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TRANSPORTATION RESEARCH BOARD

1ST INTERNATIONAL ROADSIDE SAFETY CONFERENCE

SAFER ROADS, SAVING LIVES, SAVING MONEY

Sponsored by
TRB Standing Committee on Roadside Safety Design (AFB20)

Co-Sponsored by
Transportation Pooled Fund Program Project No. TPF-5(329), including US State Departments of Transportation for Kentucky, Minnesota, Nebraska, Ohio, Washington, and West Virginia

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As a courtesy to other attendees,
please observe good mobile manners.
Please mute or turn off cell phones.

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Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Dave Bergner, M.A., PWLF

Monte Vista Associates, LLC

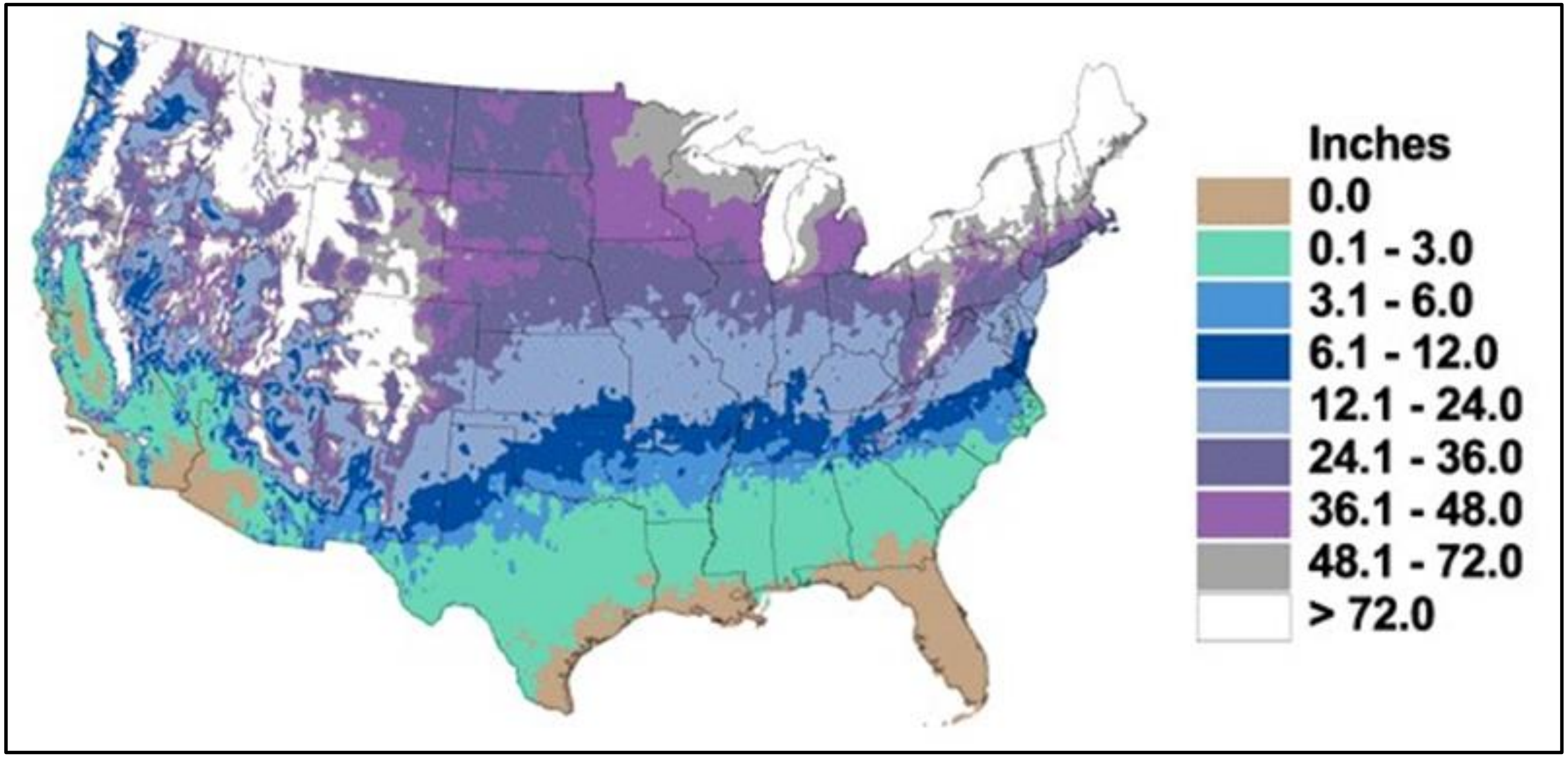
TRB First International Roadside Safety Conference

June 13, 2017

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

- Over 70% of U.S. roads in regions with more than 5” average snowfall annually.
- Nearly 70% of U.S. population lives in these regions.
- Over 1,300 people killed and more than 116,800 people injured in crashes on snowy, slushy or icy pavement annually.
- nearly 900 people killed and nearly 76,000 people injured in crashes *during* snowfall or sleet each year.
- Freeway speeds reduced 3 -13% in light snow; by 5 -40% in heavy snow.
- Average speeds on arterial roads decline by 30 to 40% on snowy or slushy pavement.

Advances in Winter Road Maintenance Practices to Improve Road Side Safety



Advances in Winter Road Maintenance Practices to Improve Road Side Safety

- About 24% of all vehicle collisions in U.S. are due to snowy or icy roadways.
- 15% *happen during* snow or sleet.
- Many of these crashes involve run-off roadway (ROR) vehicles that strike objects.
- Collisions with fixed objects and non-collisions account for 19% of all reported crashes in U.S., resulting in 44% of all fatal crashes (*National Highway Traffic Safety Administration*)

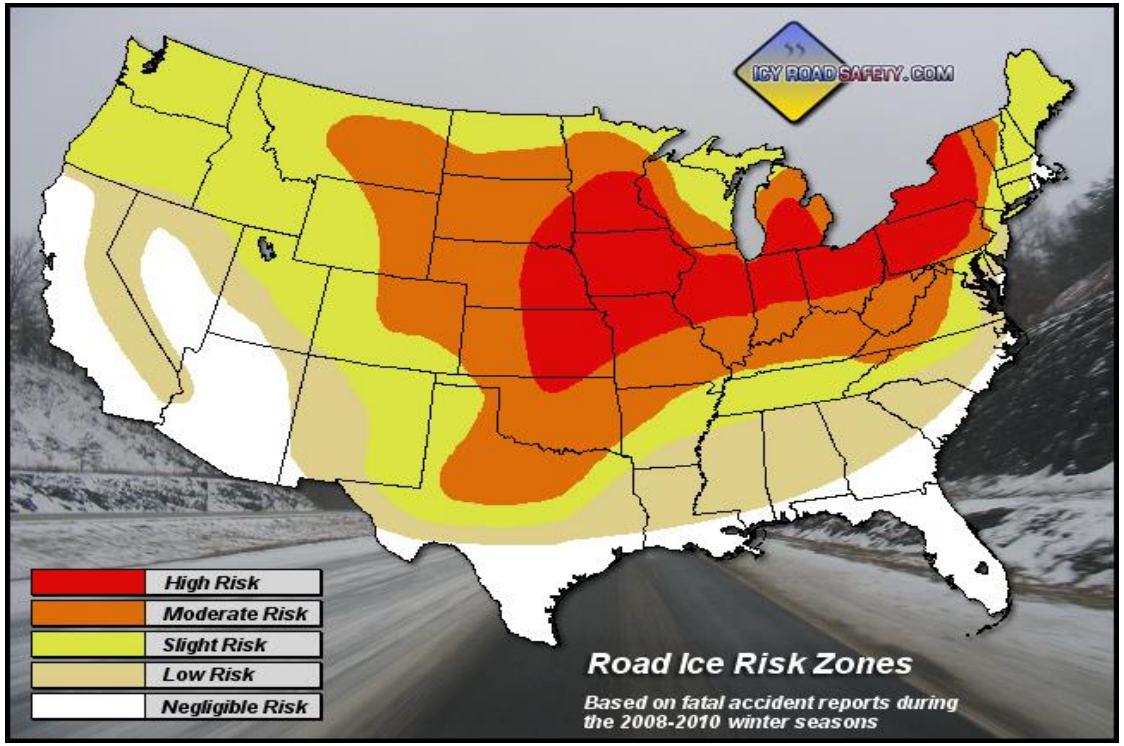
Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Correlation of winter road maintenance with ROR is difficult to determine:
“Although a large number of studies have attempted to draw conclusions about factors contributing to road departures, most rely on
crash data … a second hand and incomplete picture of the events leading to the crash.”

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Snow or ice *increases* the likelihood (of ROR events) *by seven times* that of dry conditions.

(NHTSA)



Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Goal of transportation agencies:

Restore safety and mobility effectively and efficiently within a reasonable time.

Winter maintenance has substantially evolved due to advancements in:

- weather forecasting and reporting,
- equipment,
- materials,
- science and art of plowing and material applications.

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Snow and ice control is 20% of state transportation agencies maintenance budgets.
Develop ways to improve efficiency and effectiveness while encountering:

- budget reductions,
- increased retirements,
- difficulty in recruiting and retaining new employees,
- aging infrastructure
- obsolete equipment,
- stricter environmental mandates,
- higher demands and expectations from the public.

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Snow and ice and control measures may adversely affect roadside safety:

- Plowing and abrasive materials destroy pavement markings.

- Snow cast by plows accumulates on warning signs.
- Plows knock down signs, signals and warning beacons.
- Snow plows wear down special friction surfaces.
- Abrasives on bare pavement can cause a loss of traction.
- Some liquid deicers can create slickness under certain conditions.
- Plowed snow hides roadside objects such as shorter posts, railings, hydrants, etc.
- Snow plowed against guardrails creates “ramps” that project vehicles up and over.
- Piled snow on the roadside melts and refreezes into unexpected icy patches on road.

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Research on equipment, plowing, materials, application methods conducted by:

- Transportation Research Board (TRB),
- American Association of State Highway and Transportation Officials (AASHTO),
- Pacific Northwest Snowfighters,
- Clear Roads Consortium,
- Aurora,
- FHWA,
- several state DOTs and universities

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Strategies and Tactics

- *Anti-icing*---apply liquid materials before storms to prevent bonding.
- *De-icing*---apply rock salt and/or liquid chemicals on snow/ ice.
- *Gritting* ---apply abrasives
- *Plowing*--- mechanical removal of snow and ice
- *Hauling*---remove accumulations of plowed snow
- *Snow fences*--- roadside structures reduce snow drifting.
- *Avalanche sheds*---structures cover mountain road.
- *Closures*---extreme measure.
- *Tire Chains*---mandatory in certain locations

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Anti-icing:

- not practical for all winter storms; certain conditions must be present.
- very effective, especially for preventing black ice.
- applied by sprayer trucks up to several days before a snow or ice event.
- Fixed Automated Spray systems (FAST) installed on bridges and overpasses.

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

- **De-icing**
  - materials work well at milder pavement and air temperatures.
  - less effective at colder temperatures and packed snow and ice.
- **Abrasives**
  - used with or without rock salt and liquids.
  - abrasives do not have any melting properties.
  - agencies reducing/eliminating sand due to environmental considerations.
  - traction improvement very short-lived.

- **Plowing**
  - size, shape and composition of plows and blades increases capability.
  - mitigates ROR by quickly improving pavement condition.

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Snow Fencing

Chain Restrictions

Road Closure

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Levels of Service Adjustments

- transportation agencies may have to adjust LOS to balance limited resources with maintaining safety and mobility.
- reduced plowing and treatment may increase potential for ROR:
  - 17% of weather -related crashes occur during snow sleet,
  - 13% occur on icy pavement and,
  - 14% take place on snowy or slushy pavement.

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

ROUTES

- lane-miles/kilometers, cycle-times, traffic patterns, distance from maintenance facilities, application rates, and quantities, types and capacities of equipment major factors in determining the routes.
- higher priority routes have shorter cycle-times.
- the faster a truck can complete its route, the better the road conditions.

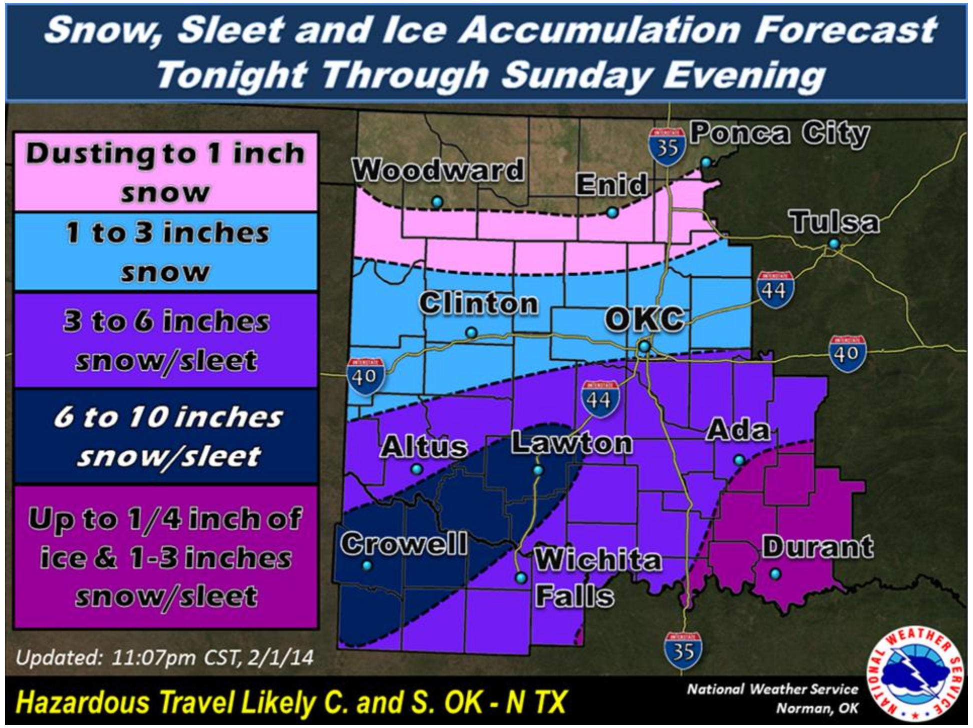
- few have been reconfigured based on optimizing for highest efficiency

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

- Identify "trouble spots" such as steep grades, curves, elevated structures, open areas susceptible to snow drifting or melt/ refreeze.
- Pre-season "dry-runs" familiarize the plow operators with those locations.
- Supervisors determine treatments for these chronic hazardous locations.

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Transportation agencies use both public and private weather services to plan, prepare and conduct winter road operations. Accuracy and reliability rapidly improving .



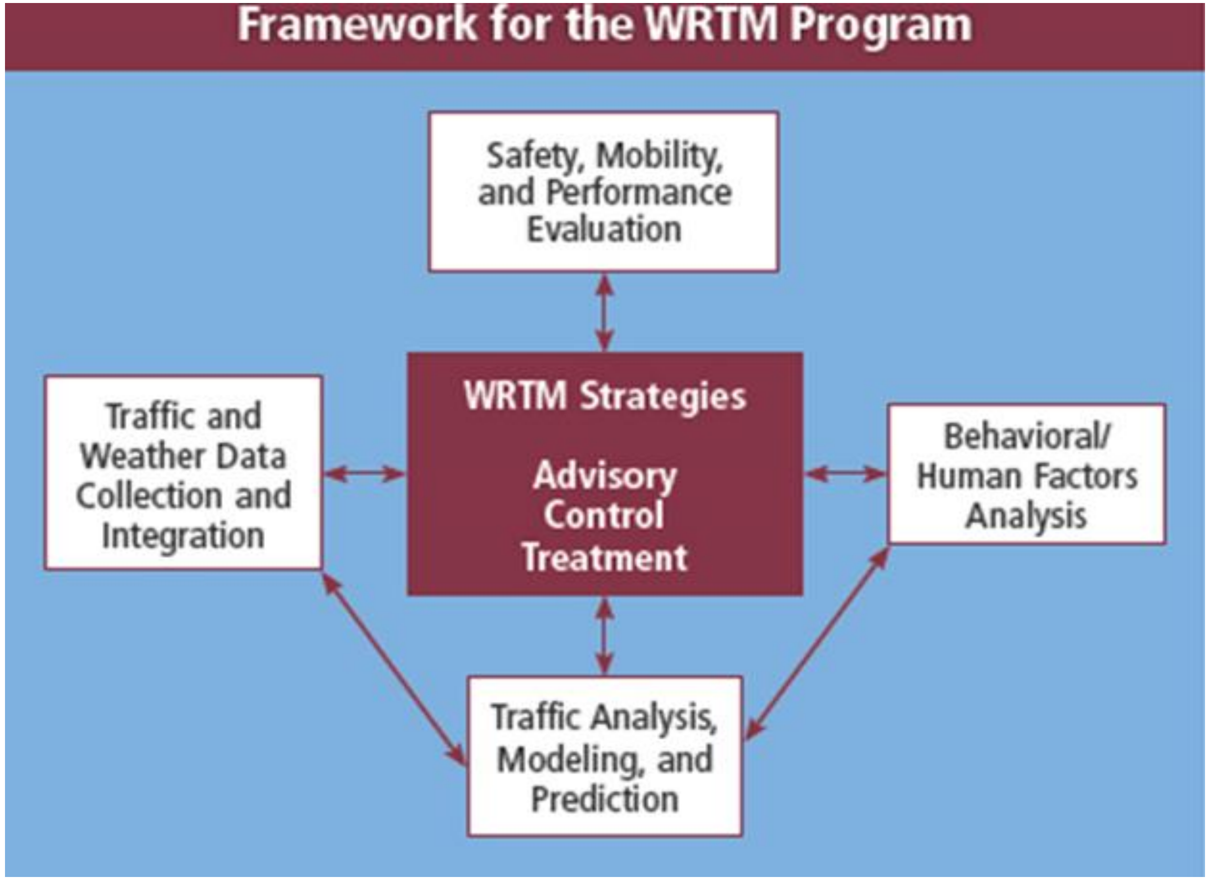
Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Road Weather Information Systems (RWIS) provide real-time data:

- air temperature,
- amount and type of precipitation,
- visibility,
- dew point,
- relative humidity,
- wind speed and direction,
- pavement temperature,
- subsurface temperature,
- surface condition (dry, wet, frozen),
- pavement salinity and freezing point of the road surface.

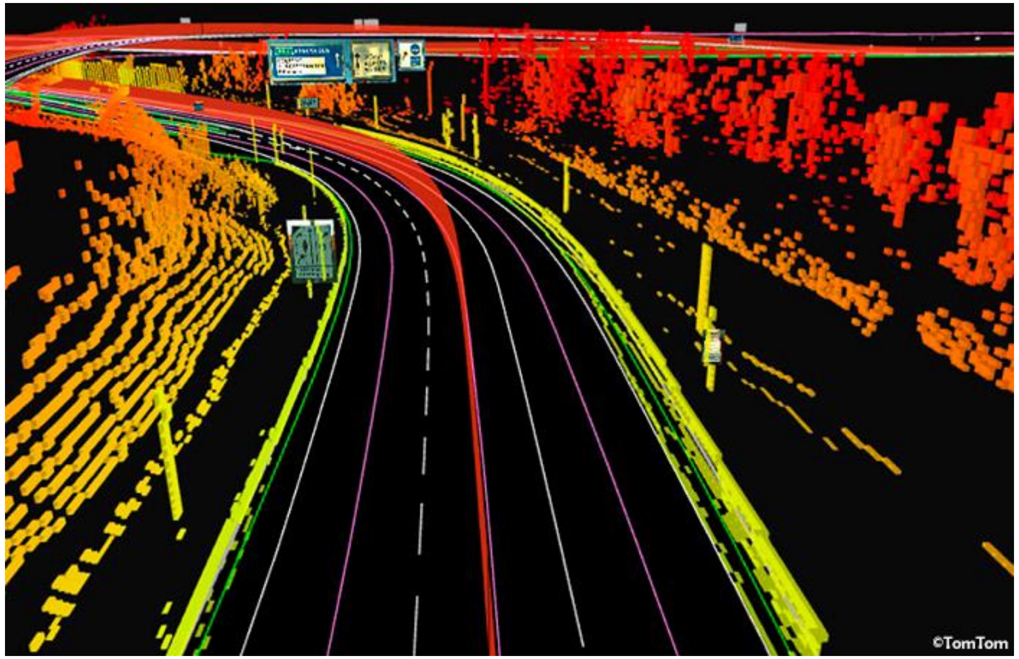
Advances in Winter Road Maintenance Practices to Improve Road Side Safety

FHWA's Road Weather Management Program is developing and implementing weather responsive traffic management (WRTM) solutions to improve traffic flow and operations during inclement weather. It uses existing ITS to make connected vehicles into mobile weather stations.



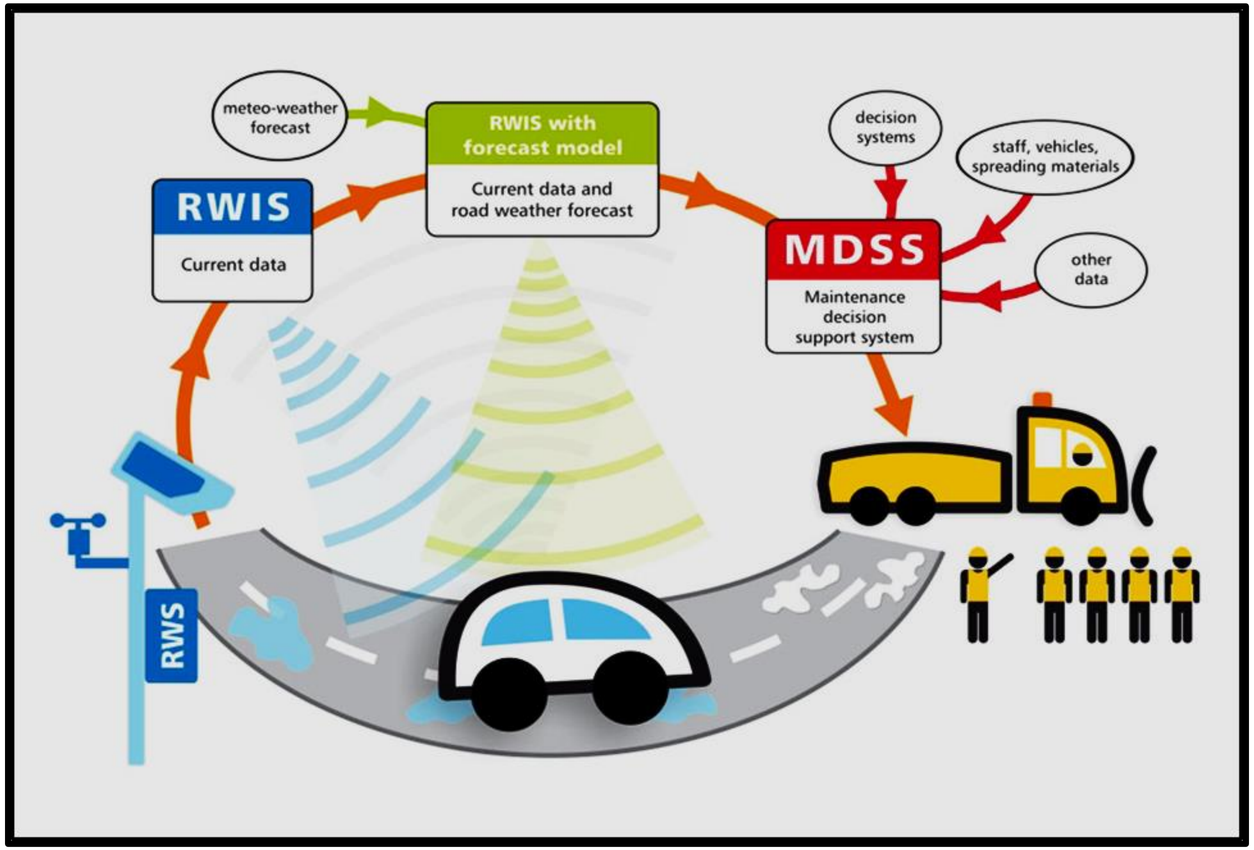
Advances in Winter Road Maintenance Practices to Improve Road Side Safety

- Automated vehicles "read the road" by identifying presence, proximity and type of markings, signs, signals, posts, poles, guardrails and barriers.



Advances in Winter Road Maintenance Practices to Improve Road Side Safety

- Connective vehicle (CV) technologies and mobile networks help deliver faster, more accurate traffic risk and incident information to drivers, traffic management centers and highway maintenance depots.



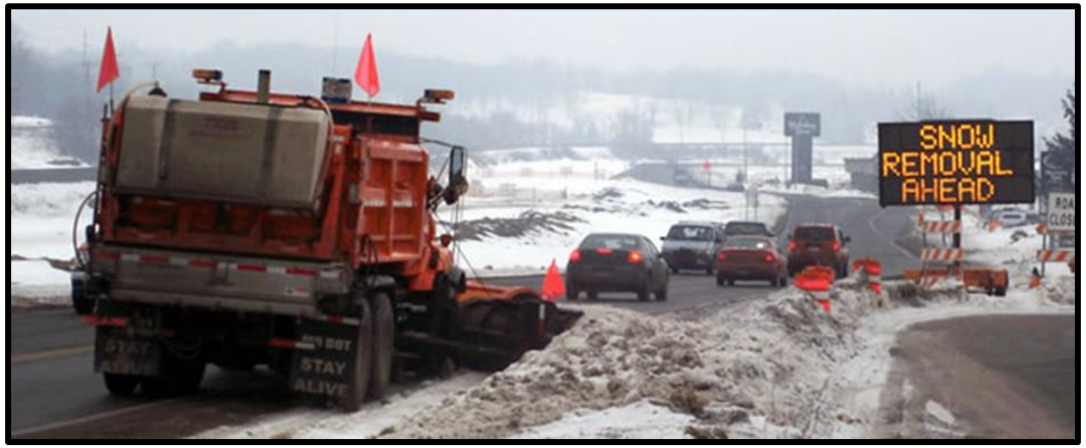
Advances in Winter Road Maintenance Practices to Improve Road Side Safety

- vehicles equipped with air and pavement surface temperature sensors.
- Some sensors detect surface moisture and salinity.
- Sensors being developed to measure the thickness of ice or snow.
- More plow trucks now equipped with
- AVL (Automatic Vehicle Locator) that report direction, speed, plow position, operation , material application rate.
- Friction sensors in development

Ben Hodges, transportation maintenance supervisor at MDOT's Grand Ledge garage, checks on plow AVL information. Photo courtesy of MDOT.

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

"Preventive treatment of the road is important to reduce the risk of ice forming on the road. The use of advanced systems in weather forecasting and monitoring along with staff education and improved procedures is expected to improve the winter traffic safety." (Thordasonn and Olaffsonn)



Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Winter road operations control is trending towards co-location with Traffic Management Centers (TMC) to share technology and information. Managers can adjust operations faster and more effectively when they have access to real-time traffic information combined with the data from telematics on-board the plow trucks.

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

PUBLIC INFORMATION

- Educating, informing and alerting the public reduce risk of ROR on winter roads.
- Transportation agencies use radio, television, newspapers (print and digital), agency websites, social media, mass e-mails and texts to inform the public.
- Highway Advisory Radio (HAR) and Dynamic Message Signs (both portable and stationary).

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

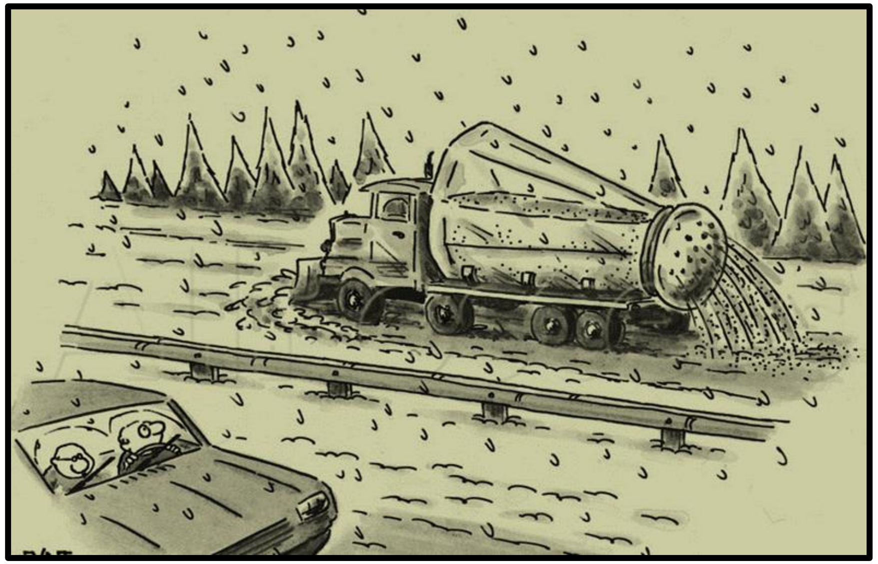
Summary:

- Transportation agencies place highest priority on safety and mobility.
- Much progress on snow and ice control methods, materials and machinery.
- Continued advances in the technology, science and “art “ of winter roadway operations blended with ITS and Automated/Connected Vehicles will result in significant reduction of collisions including ROR.

Advances in Winter Road Maintenance Practices to Improve Road Side Safety

Sometimes, it's just too slick even for the plow trucks!

Advances in Winter Road Maintenance Practices to Improve Road Side Safety



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TRB First International Roadside Safety Conference, San Francisco.CA

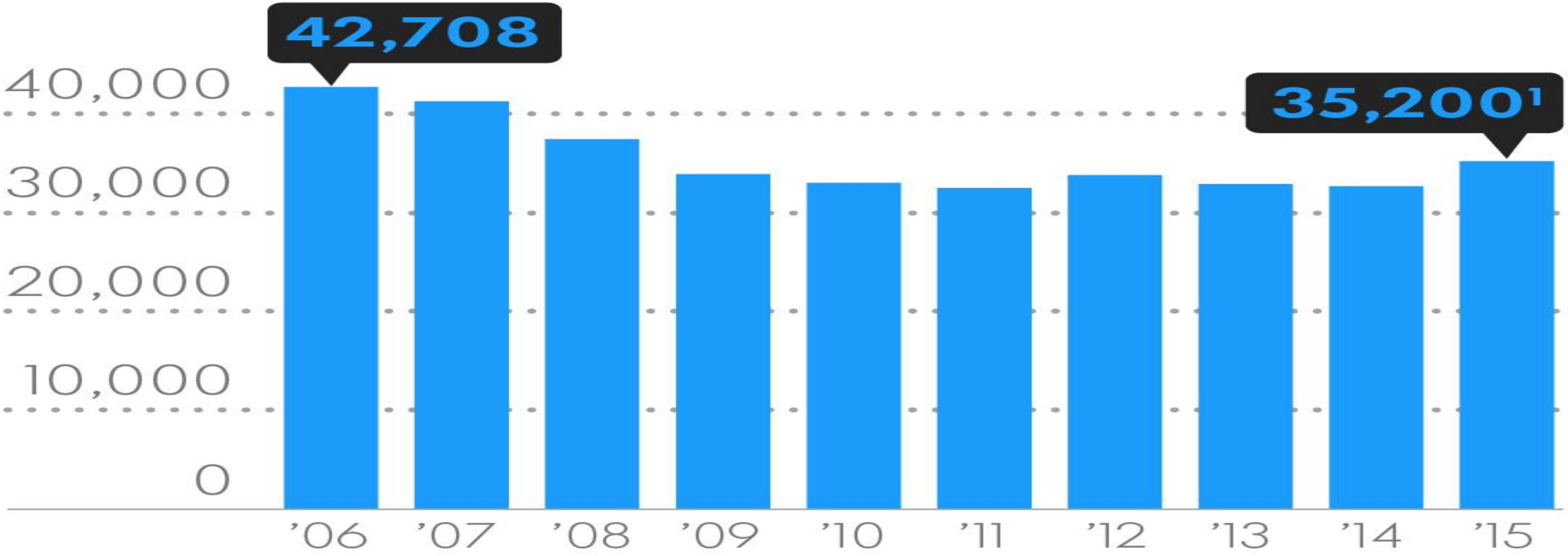
High Friction Surfacing Treatment, how a 45 year old process has been re-engineered into one of the leading national safety systems deployed by the US highway agencies

Lives Saved, Serious Injuries Reduced Through the use of HFST: How Highway Agencies are Deploying HFST Nationally.

How does HFST function in a curve

TRAFFIC FATALITIES ROSE IN 2015

Traffic deaths increased about 7.7% last year from 2014, according to preliminary estimates. Deaths from motor vehicle accidents:



1 — Projection

SOURCE: National Highway Transportation Safety Administration

George Petras, USA TODAY

USA TODAY

In **2013,** there were approximately **5.6 million crashes** reported across the nation, including **32,719 fatalities** and over **2.3 million injuries.**[1] More than half of the 2013 fatalities were roadway departure crashes.

Often, a small subset of the total highway network is responsible for a significant percentage of certain crash types. In 2008, for example, 28 percent of fatal crashes occurred on ***horizontal curves***, yet horizontal curves make up only 5 percent of our Nation's roadways. Compared to vehicles driving on a ***tangent road section***, vehicles traversing horizontal curves require a greater lateral friction due to centrifugal forces.

A roadway must have an appropriate level of pavement friction to ensure that vehicles stay safely in their lane. Poor pavement conditions, especially wet pavement, have been identified as one of the major contributing factors in roadway departure (RwD) crashes. When a pavement surface is wet or polished from wear, the level of pavement friction is reduced which may lead to skidding or hydroplaning. A high friction surface treatment (HFST) is an ideal countermeasure for such locations because it significantly increases pavement friction and helps prevent drivers from losing control on severe curves…

Despite gains in safety, **2015** saw the *largest percentage rise in motor vehicle deaths in the past 50 years*, according to the National Safety Council. Cheaper gas and a stronger economy were likely key factors in the rise, the nonprofit group says.

The figures are estimates from the National Safety Council, which says it currently estimates that last year, "**38,300 people** were killed on U.S. roads, and 4.4 million were seriously injured, meaning **2015 likely was the deadliest driving year since 2008**

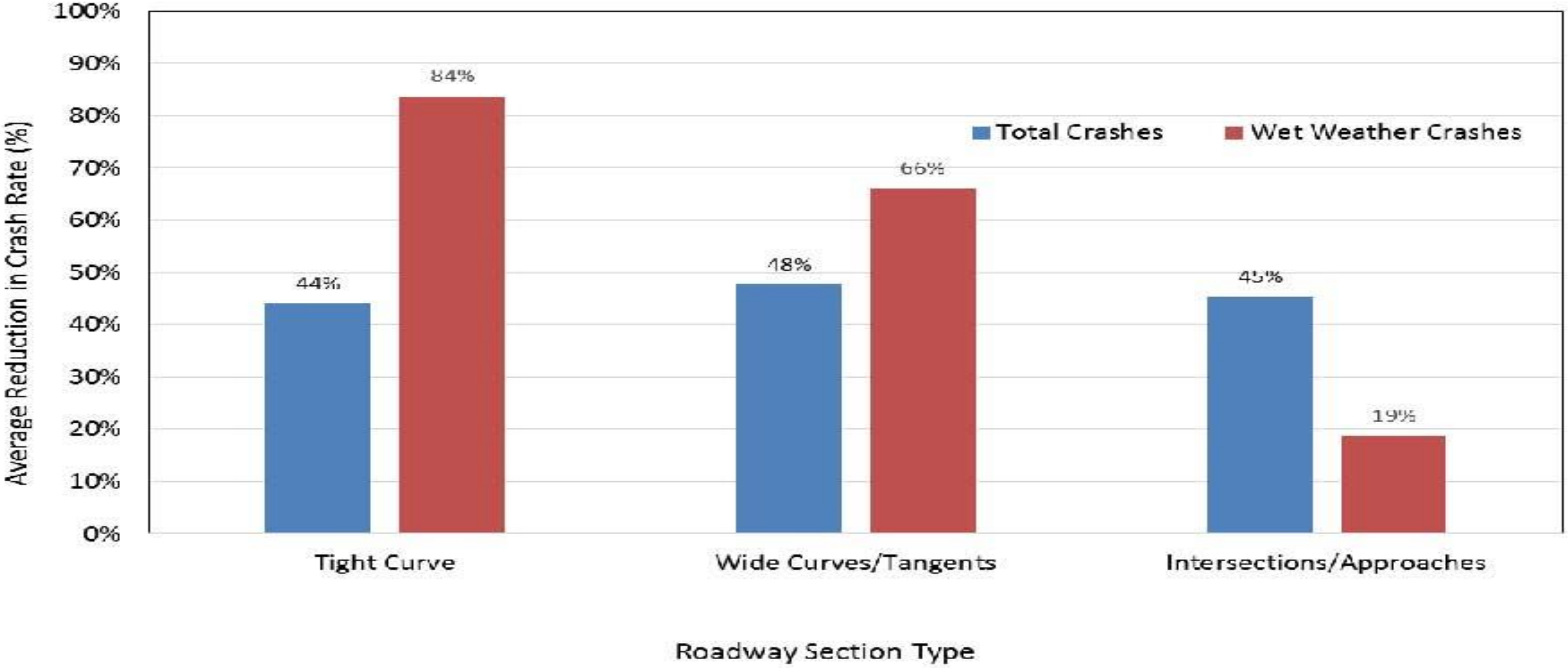
2016

A total of 40,200 people died on U.S. roads in 2016, the highest level in almost a decade, according to preliminary estimates from the National Safety Council (NSC).

The number of traffic fatalities last year represents a 6 percent increase over 2015 and a 14 percent increase over 2014 — the sharpest two-year escalation in more than 50 years, the safety group said.

The NSC draws its data from the states and the report could differ from final federal estimates. Still, safety advocates say the early data represents an **alarming trend**

Crash Performance (333 Specification)



What is a High Friction Surface Treatment?

High Friction Surface Treatment (HFST) is a pavement surfacing overlay system with:

Exceptional skid-resistant properties that are not typically acquired by conventional materials

Retains the higher friction property for a much longer time

Commercially available resin-based products

Generally applied in highway sections to improve safety locations where friction demand is critical

HFST Binder Materials

- Polymer binder systems
  - Epoxy-resin two-part systems
  - Polyester-resin three part systems

To form a laminate layer that allows for 75% aggregate embedment depth

HFST Aggregate

Recommended aggregate is calcined bauxite which provides the highest resistance to polishing

Typically referred to as a 1-3mm aggregate

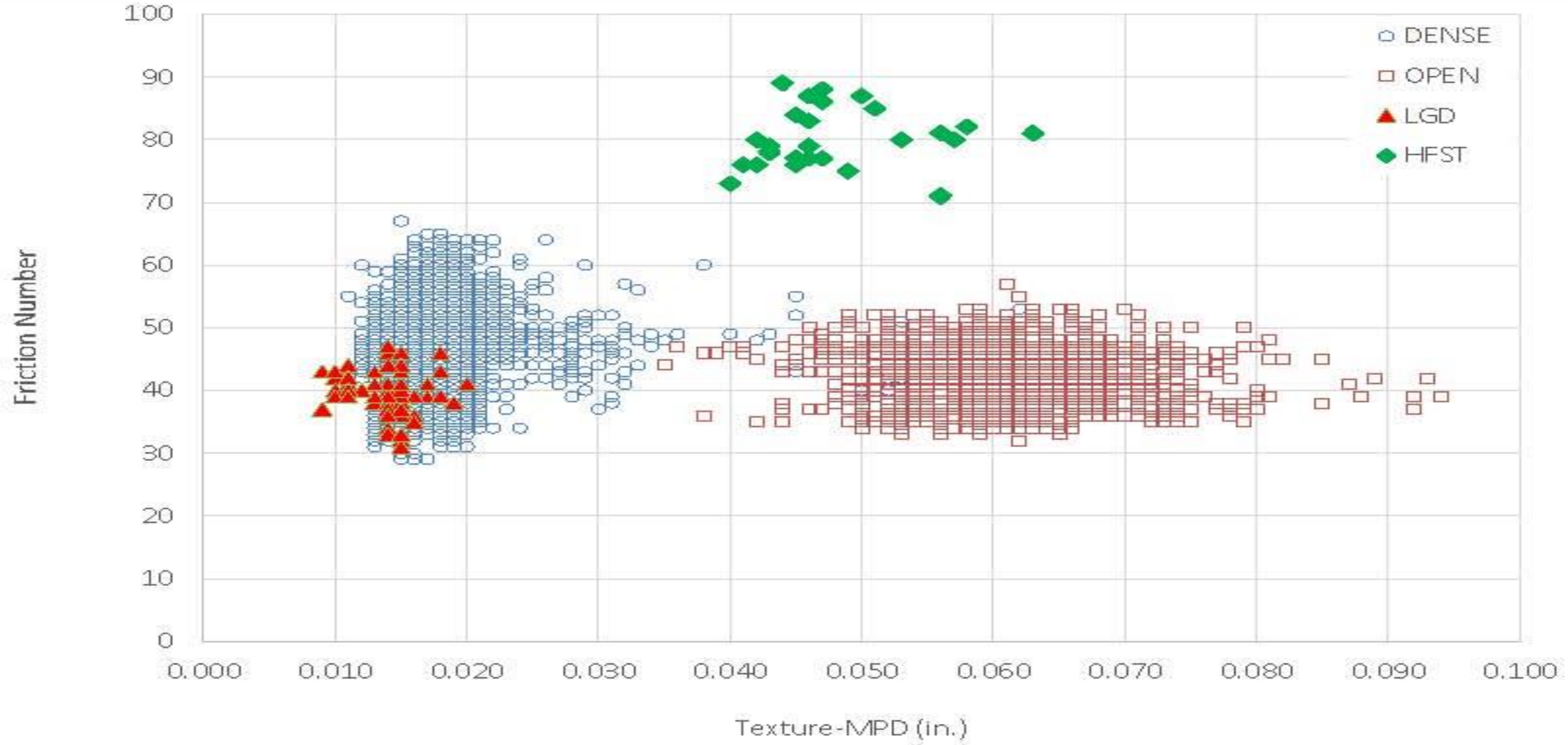
NCAT Report 17-01

Number Of Cycles	Traction Control Slab 1 (Avg)	Traction Control Slab (Avg)	Calcined Bauxite Slab 1 (Avg)	Calcined Bauxite Slab (Avg)
0	0.77	0.78	0.90	0.94
	0.80	0.81	0.95	0.97
	0.80	0.82	0.94	1.05
70,000	0.51	0.54	0.78	0.81
	0.55	0.57	0.77	0.79
	0.57	0.62	0.74	0.79
140,000	0.47	0.51	0.79	0.81
	0.47	0.54	0.79	0.80
	0.50	0.53	0.77	0.82

NCAT Report 15-04

NCAT Three Wheel Polishing Device

Friction Performance



Why Calcined Bauxite?

In-place friction characteristics must meet a minimum requirement of 65 FN40R when tested in accordance to AASHTO T 242 upon completion of the installation

Many states are using values greater than 70

Fully Automated HFST Application Generation III Vehicles

A typical HFST installation (photo thanks to Alaska DOT)

Texas Transportation Institute is *one of the leading engineering consultants for transportation studies compared* friction performance of a HFST surface and conventional concrete pavement at the TTI Testing Facilities

Skid testing conducted at the TTI test track
College Station, TX

Skid Numbers:

Concrete: 54.1, 50.2, 50.9 without HFST

HFST: **85.8, 85.8, 83.2 with HFST**

Stopping Distance @ 45 mph (ft.):

Concrete: 99, 91, 101, 91* without HFST

HFST: **76, 76, 79, 76* with HFST**

*Cars changed lanes

A recent industry high speed braking test in the UK

IA DOT I-235 Des Moines

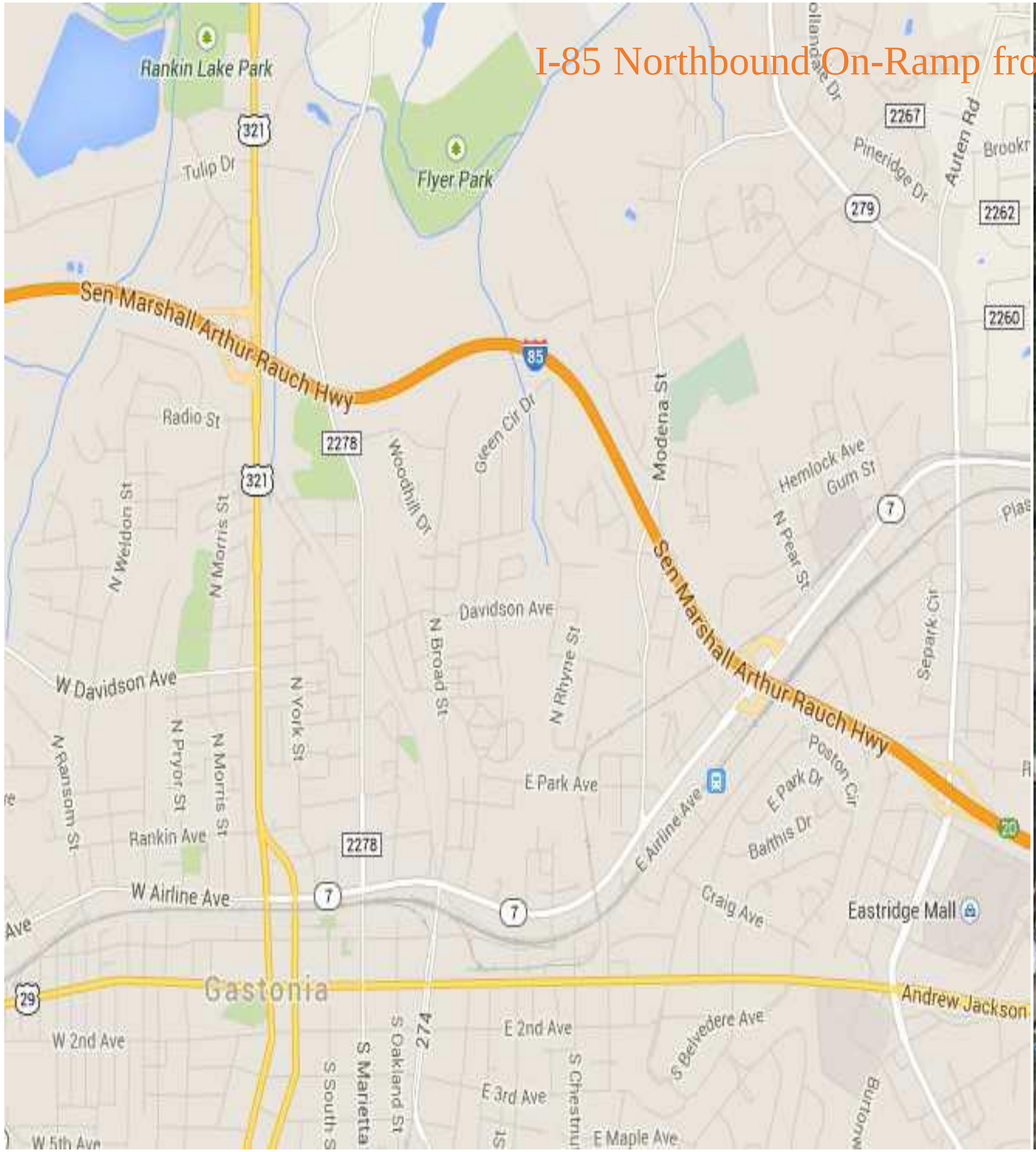
GA DOT 1,200,000 square yards of HFST spread across 3 districts and 16 counties, extending for 10 months. Represents the largest series of projects ever undertaken in the US.

NC DOT 2008
SC DOT 2009

Lives Saved, Serious Injuries Reduced Through the use of HFST.

How Highway Agencies are Deploying HFST nationally.

I-85 Northbound On-Ramp from NC-7 (Ozark Ave) – Exit 19




CRETE

I-85 Northbound On-Ramp from NC-7 (Ozark Ave) – Exit 19

Injury Crash Summary Before After Percent Reduction

Class B injury Crashes 5 0 - 100.0 %

Class C Injury Crashes 20 2 - 90.0 %

Property Damage Only 25 9 - 64.0 %

Overall Summary Results

Total Crashes: - 78 % (reduction)

Total Crash Severity: - 50 % (reduction)

Target LD Crashes: - 81 % (reduction)

Target LD Crash Severity: - 44 % (reduction)

Additional Summary Results

Lane Departure Wet Crashes: - 84 % (reduction)

Night Crashes: - 60 % (reduction)

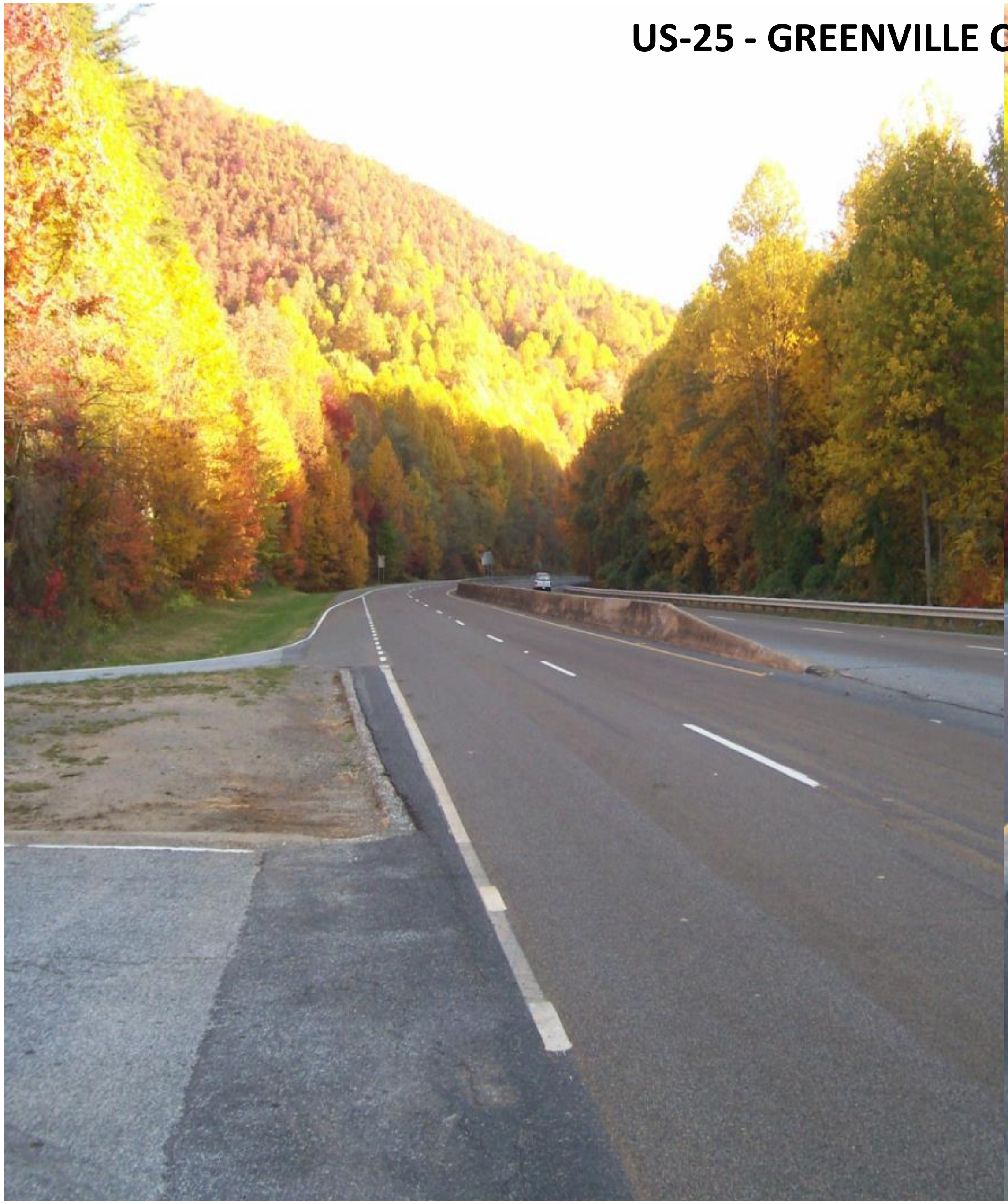
Citing a before and after study of seven HFST project locations, SCDOT experienced an
81 percent reduction in wet crashes and 71 percent reduction in total crashes. Since HFST has proven to be a very cost-effective safety countermeasure, SCDOT has installed 20 HFST projects, with approximately 20 more locations planned for 2015. Widespread deployment will be incorporated once the DOT identifies the horizontal curves throughout the State. The benefit/cost analysis for these locations has proven HFST to be a very cost-effective countermeasure.

FRICTION TESTS

US-25 - GREENVILLE CO. - RESEARCH - 7/28/2009

TEST NO.	ROUTE	DIRECTION	LANE	MILEPOST	WHEEL	FRICTION NUMBER	SPEED	PAVEMENT	COUNTY
0	US-25	N	2	3.666	L	49.6	40.1	AC	23
1	US-25	N	2	3.333	L	49.1	40.9	AC	23
2	US-25	N	2	3	L	47.7	40.7	AC	23
3	US-25	N	2	2.667	L	51	41	AC	23
4	US-25	N	2	2.334	L	49	40.6	AC	23
5	US-25	N	2	2.001	L	47.8	41.3	AC	23
6	US-25	N	2	1.668	L	**79.9**	37.3	TEST	23
7	US-25	N	2	1.335	L	**79.6**	40.1	TEST	23
8	US-25	N	2	1.002	L	**79.1**	40.1	TEST	23
9	US-25	N	2	0.669	L	50.7	41	AC	23
10	US-25	N	2	0.336	L	44.9	40.7	AC	23
11	US-25	N	2	0	L	46.6	41.6	AC	23
0	US-25	N	1	3.666	L	44.2	40.7	AC	23
1	US-25	N	1	3.333	L	44.1	41.2	AC	23
2	US-25	N	1	3	L	43.2	40.9	AC	23
3	US-25	N	1	2.667	L	43.5	41.2	AC	23
4	US-25	N	1	2.334	L	41.6	41.3	AC	23
5	US-25	N	1	2.001	L	45.5	39.2	AC	23
6	US-25	N	1	1.668	L	**74.4**	38.1	TEST	23
7	US-25	N	1	1.335	L	**74.1**	40.6	TEST	23
8	US-25	N	1	1.002	L	**67.9**	40.5	TEST	23
9	US-25	N	1	0.669	L	43.8	38.3	AC	23
10	US-25	N	1	0.336	L	42.3	38.5	AC	23
11	US-25	N	1	0	L	44.8	40.7	AC	23
0	US-25	S	1	0	L	46.1	41	AC	23
1	US-25	S	1	0.333	L	43.1	45.4	AC	23
2	US-25	S	1	0.666	L	42.9	45.7	AC	23
3	US-25	S	1	0.999	L	**72.9**	41.4	TEST	23
4	US-25	S	1	1.332	L	**75.3**	42.2	TEST	23
5	US-25	S	1	1.665	L	**73.8**	42.7	TEST	23
6	US-25	S	1	1.998	L	46.6	42.5	AC	23
7	US-25	S	1	2.331	L	41.9	43.8	AC	23
8	US-25	S	1	2.664	L	45	45	AC	23
9	US-25	S	1	2.997	L	45.3	44.3	AC	23
10	US-25	S	1	3.33	L	46.3	40.7	AC	23
11	US-25	S	1	3.663	L	48.4	39.3	AC	23
0	US-25	S	2	0	L	49.1	41.1	AC	23
1	US-25	S	2	0.333	L	44	41.2	AC	23
2	US-25	S	2	0.666	L	48.1	42.4	AC	23
3	US-25	S	2	0.999	L	**77.3**	39.9	TEST	23
4	US-25	S	2	1.332	L	**81.4**	39.3	TEST	23

US-25 - GREENVILLE COUNTY. - 2009



Lessons learned and improvements made / NC DOT

Installed three times because of the variable application method, ramp is on a grade the resin binder thickness couldn’t be controlled with manual squeegees. The resin binder ran off the side of the pavement, the aggregate distribution was uneven with bare spots because of not being able to control the aggregate spread rate and identify missed spots working at night

2009 application advancement SC DOT

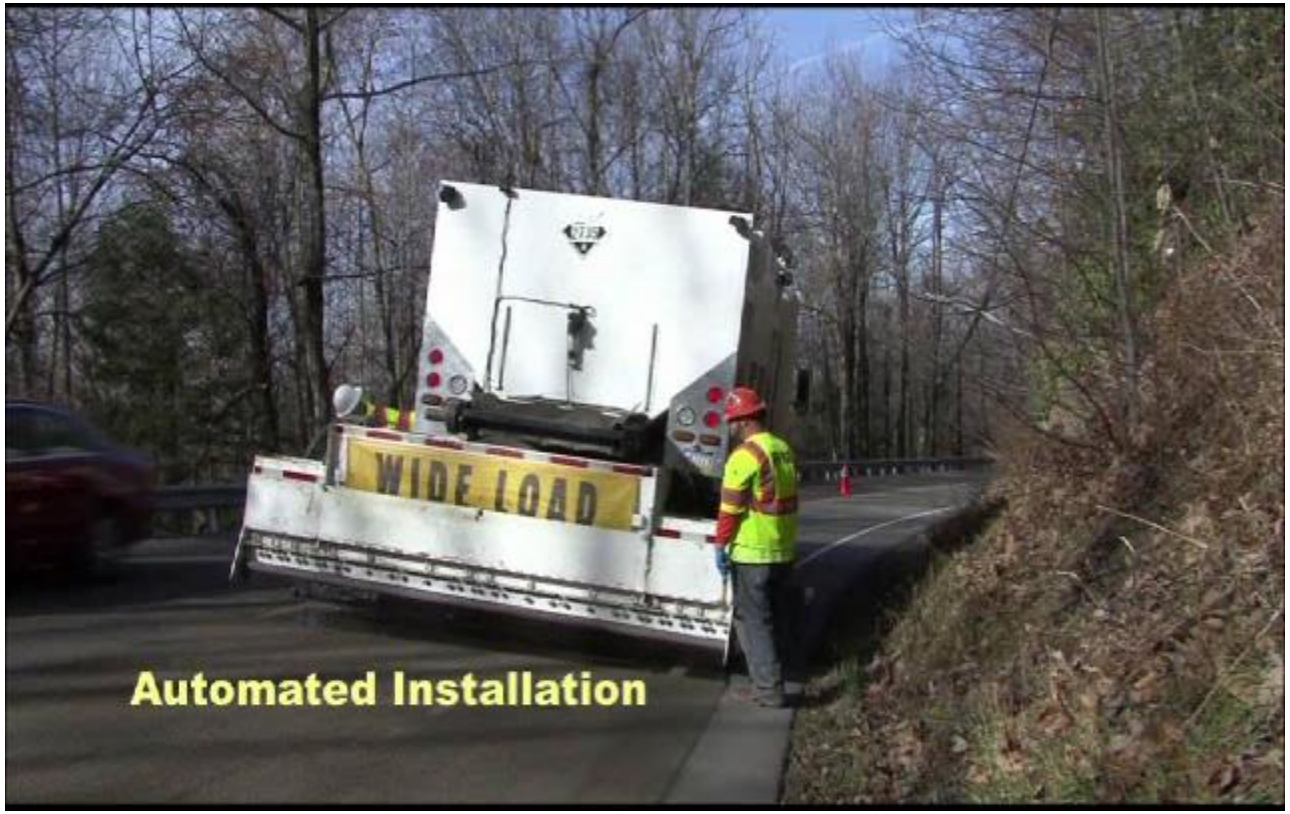
Automated metering and mixing of the resin binder, self adjusting telescoping application bar with a thickness control device, a creep drive activated aggregate spreader.

A two mile project was completed within the specification tolerances in half of the estimated application time by progressing to an automated application.

2016 state of the art development

Full lane width application, electronic “real-time” live stream reporting on the resin binder thickness, pavement and ambient temperatures, aggregate usage per square yard and materials consumption.

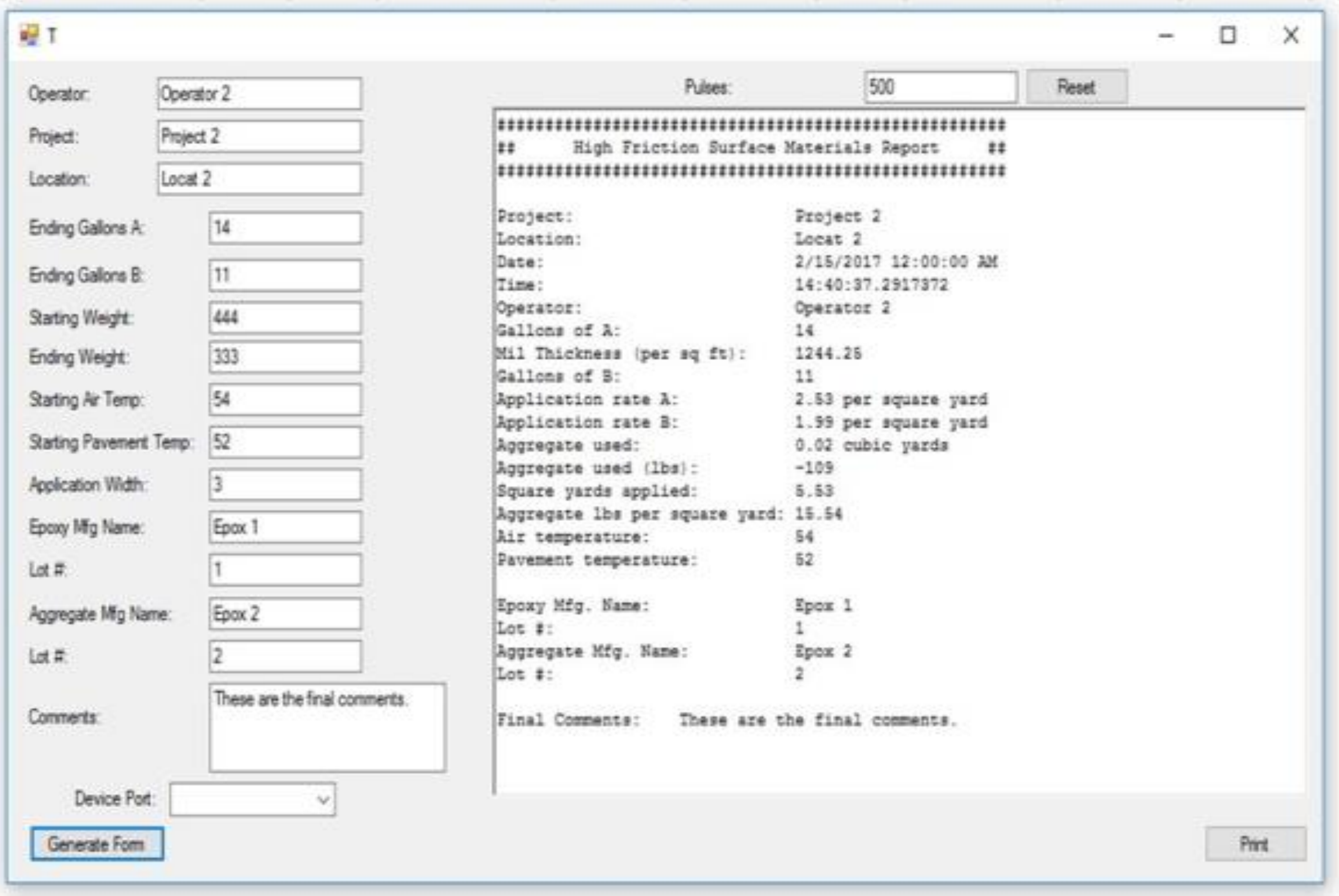
Grade control, long range continuous applications with no breaks for constant quality control.



DBi SERVICES

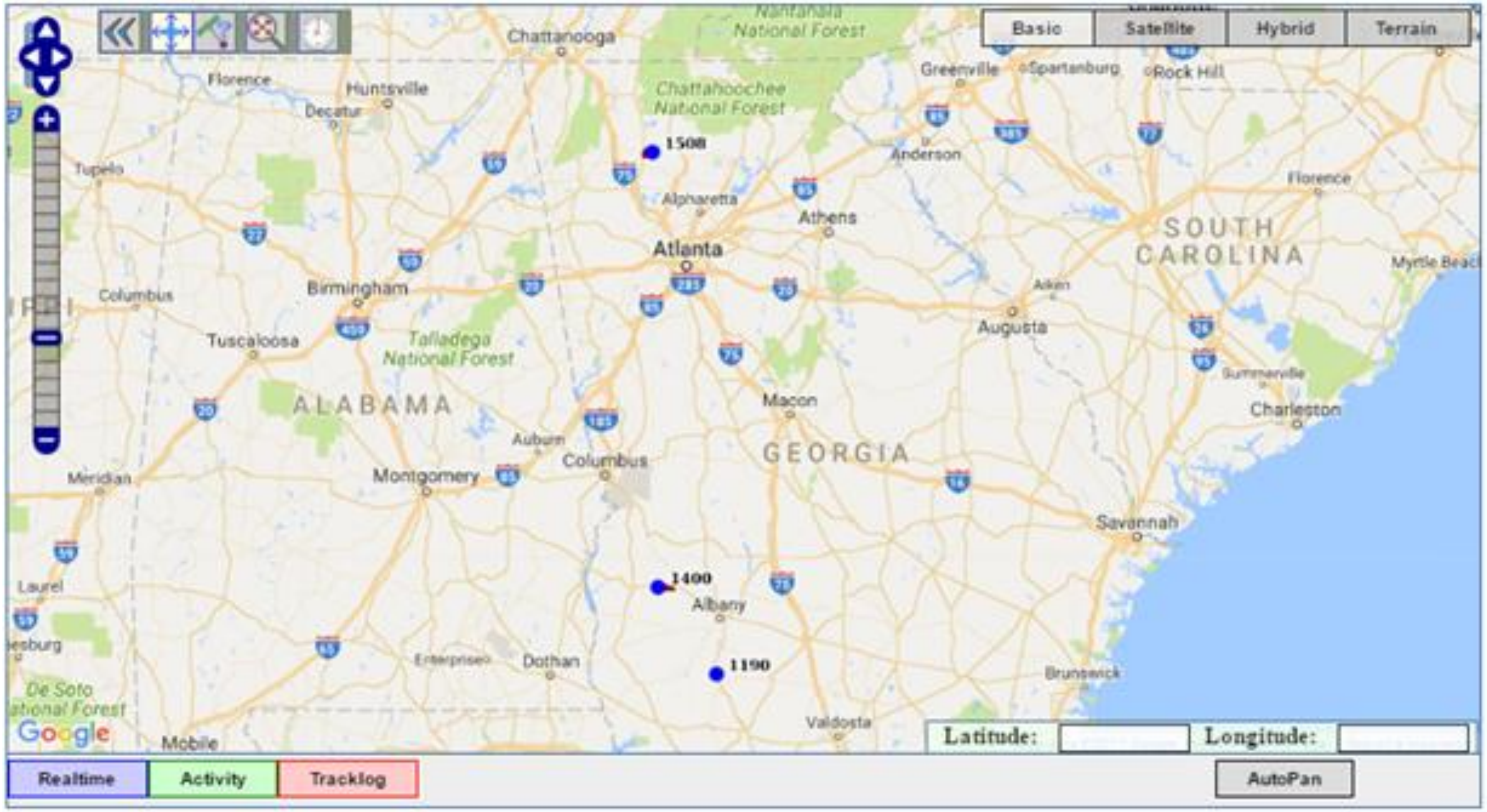
High Friction Surface treatment Automated Reporting System

HFST Real-time Reporting System



Real time report generated in truck

HFST Real-time Reporting System

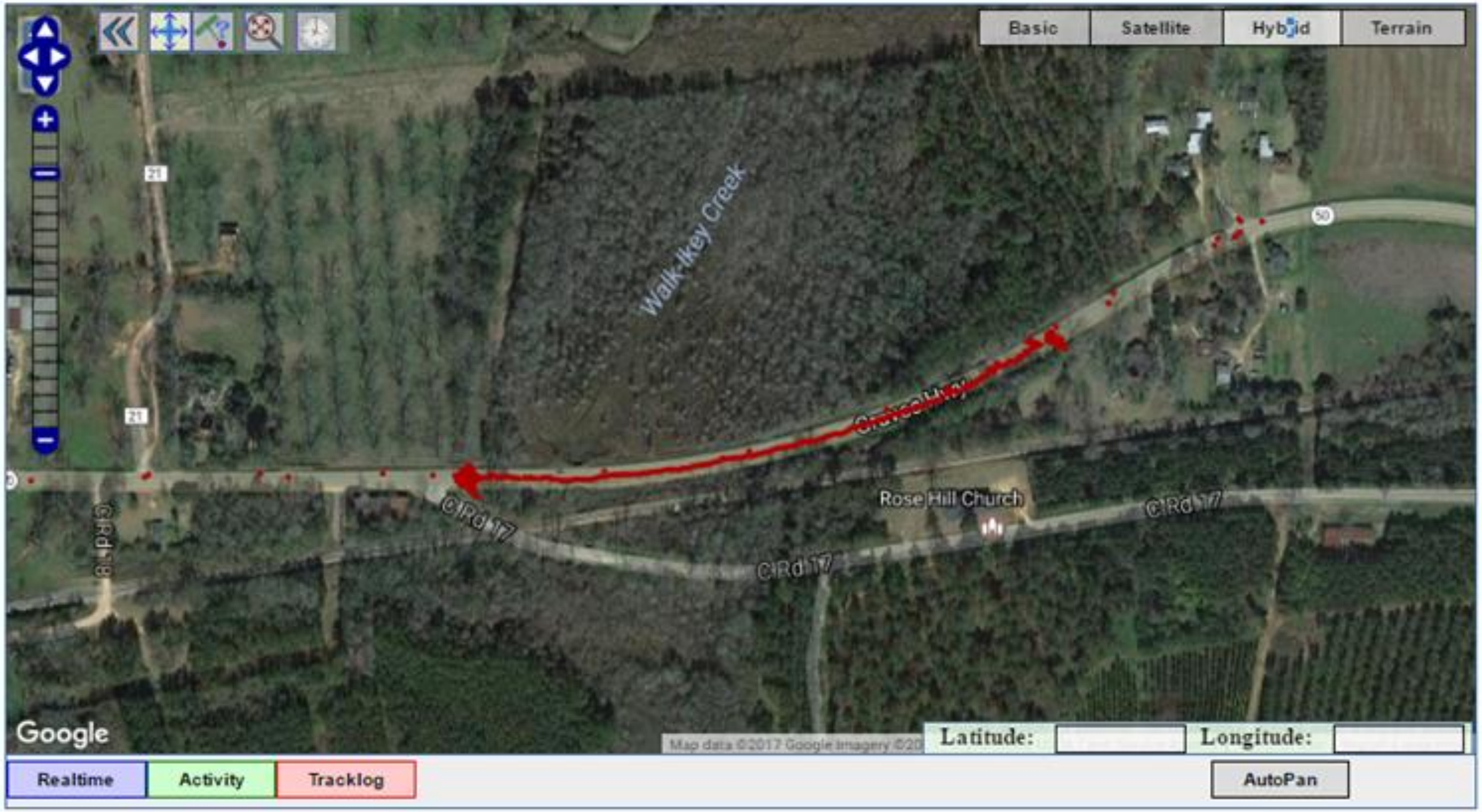


Vehicle	Type	Date	Time (et)	Speed Mi/H	Heading	Ignition
1190 (#1534)	High Friction	2017-04-10	10:59:33AM	0.00	S	On
1400 (#350)	High Friction	2017-04-10	10:59:39AM	10.56	S	On
1508 (#1354)	High Friction	2017-04-10	10:59:46AM	0.00	NW	On
2249 (#1368)	High Friction	2017-04-08	04:55:10PM	0.0	S	Off
2250 (#1369)	High Friction	2016-09-20	04:05:59PM	0.0	NW	Off

Real-time fleet tracking

Fully automated application truck with “real time” reporting module, four application staff 42,000lbs of bauxite and 1200 gallons of resin binder applying HFST at full lane widths up to the road markings. Application speeds of up to 26 linear feet per minute.

HFST Real-time Reporting System

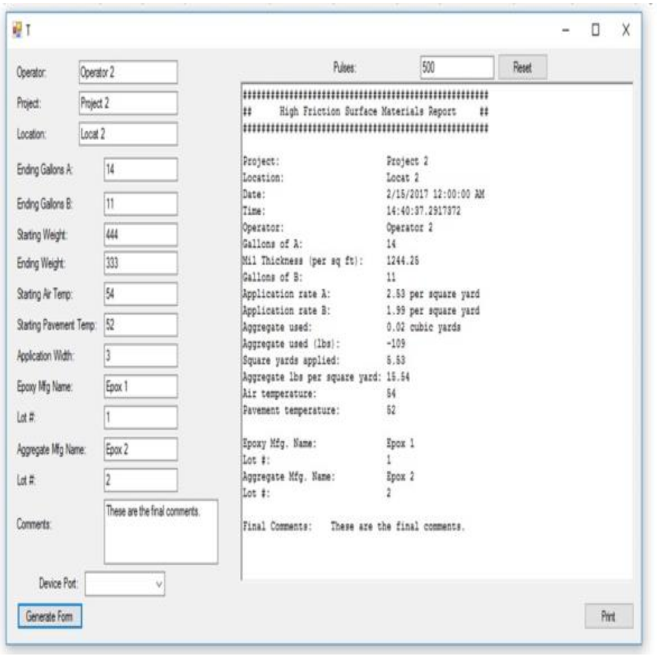


Vehicle	Type	Date	Time (et)	Speed Mi/H	Heading	Ignition
1190 (#1534)	High Friction	2017-04-10	10:56:33AM	0.00	E	On

Real time page shows actual application areas

HFST Real-time Reporting System

Application reports for any vehicle can be pulled up by clicking on the vehicle and then the reports tab at the top of the page

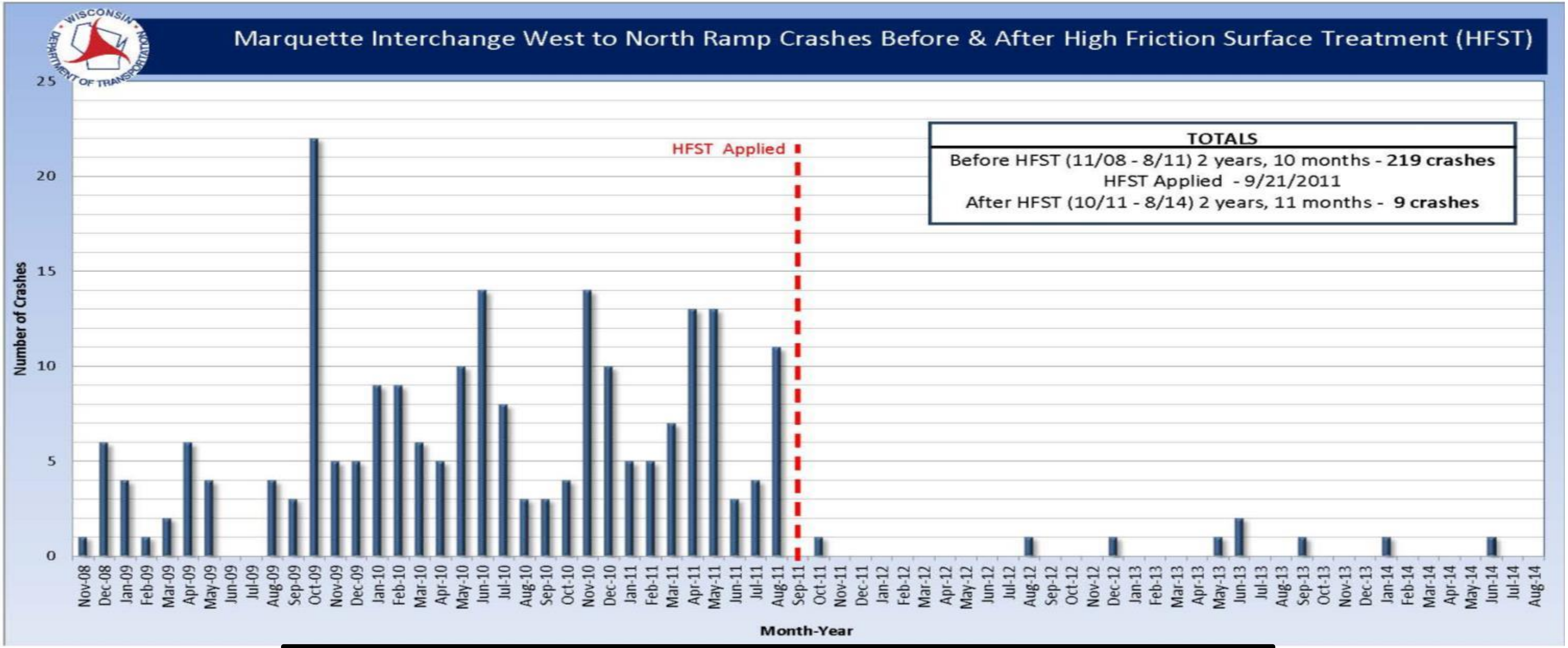


The Marquette Interchange

Systems interchange Junction of I-94, I-43, & I-794

Reconstruction completed in August 2008

Featured Context Sensitive Solutions for the surrounding community

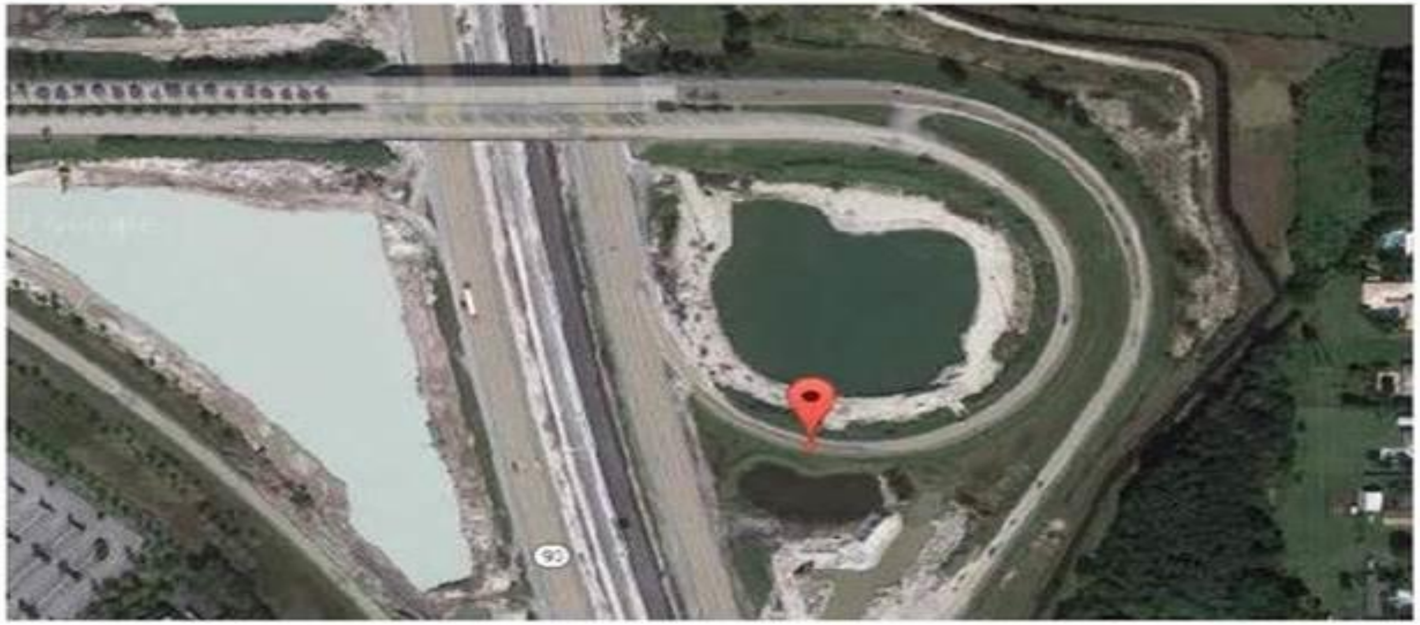


TOTALS

Before HFST (11/08 – 8/11) 2 years, 10 months – 219 crashes
HFST Applied – 9/21/2011
After HFST (10/11 – 8/14) 2 years, 11 months – 9 crashes

Royal Palm Boulevard/I-75 NB Ramp-2006

- Built in 2006
- High FN
- Yearly crash rate reduced 45%
- Safety reported reduced driving speed

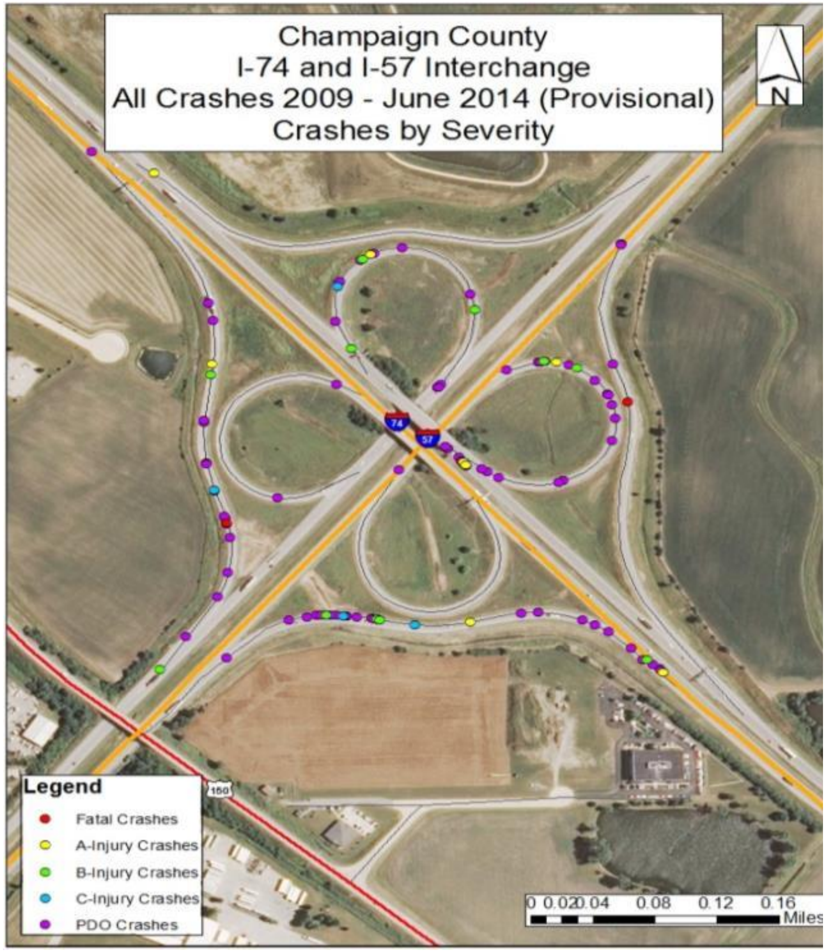


Friction Number (FN)		
Northbound Ramp		Test Date
Lane 1	Material	
35	Asphalt (FC-2)	4/11/2006
104	HFST	5/23/2006
66	HFST	3/8/2010
67	HFST	11/8/2013
68	HFST	12/6/2016

- A ramp to north I-75 in District 4 was treated with HFST in 2006 and still performs well with more than 60 of FN.

I-74 and I-57 Crash Data

(2009 – June 2014)

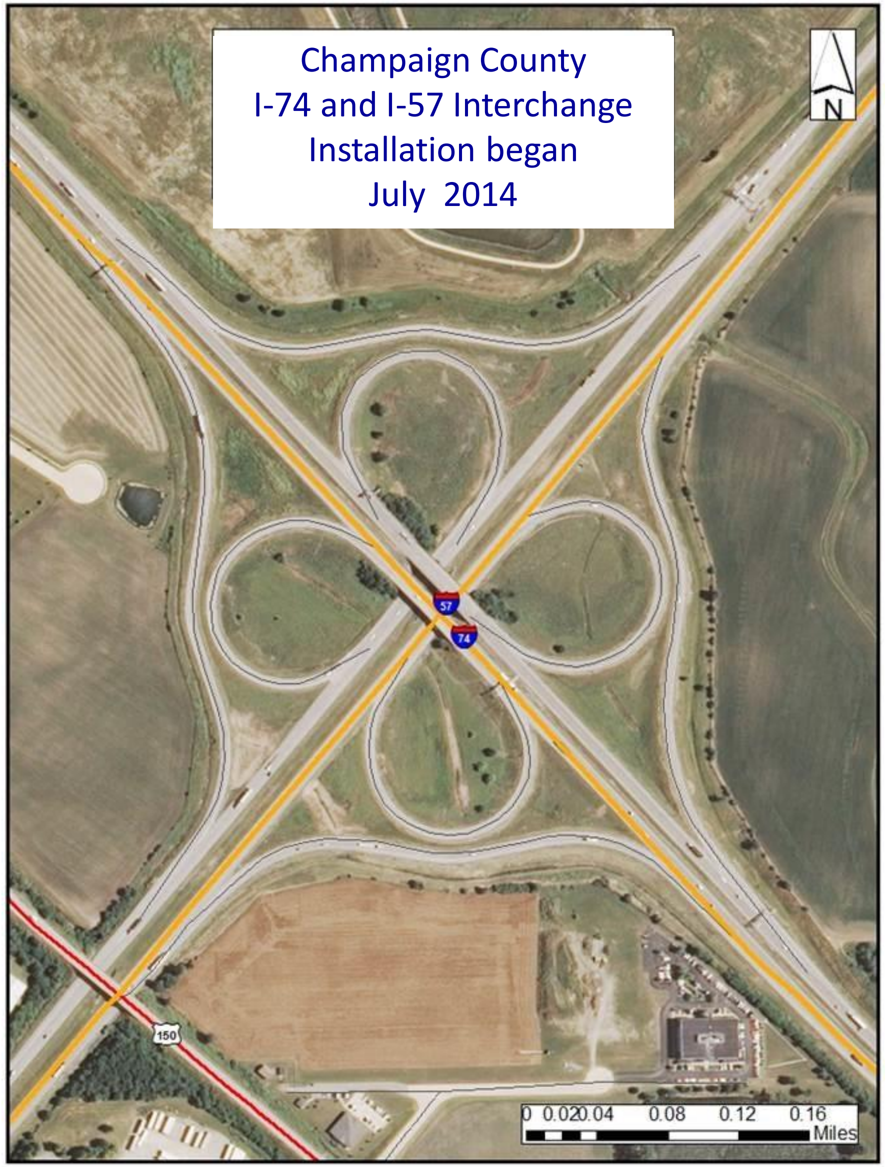


Collision Type	Total	Fatal	A-Injuries	B-Injuries	C-Injuries	PDs
Fixed Object	79	2	3	3	3	71
Overturned	21	0	3	7	1	11
Angle	5	0	3	0	0	2
Sideswipe Same Direction	5	0	0	0	0	5
Rear End	3	0	0	2	0	1
Other Non-Collision	3	0	0	0	0	3
TOTAL:	116	2	9	12	4	93

Road Surface		
Wet	78	67%
Dry	28	24%
Ice	7	6%
Snow or Slush	3	3%
Total:	116	

Slide Courtesy of Illinois DOT

I-74 and I-57 Interchange Crash Totals



Zero Crashes have been reported since HFST was installed!

Slide Courtesy of Illinois DOT

1997 – 2005, 21 Crashes
ADT is 5,000 with 8% trucks

Install HFST June 13, 2007
Southbound Lane Only

Installed Safety Features:

- **Chevrons**
- **Painted Slows**
- **Advanced Signs**
- **Reduced speed**
- **GR & Reflectors**
- **CLRS**

SR 611 Northampton County, PA

Skid Testing & Crash Results

Skid Results

	Test Lane	Control Lane	
Before Installation	Avg. 24 *	Avg. 34 *	* 11/30/06
After Installation (June 13th, 2007)			
Aug ’07	= Avg. 75	Avg. 34	
Apr ’08	= Avg. 75	Avg. 40	
Nov ‘08	= Avg. 72	Avg. 44	
Mar ‘09	= Avg. 74	Avg. 58 * Repaved	
Nov ‘09	= Avg. 72	Avg. 44	
Jun ‘10	= Avg. 71	Avg. 44	

Reportable Crash Results

Before Installation = 21 (south lane) After Installation = 0

Slide Courtesy of Pennsylvania DOT

Pennsylvania Success Story

Pennsylvania Project Summary
Installed 10/27/12

Traffic

SR 2017 - 9,000 AADT

SR 2024 - 4,600 AADT

Crashes

3 yrs. prior to install - 26

Since installation - 1

Skid Number

Before Install - 22

After Install - 75

Slide Courtesy of Pennsylvania DOT

Case Studies: PennDOT District 5
“Like a Miracle”

PennDOT District 5-0 evaluated 12 curves

Before installation (3 yrs.) = 136 crashes

After installation (3 yrs.) = 17 crashes

Slide Courtesy of Pennsylvania DOT

Kentucky HFST Program

Avg. Annual (70 locations)	Before	After
Wet Avg.	212	21
Dry Avg.	65	15
Total Avg.	277	36

(As of 6/22/2015)

Kentucky HFST Program

Avg. Annual (70 locations)	Reduction %
Wet Avg.	90%
Dry Avg.	77%
Total Avg.	87%

(As of 6/22/2015)

Slide Courtesy of Kentucky Transportation Cabinet

U.S. Department of Transportation
Federal Highway Administration

NORTHERN CALIFORNIA
US 199-Del Norte County

CASE STUDY

HIGH FRICTION SURFACE TREATMENT (HFST)

A Life-Saving and Cost-Effective Solution for an Environmentally Sensitive Location


NPS Photo


30 MPH
30 MPH
NB 01-DN-199 PM 8.2

Table 1. Comparison of Factors between HFST and Curve Realignment on US 199

	HFST	Curve Realignment
Environmental Review & Design Timeframe	4-6 Months	2-5 Years
Construction Duration	10 working Days	6+ Months
Cost	~$250,000	$14,000,000+

Detour

- **Not Necessary:** Treatment can be installed one lane at a time (HFST)
- **Necessary:** Roadway must be closed during construction. (Curve Realignment)

Field Observations, installation location selections and agency supervision

Installation selection pavement conditions

- Pavement conditions are sometimes not always taken into consideration.
- Large unsealed cracks
- Potholes, alligator cracking and delamination's
- Substrate issues, moisture and drainage
- Unsound concrete, badly cracked slabs and unsealed joints

Agency supervision of installations

- Not understanding the project specification scope
- Not enforcing the project specification
- Allowing substandard materials components to be installed
- An inability to stop an installation for non-compliancy to the project specification

HFST should be a mandatory safety requirement on US Highways.

A goal we can all live by!!

Questions?

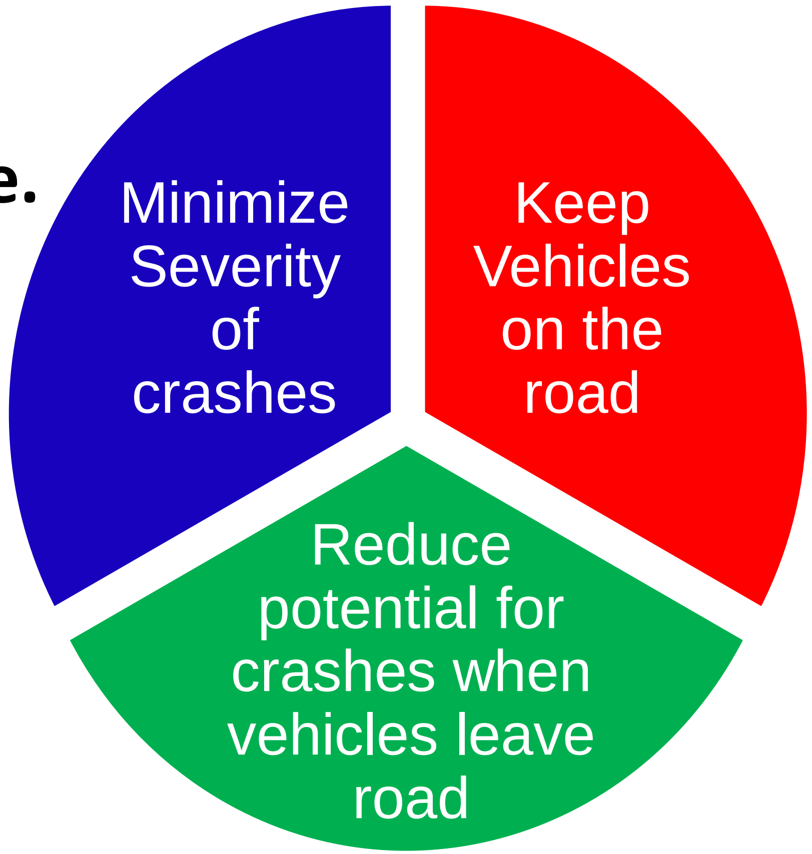
2017 TRB – AFB 20 International Roadside Safety Conference San Francisco, CA

June, 2017

Joseph Cheung P.E.
FHWA – Office of Safety

Roadway Departure Objectives

- **Keep vehicles on the roadway, in their appropriate directional lane.**
- Reduce the potential for crashes when vehicles do leave the roadway or cross into opposing traffic lanes.
- Minimize the severity of crashes that do occur.



Strategies to keep vehicles on the roadway

- Improved curve delineation
- **Friction treatments in curves and other spot locations**
- Edge line, shoulder & centerline rumble strips.

Skid related crashes are determined by many factors:

- Tire issues
- Weather Conditions
- Friction Demand - Road Geometry, Vehicle Speeds Driver Actions, Vehicle Characteristics

Forces Acting on a Vehicle

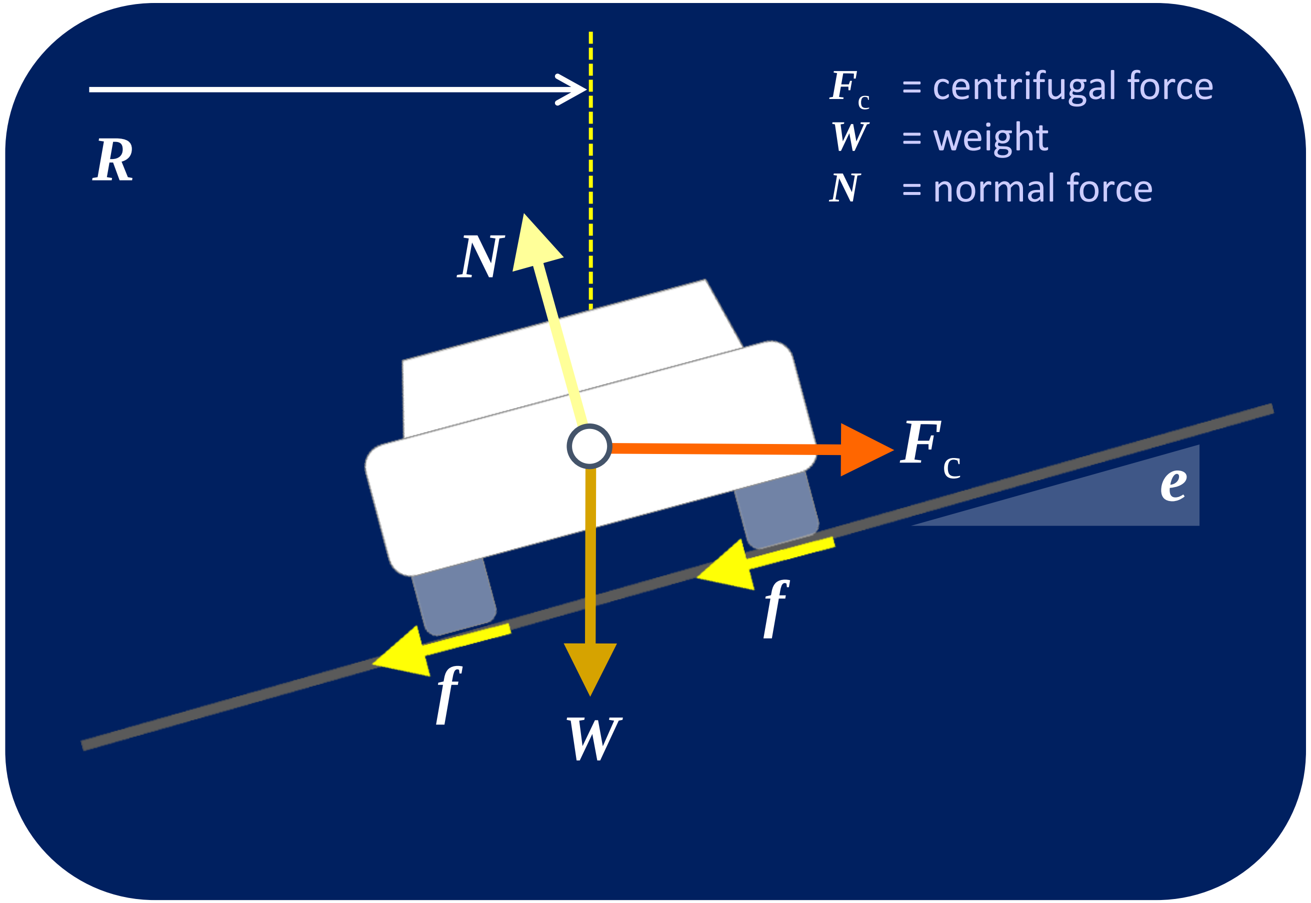
$$f + e = \frac{V^2}{15R}$$

f = side friction

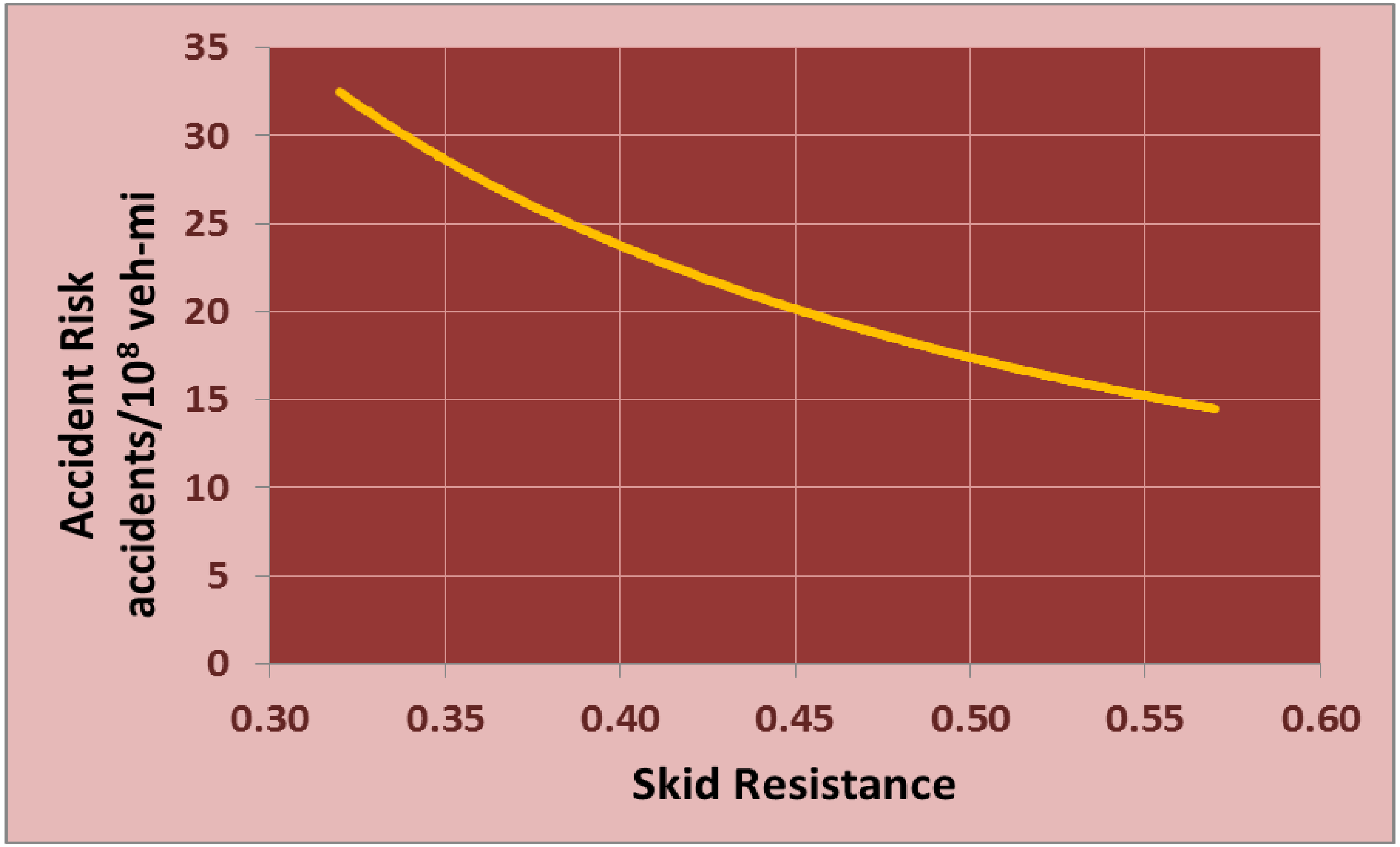
V = vehicle speed

e = superelevation

R = curve radius



Accident Risk vs Skid Resistance



Viner et al., 2004

Why High Friction Surface Treatment?

HFST is effective in reducing crashes:

- **Horizontal Curves and Ramps**
- **Intersections or braking conditions**
- **Grades**
- **Combination of all of the above**

Picture Courtesy Illinois DOT

What is a High Friction Surface Treatment?

High Friction Surface Treatments (HFST) are pavement surfacing overlay systems with:

- exceptional skid-resistant properties that are not typically acquired by conventional materials

- and retains the higher friction property for a much longer time.

- Commercially available resin-based products and processes
- Generally applied in short sections to improve **spot locations** where friction demand is critical.

Bonding Agents

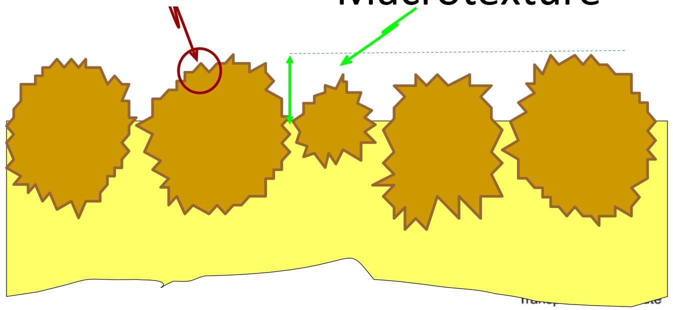
Binder	Curing Time	Curing Temp.
Epoxy-Resin	3 - 4 hours	70+ F
Rosin-Ester	As soon as it reaches ambient temperature	ambient temp.
Polyurethane-Resin	2.5 hours	
Methyl Methacrylate	1.5 hours	<20F to 100+F
Polyester-Resin	2 hours	<40F to 100+F

HFST Aggregates

- Recommended aggregate is calcined bauxite which provides the highest resistance to polishing.

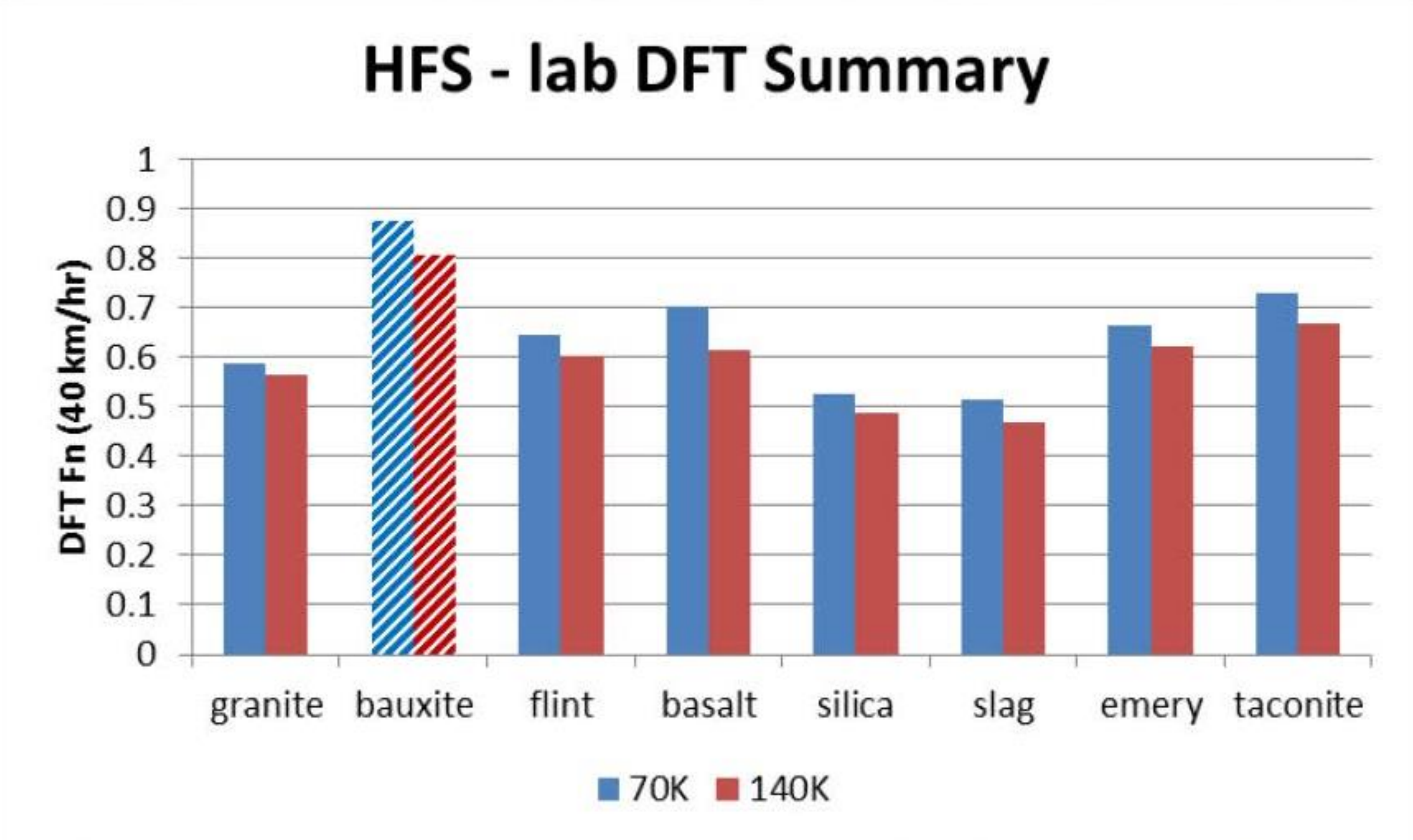
Typically referred to as a 3 mm aggregate

Typical Macrotexture Depths & Friction Factors



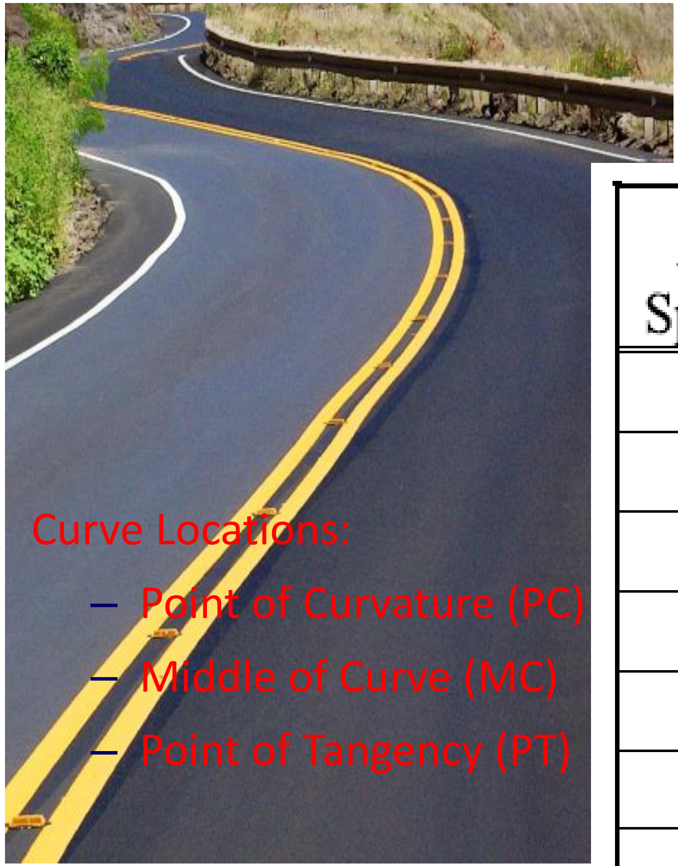
Pavement Treatment	Macrotexture Depth	Friction Factor
Slurry Seal	0.3 to 0.6 mm	
Thin Hot Mix Asphalt Overlay (Dense Graded)	0.4 to 0.6 mm	
Thin Hot Mix Asphalt Overlay (Stone Matrix)	> 1.0 mm	
Microsurfacing	0.5 to 1.0 mm	
Diamond Grinding	0.7 to 1.2 mm	
Grooving	0.9 to 1.4 mm	
Ultra-Thin Bonded Wearing Course (UTBWC)	> 1.0 mm	
Chip Seal (various binder types)	> 1.0 mm	
Open Graded Friction Course (OGFC)	1.5 to 3.0 mm	
High Friction Surfacing (HFS)	> 1.5 mm	

NCAT Aggregate Durability Study
Phase I – Laboratory Samples



limits of HFST installation

Texas Curve Margin of Safety = Friction Supply – Friction Demand



Recommended Distance Upstream of the PC to Begin HFST Application

Approach Speed (mph)	Curve Speed (mph)						
	30	35	40	45	50	55	60
35	35	-	-	-	-	-	-
40	76	41	-	-	-	-	-
45	122	86	46	-	-	-	-
50	173	138	97	51	-	-	-
55	230	194	154	108	57	-	-
60	292	257	216	170	119	62	-
65	359	324	284	238	186	130	68

Manual Installation

- **Manual mixing of epoxy material**
- **Manual application of epoxy with squeegee**
- **Hand broadcast and distribution of aggregate**
- **Production rates: 200-1000 SY/hr.**

Mechanically Assisted Installation

- **Machine mixing of binder**
- **Machine assistance in getting aggregate close to final position**
- **Binder distribution often by pump but total reliance on squeegees to attain binder thickness**
- **Production Rates:**
  1800 S.Y./hr.

Manual Installation Video

Mechanically Assisted Installation

★ This category also includes the aggregate sprayed on

- **May or may not include machine mixing of binder**
- **Binder distribution may include a pump but total reliance on squeegees to attain binder distribution and thickness**
- **Aggregate is sprayed to final position**
- **Production Rates:**

  1800 S.Y./hr.

Sprayed Aggregate Mechanically Assisted Installation Video

Automated Installation

- **Machine mixes binder**
- **Machine places binder at final location**
- **Binder depth monitored constantly by machine**
- **Aggregate is placed by machine at final location within seconds of binder**
- **Handwork is limited to irregular areas**
- **Production Rates: 2800 SY/hr.**

Manual vs. Fully-Automated Comparison

- The fully-automated HFST process installed 350 sq. yd. of full lane width in approx. 8 minutes, while the manual application installed 100 SY in 15 minutes (6 times faster).

Benefits of using the fully-automated processes include:

• Improved speed and quality result in reduced installation time; critical in states with high temperature

• Consistent proven specification;

• Full lane width 12’ continuous operation in one pass;

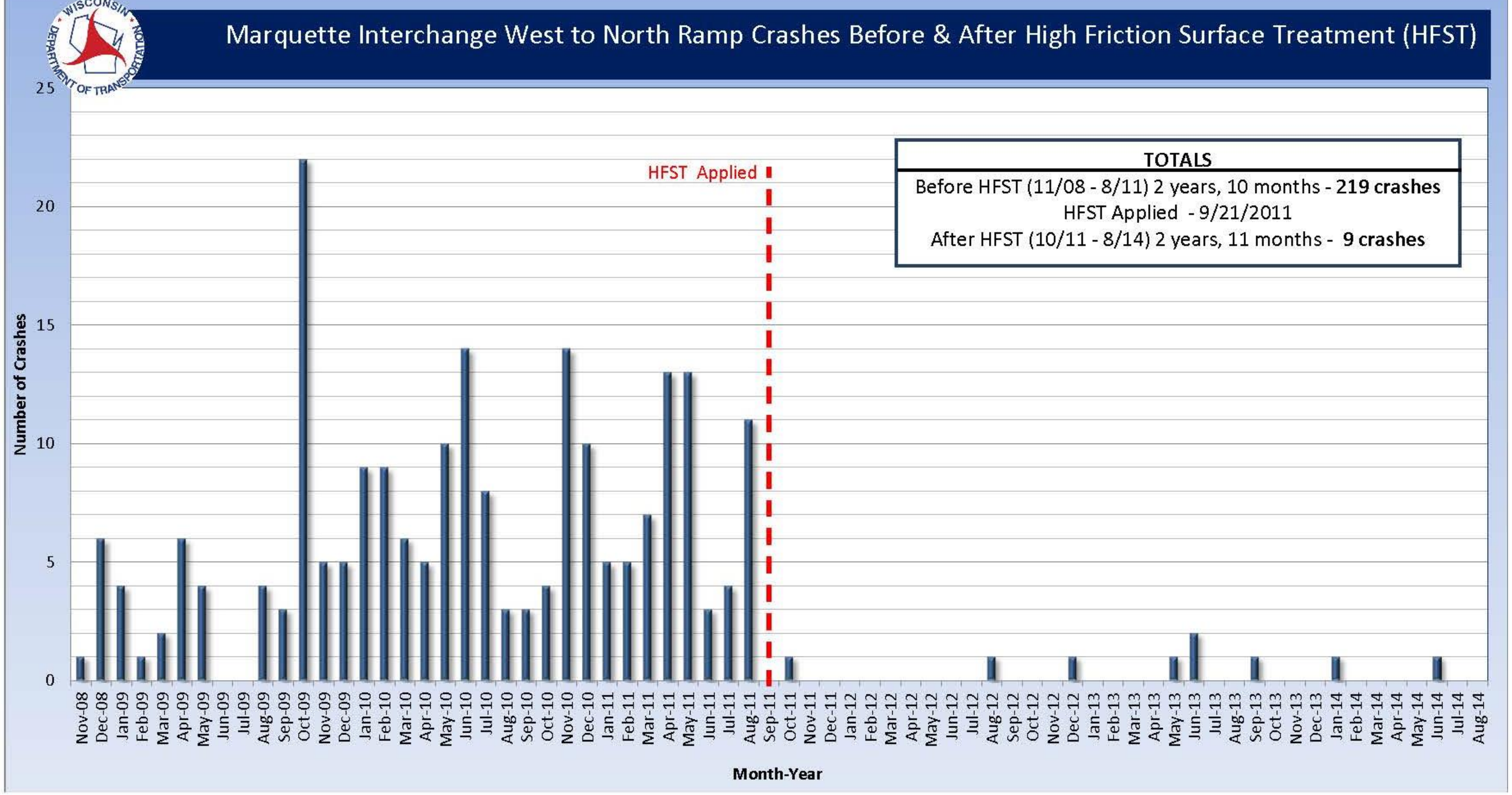
• No material component waste;

• Reduced exposure of workers to live traffic; and

• Even application of binder and aggregate.


Marquette Interchange


Caution
When it
Rains!
Milwaukee,
Wisconsin

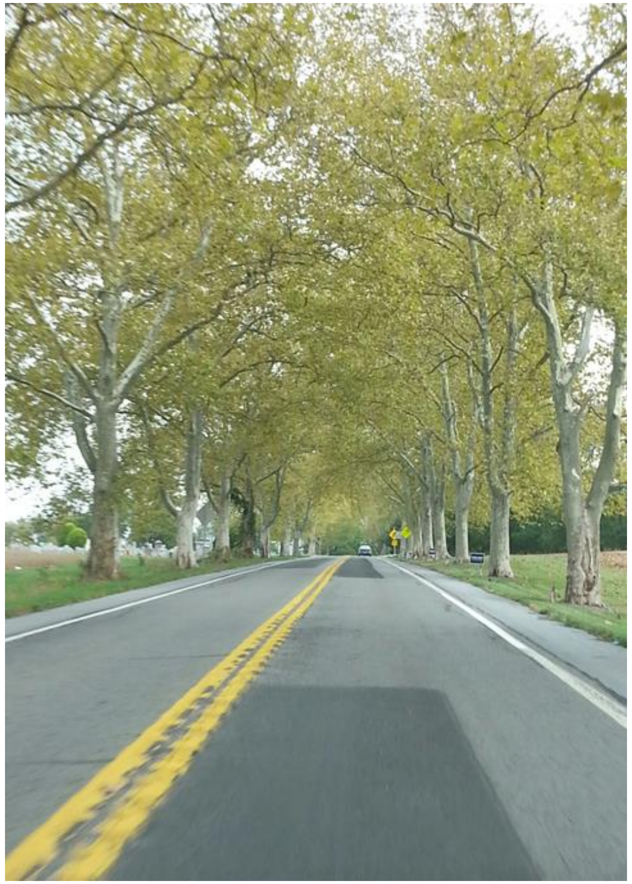


TOTALS

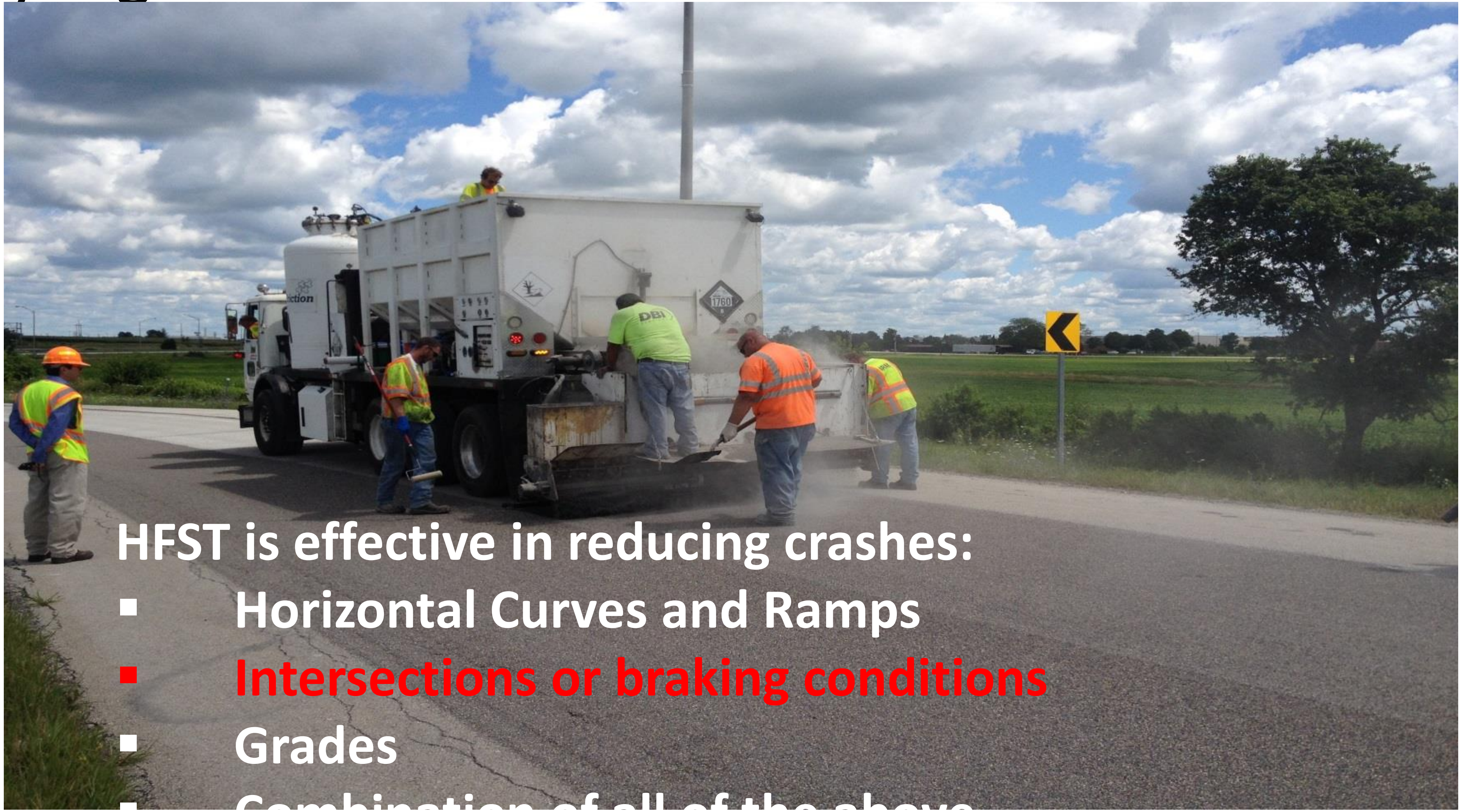
Before HFST (11/08 – 8/11) 2 years, 10 months – 219 crashes
HFST Applied – 9/21/2011
After HFST (10/11 – 8/14) 2 years, 11 months – 9 crashes

Increasing Safety in Culturally Sensitive Areas

PA Route 147 in Dauphin County -
“Sycamore Allée,” Century-old
mature sycamores line its roadsides.



Why High Friction Surface Treatment?



HFST is effective in reducing crashes:

- Horizontal Curves and Ramps
- Intersections or braking conditions
- Grades
- Combination of all of the above

Picture Courtesy Illinois DOT

Texas Transportation Institute compared friction performance of a HFST surface and conventional concrete pavement

Skid testing conducted at the TTI test track

Skid Numbers:

Concrete: 54.1, 50.2, 50.9 without HFST

HFST: **85.8, 85.8, 83.2 with HFST**

Stopping Distance @ 45 mph (ft.):

Concrete: 99, 91, 101, 91* without HFST

HFST: **76, 76, 79, 76* with HFST**

*Cars changed lanes

Gore Area

Bellevue, Washington State

- Local Road Project
- 15% downgrade
- Curve with an intersection at the bottom

<u>Before</u>

- 22 crashes in a 4 year period
- Mostly wet crashes
- Excessive speed is a factor
- Try large flashing sign
- Placed additional road markers
- Added lighting
- Installed Raised pavement markers

Installed HFST in October 2004

- Install HFST just before the intersection in 2004
- Installation time less than 6 hours

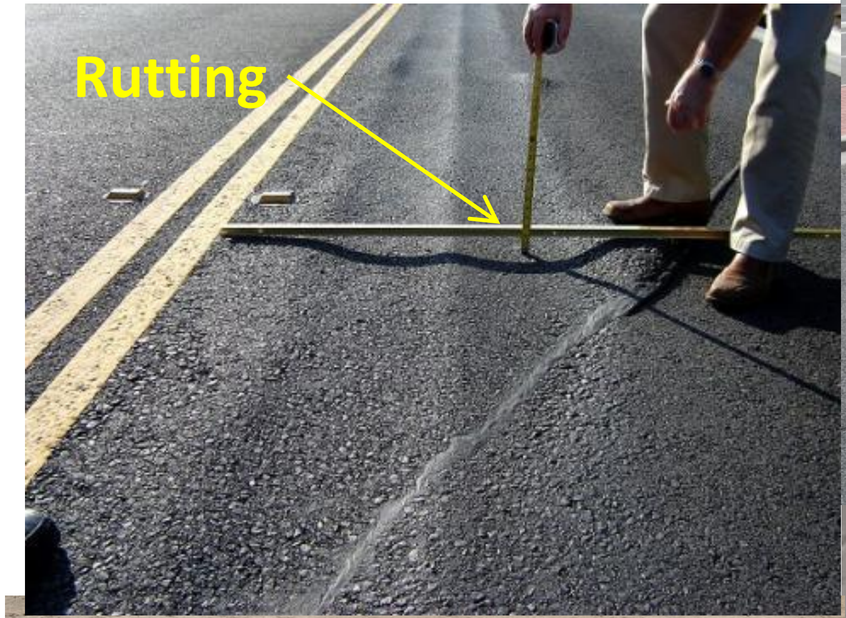
<u>After</u>

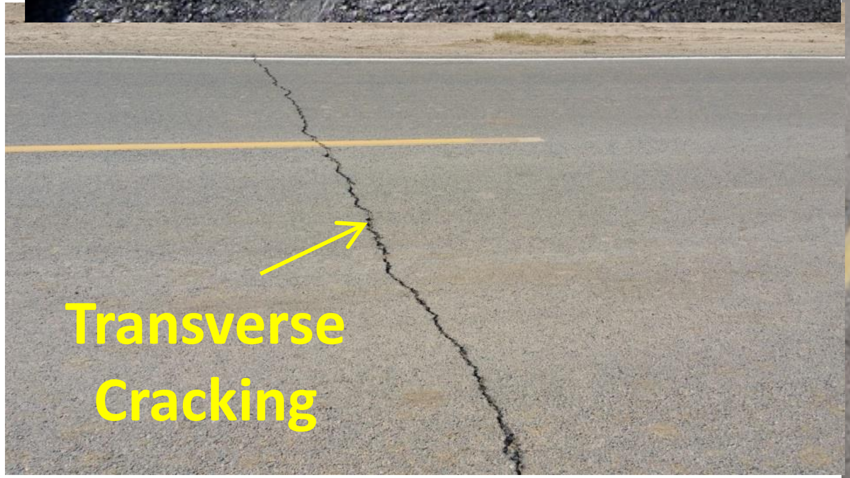
2 crashes, one brake failure, the other distracted driver

How Long Does HFST Last?

- The most significant issue is existing pavement condition
- We are expecting 10+ years based on accelerated test track results and current project experience
- But it depends on having a good specification and a good installation

Pavement Distresses





PA DOT Implementation of HFST

- 2012 RwD Safety Implementation Plan
- Utilized the curve sections identified in the plan to install HFST to reduce RwD crashes using HSIP funding
- Using Bauxite as aggregate and Epoxy for HFST application
- Conduct Benefit/Cost Analysis
- Collect crash data for 15 locations in 2 counties – approx. 1.18 miles of roadways
- HFST installations of three years or longer

Average Cost Benefit Table (15 locations)

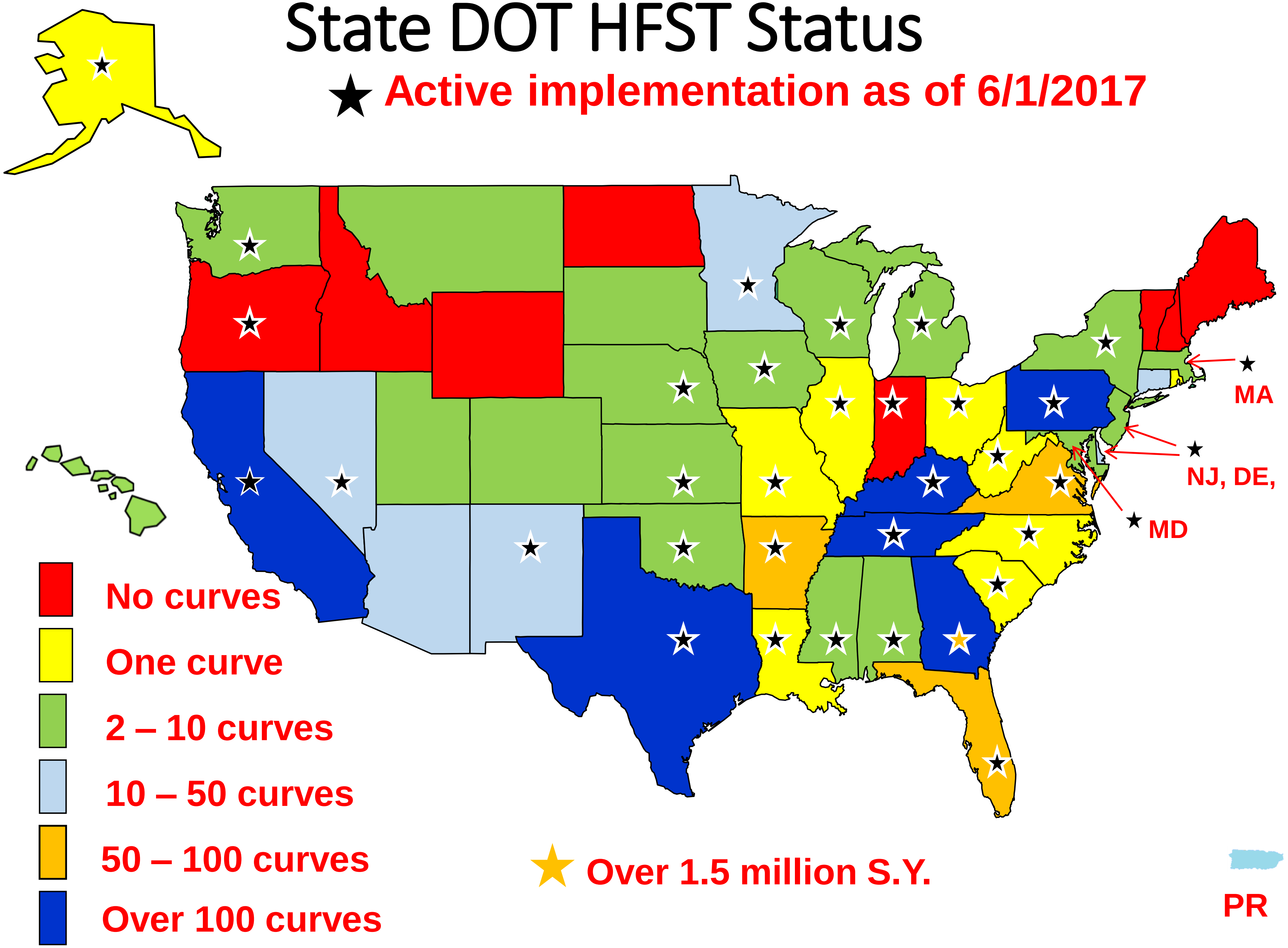
	Crashes	Fatalities	Major/moderate/ minor injuries	PDO	Unknown Severity	Economic Savings Due to Reduction in Fatality/Injury
All 15 locations Annual Reduction	49.13	.58	.79	30.71	13.92	$5,361,406
Annual Reduction per locations	3.30	0.04	0.05	2.05	.93	$357,427.08

Benefit/Cost ratio
20.49 : 1

Averaged .04 lives saved per location

State DOT HFST Status

★ **Active implementation as of 6/1/2017**



HFST – A Game Changer
"Something so simple could be this effective at stopping Run-Off the Road Crashes"

- **Keep Vehicles on the road** - **Minimize roadside hardware replacement**
- **Compensate for distracted driving and driving too fast for the conditions – the only safety countermeasure that require minimal human interaction.**
- **Reduced both wet and dry crashes with dramatic crash reductions – Marquette Interchange – from 219 crashes (2 yr, 10 months) to 9 crashes (2 yr, 11 months)**
- **Cost effectiveness – CA DN-199, $14,000,000+ for curve realignment to approx. $250,000 for HFST. Realignment takes 2 to 5 years vs 4 to 6 months for HFST.**
- **Negligible environmental impact – no additional impervious area created**
- **Minimize traffic delay - maintain 1 lane of traffic and eliminate the need for detour and reduce secondary crashes- reopen to traffic the same day**

Questions and Discussion
Joseph.cheung@dot.gov

http://safety.fhwa.dot.gov/roadway_dept/pavement_friction/

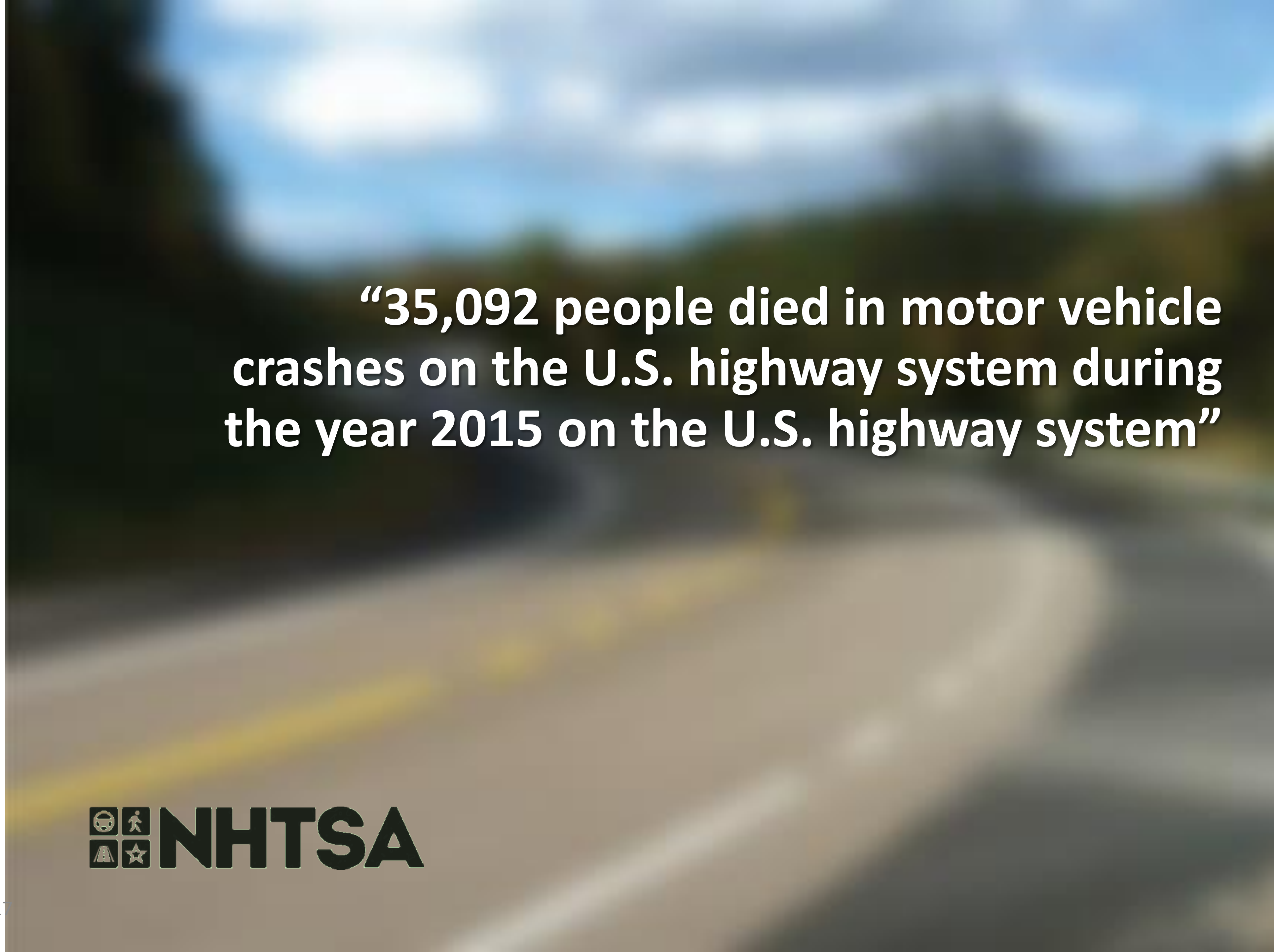
Questions?

THE SAFETY IMPACT OF HFST INSTALLATIONS IN PA

Dr. Seri Park, PhD, PTP
Assistant Professor

Kimberley Musey, EIT
Graduate Researcher

VILLANOVA UNIVERSITY


"35,092 people died in motor vehicle crashes on the U.S. highway system during the year 2015 on the U.S. highway system"
NHTSA

- **High Friction Surface Treatments:**
  - Resurfacing system
  - Aggregates = bauxite, flint, granite, slags
  - Exceptional skid resistance

- **Where to Apply HFSTs:**
  - Horizontal Curves
  - Intersection Approaches
  - Steep Grades

Benefits:

Low cost and schedule

Sustainable

Less Environmental Impact

Case Studies:

As of June 2016, 40 states in the country have applied HFST on at least one project site.

Studies have shown significant Crash Reduction!

RESEARCH OBJECTIVE

VILLANOVA UNIVERSITY

ANSWER KEY QUESTIONS:

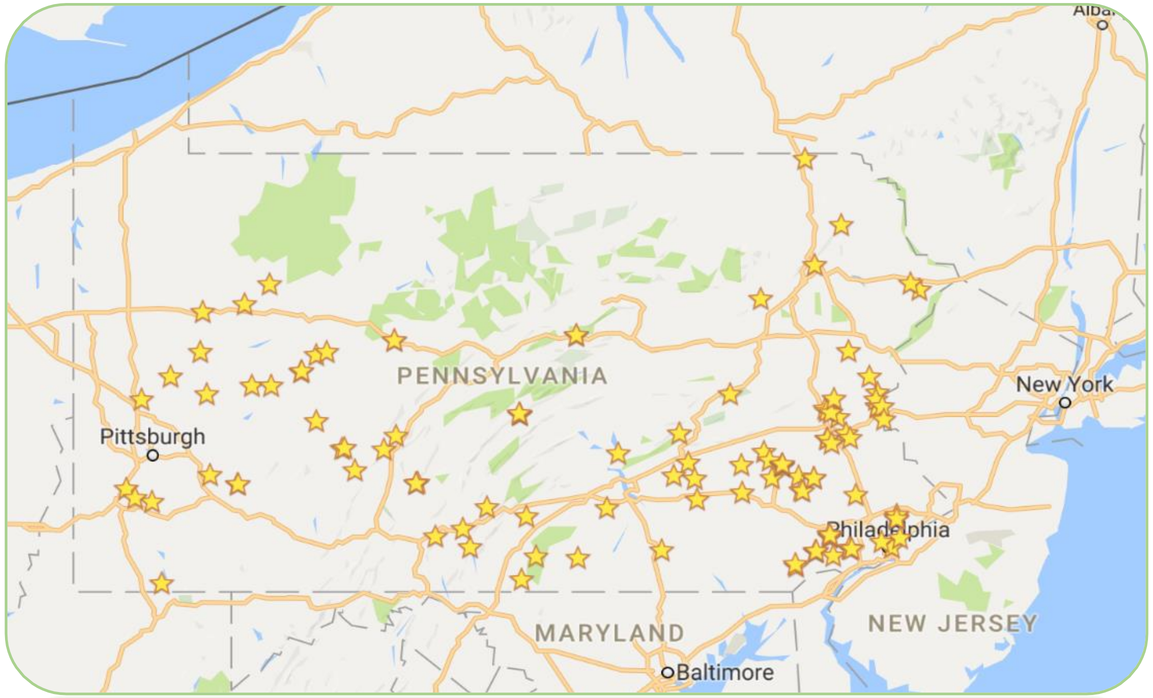
What has been the impact of these installations on safety?

Have they proven to be economical?

What types of locations should DOTs target for these treatments?

What results can DOTs expect to see?

"Review the performance of HFSTs from a safety and economic perspective through a through analysis of HFST installation projects in Pennsylvania"



pennsylvania
DEPARTMENT OF TRANSPORTATION

METHODOLOGY

VILLANOVA UNIVERSITY

Crash Data Overview

8 PennDOT District Crash Database

3322 Total Crashes from 2003-2016

Partial Sample PennDOT Resume File

MPMS 96355 Crawford SR 27 Resume

Sorted by County, Route, Segment, Offset

Date Range: 1/1/2009 to 3/16/2016

Area of Interest: (In County 20 On State Route 0027(P) Between Segment 0380 Offset 650 and Segment 0380 Offset 1150)

USER ID/QUERY ID: jgrigaloni/ 0020160316004

PENNDOT

	CRN	CO	DATE	DAY	TIME	LIGHTING	ROAD SURF	WEATHER	FAT	INJ	PED	VEH	MAX SEVERITY
1	2010093587	20	09/28/2010	TUE	08:45	DAYLIGHT	WET	RAIN	0	1	0	1	MODERATE INJURY

ENV RDWY FACTORS: NONE — HIT FIXED OBJ

MIDB 0027/0380/0704

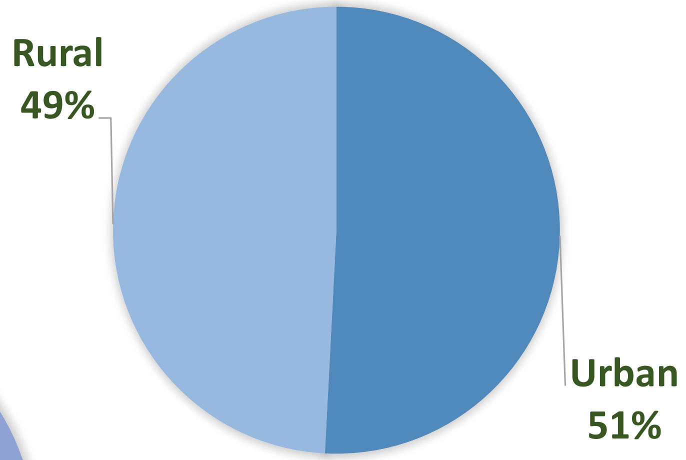
VEH: 1 AUTOMOBILE TRAVELING WEST IN RIGHT LANE NEGOTIATING CURVE - LEFT

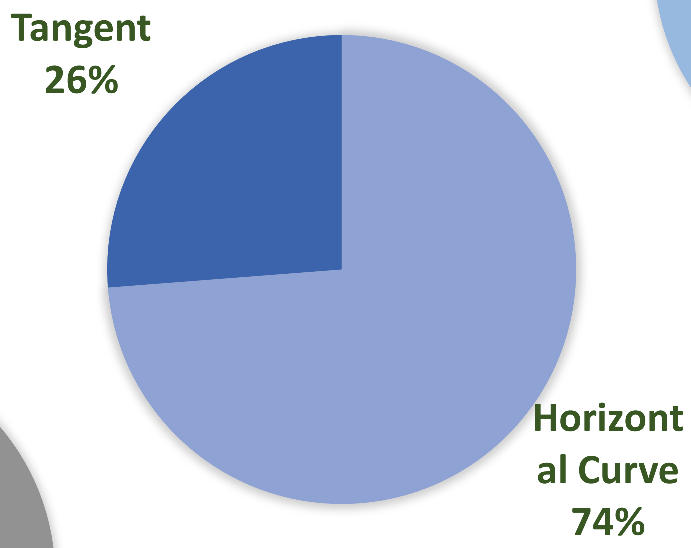
VEH EVENTS: HIT EMBANKMENT — HIT TREE OR SHRUBBERY

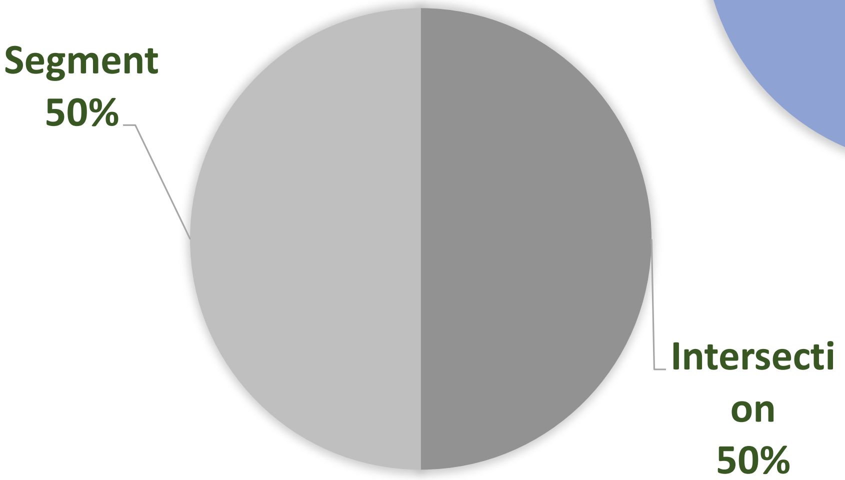
DVR ACTIONS: TOO FAST FOR CONDITIONS

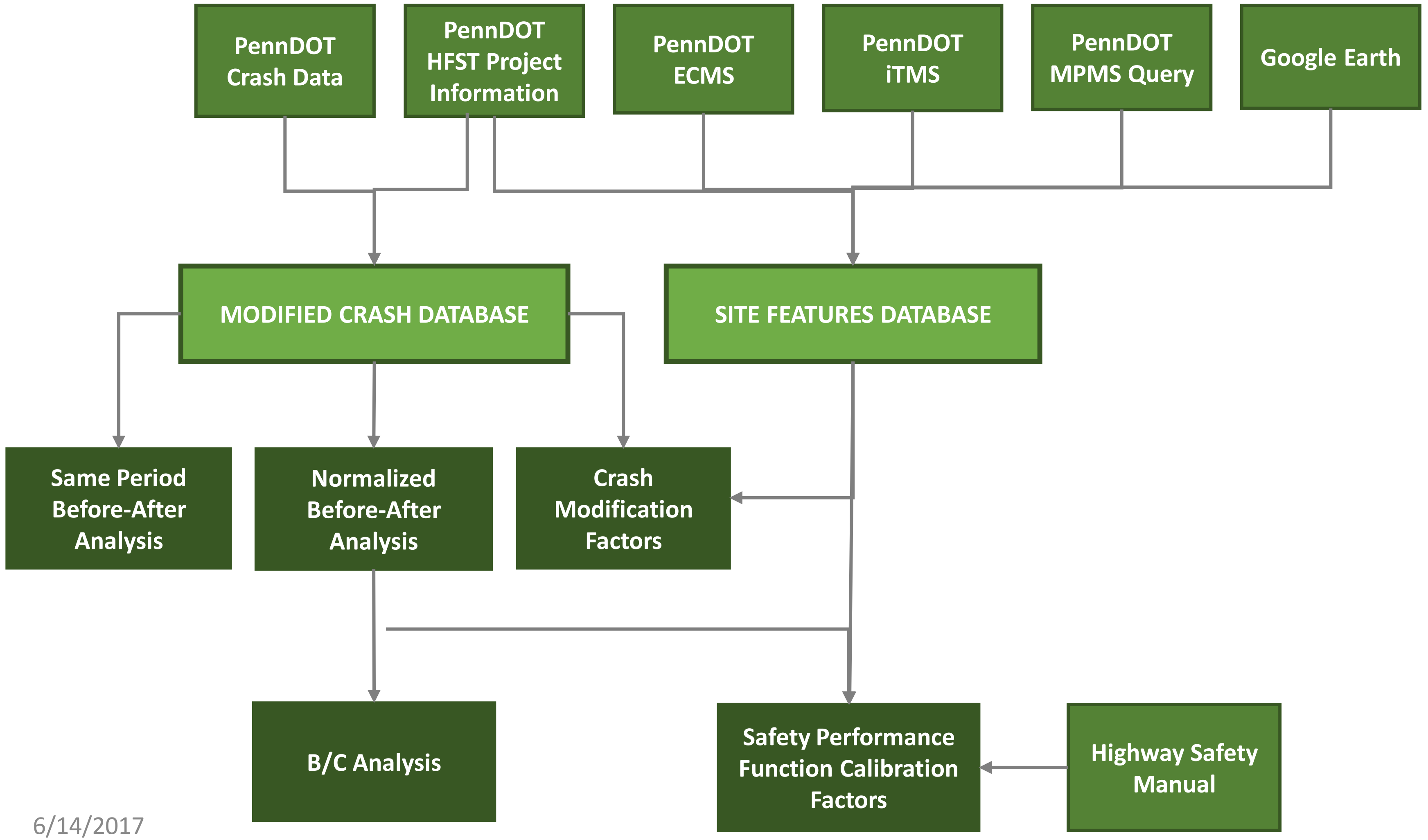
HFST Project Information

122 HFST Installation locations
Completed from 2007-2015








PennDOT Crash Data
PennDOT HFST Project Information
PennDOT ECMS
PennDOT iTMS
PennDOT MPMS Query
Google Earth
MODIFIED CRASH DATABASE
SITE FEATURES DATABASE
Same Period Before-After Analysis
Normalized Before-After Analysis
Crash Modification Factors
B/C Analysis
Safety Performance Function Calibration Factors
Highway Safety Manual

BEFORE-AFTER ANALYSIS RESULTS

TABLE 1 Simple Before-After Analysis

Crash Severity	Before	After	Crash Reduction	% Reduction
Fatal	5	0	-5	100
Major Injury	11	0	-11	100
Moderate Injury	24	0	-24	100
Minor Injury	72	0	-72	100
PDO	201	0	-201	100
Unknown Injury	31	0	-31	100
Total	**344**	**0**	**-344**	**100.0**

TABLE 2 Average Crashes Per Year Before-After

Crash Severity	Before	After	Crash Reduction	% Reduction
Fatal	2.2	0.0	-2.2	100.0
Major Injury	7.7	3.8	-3.9	50.4
Moderate Injury	22.3	5.3	-17.0	76.3
Minor Injury	59.7	4.5	-55.2	92.5
PDO	147.8	29.5	-118.3	80.0
Unknown Injury	26.3	5.3	-21.0	79.7
Total	**266.1**	**48.5**	**-217.6**	**81.8**

IMPACT OF CURVE RADIUS

High (< 300ft)
Medium (300’ – 600ft)
Low curvature (>600ft)

FIGURE 1 Examples of high, medium, and low curvature (from left to right)

TABLE 3 Average Crashes Per Year By Curvature

Crash Severity	Before	After	Reduction in Crashes	% Reduction
Low Curvature				
Death	1.1	0.0	1.1	100.0%
Major Injury	2.8	4.0	-1.3	-46.9%
Moderate Injury	6.6	5.8	0.8	12.7%
Minor Injury	16.7	2.9	13.8	82.6%
PDO	40.9	7.2	33.7	82.3%
Unknown Injury	5.3	3.2	2.1	40.0%
Total	**73.4**	**23.1**	**50.3**	**68.5%**
Medium Curvature				
Death	0.3	0.0	0.3	100.0%
Major Injury	1.0	0.7	0.4	35.6%
Moderate Injury	5.7	2.2	3.5	61.2%
Minor Injury	21.1	2.4	18.6	88.4%
PDO	39.9	6.2	33.7	84.4%
Unknown Injury	8.2	1.7	6.5	79.6%
Total	**76.2**	**13.2**	**63.0**	**82.7%**
High Curvature				
Death	0.5	0.0	0.5	100.0%
Major Injury	2.7	1.6	1.2	43.2%
Moderate Injury	6.5	0.0	6.5	100.0%
Minor Injury	15.9	0.3	15.6	98.2%
PDO	48.4	7.1	41.3	85.3%
Unknown Injury	6.5	1.0	5.5	84.9%
Total	**80.5**	**9.9**	**70.6**	**87.7%**

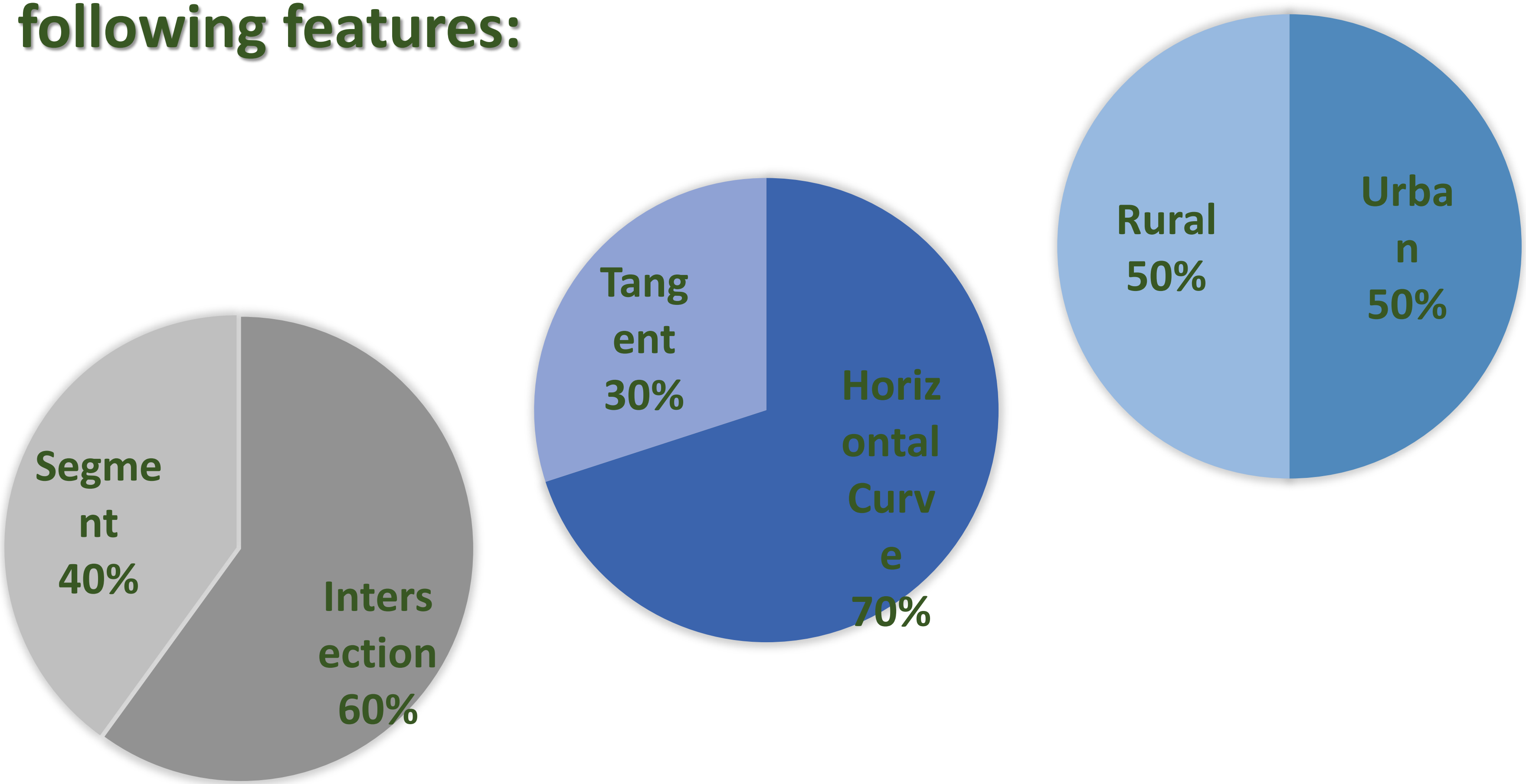
BENEFIT-COST ANALYSIS

TABLE 4 Costs Per Crash Severity

Crash Severity	Average Cost
Death	$ 6,245,689.80
Major Injury	$ 1,365,629.20
Moderate Injury	$ 91,285.40
Minor Injury	$ 7,245.00
Property Damage Only	$ 2,898.00
Unknown Injuries	$ 7,245.00

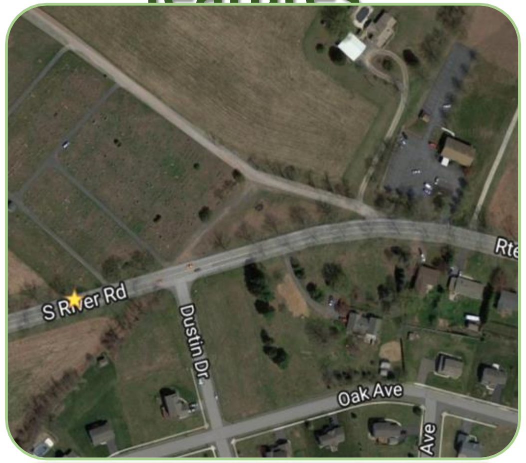
$$\text{B/C Ratio} = \frac{\text{Total Benefit from Crash Reduction}}{\text{Total Installation Costs}}$$

TOP 10% B/C Ratio were experienced by sites with the following features:

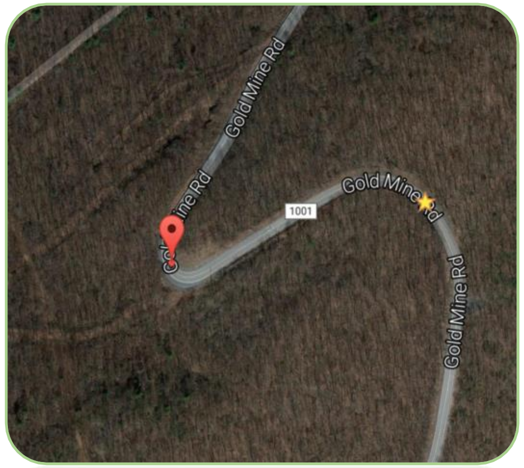


TOP 3 B/C Ratios were experienced by sites with the following features:

2-Lane
4894 ADT
4% Trucks
Urban
3-Leg Intersection
Tangent
B/C Ratio = 133



2-Lane
6253 ADT
11% Trucks
Rural
Segment
Horizontal Curve
B/C Ratio = 105



2-Lane
1488 ADT
2% Trucks
Rural
Segment
Horizontal Curve
B/C = 48

CRASH MODIFICATION FACTORS

Definition of a Crash Modification Factor

CMF
CRASH MODIFICATION FACTORS CLEARINGHOUSE

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About CMFs

A crash modification factor (CMF) is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site.

For example, an intersection is experiencing 100 angle crashes and 500 rear-end crashes per year. If you apply a countermeasure that has a CMF of 0.80 for angle crashes, then you can expect to see 80 angle crashes per year following the implementation of the countermeasure (100 x 0.80 = 80). If the same countermeasure also has a CMF of 1.10 for rear-end crashes, then you would also expect to also see 550 rear-end crashes per year following the countermeasure (500 x 1.10 = 550).

- **About CMFs**
- FAQs
- Glossary
- Star Quality Rating
- Relationship to HSM
- CMF Most Wanted List
- Submit a CMF Research Need

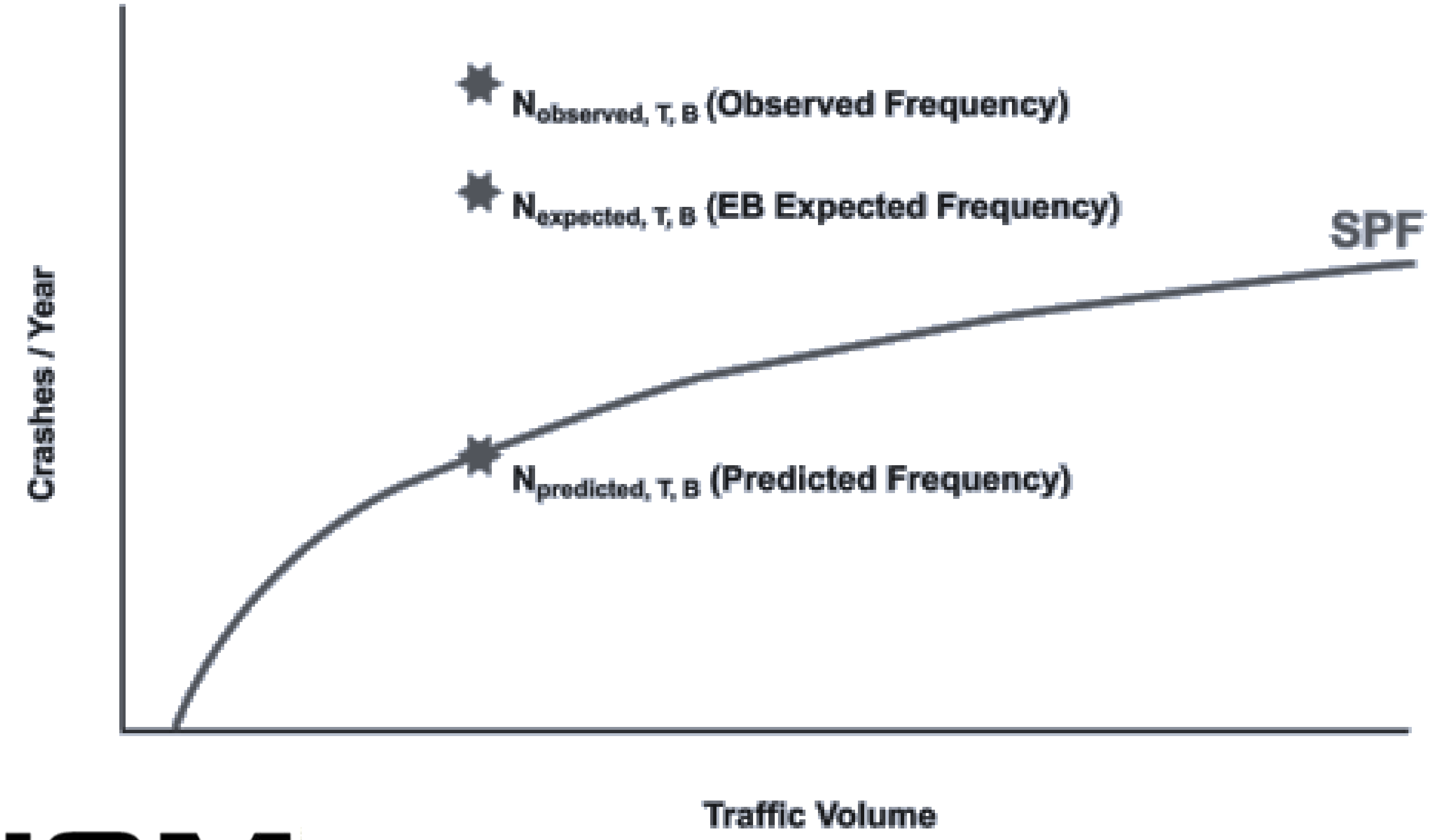

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TABLE 5 CMF for Installing HFST on Various

Facility	Number of Sites	CMF
Rural 2-Lane Intersection	26	--
Rural 2-Lane Segment	26	--
Rural Multi-Lane Intersection	0	n/a
Rural Multi-Lane Segment	8	--
Urban/Suburban Intersection	**36**	**0.55**
Urban/Suburban Segment	26	--

CONCLUSIONS
&
FUTURE RESEARCH

VILLANOVA UNIVERSITY

- **Key Findings:**
  - More than **70% reduction** in average crashes per year across **all injury categories**
  - **100% reduction** in **fatalities**

- **Conclusions:**
  - HFSTs are both an **effective** and **economical** means of improving roadway safety.
  - In order to receive the greatest safety impact and return on investment, DOTs should first target **horizontal curves** at **intersections** in both an **urban and rural** environments

- **Future Research:**
  - Complete CMF and calibration factors investigation
  - Larger dataset
  - Additional locations
  - Full Bayesian Analysis to account for regression to the mean bias for observed crashes after installation

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Questions?