000
  - **Total Crashes** before = 119 after = 72
  - **Wet Crashes** before = 33 *(28%)* after = 21 *(29%)*
  - **Wet/Year/Mile** before = 1.21 after = 1.91 *(58% +)*
  - **S9.5C (2015)** SR 30 = 51.3-57.1 MPD = 0.37-0.40

Route Summary

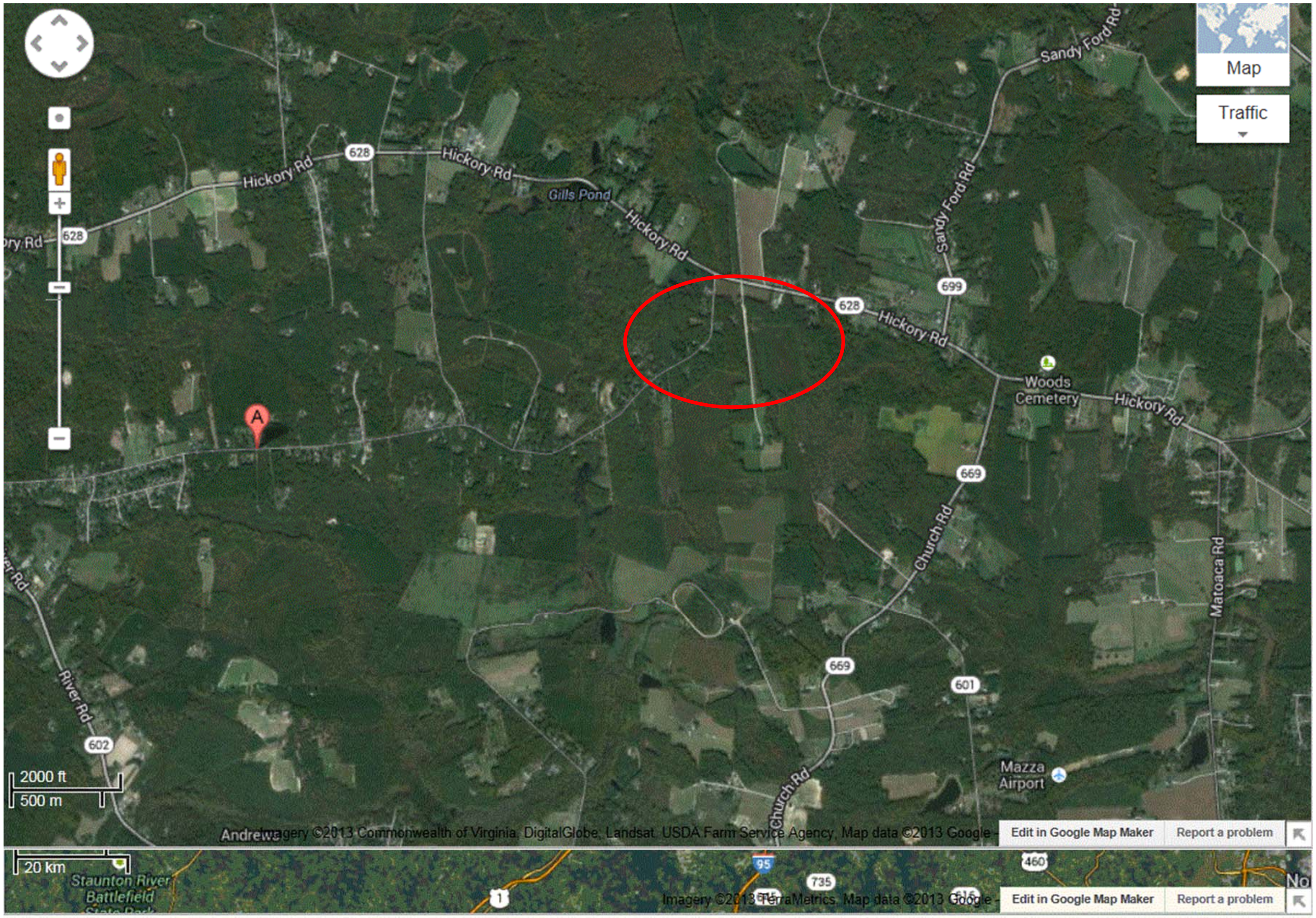
- **Section 3, 4, and 6 – 55 MPH**
  - **9.09 Miles** (years before – 3.00, years after – 1.21) ADT = 15,000-18,000
  - **Total Crashes** before = 119 after = 72
  - **Wet Crashes** before = 33 *(28%)* after = 21 *(29%)*
  - **Wet/Year/Mile** before = 1.21 after = 1.91 *(58% +)*
  - **S9.5C (2015)** SR 30 = 51.3-57.1 MPD = 0.37-0.40

- **Section 2 and 7 – 70 MPH**
  - **24.10 Miles** (years before – 3.00, years after – 1.21) ADT = 15,000-18,000
  - **Total Crashes** before = 269 after = 234
  - **Wet Crashes** before = 112 *(42%)* after = 157 *(67%)*
  - **Wet/Year/Mile** before = 1.55 after = 5.38 *(248% +)*
  - **S9.5C (2015)** SR 30 = 60.4-60.5 MPD = 0.38-0.40

6. CASE 3 – HFST Location

- ✓HFST friction measurement after installation
- ✓CFME (Grip Tester)

Center for Sustainable Transportation Infrastructure

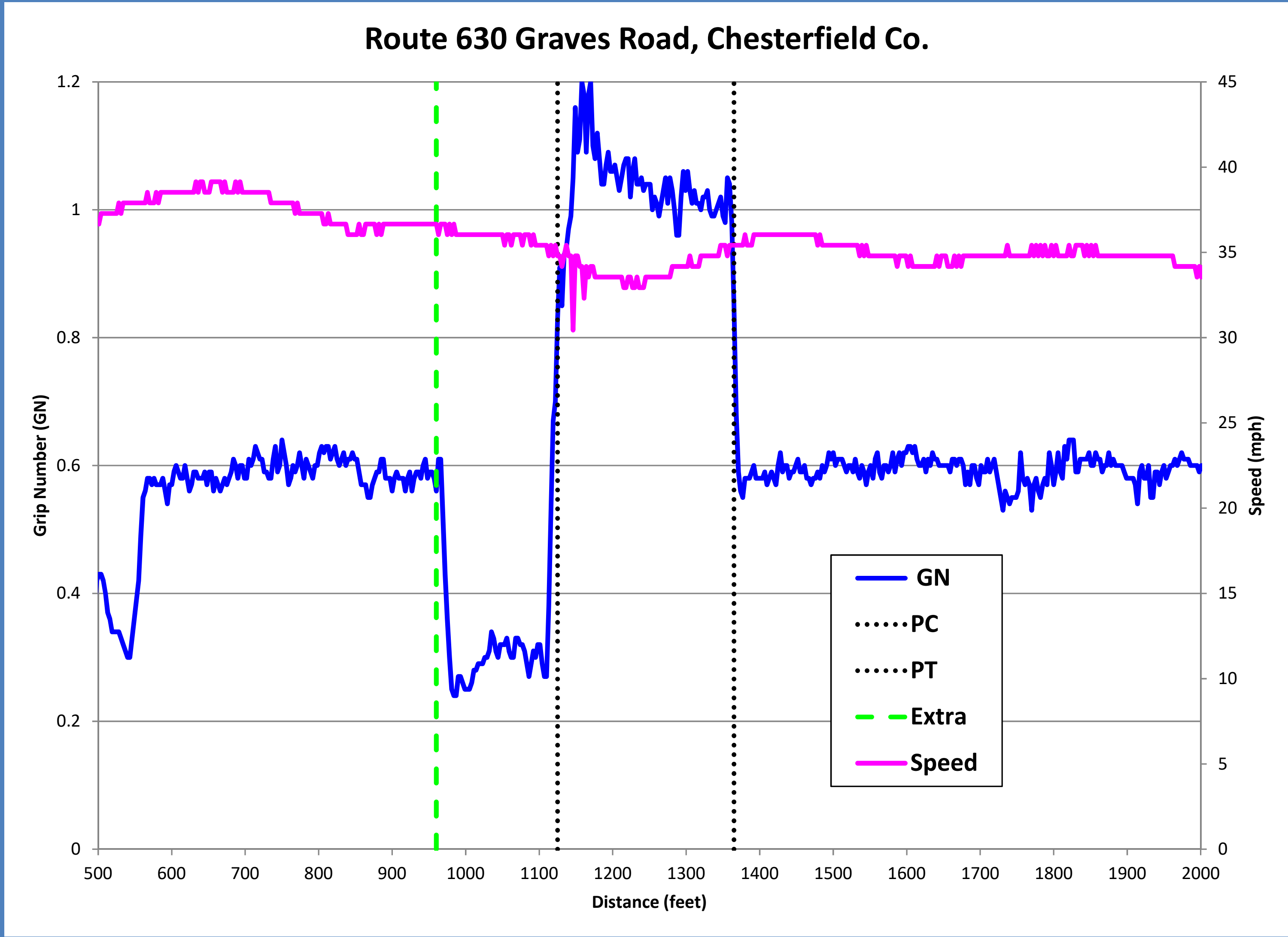


Advancing Transportation Through Innovation

Center for
Sustainable
Transportation
Infrastructure

Advancing
Transportation
Through Innovation

Center for Sustainable Transportation Infrastructure



Advancing Transportation Through Innovation

Center for Sustainable Transportation Infrastructure

7. Friction Demand

– *"Because the intensity of the polishing process increases markedly with tread element slip, all other factors being equal, the lowest friction levels are found on high-speed roads, curves, and approaches to intersections; in short, in locations at which high friction values are needed most."*

– **NCHRP Report 37, 1967**

Advancing Transportation Through Innovation

VT TRANSPORTATION INSTITUTE VIRGINIA TECH.

7. Friction Demand

Do we need the same friction everywhere?

1. **Virginia Minimum friction (SN 40S = 20)**
2. **Minnesota**
   - **Interstate: 28-41**
   - **Primary: 25-37**
   - **Secondary: 22-37**

*Perera et. al. Skid Crash Reduction Programs – Synthesis (MN SN 40R):

TRANSPORTATION INSTITUTE
VIRGINIA TECH.

Advancing
Transportation
Through Innovation

TRANSPORTATION INSTITUTE
VIRGINIA TECH.

TRANSPORTATION INSTITUTE
VIRGINIA TECH.

TRANSPORTATION INSTITUTE
VIRGINIA TECH.

TRANSPORTATION INSTITUTE
VIRGINIA TECH.

Center for Sustainable Transportation Infrastructure

Advancing Transportation Through Innovation

TATION INSTITUTE

Center for Sustainable Transportation Infrastructure

Friction Demand Categories

Site Category and definition **CS 228**

Investigatory Level: 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65

1. NONEVENTS

1. **Interstate Nonevents**
2. **Divided Primary Nonevents**
3. **Undivided Primary Nonevents**

Lower Crash Risk
= Less Friction Demand
= Lower Threshold

2. EVENTS

- Q — Approaches to and across minor and major junctions, approaches to roundabouts and traffic signals (see note 5)
- 4 **Controlled Intersections and Ramps** — K — situations (see note 5)
- 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.** — S2 — (see note 7)

Higher Crash Risk
= More Friction Demand
= Higher Threshold

Advancing Transportation Through Innovation

*__CS 228__ = Highways England (2019), "**Design Manual for Roads and Bridges, Pavement Inspection & Assessment, *Skidding Resistance***"

Center for Sustainable Transportation Infrastructure

Friction Demand Categories

CS 228

Road classification definitions		Investigatory level 30 mph							
		0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65
A	Interstate highways								
B	Divided highways-no event								
C	Two lane road-no event								
Q	Approaches to Intersection (& roundabouts)								
K	Pedestrian crossings and other high risk areas								
R	Roundabout								
G1	Slope 5-10%, longer than 160 feet								
G2	Slope >10% longer than 160 feet								
S1	Curve radius < 1600 feet - divided roads								
S2	Curve radius < 1600 feet - two lane roads								

Site category	Site description	IL	Minimum PSV required for given IL, traffic level and type of site									
			Traffic (cv/lane/day) at design life									
			0-250	251-500	501-750	751-1000	1001-2000	2001-3000	3001-4000	4001-5000	5001-6000	Over 6000
A1	Motorways where traffic is generally free-flowing on a relatively straight line	0.30	50	50	50	50	50	55	55	60	65	65
		0.35	50	50	50	50	50	60	60	60	65	65
A2	Motorways where some braking regularly occurs (eg. on 300m approach to an off-slip)	0.35	50	50	50	55	55	60	60	65	65	65
B1	Dual carriageways where traffic is generally free-flowing on a relatively straight line	0.3	50	50	50	50	50	55	55	60	65	65
		0.35	50	50	50	50	50	60	60	60	65	65
		0.4	50	50	50	55	60	65	65	65	65	68+
B2	Dual carriageways where some braking regularly occurs (eg. on 300m approach to an off-slip)	0.35	50	50	50	55	55	60	60	65	65	65
		0.4	55	60	60	65	65	68+	68+	68+	68+	68+
C	Single carriageways where traffic is generally free-flowing on a relatively straight line	0.35	50	50	50	55	55	60	60	65	65	65
		0.4	55	60	60	65	65	68+	68+	68+	68+	68+
		0.45	60	60	65	65	68+	68+	68+	68+	68+	68+
G1/G2	Gradients >5% longer than 50m as per HD 28	0.45	55	60	60	65	65	68+	68+	68+	68+	HFS
		0.5	60	68+	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS
		0.55	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS
K	Approaches to pedestrian crossings and other high risk situations	0.5	65	65	65	68+	68+	68+	HFS	HFS	HFS	HFS
		0.55	68+	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS
Q	Approaches to major and minor junctions on dual carriageways and single carriageways where frequent or sudden braking occurs but in a generally straight line.	0.45	60	65	65	68+	68+	68+	68+	68+	68+	HFS
		0.5	65	65	65	68+	68+	68+	HFS	HFS	HFS	HFS
		0.55	68+	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS
R	Roundabout circulation areas	0.45	50	55	60	60	65	65	68+	68+	HFS	HFS
		0.5	68+	68+	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS
S1/S2	Bends (radius <500m) on all types of road, including motorway link roads; other hazards that require combined braking and cornering	0.45	50	55	60	60	65	65	68+	68+	HFS	HFS
		0.5	68+	68+	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS
		0.55	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS

Advancing Transportation Through Innovation

VTTI | TRANSPORTATION INSTITUTE

*CS 228 = Highways England (2019), "**Design Manual for Roads and Bridges, Pavement Inspection & Assessment, *Skidding Resistance***"

Center for Sustainable Transportation Infrastructure

Site category	Site description	IL	Minimum PSV required for given IL, traffic level and type of site									
			Traffic (cv/lane/day) at design life									
			0-250	251-500	501-750	751-1000	1001-2000	2001-3000	3001-4000	4001-5000	5001-6000	Over 6000
A1	Motorways where traffic is generally free-flowing on a relatively straight line	0.30	50	50	50	50	50	55	55	60	65	65
		0.35	50	50	50	50	50	60	60	60	65	65
A2	Motorways where some braking regularly occurs (eg. on 300m approach to an off-slip)	0.35	50	50	50	55	55	60	60	65	65	65
B1	Dual carriageways where traffic is generally free-flowing on a relatively straight line	0.3	50	50	50	50	50	55	55	60	65	65
		0.35	50	50	50	50	50	60	60	60	65	65
		0.4	50	50	50	55	60	65	65	65	65	68+
B2	Dual carriageways where some braking regularly occurs (eg. on 300m approach to an off-slip)	0.35	50	50	50	55	55	60	60	65	65	65
		0.4	55	60	60	65	65	68+	68+	68+	68+	68+
C	Single carriageways where traffic is generally free-flowing on a relatively straight line	0.35	50	50	50	55	55	60	60	65	65	65
		0.4	55	60	60	65	65	68+	68+	68+	68+	68+
		0.45	60	60	65	65	68+	68+	68+	68+	68+	68+
G1/G2	Gradients >5% longer than 50m as per HD 28	0.45	55	60	60	65	65	68+	68+	68+	68+	HFS
		0.5	60	68+	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS
		0.55	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS
K	Approaches to pedestrian crossings and other high risk situations	0.5	65	65	65	68+	68+	68+	HFS	HFS	HFS	HFS
		0.55	68+	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS
Q	Approaches to major and minor junctions on dual carriageways and single carriageways where frequent or sudden braking occurs but in a generally straight line.	0.45	60	65	65	68+	68+	68+	68+	68+	68+	HFS
		0.5	65	65	65	68+	68+	68+	HFS	HFS	HFS	HFS
		0.55	68+	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS
R	Roundabout circulation areas	0.45	50	55	60	60	65	65	68+	68+	HFS	HFS
		0.5	68+	68+	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS
S1/S2	Bends (radius <500m) on all types of road, including motorway link roads; other hazards that require combined braking and cornering	0.45	50	55	60	60	65	65	68+	68+	HFS	HFS
		0.5	68+	68+	68+	HFS	HFS	HFS	HFS	HFS	HFS	HFS
		0.55	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS	HFS

Advancing Transportation Through Innovation

Friction Demand Categories NZTA

Table 1 Skid resistance investigatory levels

Site category	Skid site description	Investigatory level (IL), units ESC					
		0.35	0.40	0.45	0.50	0.55	0.60
1	Approaches to: a) Railway level crossings b) Traffic signals c) Pedestrian crossings d) Stop and Give Way controlled intersections (where state highway traffic is required to stop or give way) e) Roundabouts. One lane bridges: a) Approaches and bridge deck.						
2	a) Urban curves <250m radius						
	b) Rural curves <250m radius			L	M	H	
	c) Rural curves 250-400m radius		L	L	M	H	
	a) Down gradients >10%. b) On ramps with ramp metering.						
3	a) State highway approach to a local road junction. b) Down gradients 5-10% c) Motorway junction area including on/off Ramps d) Roundabouts, circular section only.						
4	Undivided carriageways (event-free).						
5	Divided carriageways (event-free).						

(From NZTA T10, 2010)

TRANSPORTATION INSTITUTE
VIRGINIA TECH.

Determining Friction Thresholds

Type of Roadway	Method 3 SR30 Investigatory Level
Divided	30-35
Undivided	50-55
Curves	50-55
Intersections	55-60

Initial Texture Depth for Trunk Roads/Motorways

Road type	Surfacing type	Average / 1,000 m	Average / 10 measures
High Speed roads >50 mph	Thin surface overlay Aggregate size<14mm	MPD 1.4 mm	MPD 1.0 mm
	Surface treatments	MPD 1.6 mm	MPD 1.25 mm
Lower Speed roads <40 mph	Thin surface overlay Aggregate size<14mm	MPD 1.4 mm	MPD 0.9 mm
	Surface treatments	MPD 1.25 mm	MPD 1.0 mm
Roundabout, high speed >50 mph	All surfaces	MPD 1.25 mm	MPD 1.0 mm
Roundabout, low speed <40 mph	All surfaces	MPD 1.0 mm	MPD 0.9 mm

(From British Standard EN 13036-1)

Center for Sustainable Transportation Infrastructure

Texture Demand Categories NZTA

Table 3 Minimum macrotexture requirements

Minimum macrotexture – mean profile depth (MPD mm)						
Permanent speed limit	Chipseal		Asphaltic concrete, ESC ≥ 0.4		Asphaltic concrete, ESC < 0.4	
	ILM	TLM	ILM	TLM	ILM	TLM
50km/h and less	1.0	0.7	0.4	0.3	0.5	0.5
Less than or equal to 70km/h but >50km/h	1.0	0.7	0.4	0.3	0.7	0.5
Greater than 70km/h	1.0	0.7	0.9	0.7	0.9	0.7

(From NZTA T10, 2010)

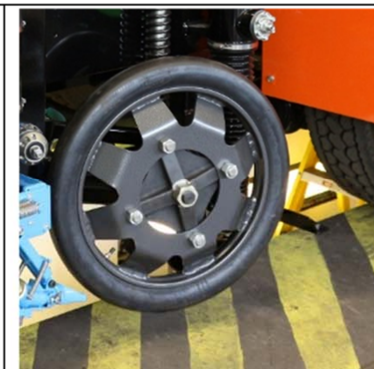
8. Pavement Friction Management

(a) Grip Tester

(b) SCRIM

(c) LWST

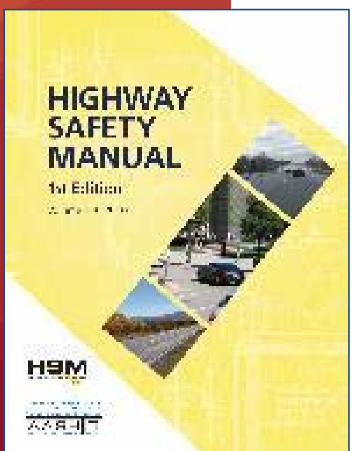
(d) GT tires



(e) SCRIM tire

Center for Sustainable Transportation Infrastructure

8. Pavement Friction Management



Safety Performance Functions

$$SPF_i = e^{\beta_0 + \sum_j (\beta_j X_{ij}) + \varepsilon}$$

***SPF_i* = crash rate for the i^{th} segment of roadway**

***X_{ij}* = value of variable j at the i^{th} road segment (friction, macrotexture, curvature, grade, intersection, etc.)**

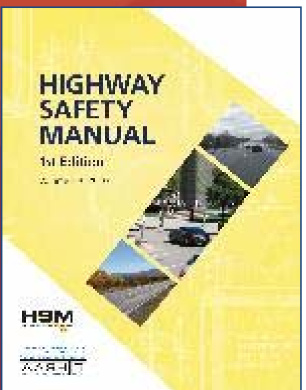
***β_j* = estimated parameter coefficient for the j^{th} variable (where: $j > 0$)**

***ε* = Gamma distributed error**

Model Variables	Coefficient
ln(AADT)	1.201
Divided	-2.685
Intersection	-0.118
Pavement Type	-0.600
SR	-0.046
Gradient	0.032
H. Curvature	0.061
SR*Intersection	0.011
SR*Divided	0.039
SR*Pave Type	0.014
Route ID	-
RTE 3	-0.274
RTE 4	0.336
RTE 5 A	-0.119
RTE 5 B	0.723
RTE 8	-0.025
RTE 12	-0.139
RTE 82	-0.368
RTE 101	0.525
RTE 395	-0.112
RTE 405	0.877

Advancing Transportation Through Innovation

8. Pavement Friction Management



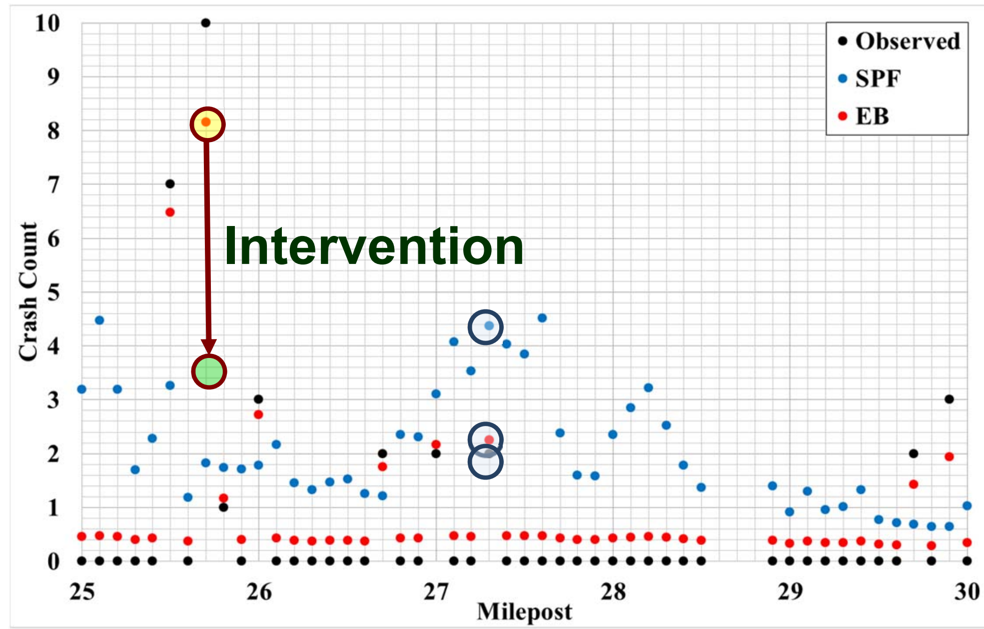
Empirical Bayes Estimation

Overdispersion

$$W_i = \frac{1}{1 + SPF_i \times \alpha}$$

Crashes

$$EB_i = W_i \times SPF_i + (1 - W_i)y_i$$



Allows to estimate B/C

Benefits crash reduction / Costs of the intervention

8. Pavement Friction Management

✓Cost/ Benefit Analysis

– Asphalt pavement only
  - Estimate the potential savings from applying the treatment.

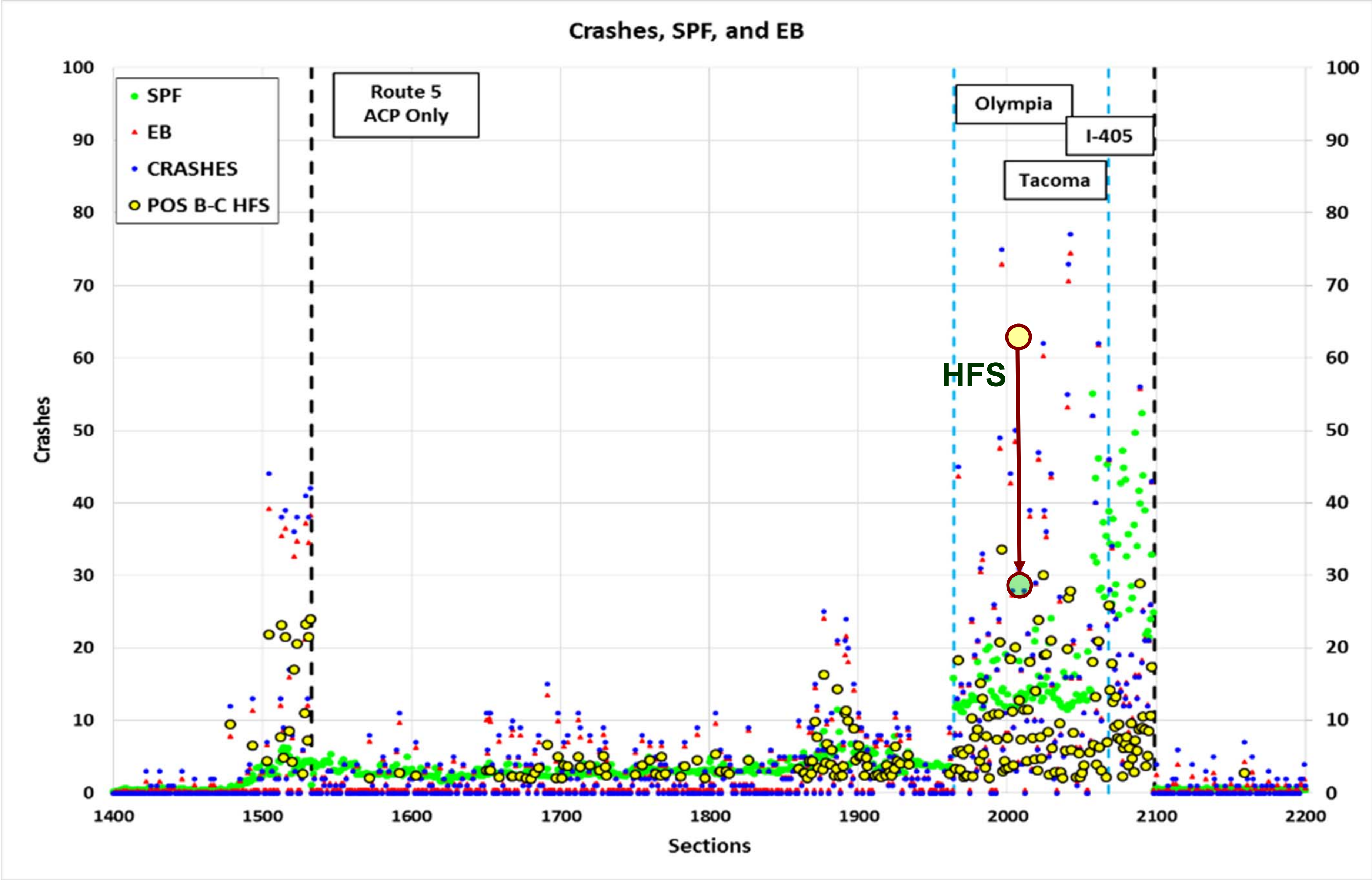
– Average crash cost = $109,271

– Two treatments:
  - HMA Overlay: Improve to SR = 65, Cost/Lane = $7,040
  - HFST: Improve to SR = 85, Cost/Lane = $19,008

– Accident reduction

$$EB_{HMA-OL,i} = \frac{\lambda_{HMA-0L,i}}{\lambda_i} \times EB_i \qquad EB_{HFS,i} = \frac{\lambda_{HFS,i}}{\lambda_i} \times EB_i$$

Center for Sustainable Transportation Infrastructure



Advancing Transportation Through Innovation

Savings per Section >	Sections			Pred. crash reductions	Total Costs	Total Savings	B/C
	Total	OL	HFS				
$2.0 M	14	0	14	378	$1,767,744	$39,586,704	22
$1.5 M	18	0	18	446	$2,337984	$46,355,183	20
$1.0 M	30	2	28	595	$3,898,584	$61,136,139	16
$0.5 M	69	7	62	894	$8,536,932	$89,106,970	10
ALL	227	102	125	1,172	$18,438,264	$109,584,039	6

Savings per Sections >	Sections			Pred. crash reductions	Total Costs	Total Savings	B/C
	Total	CDG	HFS				
$5.0 M	22	7	15	1,448	$3,885,248	$154,381,371	40
$3.0 M	67	34	33	3,126	$11,323,712	$330,248,321	29
$2.0 M	105	49	56	4,072	$17,948,608	$427,000,581	24
$1.0 M	201	104	97	5,505	$34,183,040	$567,345,342	17
$0.5 M	286	158	128	6,193	$48,335,680	$628,406,865	13
ALL	406	225	181	6,608	$67,343,808	$654,666,028	10

Center for Sustainable Transportation Infrastructure

Acknowledgements

- ✓Contributors: Kevin McGhee – Virginia Transportation Research Council & Andy Mergenmeier, FHWA
- ✓Research Team:
  - Gerardo Flintsch
  - Samer Katicha
  - Ross McCarthy
  - Edgar de León Izeppi

Advancing Transportation Through Innovation

VT | TRANSPORTATION INSTITUTE VIRGINIA TECH.

Center for
Sustainable
Transportation
Infrastructure

Questions?

Advancing
Transportation
Through Innovation