

# High Friction Surface Treatment CURVE SELECTION and INSTALLATION GUIDE



U.S. Department of Transportation  
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16. Abstract High Friction Surface Treatment (HFST) is a safety countermeasure that immediately reduces crashes, injuries, and fatalities associated with friction demand issues. The treatment can help compensate for deficient geometric designs, such as sharp curves, by providing the necessary friction to maintain traction on the intended path.  This publication provides information for identifying potential horizontal curves for HFST implementation in order to improve horizontal curve safety and prevent friction-related crashes. The report concisely describes the treatment, then step-by-step explains how to; <ul style="list-style-type: none"> <li>• Identify Curves for HFST,</li> <li>• Conduct Field Verification,</li> <li>• Select Aggregate and Binder Materials,</li> <li>• Determine Application Method and Develop Specifications, and;</li> <li>• Estimate Cost and Identify Funding.</li> </ul> The publication concludes by outlining potential results and benefits of the treatment.			
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## ► Preface

In 2013, there were approximately 5.6 million crashes reported across the nation, including 32,719 fatalities and over 2.3 million injuries.<sup>1</sup> 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 when at least one of the following conditions exist:

- Vehicle friction demand outweighs available pavement friction;
- Vehicles are traveling too fast for the geometric design of the curve;
- Vehicles are traveling too fast for roadway conditions (e.g. wet weather, icy); and/or
- Pavement has been polished from wear.

### What is a High Friction Surface Treatment (HFST)?

HFST is a safety treatment that happens to be a pavement treatment. It dramatically and immediately reduces crashes, injuries, and fatalities associated with friction demand issues. The treatment can help compensate for deficient geometric designs, such as sharp curves and/or inadequate or variable superelevations, by providing the necessary friction to maintain traction on the intended path. HFSTs can also restore pavement surface friction where traffic has polished existing pavement surface aggregates. While not a substitute for corridor repaving, HFST provides significant increases in friction for spot applications (e.g., horizontal curves, steep grades, intersection approaches).

"HFST's coefficient of friction lasts longer and reduces friction-related crashes better than any other pavement treatment." -PennDOT

<sup>1</sup> Fatality Analysis Reporting System. Available at: <http://www.nhtsa.gov/FARS>.

## HFST Benefits and Effectiveness

HFST effectiveness varies by location, but overall, agencies have found that HFST can improve pavement surface friction values by up to three times the existing condition, reduce needed stopping distance by 25 to 30 percent, and provide impressive crash reductions of anywhere from 45 to 100 percent. Table 1 summarizes HFST overall crash reductions for 5 States; the crash reductions are even greater for crashes during wet road conditions.

Table 1. High Friction Surface Treatment (HFST) Effectiveness by State.

State	Number of Sites in Study	Average Total Crash Reduction	Average Wet Crash Reduction
Kentucky	Unknown	73%	86%
South Carolina	6	70%	77%
Florida	11	45%	66%

Several States have found HFST to be an ideal alternative to horizontal curve realignment, saving 90 to 98 percent in project costs.<sup>2</sup> The treatment offers many advantages over large roadway realignment projects and other pavement treatments. These advantages include:

- **Relatively inexpensive treatment.** HFST is a low-cost crash reduction treatment<sup>3</sup> capable of providing greater safety benefits than other low-cost safety measures such as advanced curve warning signs, advisory speed plaques, pavement markings, chevrons, open-graded friction course (OGFC), open graded asphalt concrete (OGAC), and guardrail when installed in appropriate locations.
- **Quick implementation.** Agencies can expect a relatively short planning process and installation timeframe, compared to other alternatives. Some agencies have reported installation in as little as 10 days for small applications or 6 months for larger projects.
- **Minimal impact to traffic.** HFST implementation requires only one lane to be closed at a time, most likely eliminating the need for a detour.<sup>4</sup>
- **Negligible environmental impacts.** The treatment is only applied between existing pavement edges and does not require disturbances to surrounding ground.<sup>5</sup> This can result in shortened environmental review periods and lessen environmental mitigation.
- **Durable and long lasting.** HFST has excellent pavement surface functional durability, having an estimated service life from 5 to 8 years for 15,000 vehicles per day, and up to 5 years with 50,000 vehicles per day.

<sup>2</sup> Interview with Darrell Chambers and Robert Peterson, California Department of Transportation, conducted on November 25, 2014. Interview with Joey Riddle and Brett Harrelson, South Carolina Department of Transportation, conducted on November 12, 2014.

<sup>3</sup> Every Day Counts 2: HFST website, available at: <http://www.fhwa.dot.gov/everydaycounts/edctwo/2012/friction.cfm>.

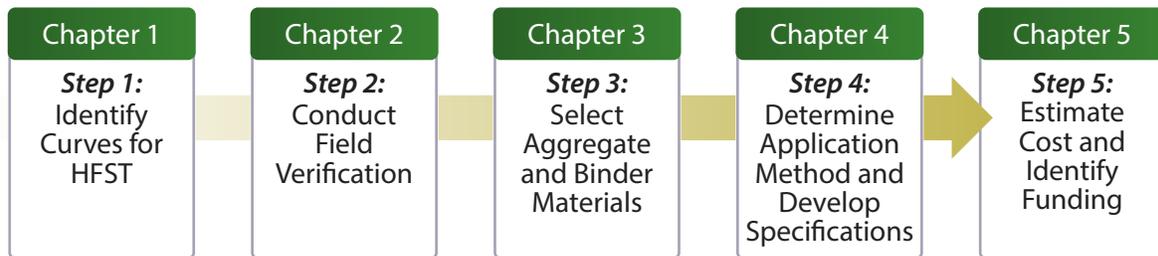
<sup>4</sup> Interview with Darrell Chambers and Robert Peterson, California Department of Transportation, conducted on November 25, 2014. Interview with Joey Riddle and Brett Harrelson, South Carolina Department of Transportation, conducted on November 12, 2014.

<sup>5</sup> Interview with Darrell Chambers and Robert Peterson, California Department of Transportation, conducted on November 25, 2014.

## Purpose and Organization of the HFST Curve Selection and Installation Guide

The purpose of this guide is to provide a step-by-step process for identifying potential curves for HFST implementation in order to improve horizontal curve safety and prevent friction-related crashes. The HFST Curve Selection and Installation Guide is organized as illustrated in Figure 1.

Figure 1. HFST Curve Selection and Installation Guide Chapter Organization.





## ► 1. Step 1: Identify Candidate Curves for HFST

Installing HFST at a few experimental locations, or spot treatments, is a valid approach as agencies test the usefulness and application of the treatment. Some States use the spot treatment approach on a large scale, consolidating multiple application locations under one contract. Other States systemically implement HFST by incorporating the treatment in agency-wide HFST initiatives, and some promote the treatment through Road Safety Audits (RSA), Roadway Departure Safety Implementation (RwD) Plans, or in Highway Safety Improvement Program (HSIP) guidelines. Implementing HFST systemically can:

- Streamline the HFST design process allowing the treatment to be applied more quickly and efficiently;
- Reduce both planning and installation costs, per location; and
- Ensure that HFST locations are tracked and are not overlaid by mistake.

Some agencies maintain a horizontal curve inventory, helping to reduce the time and resources needed to identify potential HFST sites. The inventory allows staff to overlay crashes at horizontal curve locations during crash analysis, and sync with other known horizontal curve criteria, such as superelevation, posted and advisory speeds, existing signing, etc. This speeds up the analysis process by removing an extra step as well as alleviating an initial field evaluation, in some cases.

Many States find it useful to include both safety and materials staff as the agency identifies potential locations for HFST implementation. The main criteria most States consider when choosing sites for HFST include whether the curve location exhibits:

- High Crash Frequency (e.g., wet, RwD, severity);
- Low Pavement Friction;
- Pavement Quality;
- Speed Differentials, Curve Radii, and Superelevation; and/or
- Unsuccessful Prior Low-Cost Treatment Implementations.

Within the context of FHWA's Systemic Safety Project Selection Tool, which is described in more detail in Section 1.6, these criteria would represent the risk characteristics used to identify and prioritize curve locations for HFST.

Caltrans found their biggest initial obstacle was convincing the DOT's internal materials experts that HFST was a pavement treatment used to help reduce crashes, not a pavement maintenance solution. Now, their safety and materials staff work together when narrowing candidate curves for HFST to ensure a quality produce.

Collecting information in these areas can help indicate HFST's potential to be effective at a horizontal curve. Many States found that following a data-driven process and collecting data in these areas was essential for HFST location identification. The sections within this chapter will discuss each of these criteria in greater detail.

## 1.1. High Crash Frequency

The primary reason for implementing HFST is to avoid future crashes. To maximize the actual return on investment, HFST should be applied at locations with the greatest potential to avoid the largest number of future crashes. High crash frequency is one means of estimating the frequency of future crashes that may be expected at a given location. The Highway Safety Manual, published in 2010 by the American Association of State Highway and Transportation Officials, describes limitations of relying solely on recent crash history to identify locations where treatments can be expected to have the potential to avoid the greatest number of future crashes. These limitations include the natural variability in crash frequency, regression-to-the-mean bias, and changes in roadway characteristics over time. The Highway Safety Manual provides predictive methods that address these limitations through safety performance functions and Empirical-Bayes weighting of observed crash frequencies and safety performance function estimates.

Until they implement these predictive methods, many agencies evaluate horizontal curves for safety countermeasures when they exhibit a high frequency of crashes. Some States set a threshold crash frequency, above which the curve is automatically recommended for potential countermeasure development. For instance, Tennessee Department of Transportation (TDOT) performs a safety assessment on each horizontal curve that has four or more total crashes within a 3-year period.<sup>6</sup>

Other agencies use a ranking system by developing a list of locations that exhibit a significantly high concentration of collisions. They investigate the highest ranked locations on the lists, develop a list of potential countermeasures for each location, and select as many locations as possible for treatment based on funding availability.

When selecting locations for HFST, some agencies not only look at the total crash frequency, but also at wet-crash frequency, Rwd crash frequency, and crash severity (i.e., fatal or serious injuries). For each crash, they examine the crash report narrative to determine the cause of the crash and to pinpoint the crashes' exact location within the curve. As crashes may occur or be recorded as happening before or after the horizontal curve, it is important to verify the location of the crashes in order to determine whether each crash belongs in the data set.

### 1.1.1. Wet Crashes

Wet pavement conditions can lower the available pavement friction drastically, particularly if the pavement has been polished by high friction demand. HFST is an ideal countermeasure for these conditions because it can improve pavement friction values up to 300 percent. Some agencies focus heavily on wet crashes as a HFST implementation criteria and annually identify locations that experience a high frequency of wet crashes year after year.

The process by which agencies select wet crash curve locations for potential HFST implementation varies. For example, agencies may develop a list of locations that have experienced a specified number of wet crashes within:

- A single time period (e.g., 5 or more wet crashes in 5 years); or
- Incremental time periods (e.g., 3, 6, or 9 wet crashes in 1, 2, or 3 years, respectively).

For wet crashes, agencies may even normalize the yearly wet crash frequency by historical percent wet-time values obtained per location, to understand the overrepresentation of wet crashes for locations that are either particularly wet or dry.

<sup>6</sup> Interview with Brian Hurst, Danny Lane, and Matt Givens, Tennessee Department of Transportation, conducted on December 9, 2014.

### 1.1.2. Roadway Departure Crashes

HFST is effective at combating RwD crashes on horizontal curves and, as a result, many agencies use HFST to target RwD crashes on horizontal curves by incorporating them into their Statewide RwD Safety Implementation Plan (RwDIP). In 2009, the Kentucky Transportation Cabinet (KYTC) was one of the first States to begin this process. Their RwDIP included a data analysis process that resulted in identifying 159 sections that had the potential to benefit from HFST. They selected to treat the 30 highest RwD crash locations that had a wet/dry crash ratio greater than 50 percent.

A benefit of HFST compared to other curve-related RwD countermeasures (e.g., edge line or shoulder rumble strips, edge line pavement markings, horizontal curve delineation, etc.) is that HFST does not depend on the driver to recognize the information associated with delineation or noise/vibration and make corrections. Rather, HFST interacts directly with the vehicle, independent of the driver's awareness, by providing the necessary friction needed to keep the vehicle on the roadway.

### 1.1.3. Crash Severity

While some agencies prioritize improvement locations by the frequency and severity of crashes, it is also important to capture where frequent non-severe or property-damage-only (PDO) crashes occur. These less severe crashes may be predictors of future serious injury or fatal crashes, if left untreated.

Many agencies use a weighted scale to assign either numeric or monetary values to each crash severity level, in order to capture instances where frequent, less severe crashes may accumulate to a situation that requires addressing. FHWA's Highway Safety Improvement Program Manual provides monetarily values to an injury level scale (the KABCO scale).

By using the KABCO scale, or similar, agencies may be able to identify a threshold at which horizontal curves with few fatalities or serious injuries but frequent, less severe crashes can be identified and treated.

## 1.2. Low Pavement Friction

Studies have shown that doubling pavement surface friction reduces crash frequency by half by providing a large margin of error for the drivers to compensate for their mistakes (e.g., driving too fast for conditions).<sup>7</sup> HFST can as much as triple existing pavement friction values. Thus, many States use friction values to identify curves that will benefit the most from HFST.

HFST provides high surface friction values immediately after implementation and retains those values for several years.

Pennsylvania Department of Transportation (PennDOT) uses a Skid Trailer to collect pavement friction values on curves both before and after HFST implementation, even though the instrument's main purpose is testing pavement friction on tangential section. PennDOT has found that HFST implementation provides friction values of 60+ after multiple years; whereas, a normal pavement overlay, such as micro-surfacing, has friction values of 50-55 that can reduce to the 40s within a few years.<sup>8</sup>

<sup>7</sup> FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.

<sup>8</sup> Interview with Gary Modi, Pennsylvania Department of Transportation, conducted on January 20, 2015.

At one location in Pennsylvania, HFST tripled the existing pavement friction after it was applied on a curve that had an average friction/skid value of 24. After HFST implementation, the average friction/skid value increased to 75. Three years later, the average had only decreased to 71. The location experienced 21 crashes over the 8 years before HFST was implemented and no crashes for a period of five years after implementation.

A study by Texas Transportation Institute (TTI) quantifies the increase in crash likelihood due to decreased friction values.<sup>9</sup> The study involved development of a crash modification factor (CMF) for skid numbers on two-lane rural highway horizontal curves. The study set the CMF equal to 1 for a skid number of 40. This value is not an indication that a skid number of 40 is a universal average, but rather a nominal base condition. The study found that as pavement friction increases, crash likelihood decreases, particularly for wet weather crashes. The results of the study are summarized in Figure 2.

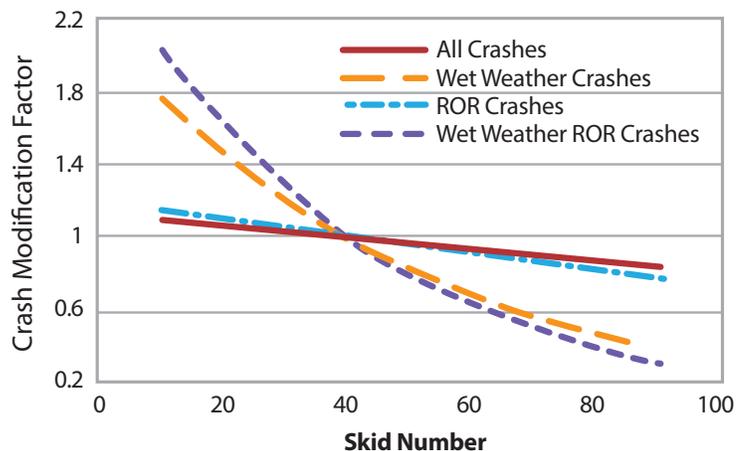


Figure 2. Skid Number CMF.

Even though some agencies assess pavement friction when considering HFST, they do not routinely collect or publish pavement friction measurements. Instead, agencies typically collect pavement friction values after site identification in order to verify and support the need for HFST. A few State DOTs systemically collect and archive pavement friction measurements in order to speed up the curve identification process.

### 1.3. Pavement Quality

Most agencies examine existing pavement and base quality when determining whether or not HFST can be used at a specific site. HFST is not intended as a repair for rutting or heaving and will not level pavements, although minor rutting or heaving is acceptable for HFST application.<sup>10</sup> Oregon Department of Transportation requires an existing pavement condition rating of Good or better prior to placing HFST.<sup>11</sup> Pavement deterioration, uneven joints, rutting, and cracks greater than ¼ inch in width and depth must be repaired at least 30 days prior to HFST installation. It is suggested that agencies not place HFST on pavement with known structural issues, or else structural pavement rehabilitation may be needed before HFST's full lifespan is realized, thereby reducing HFST's cost-effectiveness.

#### HFST Lifespan

Just like pavement performance, HFST's wear is dependent on many factors such as initial construction quality, friction demand, choice of aggregate and binder, and traffic volume as well as the severity of the climate and the weight and number of heavy truck axles. Vendors have reported life spans from 5 to 8 years for locations with 15,000 vehicles per day, and up to 5 years with location having 50,000 vehicles per day.

<sup>9</sup> Pratt, M.P., S.R. Geedipally, A.M. Pike, P.J. Carlson, A.M. Celozza, and D. Lord, *Evaluation Need for Surface Treatments to Reduce Crash Frequency on Horizontal Curves*. May 2014.

<sup>10</sup> FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.

<sup>11</sup> Oregon Department of Transportation, *GFP Pavement Condition Rating Manual*. July 2010. Available at: [http://www.oregon.gov/odot/hwy/construction/docs/pavement/gfp\\_manual.pdf](http://www.oregon.gov/odot/hwy/construction/docs/pavement/gfp_manual.pdf).

If a corridor repaving project is planned in the near future, some agencies choose to wait to implement HFST on the corridor's curves until 30 days after the repaving project is complete.<sup>12</sup> While the new pavement inherently improves roadway friction, studies have shown that standard pavement friction values quickly reduce after a few years. HFST provides greater initial and lasting friction values than new pavement and is used by some States as an enhanced friction improvement at spot locations after corridor repaving.

#### 1.4. Speed Differentials, Curve Radii, and Superelevation

On horizontal curves, a speed differential can be defined as the difference between the tangential posted speed limit and the curve advisory speed.<sup>13</sup> This measurement can sometimes be a good indicator of the usefulness of a HFST treatment. Larger speed differentials directly correspond to greater vehicle deceleration when entering the curve. If motorists do not decelerate to the curve advisory speed and/or if wet weather or low pavement friction conditions are present then the vehicle has an increased likelihood of exceeding the available pavement friction and resulting in a RwD crash. Installing HFST can provide additional friction that allows motorists to break and navigate successfully without losing control.

Advisory speed is often set based on several factors, including the speed at which motorists feel comfortable traversing the curve, which is partially determined by the curve's radius, superelevation, and sometimes vertical grade. Typically, the smaller the curve radius and/or larger the superelevation variance (actual superelevation compared to design speed superelevation), then the lower the advisory speed, resulting in a larger speed differential compared to the posted speed limit.

Studies have linked curve radii to crash likelihood. Figure 3 illustrates that as curve radius decreases, the crash rate increases. Since a smaller curve radius corresponds to a lower advisory speed and a greater speed differential, radius and speed differential can be deductively linked in many cases.

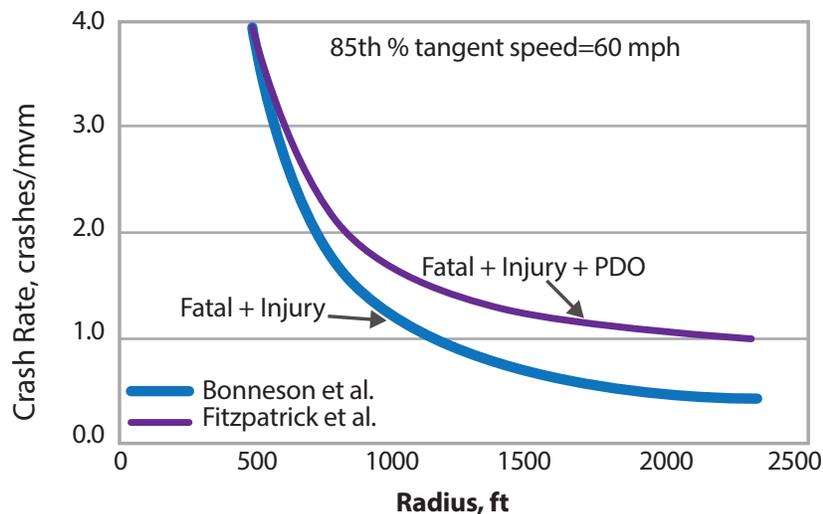


Figure 3. Curve Crash Rate as a Function of Radius.<sup>14</sup>

12 FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.

13 B. Brimley and P. Carlson, *Using High Friction Surface Treatments to Improve Safety at Horizontal Curves*. July 2012. Available at: <http://d2dtl5nnlpr0r.cloudfront.net/tti.tamu.edu/documents/TTI-2012-8.pdf>.

14 Bonneson, J, M. Pratt, J. Miles, and P. Carlson. *Development of Guidelines for Establishing Effective Curve Advisory Speeds*. FHWA/TX-07/0-5439 1. Texas Department of Transportation, Austin, Texas, 2007.

Many agencies consider the curve's speed differential – the difference between the posted speed and the curve advisory speed – when determining whether to use HFST. A greater speed differential causes vehicles to experience greater tangential and lateral accelerations if they do not heed the curve advisory speed. When coupled with low friction values brought on by polished pavement or wet weather conditions, these instances can have an even greater effect on severe curves. HFST can counteract loss of control when high friction demand from increased tangential and lateral forces exceeds normally available pavement friction. A curve's speed differential is typically not the main evaluation criteria when considering HFST, but rather another indication that HFST may be effective at certain locations.

## 1.5. Unsuccessful Prior Low-Cost Treatment Implementations

Typically, agencies first employ low-cost horizontal curve safety improvements that can be implemented immediately as a “quick fix” before progressing to a more expensive countermeasure. These may include:

- Horizontal alignment signs recommend by the Manual on Uniform Traffic Control Devices (MUTCD);
- Center line and edge line pavement markings;
- On-pavement or vertical roadside delineators;
- Advanced curve warning pavement markings; or
- Guardrail.

Signs, pavement markings, and delineation require drivers to perceive and then react to the need to slow down. Guardrails help mitigate the severity of a crash once a driver has lost control but it does not prevent the crash. If these countermeasures do not reduce crashes sufficiently, HFST may be the next likely alternative. HFST requires the driver to neither perceive nor react to a lost-control situation, rather it acts on the vehicle without involving the driver whatsoever, providing a hidden advantage.

## 1.6. Systemic Approach

For agencies with more sophisticated data analysis capabilities and good roadway inventory, the systemic approach for selecting curves for HFST installation should be considered. The following provides a general description of the Systemic Approach to Safety and provides links for resources with more details. The process may or may not lead to selecting HFST as the recommended safety countermeasure.

### 1.6.1. The Process

The Systemic Approach to Safety involves widely implementing low-cost safety improvements based on high-risk roadway features correlated with specific severe crash types. The approach provides a more comprehensive method for safety planning and implementation that supplements and complements traditional site analysis. The approach helps agencies broaden their traffic safety efforts and consider risk as well as crash history when identifying where to make low-cost safety improvements.

The Systemic Approach does not replace the need to focus on individual locations with high numbers of severe crashes; instead it provides an expanded comprehensive and proactive approach to road safety efforts. Agencies can use the Systemic Approach to address the requirements for the Highway Safety Improvement Program, which focuses on fatal and serious injury crashes on ALL public roads.

The key to the systemic approach is evaluating an entire system using a defined set of criteria, which results in an inferred prioritization that indicates some elements of the system are better candidates for safety investment than others.

### 1.6.2. Benefits of the Systemic Approach

- **Identifies “issues” based on a system-wide analysis of the data.** A significant number of severe crashes are spread over a wide area and relate to specific crash types. Some of these crashes are rarely identified through the traditional site analysis approach because it is difficult to isolate severe crash locations. The Systemic Approach provides State, regional, and local transportation agencies an alternative method to address severe, targeted crash types and fulfill a previously unmet need.
- **Looks for roadway characteristics that are frequently present in severe crashes, i.e., risk factors.** The Systemic Approach starts with a different premise for identifying safety concerns. Site analysis is based on crash history at individual locations. The Systemic Approach looks at crash history on an aggregated basis to identify high-risk roadway characteristics that may contribute to future severe crashes. The site analysis approach results in safety investments at high-crash locations and systemic leads to widespread implementation of low-cost improvements to reduce the potential for severe crashes.
- **Focuses on one or more low-cost countermeasures that can be deployed widely across the system while identifying and prioritizing implementation locations.** The Systemic Approach considers multiple locations with similar risk characteristics. When examining the system as a whole, a particular roadway characteristic may contribute to frequent or severe crash experiences. It is more cost-effective to correct the issue on a system-wide basis rather than by individual crash location which facilitates a wider deployment of low cost countermeasures.

### 1.6.3. Challenges

Just as specific processes for conducting site analysis vary widely, the Systemic Approach used by individual agencies will vary. Some of the challenges include the following:

- Data availability dictates the level of detail in the analysis. While a systemic analysis can be completed with nearly any amount of data, using more data will allow for refinement of potential risk factors.
- The availability of resources determines the extent of improvements that can be made. Resources may also impact the level of analysis that can be completed.
- The established priorities of an agency may define the direction of the analysis.
- The relationship between State and local transportation agencies may impact the funding available for systemic analysis on non-State routes as well as the extent to which systemic improvements are applied to non-State routes.

#### 1.6.4. Resources

More information on the Systemic Approach to Safety is available at the following resources:

- *A Systemic Approach to Safety – Using Risk to Drive Action* on FHWA’s Office of Safety website.<sup>15</sup>
- *FHWA’s Systemic Safety Project Selection Tool* is a guide that includes a step-by-step process for conducting systemic safety analysis; analytical techniques for determining a reasonable balance between the implementation of spot safety improvements and systemic safety improvements; and, a mechanism for quantifying the benefits of safety improvements implemented through a systemic approach.<sup>16</sup>
- The *United States Road Assessment Program* (usRAP) is a validated system of protocols for rating roadway segments for safety. Using video logs coded in 100-meter segments, usRAP produces a proactive safety investment plan based on the observed design features of the road. usRAP’s predictive modeling ensures that highway authorities can make data-driven safety management decisions—even before deaths and injuries occur, or in the absence of crash data. FHWA cites specific tools, such as usRAP, as an example of ways to implement safety analysis approaches, not as an endorsement of usRAP over others. The Roadway Safety Foundation is the primary supporter of usRAP. Contact the Roadway Safety Foundation at [info@roadwaysafety.org](mailto:info@roadwaysafety.org).

<sup>15</sup> FHWA Systemic Approach to Safety website, available at: <http://safety.fhwa.dot.gov/systemic/index.htm>.

<sup>16</sup> FHWA Systemic Safety Project Selection Tool, available at: <http://safety.fhwa.dot.gov/systemic/fhwasa13019/>.

## ► 2. Step 2: Conduct Field Verification and Design

Field verification is an important step in determining whether HFST could be implemented, and if implemented, the limits of the HFST installation. Below is a check list of items that may be considered during a field review.

- ☑ **Select an Appropriate Timeframe.** Consider scheduling field reviews to correlate with the primary conditions of collision patterns: time of day, day of week, season (e.g., winter, summer), pavement conditions (e.g., wet, dry), light conditions (e.g., dark, daylight), etc.
- ☑ **Physically Locate Crashes.** Bring a populated crash report diagram so that crashes within the curve can be easily located and studied during the field visit. Having a better understanding of crash contributing factors and location within the curve can help determine whether HFST is a viable solution and identify the limits of implementation.
- ☑ **Record Roadway and Traffic Characteristics.** Drive through the location several times to observe roadway and traffic characteristics, driver responses, signs, signals, and pavement markings. Observe drivers to determine behavior at the location. Take photo and/or videos and maintain a log of all photos and videos taken: location, direction, date and time of photo/video, photographer's name, etc. When possible, take a series of panoramic photos. Measure, document, and confirm a variety of data such as:
  - Presence of skid marks or trees missing bark where vehicles have made impact within the curve;
  - Presence and condition of previous low-cost countermeasures (e.g., signing, pavement markings);
  - Damage to roadside barriers;
  - Superelevation;
  - Speed advisory measurements;
  - Point of Curvature (PC) and Point of Tangent (PT) of the horizontal curve;
  - Horizontal and vertical sight distances;
  - Intersections near or within the curve;
  - Whether any of the "curve-related" crashes are incorrectly categorized and may actually be intersection-related;
  - Heavy vehicle use (especially where vehicles frequently use winter tire chains); and
  - Speed differentials between the advisory speed and the posted speed limit.

- Determine HFST Start and End Points.** Identify exact limits of the application if HFST is chosen as a safety countermeasure. Typically, HFST is installed at the point where vehicles start to brake. Brake lights are a good indication of where treatment could start, as the intention is to slow down the drivers as they are going into the curve. Many agencies end their treatment at the PT.<sup>17</sup> The Texas Transportation Institute published a paper that provides further recommendations on how to select start and end points for HFST installation.<sup>18</sup>
- Conduct a Friction Test.** Lower friction values have been shown to increase crash frequency. Typical means to determine friction include the British Pendulum Test (BPT), the Dynamic Friction Tester (DFT), the Griptester, and the Locked Wheel Skid Trailer.<sup>19</sup> While agencies set different thresholds for satisfactory pavement friction, it is generally accepted practice to focus on pavement sections where skid numbers are below 30.
- Check Pavement Condition.** If not already known, collect a pavement core sample to determine the pavement's composition, age, and quality. Also, conduct a visual inspection and record any defects in the pavement that will need to be repaired prior to HFST installation (e.g., cracks, pot holes, unstable joints, etc.). A pavement condition rating of "Good" or better is needed prior to placing HFST.<sup>20</sup>
- Screening Sample Questions.** These questions may be considered while conducting a field review. The answers to some may indicate that HFST is not the best solution. Due to the site-specific nature of some of the questions, they cannot be applied universally.

  - Are the collisions related to physical conditions of the location?
  - Are existing signs, delineation, and pavement markings accomplishing their purpose? (I.e., Are there too few or in poor shape? Are they visible?)
  - Are there any specific traffic movements to be prohibited or favored?
  - Is special nighttime enhancement needed? Is existing lighting satisfactory? Are existing signs and delineation visible and retro-reflective at night?
  - Are selective enforcement or maintenance procedures needed?
  - Is parking contributing to collisions? Is sight distance impaired by the parking?
  - Are there adequate advance guide signs so that motorists may choose proper lanes and directions well in advance of need?

<sup>17</sup> FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.

<sup>18</sup> B. Brimley and P. Carlson, *Using High Friction Surface Treatments to Improve Safety at Horizontal Curves*. July 2012. Available at: <http://d2dt15nnlpr0r.cloudfront.net/tti.tamu.edu/documents/TTI-2012-8.pdf>.

<sup>19</sup> American Traffic Safety Services Association, *Safety Opportunities in High Friction Surfacing*. February 2013.

<sup>20</sup> Oregon Department of Transportation, *GFP Pavement Condition Rating Manual*. July 2010. Available at: [http://www.oregon.gov/odot/hwy/construction/docs/pavement/gfp\\_manual.pdf](http://www.oregon.gov/odot/hwy/construction/docs/pavement/gfp_manual.pdf).

## ► 3. Step 3: Select Aggregate and Binder Materials

HFST improves roadway surface friction by increasing pavement roughness. The treatment is composed of a thin layer of specially engineered, durable, high-friction aggregate bonded to the existing pavement by a thermosetting polymer resin binder as illustrated in Figure 4. The binder locks the aggregate firmly in place, creating an extremely rough, hard, durable surface capable of withstanding everyday roadway demands, such as heavy braking and even snowplowing. In fact, snowplowing can further roughen HFST by breaking the aggregate into more angular bits, which increases the pavements friction level even further.<sup>21, 22</sup> This section will discuss the various aggregates and binders that can be used for HFSTs.

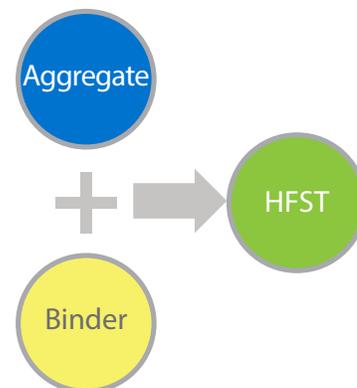


Figure 4. HFST Components.

### 3.1. HFST Aggregates

HFST aggregates, typically between 3 to 4 mm in size, come in different sizes with varying friction values and durability. Once the binder has been applied to the pavement surface, the aggregate is spread on top of the binder. Currently, calcined bauxite is the most widely used HFST aggregate in the United States and the only aggregate recommended by FHWA.

Calcined bauxite is the only aggregate recommended by FHWA.

The National Center for Asphalt Technology (NCAT) report released in 2015 titled High Friction Surface



SOURCE: Federal Highway Administration

Treatment Alternative Aggregates Study showed that of all aggregates tested, the calcined bauxite, shown in Figure 5, produced the greatest initial and long-term friction values, proving it to be the most durable and wear resistant aggregate used for HFST.<sup>23</sup> All aggregates tested, and a description of their composition, included:

- **Calcined bauxite** is a mineral derived from aluminum ore that, when heated to a high temperature, increases in physical hardness and stability.
- **Taconite** is an iron bearing sedimentary rock that contains quartz, chert, or carbonate.
- **Basalt** is a volcanic rock formed by the rapid cooling of lava which is rich in magnesium and calcium oxides. It is one of the most common rocks found on Earth.
- **Emery** is a rock containing corundum (aluminum oxide) and iron oxide that has been used as an abrasive in products such as sandpaper.

21 FHWA's Every Day Counts HFST - A Road Surface Treatment for Critical Safety Spot Locations that Helps Vehicles Stay in Their Lane. Available at: <http://www.fhwa.dot.gov/everydaycounts>.

22 FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.

23 National Center for Asphalt Technology, Asphalt Technology E-News. Volume 26, Number 2. Available at: <http://www.eng.auburn.edu/research/centers/ncat/info-pubs/newsletters/fall-2014/traction.html>.

- **Flint silica** is an oxide categorized as a microcrystalline variety of quartz. It occurs chiefly as nodules and masses in sedimentary rocks, such as chalk and limestone.
- **Granite** is a combination of quartz and potassium feldspar. Its mineral composition and interlocking crystals result in hardness and abrasion resistance.
- **Silica sand** is an oxide made up of broken down quartz crystals taken from sedimentary rocks that form naturally in nature.
- **Steel slag** is an impurity by-product of steel production, consisting of a complex solution of silicates and oxides.

### 3.2. Bonding Agents

HFST binder choice may be influenced by cost, climate, road volume, binder availability, and vendor selection. HFST's overall durability can vary as a result of the chosen binder, which are spread on the pavement surface before aggregate is applied.

Typical HFST binders are the following:<sup>24</sup>

- **Epoxy-Resin** is a binder system consisting of an epoxy resin and a hardener that are mixed together at the treatment site, most commonly in equal quantities by volume. This system possesses high strength and good adhesion properties to asphalt and concrete pavements. The epoxy system is waterproof after cure but requires a dry surface during the installation process. Currently, epoxy-resin is the most commonly used HFST binder and has shown good performance over time.
- **Rosin-Ester** is a thermoplastic binder applied to the aggregate during the manufacturing process, prior to delivery. On site, the dried aggregate binder mixture is heated causing the binder to melt. The melted binder bonds the aggregate to the pavement surface as it cools. The binder is ideal for rapid curing, allowing the roadway to reopen to traffic once the roadway surface reaches an ambient temperature.
- **Polyurethane-Resin** is a multi-component binder system that is most often mechanically mixed and dispensed on site. This binder retains some flexibility, reducing issues with brittleness and breakage. Polyurethane systems can be installed at cooler temperatures, but often have a sensitivity to any moisture present during the installation process.
- **Methyl Methacrylate (MMA)** is a two-component binder that can be mixed and spread either mechanically or manually over the treatment surface. MMA systems typically have lower strength than the other binder systems. The binder is waterproof after cure but is moisture-sensitive during curing. The advantage often considered for using an MMA binder system is its ability to gain strength and return traffic to the roadway quickly in cool temperatures.
- **Polyester-Resin** is a multi-component binder that is mixed and spread either mechanically or manually over the treatment surface. It retains high strength and is known to have better UV stability than many other systems. The binder is waterproof after cure but is moisture-sensitive during curing. The polyester system is reacted with a catalyst and an accelerating agent to adjust the rate of cure. This is advantageous in cooler temperatures as many other binder systems, such as epoxy, cure much slower in cooler temperatures.

<sup>24</sup> American Traffic Safety Services Association, *Safety Opportunities in High Friction Surfacing*. February 2013.

Epoxy binder systems typically take the longest to cure in cooler temperatures. Catalyzed binder systems such as the MMA and polyester systems can be adjusted to cure faster in cooler temperatures. The curing times discussed in this section are estimated based on average ambient temperatures (approximately 70 degrees Fahrenheit). In comparatively colder or warmer climates, ideal binders for projects may vary due to temperature fluctuations.<sup>25</sup> Table 3 summarizes binder curing times.

Table 2. Potential HFST Binders<sup>26</sup>

Binder	Quickest Curing Time*	Curing Temperature
Epoxy-Resin	3 - 4 hours	70+ F
Rosin-Ester	As soon as it reaches ambient temperature	ambient temperature
Polyurethane-Resin	2.5 hours	
Methyl Methacrylate	1.5 hours	<20F to 100+F
Polyester-Resin	2 hours	<40F to 100+F
*All manufactured binder systems have temperature limitations for installation. Read the individual manufacturer's requirements prior to use.		

<sup>25</sup> American Traffic Safety Services Association, *Safety Opportunities in High Friction Surfacing*. February 2013.

<sup>26</sup> Ibid.



## ► 4. Step 4: Determine Application Method and Develop Specifications

Once HFST has been selected for use, it is appropriate to evaluate site specific specifications and implementation controls. This section will help answer the following questions:

- What kinds of pavement preparation is required to install HFST?
- Are applications constrained by weather?
- How is HFST typically applied? What equipment is required? Which application method is better for my situation?
- What do HFST specifications entail? Are resources available?

### 4.1. Application Methods

HFST can be implemented using any of three main application methods: fully-automated, semi-automated, and manual. The preferred application method varies and can depend on the size of the project, the number of installations within the contract, and specific project needs.

For instance, manual installation may be used for small spot-treatments while a fully-automated process might be used for larger systemic contracts consisting of numerous sites. Most transportation agencies contract out their HFST installations, which is done primarily to avoid purchasing HFST-specific equipment.

This section briefly describes the differences between manual, semi-automated, and fully automated application methods.

#### 4.1.1. Manual

Manual HFST application, shown in Figure 6, is ideal for small spot locations of 200 sq. yd. or less. For a completely manual application, the binder components and any additives that affect curing time are manually mixed on site in buckets. Workers pour the mixed binder onto the prepared surface and spread it using squeegees. Next, the aggregate is spread on top of the binder. There is no preferred method to spread the aggregate, but the binder must be completely covered.



SOURCE: DBI Services

Figure 6. Manual Application.

While the manual application method is ideal for keeping costs low on small spot-treatments, this method has a few drawbacks. Working under live traffic conditions increases safety risks by prolonging workers' exposure to traffic. Further, given the opportunity for human error and inconsistency, quality and uniformity in manually applied treatments are a concern. In addition, the prolong presence of work zone can potentially cause secondary crashes.

When agencies plan to apply HFST at several locations or on a long roadway section, the semi-automated and fully-automated approaches may be preferred as they provide a higher-quality application at a less-expensive cost point.

#### 4.1.2. Semi-Automated

Semi-automated HFST application involves a combination of manual labor and machine-aided application. The exact combination of manual and automated application largely depends on the type of application truck. The simplest trucks are equipped with a wide spreader bar that distributes either the aggregate or the binder. More expensive trucks are equipped with any combination of a mixing machine, binder spreader, and aggregate spreader.

The Kansas Department of Transportation (KDOT) and the Montana Department of Transportation (MDT) both use trucks that mix the binder components and additive (proportional to the ambient temperature) to ensure proper curing time. The truck then pours the binder out a spigot located directly behind the truck (Figure 6) as the truck slowly drives down the lane. Workers use squeegees to evenly spread the binder behind the truck. A 15-20 ft. arm stretching behind the truck distributes the aggregate onto the recently squeegeed binder (Figure 7).

This semi-automatic method allows the roadway surface to be covered more quickly than manual application methods and the onboard mixer ensures a quality binder that will cure at current temperatures. On larger projects, the reduced labor hours can offset the cost of the additional equipment resulting in a lower installation unit cost. There are tradeoffs associated with increased labor using the manual method versus the need and cost for more equipment using the automated method; the semi-automatic method falls somewhere in between.



SOURCE: MYDOT/Transtec Group

Figure 7. Semi-Automated Binder Pour Spigot.



SOURCE: MYDOT/Transtec Group



SOURCE: KSDOT/Transtec Group

Figure 8. Semi-Automated Aggregate Spreader.

### 4.1.3. Fully-Automated

Fully-automated HFST application, shown in Figure 8, typically involves a truck customized to mechanically mix each component of the binder, in accordance with the current ambient or surface temperature, and apply a consistent layer of the binder and aggregate to the pavement surface, without any manual squeegeeing or spreading. The truck contains the binder and aggregate in large bulk containers on its chaise and can be customized to the intended width and thickness of the treatment. It can install as much as 2600 sq. yd. in 12 foot widths before the need to refill. This application method minimizes lane closures due to quick installation time, reduces the number of workers on the roadway, ensures a more quality application, and reduces overall project costs on large systemic installations.<sup>27</sup>



SOURCE: DBI Service

Figure 9. Fully-Automated Installation.

### Manual vs. Fully-Automated Comparison<sup>28</sup>

At an infrastructure maintenance symposium held in Columbus, Ohio, a manual application of HFST was compared with a fully automated application. The manual application used a crew of 5 with bucket and rubber squeegees. The fully-automated HFST process installed 350 sq. yd. of full lane width in approximately 8 minutes, while the manual application installed 100 sq. yd. in 15 minutes, exhibiting that the fully-automated process can be 6 times as faster as the manual process. Benefits of using the fully-automated processes include:

- Improved speed and quality result in reduced installation time;
- 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.

<sup>27</sup> <http://www.dbiservices.com/high-friction-surfacing-treatment>.

<sup>28</sup> DBI Services HFST Automated Manual Comparison Video: <https://www.youtube.com/watch?v=jetAFKWm-Vw>.

## 4.2. HFST Application Specifications

HFST is best applied on a clean and dry surface that is free of debris and standing or accumulated water throughout installation. The ambient temperature must be above the binding material's manufacturer recommendations. In general, ambient temperatures need to be between 50 to 100 degrees Fahrenheit, preferably between 60 to 95 degrees Fahrenheit. Temperatures outside this range may affect working time for installing or curing the material as well as the final strength of the product. Many polymers, such as epoxy resins, will not reach their fully designed strengths when cured at lower temperatures. This can result in early loss of aggregates and premature wear in the wheel path. However, some manufacturers have developed binders or binder additives that enable the binder to perform well at lower temperatures.<sup>29</sup> Always refer to the manufacturer's instructions to ensure the best quality performance of each application.

Detailed HFST specifications for eight States and the United Kingdom Highway Agency can be found on ATSSA's High Friction Surface website.<sup>30</sup> Additional provisional high friction surface treatment standard specifications can be found in AASHTO's Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 35th Edition and AASHTO Provisional Standards, 2015 Edition.<sup>31</sup>

Surface preparation, cleanliness, as well as good pavement and weather conditions at the time of installation are all necessary for successful HFST installations.

## 4.3. Application Lessons Learned

Several leading HFST implementation States shared the lessons they learned over copious installations. Caltrans found that if the aggregate is unevenly applied to the binder, the binder might intersperse into the aggregate at different rates, creating a slight rumble in the roadway surface. Excess materials need to be removed soon after application to provide a uniform surface.

North Carolina Department of Transportation (NCDOT) and Colorado Department of Transportation (CDOT) discovered that a combination of two different issues occurring simultaneously caused the underlying asphalt pavement to delaminate. The first was associated with poorly draining pavement that trapped water underneath the HFST. The second was cracking of the underlying asphalt pavement that reflected through the HFST. Even though these issues caused the asphalt to delaminate, the HFST remained intact on the asphalt material.<sup>32</sup>

States also encountered problems when installing HFST on open-grade concrete. The HFST tends to sink into the gaps in the OGAC. To solve this, States applied two layers of HFST. The first layer filled gaps while the second layer provided the needed friction and ensured a good bond and service life.<sup>33</sup> Double layers may also be used on roads where snow chains or studded tires are common.<sup>34</sup>

<sup>29</sup> FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.

<sup>30</sup> <http://www.highfrictionsurface.net>.

<sup>31</sup> [https://bookstore.transportation.org/item\\_details.aspx?id=2347](https://bookstore.transportation.org/item_details.aspx?id=2347).

<sup>32</sup> FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.

<sup>33</sup> Interview with Darrell Chambers and Robert Peterson, California Department of Transportation, conducted on November 25, 2014.

<sup>34</sup> FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.

## ► 5. Step 5: Estimate Costs and Identify Funding

This section discusses how to estimate HFST implementation costs and potential means of funding the safety improvement.

### 5.1. Cost

Costs will fluctuate based on choice of aggregate, binder, and application method. Many agencies can find the lowest unit cost when they are able to get two or more contractors to compete for the project.

On average, the cost breakdown for HFST installation is approximately comprised of 50 percent for labor and application and 50 percent for materials (i.e., aggregate and binder). Of the materials cost, roughly two-thirds of that cost can be attributed to the binder, as approximated in Figure 10.<sup>35</sup> Most of the aggregates used for HFST generally range from \$350 to \$500 per ton.

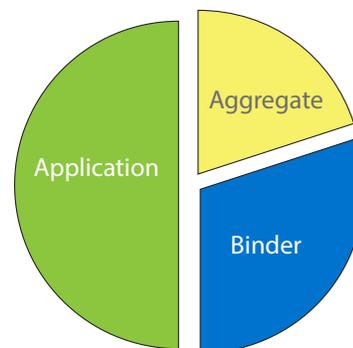


Figure 10. HFST Cost Breakdown Approximation.

States' HFST unit costs range from \$22 to \$35 per sq. yd. Typically, unit costs are lower when:

- A large volume of HFST is to be applied at a single location or multiple small installations are bundled into a single contract;
- HFST is only one component of a larger contract; or
- HFST installers directly perform the application rather than hiring a general contractor to then subcontract the work.

Other factors affecting unit cost are the amount of traffic control needed, availability of staging areas, and agency specification requirements.<sup>36, 37</sup>

Overall, HFST's benefit-cost ratio is high since the crash reductions are typically drastic and continue for many years indicating a positive return on investment for each dollar spent on the treatment. SCDOT found a benefit-cost ratio of about 24 to 1 during a before and after study for a series of HFST curve installations.<sup>38</sup> A report commissioned by Transit New Zealand showed a benefit-cost ratio of 40, whereas Virginia Tech Transportation Institute (VTTI) found that HFSTs produce benefit-cost ratios ranging between 2.23 and 8.45.<sup>39, 40</sup> TTI estimates HFST return on investment to be approximately five-fold if an initial application prevents one fatal or injury crash (valued at over \$158,000). If a fatality is averted, the return is over 100 times the amount invested.<sup>41</sup>

<sup>35</sup> FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.

<sup>36</sup> Ibid.

<sup>37</sup> Interview with Joey Riddle and Brett Harrelson, South Carolina Department of Transportation, conducted on November 12, 2014. Interview with Gary Modi, Pennsylvania Department of Transportation, conducted on January 20, 2015.

<sup>38</sup> FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.

<sup>39</sup> Every Day Counts HFST Fact Sheet Brochure. Available at: [www.fhwa.dot.gov/everydaycounts](http://www.fhwa.dot.gov/everydaycounts).

<sup>40</sup> Izeppi, Edgar, Gerardo Flintsch and Kevin McGee. *Field Performance of High Friction Surfaces*. Virginia Transportation Research Council, Richmond, June 2010.

<sup>41</sup> B. Brimley and P. Carlson, *Using High Friction Surface Treatments to Improve Safety at Horizontal Curves*. July 2012. Available at: <http://d2dtl5nnlpr0r.cloudfront.net/tti.tamu.edu/documents/TTI-2012-8.pdf>.

The exact nature of each particular installation and the problem it addresses will have a direct bearing on the exact benefit-cost ratio that can be achieved, but in general, HFSTs have shown to produce a significant return on investment in a short period of time.

## 5.2. Funding

HFST qualifies for Federal funding under the Highway Safety Improvement Program (HSIP), which is geared toward reducing crashes, fatalities, and injuries on all public roads. While each State's process varies, local agencies can apply to receive funding for HFST projects within their jurisdiction.

In the past, the Federal Highway Administration (FHWA) has matched HFST project costs through a 90/10 split utilizing funds in the HSIP program. In the future, the Federal government may cover the entire cost.<sup>42</sup>

PennDOT's HFST projects have been entirely funded through the HSIP program, which allocated \$8 million to be spent over two years using the treatment. TDOT primarily utilizes HSIP funds for HFST projects, and supplements with 23 U.S.C. 154 Open Container funds, to cover 100 percent of project costs. Caltrans has completed and/or planned approximately 139 HFST projects on their State highway system using HSIP funding, with an additional 30 to 40 completed and/or planned on the local system.

<sup>42</sup> Interview with Darrell Chambers and Robert Peterson, California Department of Transportation, conducted on November 25, 2014.

## ► 6. Conclusion

With over 28 percent of all highway fatalities in the United States occurring at or near horizontal curves, it is imperative that transportation professionals continue to identify and implement horizontal curve safety improvements. This guide presented a five-step process for identifying and implementing HFST on horizontal curves which can help practitioners direct financial resources to locations with potential for the greatest benefit.

When used appropriately, HFST may provide up to a return of 100 times the original investment if one fatality is averted during its lifespan.<sup>43</sup> Currently, HFST qualifies for Federal funding under the Highway Safety Improvement Program with up to a 90/10 Federal/State match, which may increase to being fully-funded in the future.

<sup>43</sup> B. Brimley and P. Carlson, *Using High Friction Surface Treatments to Improve Safety at Horizontal Curves*. July 2012. Available at: <http://d2dtl5nnlpr0r.cloudfront.net/tti.tamu.edu/documents/TTI-2012-8.pdf>.



## ► Appendix A - HFST Curve Identification Summary

The process of identifying curves for HFST varies by agency. Questions agencies may ask while identifying candidate curves for HFST include:

- Is there an existing safety issue?
  - » Is wet weather contributing to the issue?
  - » Is the friction demand outweighing available friction?
- Are speed differentials, the difference between the tangential posted speed limit and the curve advisory speed, contributing to crash frequency?
- Are prior low-cost treatments not sufficiently effective?

These questions can be answered and navigated using a decision tree. Figure 11 displays a possible decision tree scenario that agencies may use when considering HFST. After evaluating the effectiveness of multiple HFST implementations, agencies may migrate from spot treatments to systemic implementation, which both streamlines the HFST design process and reduces costs. Table 3 displays the HFST feasibility criteria considered by four States, each of whom have or are planning to implement HFST at 25 to 150 locations. Agency's process may vary from information presented in this chapter.

Table 3. HFST Considerations by Agency.

	Crash Frequency	Wet Crashes	RwD Crashes	Skid/ Friction Values	Curve Speed Diff.	Prior Treatments Installed	Pavement Quality	Spot/ Systemic Identification and/or Implementation
SCDOT	X	X	X	X	X	X	X	<b>Systemic</b> – State RwD Plan
Caltrans	X	X	X			X	X	<b>Spot Treatment</b> Bundles projects into large contracts
PennDOT	X	X		X	X	X	X	<b>Systemic</b> – Statewide HFST initiative
TDOT	X	X	X	X		X	X	<b>Systemic</b> – Statewide HFST initiative
KYTC	X	X	X	X		X	X	<b>Systemic</b> – Statewide HFST initiative

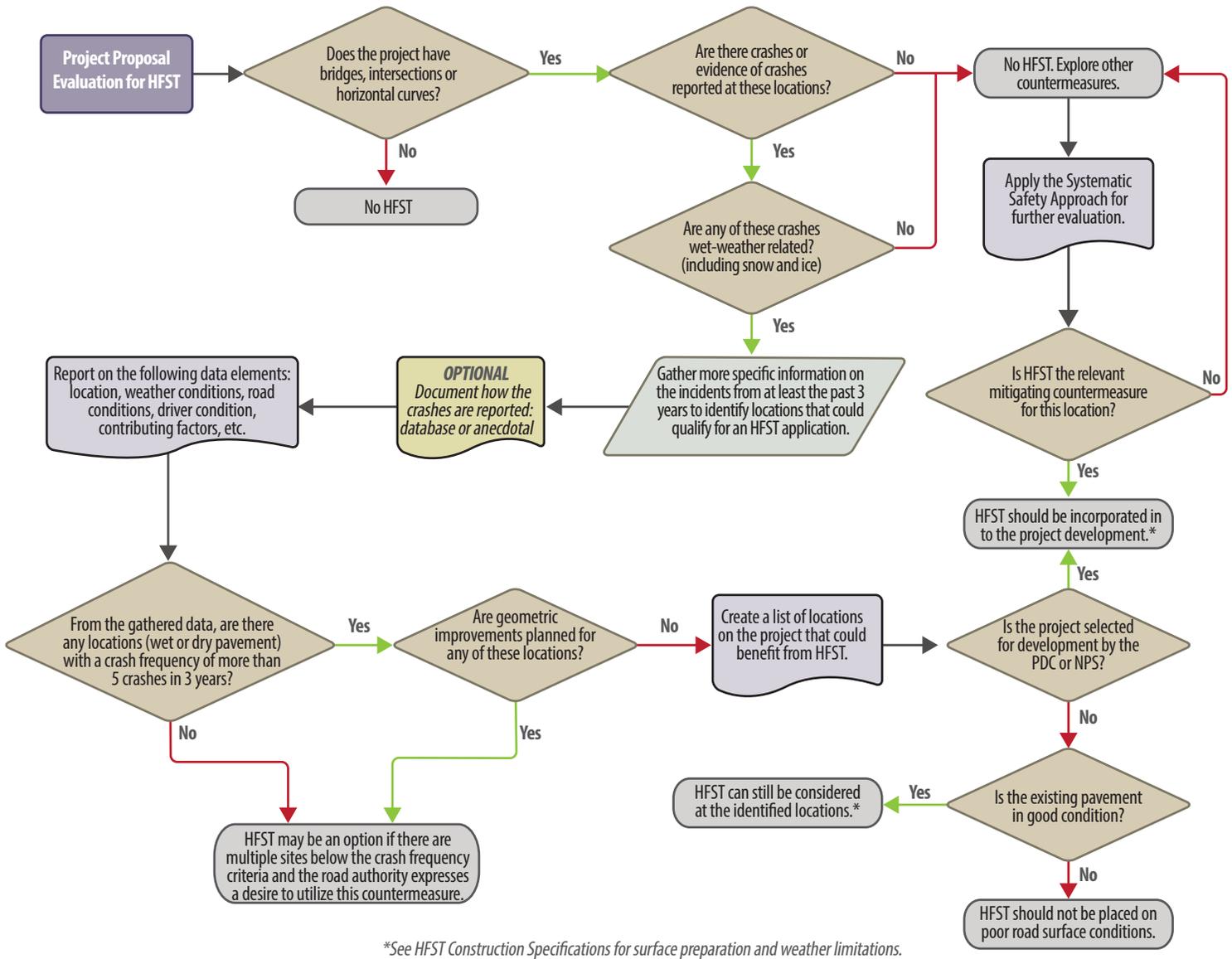


Figure 11. Identifying HFST Appropriateness and Feasibility on Horizontal Curves Flow Chart.

## ► Appendix B - Other HFST Potential Locations and Uses

HFST is an appropriate safety countermeasure for locations where friction demand is an issue, other than horizontal curves. Such locations typically requiring large changes in tangent or lateral (centrifugal) acceleration. HFST is a cost-effective countermeasure for these locations because it enhances pavement friction in critical braking or cornering maneuvers. Several States have emphasized HFST success at the following locations.

**Specific highway locations, on- and off-ramps, transition lanes, and tolling areas** are subject to large speed differentials and changes in acceleration.

**High-speed signalized intersections** exhibit greater longitudinal force friction on approaching vehicles that are decelerating for a red signal indication and/or turn maneuvers. Increasing friction at these locations is especially important for those with sight distance deficiencies as perceived stopping distance may be inadequate.

**Bridge decks** tend to polish and wear more quickly due to vertical and lateral forces as vehicles bounce or skip from uneven grades on the bridge approach slab.

**Steep vertical grades** can be challenging for large commercial vehicles traveling up or down the grade. Areas where pavement friction demands for passenger cars are met might be insufficient for large commercial vehicles.

**Environmental restrictions** at any of the above locations could hinder countermeasure development. HFST is ideal for environmental restricted locations because the treatment is only applied between existing pavement edges and does not require disturbances to surrounding ground.

Excessive braking at these locations due to speed differentials, sharp curves, and intersection approaches can prematurely polish pavement surfaces, reducing the pavement friction. In such instances, the reduced friction can contribute to vehicles losing control or skidding when they speed, turn abruptly, or brake excessively, particularly during wet conditions. Reduced friction levels also increase a vehicle's required stopping distance, thereby affecting the likelihood of a collision.

HFST has also proven to be an effective treatment at approaches to **railroad crossings, schools, and trail crossings**. In addition, HFST has been used to delineate and improve traction on **bicycle lanes**. Since durability is typically not an issue, the treatment is often installed using a dyed aggregate such as glass, instead of calcined bauxite, which clearly delineates the bicycle lane from the motor-vehicle lanes. It also provides a smoother riding surface and improved friction with no negative safety effects.<sup>44</sup>

There are scenarios for which HFST is not ideal. Some States have indicated that they do not apply HFST on Interstates where heavy trucks frequently use chains in winter because this depletes the life of HFST significantly.<sup>45</sup> Other States have found that applying a double layer of HFST at such locations can help minimize the effect of the chains.<sup>46</sup>

<sup>44</sup> FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.

<sup>45</sup> Interview with Darrell Chambers and Robert Peterson, California Department of Transportation, conducted on November 25, 2014.

<sup>46</sup> FHWA's High Friction Surface Treatments Frequently Asked Questions. Publication No. FHWA-CAI-14-019.











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