

# IMPROVING HIGHWAY SAFETY THROUGH PAVEMENT FRICTION MANAGEMENT PROGRAMS

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## ABSTRACT

In recent years, there has been a major increase in activities related to improving highway safety in the U.S. Much of the emphasis has been placed on driver behavior (e.g., addressing aggressive, distracted, and impaired driving and the neglected use of seat belts) and roadway design (e.g., geometrics, roadside, and traffic control features), and this has led to updated FHWA regulations and guidance regarding the Highway Safety Improvement Program and major research publications, such as the NCHRP 500-series reports (*Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*) and the 2010 American Association of State Highway and Transportation Officials (AASHTO) *Highway Safety Manual* (first edition).

A similar upswing in activities has taken place with regard to the safety of pavement surfaces. Following efforts in the mid-1990s to comprehensively examine pavement surface characteristics (PSCs) (e.g., texture, friction, noise, hydroplaning potential), FHWA has developed policy guidance for *Surface Texture for Asphalt and Concrete* (Technical Advisory T5040.36) (2005), AASHTO has published the *Guide for Pavement Friction* (2008), and FHWA has developed policy guidance on *Pavement Friction Management* (Technical Advisory T5040.38) (2010).

Building off these and other PSC-related technical advancements, and recognizing the need to apply pavement friction management (PFM) concepts and technologies in the U.S., the FHWA has sponsored a major, multi-year study to develop and demonstrate PFM programs at four state highway agencies (SHAs) using guidance contained in the *AASHTO Guide for Pavement Friction*. In Phase 1 of the two-phase study, a review of past efforts of quantifying the relationship between friction/texture and crashes was done, along with a review of both U.S. and International pavement safety programs/practices. In addition, a detailed evaluation of currently available friction/texture measurement equipment was performed to identify those best suited for the PFM programs to be developed in Phase 2 of the study.

This paper discusses the examination of past studies investigating the friction/texture–crash relationship and the review of pavement safety programs/practices. It presents the main conclusions of these two research activities, as they relate to the planned development of PFM programs in four states (yet to be identified).

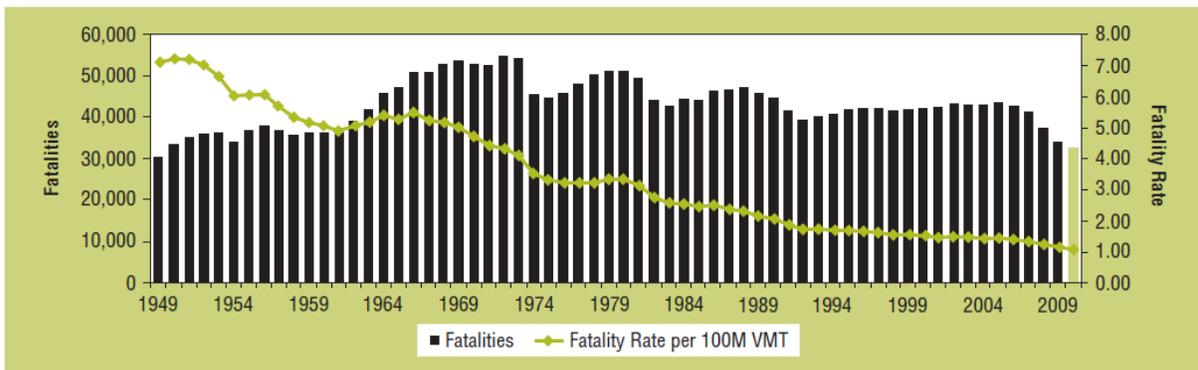
# 1. INTRODUCTION

## 1.1. Background

Highway safety is a critical transportation issue in the United States (U.S.). As reported by the National Highway Traffic Safety Administration (NHTSA), a total of 5,419,000 crashes on the nation's highways in 2010 resulted in nearly 33,000 fatalities and 2,300,000 injuries (NHTSA 2012). These crashes are estimated to cost society hundreds of billions of dollars per year in medical, emergency services, property damage, and lost productivity, based on past estimates by the NHTSA (Blincoe et al. 2002), the Transportation Construction Coalition (TCC) (Miller and Zaloshnja 2009), and the American Automobile Association (AAA) (Cambridge Systematics 2011).

For many years, the U.S. Department of Transportation (DOT) has tracked the total number of highway fatalities and the corresponding highway fatality rate (number of fatalities per 100 million vehicle miles travelled [VMT]). It has also tracked injuries associated with highway crashes and the corresponding injury rate (number of injuries per 100 million VMT). The DOT has had a long-standing goal of reducing the fatality rate by a certain amount over a certain time period; the most recent goal being a reduction from 1.5 fatalities per 100 million VMT in 2003 to 1.0 fatality per 100 million VMT in 2008 (Ostensen 2005).

As figure 1 indicates, the number of fatalities has fluctuated but slowly decreased since peaking in 1972 (NHTSA 2010). And, while the number remained above 40,000 through 2007, considerable drops occurred in 2008 (37,262), 2009 (33,808), and 2010 (32,885) (NHTSA 2012). With respect to the fatality rate, this figure shows a long continuous reduction extending back to the mid-1960s. And, although the most recent fatality rate goal was not achieved (1.26 versus 1.0 in 2008), the rate has continued to edge down reaching 1.14 in 2009 and 1.09 in 2010 and estimated to reach 1.04 in 2011 (NHTSA 2011). Higher fuel prices and the recession have likely contributed to the recent decline in the number of fatalities—VMT decreased by about 2 percent between 2007 and 2010—however, recent safety-related engineering activities are believed to be making significant contributions.



1949–1974: National Center for Health Statistics, HEW, and State Accident Summaries (Adjusted to 30-Day Traffic Deaths by NHTSA)  
FARS 1975–2009 (Final) 2010 Annual Report File (ARF); Vehicle Miles Traveled (VMT): Federal Highway Administration.

Figure 1. Fatality and fatality rate trends in the U.S.—1950 through 2010 (NHTSA 2012).

Figure 2 shows the annual number of injuries and the injury rate for a shorter time period—1988 through 2010. Like the fatality rate, the injury rate has shown a gradual reduction over time. The number of injuries has shown only one notable upswing in the early to mid 1990s. Unlike fatalities which stayed constant for several years following this upswing, injuries began decreasing steadily within 2 to 3 years after the upswing—an effect attributed in large part to the increased use of seat belts and child safety seats, more and improved vehicle safety features (air bags, electronic stability control systems), and reductions in drunk driving (Starnes 2008). Highway safety measures (increased use of edge and centerline rumble strips, improved signing [chevrons, etc.] and striping) may have also been contributing factors.

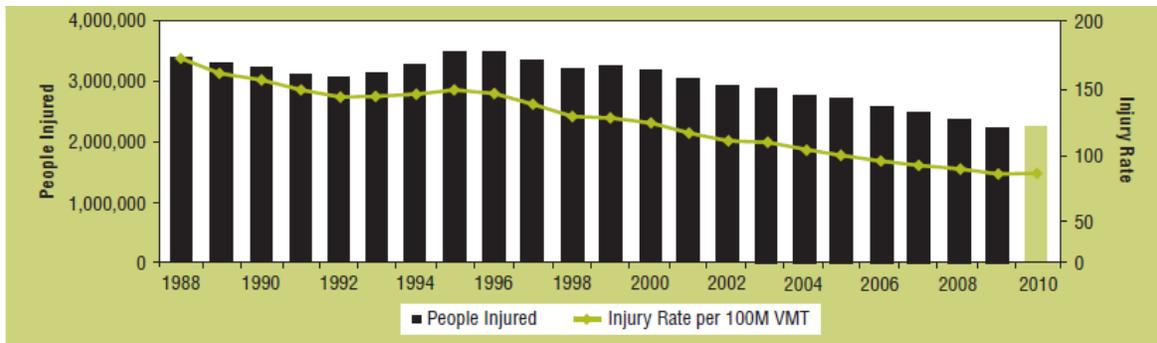


Figure 2. Injury and injury rate trends in the U.S.—1988 through 2010 (NHTSA 2012).

Recently, the U.S. safety goal has been revised from the fatality rate-based goal to fatality number goal. The new goal is to reduce the number of fatalities in half in 20 years (time period of 2010-2030). In addition, the American Association of State Highway and Transportation Officials (AASHTO) have endorsed the Global Safety Initiative to reduce fatalities in half in 10 years (2010 to 2020) and there is growing support for the *Towards Zero Deaths* program championed by the Minnesota Department of Transportation (DOT) and AASHTO.

The United Kingdom (U.K.) is one of several European Union (EU) countries that has reduced fatalities in half over a 20-year span—from 5,402 in 1990 to 2,337 in 2009 (ERF 2011). Because the baseline from which these countries' improvements have been made is higher as compared to the U.S. baseline—fatality rates at the beginning of the 20-year time period were considerably higher than in the U.S.—the U.S.'s new safety goal is considered to be quite lofty. However, one state has nearly accomplished this goal in the past—New York reduced fatalities from 2,217 in 1990 to 1,156 in 2009—and a few others (e.g., California, Connecticut, Massachusetts, Washington) have shown significant reductions (greater than 40 percent) over that same 20-year time period (U.S. Census Bureau 2012).

There are a number of factors that contribute to the high number of traffic crashes and the resulting fatalities and injuries. The factors fall under three broad categories, as follows:

- Human (driver and/or passenger behaviour)—Factors include aggressive, distracted, and impaired driving and the neglected use of seat belts.
- Vehicle (design and condition)—Factors include mechanical deficiencies, such as steering or braking failures and inoperative safety restraint/impact systems.

- Roadway environment (design and condition)—Factors include roadway geometry (horizontal and vertical curves, lane configurations and widths), roadside design (e.g., shoulders and slopes, guardrails and median barriers), traffic control features (e.g., signs, signals, and striping) and pavement surface characteristics (PSCs) (e.g., friction, texture, profile, and roughness) and conditions (e.g., potholes, drop-offs).

Although the exact percentages are unknown and certainly vary over time and by location, it is commonly accepted that human factors play a predominant role in highway crashes, followed by roadway factors and vehicle factors, and that a significant level of interaction between two or all three categories takes place. For example, AASHTO referenced a 1979 report by Indiana University (*Tri-Level Study of the Causes of Traffic Accidents*) that estimated human factors contributed to about 93 percent of all crashes, while roadway factors and vehicle factors contributed to about 34 and 13 percent of crashes, respectively (AASHTO 2010). Similarly, Herbel et al. (2010) referenced a 1996 New South Wales (Australia) Roads and Traffic Authority that approximated the relative contributions of driver, vehicle, and roadway factors shown in figure 3.

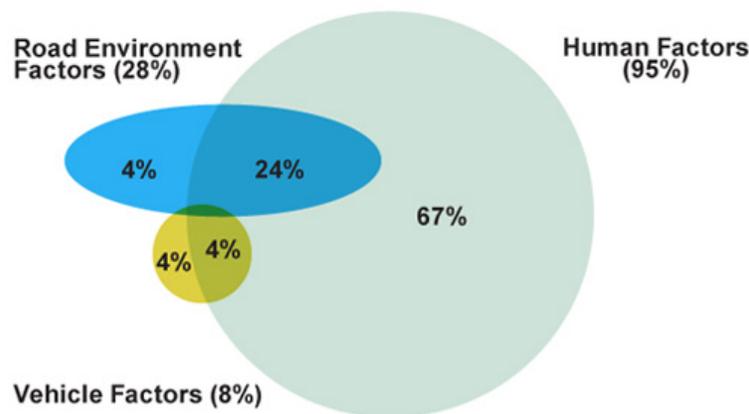


Figure 3. Approximation of the relative contribution of driver, vehicle, and roadway factors in highway crashes in New South Wales, Australia (Herbel et al. 2010).

An evaluation of U.S. traffic crashes in 2006 indicated that roadway condition—defined to include up to 22 specific conditions, including non-functioning traffic control devices, traffic congestion, pavement crown and superelevation issues, wet and/or icy pavement surfaces, and inadequate road geometrics—was a contributing factor in 31.4 percent of the total 16.95 million crashes, 52.7 percent of the 42,642 fatalities, and 38.2 percent of the 5.75 non-fatal injuries (Miller and Zoloshnja 2009). Although this and other studies have not evaluated the relative contribution of PSCs to crashes (and to fatalities and injuries), a 1980 report by the National Transportation Safety Board (NTSB) concluded that, in the U.S., fatal accidents occur on wet pavements at a rate of between 3.9 and 4.5 times the rate of occurrence on dry pavements (IIHS 1980). The NTSB and the Federal Highway Administration (FHWA) have also reported that 13.5 percent of fatal crashes and 18.8 percent of all crashes occur when the pavement surface is wet (Dahir and Gramling 1990; FHWA 1990). The literature also supports that up to 70 percent of the wet-pavement crashes can be prevented or minimized by improved pavement friction and texture (Henry 2000).

## 1.2. Safety Improvement Activities

Most past safety improvement efforts in the U.S. have focused on driver behavior and vehicle design factors, as well as roadway geometric design and traffic safety features. The regulations and guidance put forth in the FHWA Highway Safety Improvement Program (HSIP), the NCHRP 500-series reports (*Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*), and AASHTO *Highway Safety Manual* represent major advancements in the latter category of safety improvements. And, the on-going Strategic Highway Research Program (SHRP) 2 highway safety focus area represents a major effort to evaluate the roles of both the driver and the vehicle in highway crashes and near crashes.

A similar upswing in activities has taken place with regard to the safety of pavement surfaces. Following efforts in the mid-1990s to comprehensively examine (PSCs), FHWA has developed policy guidance for *Surface Texture for Asphalt and Concrete* (Technical Advisory T5040.36) (2005), AASHTO has published the *Guide for Pavement Friction* (2008), and FHWA has developed policy guidance on *Pavement Friction Management* (Technical Advisory T5040.38) (2010).

Building off these and other PSC-related technical advancements, and recognizing the need to apply pavement friction management (PFM) concepts and technologies in the U.S., the FHWA has sponsored a multi-year study to develop and demonstrate PFM programs at four state highway agencies (SHAs) using guidance contained in the AASHTO *Guide for Pavement Friction*. In Phase 1 of the two-phase study, a review of past efforts of quantifying the relationship between friction/texture and crashes was done, along with a review of both U.S. and International pavement safety programs/practices. In addition, a detailed evaluation of currently available friction/texture measurement equipment was performed to identify those best suited for the PFM programs to be developed in Phase 2 of the study.

This paper discusses the examination of past studies investigating the friction/texture–crash relationship; it summarizes the important aspects of the studies and describes/illustrates the main approaches used to link friction/texture with crashes. This paper also discusses the review of pavement safety programs/practices, ranging from those driven solely by crash information to those that utilize both network-level friction and crash data. Lastly, this paper presents the main conclusions of these research efforts, as they relate to the planned development of PFM programs in four states (yet to be identified).

## **2. EXAMINATION OF STUDIES INVESTIGATING THE RELATIONSHIP BETWEEN PAVEMENT FRICTION/TEXTURE AND CRASHES**

Although most highway crashes involve multiple causative factors, research has consistently shown a basic link between crashes and pavement surface conditions/characteristics, such as friction and texture. The link is most profound when wet pavement conditions exist in conjunction with low friction levels and moderate-to-high traffic speeds, but there are also indications that dry pavements with inadequate friction can adversely affect the number or rate of roadway crashes.

As discussed above, a detailed examination was performed of past studies that investigated the friction/texture-versus-crashes relationship. The main goal of this examination was to provide benchmark information for the PFM programs to be developed

in Phase 2, particularly as it relates to (a) establishing a framework for continually monitoring the safety of pavements, (b) identifying the best friction/texture measurement equipment to drive the PFM program (i.e., equipment uniquely capable of predicting crashes or crash severity levels for a variety of roadway conditions and circumstances), and (c) establishing effective investigatory and intervention friction/texture levels.

The detailed examination was primarily focused on studies done in the last 5 to 10 years. Similar efforts by Cairney (1997) and Hall et al. (2009), which synthesized works from the 1960's through the early 2000's, were recognized and briefly reported. In all, approximately 25 different studies (excluding those presented in Cairney [1997] and Hall et al. [2009]) were examined, about half of which were represented by state DOTs (e.g., Florida, Virginia, Ohio, New York, North Carolina) and the USDOT/FHWA and the other half by highway agencies in other countries (e.g., UK, Australia, Saudi Arabia, Canada, New Zealand, and Switzerland). Each examination culminated in a study summary consisting of the following items:

- Physical scope of the study and timeframe.
- Area of safety interest and crash types.
- Types of friction/texture and crash data evaluated.
- Analysis technique used.
- Findings/results of the study.

Table 1 provides a synopsis of the studies in terms of the above five items. In some studies, specific segments of highways or specific highway corridors were analyzed for friction/texture and crashes, whereas in others a particular network of roads was selected for the analysis. The analysis intervals varied between 1 and 8 years, with before-and-after comparisons typically represented by longer intervals. And, as table 1 shows, the data used in analyses were primarily from the 1998 to 2005 time frame.

Various areas of safety interest were covered in the subject studies, with hot-spots, intersections, and curves being the most common. Likewise, various types of crashes were included in the investigations, with all crashes, intersection crashes, and rear-end crashes being the most common.

The state DOT studies typically involved the locked-wheel friction tester FN statistic. Generic surface texture types and surface material types served as an analysis variable in a couple state studies, and one state examined the relationship between macrotexture and crashes. Foreign country studies generally sought to identify friction/texture–crash correlations using SCRIM friction data or macrotexture data.

As table 1 shows, a variety of crash data types were used in the studies. Most analyzed total and/or wet pavement crashes or the corresponding total and/or wet crash rates, while some focused on the wet-to-dry or wet-to-total crash rates. To normalize crash numbers involving highways in two different climatic regions with distinctly different percentages of wet pavement time, one study used a crash statistic referred to as the liquid precipitation safety ratio (LPSR).

With the exception of one study that directly compared the year-to-year crash rates and wet-to-dry crash ratios of pavement with different surface texturing, the studies were organized around the following three basic methods of examining the friction/texture–crash relationship:

Table 1. Synopsis of studies reviewed for friction/texture-versus-crashes relationship.

Review Item	Aspects Covered in Studies
Physical scope	<ul style="list-style-type: none"> <li>• Highway segments: state trunk highways, interstates</li> <li>• Highway corridors: interstates, US routes, state routes</li> <li>• Highway networks: interstates, freeways, 2-lane roads, multi-lane divided and undivided roads, strategic routes, principal roads, main distributor roads</li> </ul>
Spans of years for data analyzed (and corresponding timeframe of data)	<ul style="list-style-type: none"> <li>• 1 year (2002)</li> <li>• 2 years (2004-2005), (2006-2007), (2007-2008)</li> <li>• 1-3 years (early 2000s)</li> <li>• 3 years (2003-2005), (2006-2008)</li> <li>• 4 years (1999-2002)</li> <li>• 5 years (2002-2006) (2005-2009), (1998-2002)</li> <li>• 6 years (1996-2002)</li> <li>• 7 years (depending on location, a 7-year period between 1995 and 2005)</li> <li>• 8 years (1991-1998)</li> </ul>
Area of safety interest	<ul style="list-style-type: none"> <li>• Hot-spot locations</li> <li>• Intersections (signalized and unsignalized, major and minor)</li> <li>• Congested freeways</li> <li>• Curves (horizontal and vertical)</li> <li>• Roundabouts</li> <li>• Interchange ramps</li> </ul>
Crash types	<ul style="list-style-type: none"> <li>• All crashes</li> <li>• Intersection crashes</li> <li>• Rear-end crashes</li> <li>• Run-off-road crashes</li> <li>• Rear-end/side-swipe crashes</li> <li>• Rollover crashes</li> <li>• Jackknife crashes</li> <li>• Object-in-road crashes</li> <li>• Fixed object crashes</li> </ul>
Type of friction/texture data (and measurement equipment)	<ul style="list-style-type: none"> <li>• Locked-wheel FN (FN40S, FN40R, FN20S, FN20R, FN60S, and FN60R)</li> <li>• Generic surface texture types (e.g., PCC with different types of tining, HMA with different aggregate gradations, high-friction surfaces)</li> <li>• High-speed profiler EMTD</li> <li>• Generic surface material types (HMA overlay, PCC, microsurfacing)</li> <li>• SCRIM SFC and SCRIM MSSC</li> <li>• Multi-laser profilometer SMTD</li> <li>• SPTD</li> <li>• Mu-meter FN</li> </ul>
Type of crash data	<ul style="list-style-type: none"> <li>• Total crashes or total crash rate (all components or just severe [fatal/serious])</li> <li>• Wet pavement crashes, wet crash rate</li> <li>• Dry pavement crashes, dry crash rate</li> <li>• Wet-to-dry crash ratio</li> <li>• Wet-to-total crash ratio</li> <li>• LPSR</li> <li>• Time of day crashes (day vs. night)</li> <li>• Seasonal crashes</li> </ul>
Analysis technique	<ul style="list-style-type: none"> <li>• Direct comparison</li> <li>• Before-and-after comparison</li> <li>• Comparison to the norm</li> <li>• Regression analysis</li> </ul>

EMTD: Estimated mean texture depth.

LPSR: Liquid precipitation safety ratio.

SFC: Side-force friction coefficient.

MSSC: Mean summer SCRIM coefficient.

SMTD: Sensor measured texture depth.

SPTD: Sand-patch texture depth

- **Before-and-After Comparison**—In this method, crash data and/or friction/texture data prior to and after a resurfacing event along a stretch of roadway are collected and analyzed to determine the extent of crash reduction effected by the resurfacing activity. An example illustration of this method is provided in table 2, which shows crashes prior to and after the application of an asphalt rubber porous friction course (AR PFC) on an interstate roadway in Texas (RPA 2008).
- **Comparison to the Norm**—In this method, sites or locations where skid crashes occurred are identified and the associated friction/texture values at these sites are compared with values at a number of randomly selected control sites that are representative of the distribution of friction/texture found on the road network. An example illustration of this method is provided in figure 4.
- **Regression**—This method entails plotting one variable (e.g., wet-weather crashes) as a function of another (e.g., friction/texture) and observing how changes in one variable relate to changes in the dependent variable. Typically, data from a large number of sites are compiled and plotted so as to show the relationship between crashes and friction/texture over a wide range of values encountered. An example illustration of this method is provided in figure 5.

Table 2. Example illustration of before-and-after analysis methodology (RPA 2008).

Year	Prior to Application of AR PFC			After Application of AR PFC		
	2001	2002	2003	2004	2005	2006
Total No. of Accidents	25	48	36	17	6	22
Dry Weather Accidents	10	22	13	16	5	21
Wet Weather Accidents	15	26	23	2	1	1
Fatalities	0	1	5	0	0	1
Total Injuries	25	16	21	6	2	13
Incapacitating Injuries	6	4	3	0	1	0
Non-incapacitating Injuries	19	12	18	6	1	5
Annual Rainfall (in)	42.9	36.0	21.4	52.0	22.3	34.7
Total Rain Days (>0.1 in)	57	58	37	70	45	43

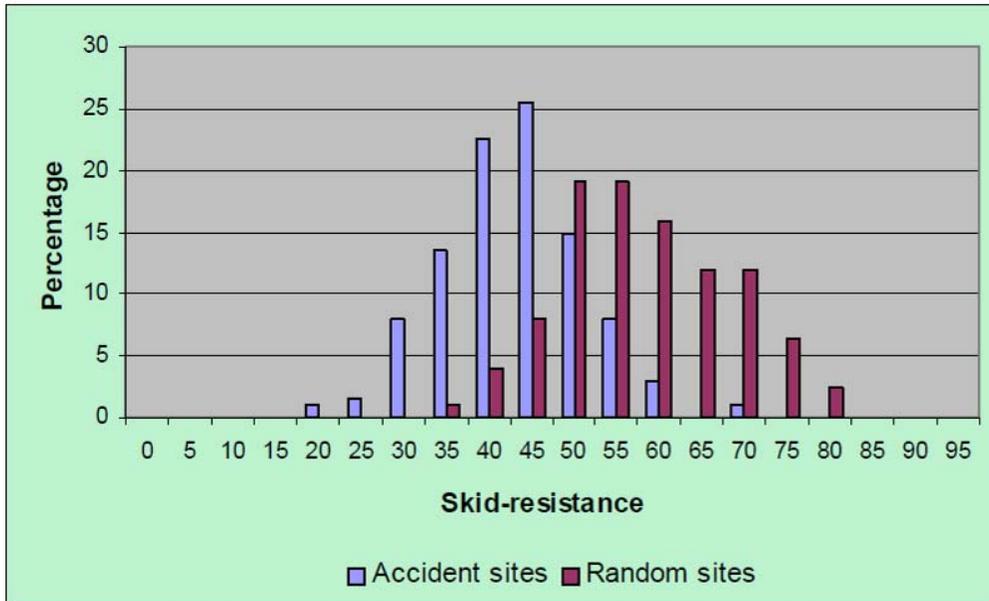


Figure 4. Example illustration of Comparison-to-the-Norm analysis method (distributions of skid resistance measured at skidding accident sites and samples of sites selected at random (Wallman and Astrom 2001).

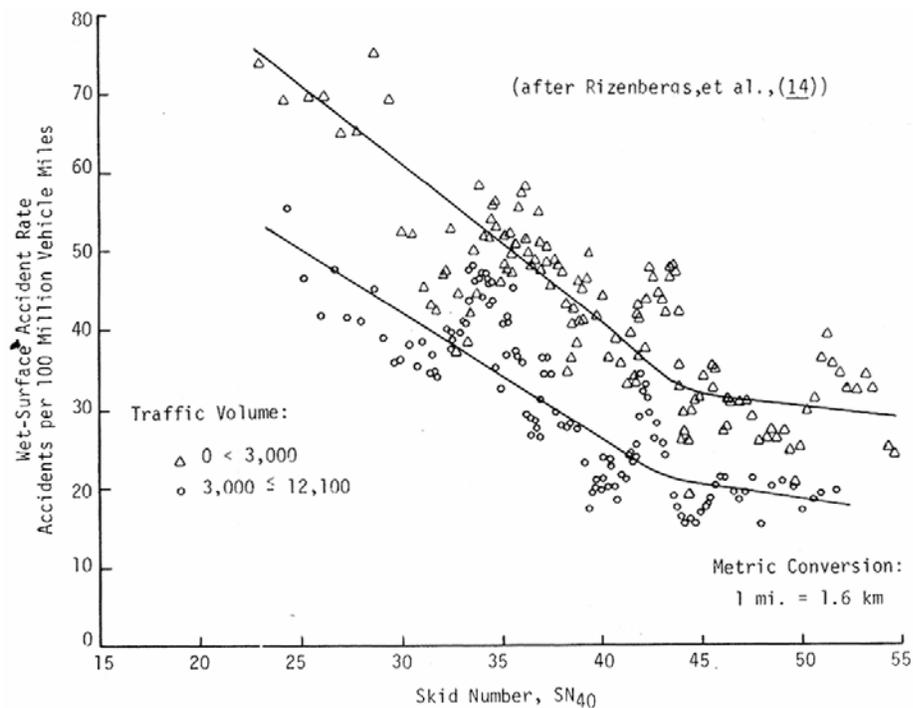


Figure 5. Example illustration of regression analysis method (relationship between wet-weather crash rates and pavement friction for Kentucky highways (Rizenbergs et al. 1973).

### 3. PFM-RELATED PRACTICES

FHWA Technical Advisory T 5040.38 (*Pavement Friction Management*) states that PFM includes engineering practices to provide surfaces with adequate and durable friction properties plus data collection and analysis to ensure the effectiveness of those engineering practices (FHWA 2010). It further states that the main purpose of a PFM program is to minimize friction-related vehicle crashes by ensuring that new pavement surfaces are designed, constructed, and maintained to provide adequate and durable friction properties, by identifying and correcting sections of roadways that have elevated friction-related crash rates, and by prioritizing use of resources to reduce friction-related vehicle crashes in a cost-effective manner.

The 2008 AASHTO *Guide for Pavement Friction* defines PFM as a systematic approach to measuring and monitoring the friction qualities and wet crash rates of roadways, identifying those pavement surfaces and roadway situations that are or will soon be in need of remedial treatment, and planning and budgeting for treatments and reconstruction work that will ensure appropriate friction characteristics (AASHTO 2008). While it recognizes that successful control of pavement friction requires strategies at both the management and design/construction level of a highway pavement program, it narrows the focus of PFM to policies and practices that result in sufficient monitoring of friction and/or crashes, and to proper and timely responses to potentially unsafe roadway surfaces.

The *Guide for Pavement Friction* provides an overall approach for managing pavement friction and a process for implementing it (AASHTO 2008). It serves as the model for the PFM programs to be developed and demonstrated in four states. The approach is illustrated in figure 6 and is comprised of the following components:

- Network Definition—Subdivide the highway network into distinct pavement sections and group the sections according to levels of friction need.
  - Define pavement sections.
  - Establish friction demand categories.
- Network-Level Data Collection—Gather all the necessary information.
  - Establish field testing protocols (methods, equipment, frequency, conditions, etc.) for measuring pavement friction and texture.
  - Collect friction and texture data and determine overall friction of each section.
  - Collect crash data.
- Network-Level Data Analysis—Analyze friction and/or crash data to assess overall network condition and identify friction deficiencies.
  - Establish investigatory and intervention levels for friction. Investigatory and intervention levels are defined, respectively, as levels that prompt the need for a detailed site investigation or the application of a friction restoration treatment.
  - Identify pavement sections requiring detailed site investigation or intervention.
- Detailed Site Investigation—Evaluate and test deficient pavement sections to determine causes and remedies.
  - Evaluate non-friction-related items, such as alignment, the layout of lanes, intersections, and traffic control devices, the presence, amount, and severity of pavement distresses, and longitudinal and transverse pavement profiles.
  - Assess current pavement friction characteristics, both in terms of microtexture and macrotexture.
  - Identify deficiencies that must be addressed by restoration.
  - Identify uniform sections for restoration design over the project length.

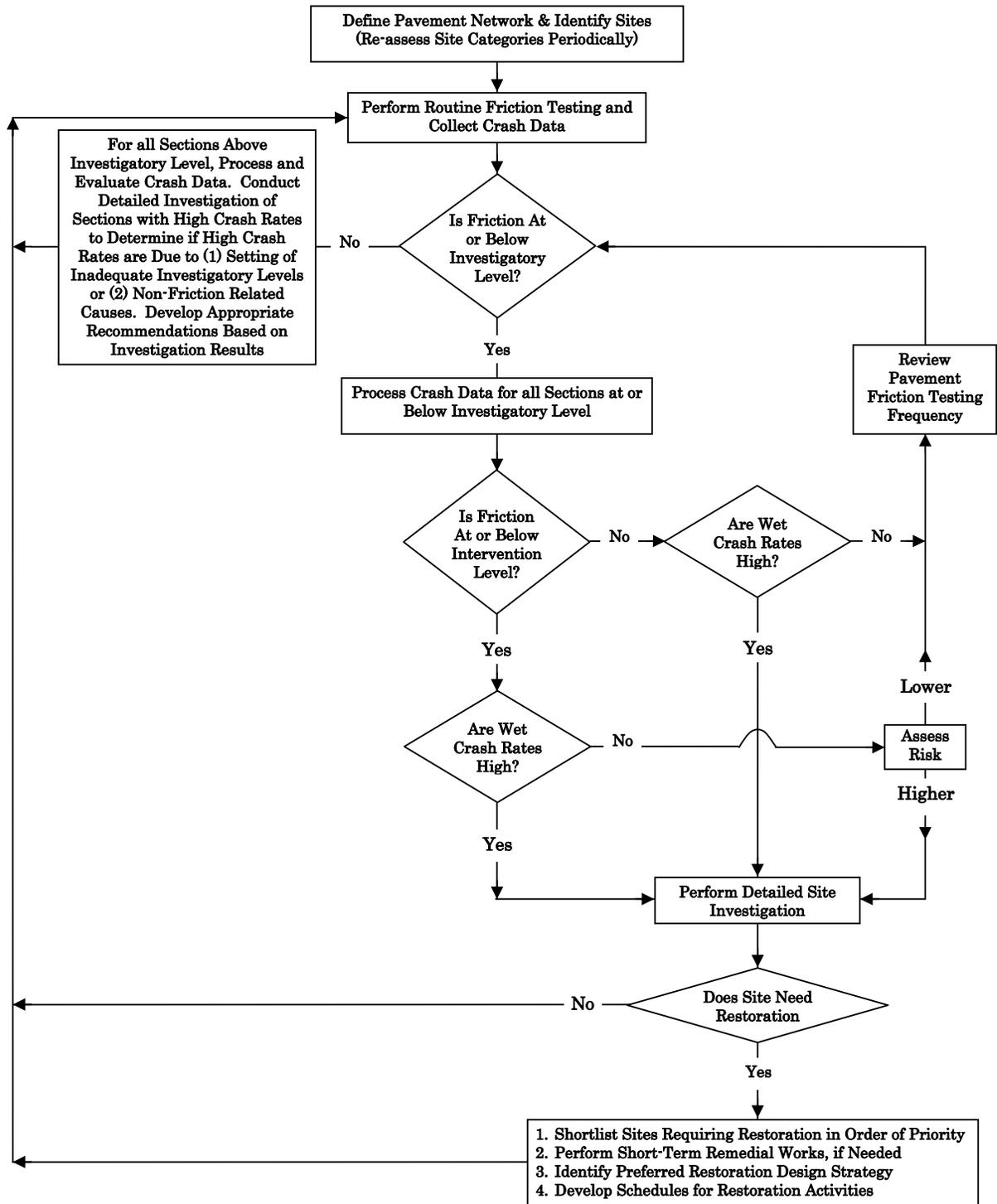


Figure 6. Example PFM program (AASHTO 2008).

- Selection and Prioritization of Short- and Long-Term Restoration Treatments—Plan and schedule friction restoration activities as part of overall pavement management process.
  - Identify candidate restoration techniques best suited to correct existing pavement deficiencies.
  - Compare costs and benefits of the different restoration alternatives over a defined analysis period.
  - Consider monetary and non-monetary factors and select one pavement rehabilitation strategy.

The *Guide for Pavement Friction* approach calls for routine friction testing of the roadway network and the subsequent analysis of friction and crash data to identify locations with potentially inadequate levels of friction/texture. This approach differs from the approach recommended in the recently superseded FHWA Technical Advisory T 5040.17 (*Skid Accident Reduction Program*), which focused on analyzing only crash data to identify problem areas and then testing those areas for friction (as necessary) as part of a detailed site investigation (see figure 7) (FHWA 1980).

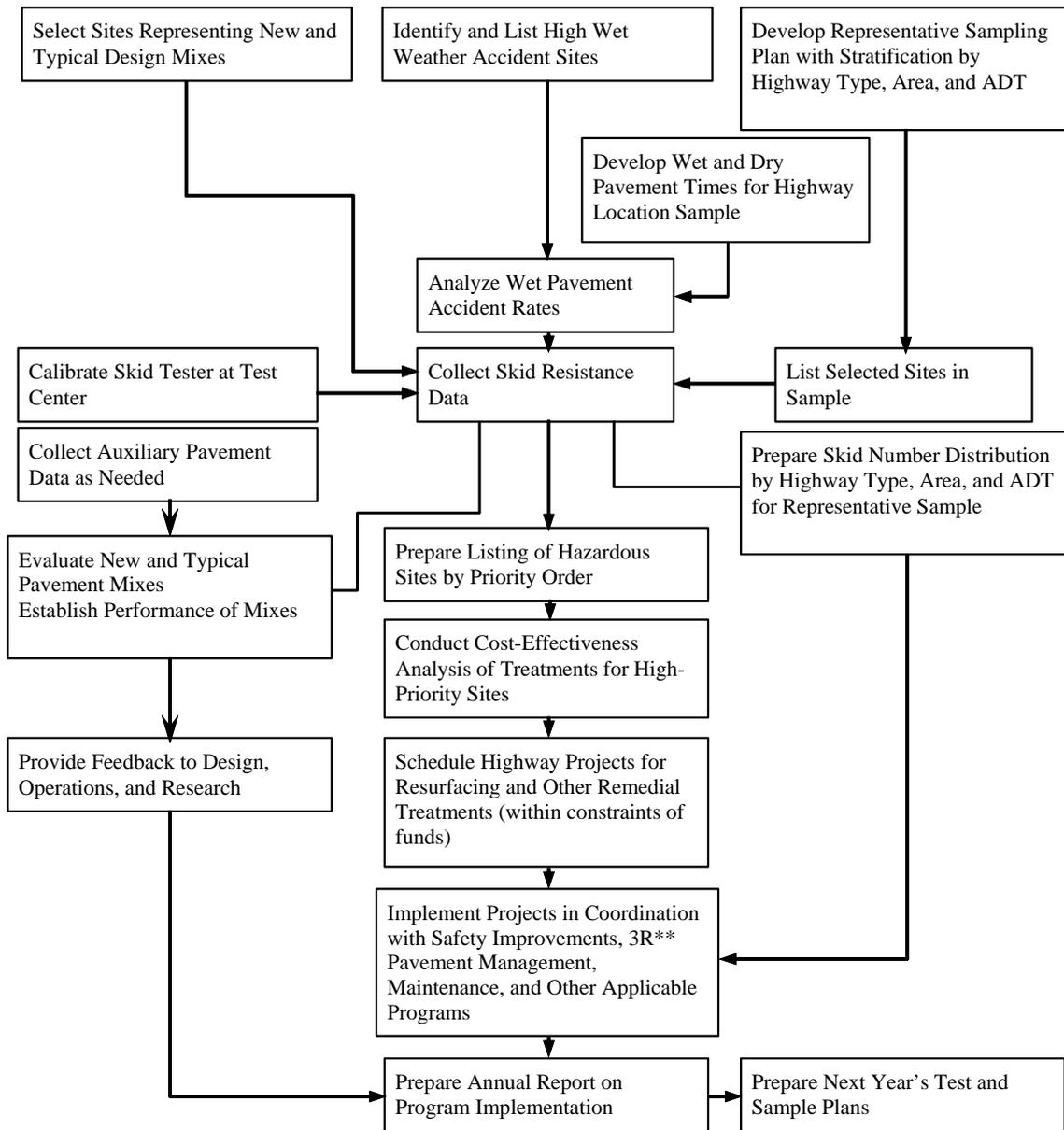
As a supplement to the work described in the previous section, a review of the pavement safety programs/practices (e.g., Skid Crash Reduction Programs, Wet Accident Reduction Programs, Skid Hazard Elimination/Reduction Programs) in use at several U.S. and international highway agencies was performed. The main goal of this effort was to provide benchmark information for the PFM programs to be developed in four states, particularly as they relate to the following:

- Network segmentation and friction demand category assignments.
- Friction and texture threshold levels.
- Friction and texture testing equipment.
- Friction and texture testing frequencies and timings.
- Alternative approaches to managing pavement safety.

#### **4. FINDINGS/CONCLUSIONS**

Presented below are some of the main findings/conclusions derived from the reviews of friction/texture–crash relationship studies and pavement safety programs, as they relate to the development of PFM programs in four states.

- Friction–Crash Relationships—The idea to correlate pavement friction with highway skid crashes is a longstanding and enduring one. Many attempts to do so have been made over the past half century, with varied levels of success largely determined by the unique set of roadway circumstances and unique data collection and analysis practices of individual highway agencies. Still, because there are several other factors that govern or contribute to crashes, the ability to develop an accurate relationship that can reliably detect the need for friction restoration is somewhat limited.



\* ADT: Average Daily Traffic  
 \*\*\* 3R: Resurfacing, Restoration, and Rehabilitation

Figure 7. Model skid accident reduction program (FHWA 1980).

- **Role of Equipment in Friction–Crash Relationships**—Although similar difficulties were noted in developing good friction–crash relationships using output from different friction measuring devices, the SCRIM side-force friction tester has a distinct advantage over the locked-wheel tester in terms of the opportunity of achieving a good relationship and more closely resembling the anti-lock braking system (ABS) braking mechanism on most of today’s vehicles operate (i.e., with the slip speed held near peak friction). This is in large part due to its CFM capability, which can better characterize and represent the available friction at specific crash locations, and its operation of measuring the near-peak friction. A major concern, however, in shifting from the locked-wheel tester is the ability to correlate friction data from a CFM device to friction from locked-wheel testers, so that continuity of historical FN data at most of the SHAs can be maintained.
- **Macrottexture–Crash Relationships**—The role of macrottexture in minimizing crashes is still unclear. Only a few studies attempting to correlate texture depth (e.g., MTD, MPD) with crashes have been performed to date, with somewhat conflicting results as per the impact on wet-weather crashes (i.e., no effect on crashes versus a significant increase in crashes, corresponding to decreased macrottexture) and a little more definitive results as per the impact on total crashes (significant increase in crashes for texture depth below 0.024 and 0.04 in [0.6 and 1.0 mm]). However, macrottexture is a very important parameter to obtain the full pavement frictional properties, especially if a low-slip device is used.
- **Pavement Type Considerations**—The effect of pavement type on measured friction throughout the year continues to be an area of focus, particularly as it relates to HMA pavements which experience greater seasonal variations in friction. Moreover, a preliminary evaluation by the FHWA of the effect of pavement type on reported crashes in one state indicates that crash rates on flexible pavements increase dramatically during the warm season months (reinforcing the need to test for friction during this time period), whereas during those same months, a slight increase in the crash rate can be expected for composite pavements (i.e., HMA overlays on PCC) and essentially no increase can be expected for PCC pavements. Recent research has also verified that many HMA pavement surfaces have higher crash rates the first year or two after construction and some researchers have named this effect bituplaning (Bullas and Hounsell 2008).
- **Climate/Weather Considerations**—Available friction decreases dramatically when the pavement surface becomes wet. This can, of course, be related to rainfall but condensation on pavements during cool evenings under certain conditions (particularly in a desert environment) may also be a factor. Because skid-related crashes occur more often when the pavement surface is wet, consideration must be given to the relative proportion of the time the pavement is wet. The appropriate crash statistics for accounting for significantly different climates that result in different percentages of wet pavement time are the wet-to-total crash ratio or the wet-to-(wet+dry) crash ratio (which ignores ice- and snow/slush-related crashes). These parameters appear to be the best single indicators of pavement safety performance and should be supplemented with the total number of crashes to highlight sections with potentially unsafe pavement surfaces. Other suitable parameters for comparing crashes on facilities across significantly different climates are the liquid precipitation safety ratio (LPSR) and the wet safety factor (WSF), which are the mathematical inverse of each other.

- **Vehicle Type Considerations**—There are many different factors that influence the stopping, steering, and acceleration capabilities of different vehicle types. These factors greatly complicate the crash analysis process, which is a likely reason for the very limited amount of research into the role of vehicle type in the friction/texture–crash relationship. However, there have been a number of recent attempts to develop 3-D models to analyze the tire-pavement interface (particularly, texture in the macrotexture and upper microtexture ranges) and to determine the most critical factors (Larson and Smith 2011). In addition, it is expected that the “black boxes” being installed in the vehicles instrumented for the SHRP 2 Naturalistic Driving Study will help demonstrate some of the stopping characteristic differences for automobiles.
- **PFM Development**—In the development and implementation of a PFM program, careful consideration must be given to defining the scope of network friction testing (i.e., concentrate efforts in areas or on facilities where friction is significantly brought into question and the benefits of routine testing are more profound) and recognition must be given to the unique highway conditions and network configuration dealt with by the agency, as well as the agency’s unique styles, policies, and practices of managing its highway system.
- **Friction Demand Categories**—The establishment of friction demand or site categories in accordance with friction demand is a critical component in the PFM process. The categories and the assignment of investigatory and intervention friction levels help normalize and minimize the risk of skid-related crashes throughout the network.
- **Friction Threshold Levels**—The concept of investigatory and intervention friction levels recognizes the inaccuracies of friction–crash relationships and provides an appropriate approach to determining if friction is contributing to (or even causing) crashes and/or the severity of crashes. It flags sections that are considered to have reached a marginal friction level, based on skid crash trends, and provides for project-level evaluation of friction and other possible factors for those sections. Because friction demand varies throughout the network, as do crash levels, individual sets of investigatory and intervention friction levels must be established for different site categories. Moreover, for a given site category, it may be appropriate to specify a range for the investigatory level to better account for risk at the local level.
- **Texture Threshold Levels**—Investigatory and intervention macrotexture levels have been established and put into use in at least two international agencies. The thresholds are generally used in conjunction with friction thresholds; application of the criteria without friction information does not appear appropriate at this time, given that studies have suggested that high-speed laser measured MPD (or EMTD) is not an adequate descriptor of texture that correlates with increased crash potential. Nonetheless, there is potential for using such criteria in monitoring/managing pavement safety in low-risk areas.
- **Calibration/Harmonization of Equipment**—Despite extensive international efforts (PIARC, HERMES, TYROSAFE) to develop calibration/harmonization constants for relating the friction of numerous friction devices to one universal friction index, there are still major shortcomings that prevent full harmonization from occurring.

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