# PROVIDING DURABLE, SAFE, AND QUIET HIGHWAYS

Roger M. Larson[1], Member ISCP, Larry Scofield[2] and James Sorenson[3]

## Abstract

Most pavement design and construction specifications do not adequately define the pavement functional surface characteristics that are important to highway users. The result is that sometimes completed highway projects do not meet user expectations. Currently, most specifications address only smoothness (ride quality), whereas other desirable surface characteristics such as durability, and surface texture [friction (safety) and noise (environment)] are not often specifically addressed. The purpose of this paper is to look primarily at the functional characteristics of paved highway surfaces. First, functional performance will be described. Secondly, the individual surface characteristics affecting functional performance will be discussed with emphasis on pavement texture which has a major effect on friction (safety) and noise (environment). Next, recent innovative techniques and equipment to measure and evaluate these characteristics will be explained. Safety efforts underway both internationally and in the U.S. will be addressed. Finally, examples of the best practices will be described. Consideration of these factors by the engineering profession will help ensure that the highway user expectations are met on completed projects by providing durable, safe and quiet highways.

## Introduction

In the past, the greatest emphasis in pavement design and rehabilitation has been on structural design components, with materials quality issues addressed separately in the specifications. Only recently have material properties been tied more directly to structural design and individual distresses modeled (NCHRP Project 1-37A 2003). However, with the exception of smoothness, the surface characteristics that contribute to good functional performance have largely been ignored until after problems develop. Thus, there is a major need to focus on improving the functional pavement surface characteristics of new, reconstructed, rehabilitated, and pavement preservation projects (Larson, Scofield, and Sorenson 2003).

This issue becomes increasingly important as the focus has shifted away from pavement construction and rehabilitation to pavement preservation activities. With the increasing use of surface treatments, thin overlays, or restoration activities on a large number of miles of structurally adequate pavement sections, the functional characteristics of a significant portion of the highway network can be improved at a

[1] Senior Engineer, Applied Pavement Technology, Inc., 7501 Candytuft Court, Springfield, VA, 22153, email: rlarson@pavementsolutions.com
[2] Director of Environmental Technology, American Concrete Pavement Association, 807 W. Keating Ave., Mesa, AZ, e-mail: lscofield@pavement.com
[3] Senior Construction and Preservation Engineer, Federal Highway Administration, 400 7th St. SW, Washington, DC 20590, e-mail: james.sorenson@fhwa.dot.gov

relatively modest cost. The pavement texture is very important as it affects both friction and noise.

The focus of this paper is primarily on portland cement concrete (PCC) pavements. Although bituminous-surfaced pavements constitute the largest percentage of paved highway surfaces, a 1996 survey revealed that 21 of the 48 state agencies had no requirements for friction or texture for hot-mix asphalt (HMA) materials (Jayawickrama, Prasanna, and Senadheera 1996). This issue has been previously addressed (Larson, Scofield, and Sorenson 2004). Most states do have some texture requirements for PCC pavements. However, even in most PCC warranty specifications, functional characteristics (other than ride), when specified, are generally minimum values rather than desirable values (Anderson and Russell 2001). There is no specific information available that suggests desirable levels of friction and texture vary by pavement type. However, improvements can be made by focusing on some considerations unique to PCC pavements. Research needs in this area have been recently identified (Karamihas and Cable 2004).

## Description of Functional Performance

***General.*** The functional performance of a pavement concerns how well the pavement serves the user. In this context, riding comfort or ride quality was previously considered the dominant characteristic. In order to quantify riding comfort, the "serviceability-performance" concept was developed as part of the research conducted at the AASHO Road Test in the late 1950s (AASHTO 1993). The dominant factor contributing to the riding comfort was roughness, although distress (cracking, patching, and rut depth) was also considered. This concept has now been largely replaced by more objective methods of expressing pavement smoothness or roughness, such as the International Roughness Index (IRI). However, factors other than ride must be included in order to adequately describe the functional performance of a pavement.

***Highway User Surveys***. In May 1996, a National Highway User Survey report was published that identified nationwide highway user concerns in more detail (NQI 1996). The stated priorities for improvement were safety (#1), pavement condition (#2), and traffic flow (#3). From the survey it is clear that the highway user wants a focus on the quality of the roadway surface, with the quality reflected primarily by the pavement condition and safety-related characteristics.

A follow-up survey in 2000 showed an overall increase in satisfaction with the quality of the roadway surface(15 percent), but also a 6 percent overall increase in dissatisfaction (less in the undecided category) (FHWA 2001a). In the pavement condition area, there is a 10 percent increase in dissatisfaction and in the safety area there is about a 3 percent increase in dissatisfaction. These results support the need for greater consideration of functional characteristics by the engineering profession in order to specifically address highway user concerns.

For pavement conditions, more durable surfaces, smooth ride, quiet ride, and surface appearance are the most important factors. In terms of safety, these factors include pavement markings, friction in wet weather, and clearing accidents more quickly. In the 2000 survey, highway users rate improvements in traffic flow (28 percent), safety (26 percent), and pavement condition (21 percent) as their highest priority.

***Surface Durability***. Because it affects all other characteristics, the issue of durability is addressed first. The highway user is increasingly concerned about traffic delays. In the 2000 survey, it was found that (FHWA 2001a):

- 67 percent of highway users want more durable surfaces.
- 66 percent of highway users want repairs during non-rush hours.
- 52 percent of highway users want reduced repair time.
- 43 percent of highway users want accidents cleared more quickly (or preferably the number of accidents reduced or minimized).

All of these concerns can be addressed through improved PCC designs that incorporate higher quality materials, higher quality construction, and the use of cost-effective maintenance activities. Longer life pavements and more durable pavement surfaces will meet these users concerns (FHWA 2002a).

Given current reductions in SHA inspector numbers and experience levels, the increased use of warranty, guarantee, or performance-related specifications may be needed to ensure more durable pavement surfaces for the highway users. NCHRP Report 451 (Anderson and Russell 2001) summarizes the use of innovative practices in this area. Improved guidelines and incentives for desirable, not minimum levels, of important pavement surface characteristics for specific site conditions are clearly needed, as is guidance related to the establishment of maintenance planning (investigatory or warning) levels of texture/friction in order to identify potentially hazardous locations before significant numbers of crashes occur.

Monitoring the surface condition by periodic pavement management distress surveys is the major means of evaluating surface durability. Absence of distress is a good indicator of surface durability.

Another critical factor affecting both durability and safety is the cross slope of the pavement. This is important to facilitate surface drainage, improve ride quality, improve wet weather friction, and reduce splash and spray (Anderson et al. 2002). Cross slope deficiencies should be corrected during maintenance and rehabilitation projects. Good pavement surface and pavement structural section drainage are needed to extend pavement service life and increase surface durability by eliminating or minimizing spalling and cracking.

***Ride Comfort***. Perhaps the greatest contribution of the AASHO Road Test was the development of the "serviceability-performance" concept, which established riding comfort as a primary design factor. Over the years, many reports have been published on the measurement and importance of pavement rideability. Most recently, the FHWA has published a report providing concise technical guidance on the "best practices" for measuring, expressing, specifying, and achieving smoothness for PCC pavements (Grogg and Smith 2002). The International Roughness Index (IRI) is the most widely used index to describe the roughness of highway pavements (Perera and

Kohn 2001). It is based on a quarter-car simulation model that is influenced by wavelengths from 4 to 100 ft. A significant research effort is underway to modify the equipment so that texture and joints do not adversely affect the reported ride quality.

***Pavement Texture (Safety-Friction and Environment-Noise)***. The most important functional pavement characteristic often overlooked in current specifications is pavement texture. In 1996, 21 of the 48 States responding to a survey had no requirements for texture or friction of HMA surfaces (Jayawickrama, Prasanna, and Senadheera 1996). Most states do have PCC texturing requirements but require little verification of the adequacy of the resultant pavement texture.

NCHRP Synthesis 291 reports that six highway agencies are collecting pavement macrotexture data (which can now be collected at highway speeds) but are not routinely using it (Henry 2000). Very little emphasis has been placed on providing friction above minimum levels, possibly because of potential liability issues.

There is now considerable evidence suggesting that increasing texture/friction to higher desirable levels at sites with higher accident risk (two-lane roads, intersections, curves, work zones, freeway ramps, etc,) will significantly reduce fatalities, injuries, and resulting traffic delays (Larson 1999; Wallman and Anstrom 2001). Improved guidance on desirable macrotexture to reduce splash and spray and hydroplaning and microtexture to increase the friction at both low and high speeds is needed (Hibbs and Larson 1996).

Safety (reducing deaths, injuries, and traffic delays) in work zones is also a particular highway user concern. In 2003, 1028 highway workers or users were killed in highway work zones. This is another critical area where there are few guidelines on desirable texture/friction characteristics, particularly in the work zone transition areas where considerable lane changing and slowing or stopping occurs. Frictional demands for this condition are significantly higher than for typical divided roadway operations before the work zone was established. Increasing the texture/friction requirements would significantly reduce the stopping distance. The FHWA recently published a final rule on work zone safety and mobility (FHWA 2004a).

***Surface Appearance***. Relatively little attention is given in specifications to obtaining a uniform, pleasing surface appearance. Spot grinding to remove bumps can result in differential friction qualities and can also result in non-uniform appearance. This is also true for surface repairs including partial-lane patches. Specifications should not reward corrective measures that result in poor appearance or in differential friction values.

Traffic markings are very important to improve night-time and poor weather visibility. Sixty percent of roadway departure crashes occur during dark or reduced light conditions. The night-time crash rate is about twice the day-time rate (excluding alcohol-related crashes). Greater attention to improved traffic marking durability is required. It is also important that the markings not increase risk of skidding due to poor or low frictional characteristics. At the same time, rumble strips are seeing more widespread use to warn drivers of roadway departures or crossing into area where the potential exists for head-on crashes. These low-cost treatments have been very effective in reducing crashes.

### Improved Evaluation Techniques and Equipment

***General***. Technological advances have made various data collection, storage, and analysis procedures possible for routine use. Many of these can now be done in real time with the results available immediately in graphical or summary statistics format. These powerful tools can be used to improve the quality of engineering decisions to extend the service lives of highway pavements and to increase highway user satisfaction (FHWA 2002b). However, to increase the cost effectiveness of preventive maintenance for PCC pavements, changes need to be made in the data collected. This is particularly important to help optimize the timing of the treatments (Peshkin, Hoerner, and Zimmerman 2004). Both structural and functional performance need to be addressed. Consequently, there needs to be increased integration of pavement management, maintenance management, and safety management systems (FHWA 2001b; Tighe et al. 2000; Zimmerman and Wolters 2004; Depue 2003).

In the past, there has often been a weak link between friction numbers and accident rates. One of the reasons for this is due to the widespread use of the ribbed tire to obtain friction numbers, as the ribbed tire "masks" the pavement surface drainage characteristics (the use of the blank tire overcomes this deficiency). Also, consideration should be given to the use of fixed-slip friction testers that allow continuous measurement, rather than the locked-wheel friction tester typically used in the U.S. Furthermore, the capability of lasers to obtain macrotexture at highway speeds on 100 percent of the network during pavement management surveys and during friction testing also significantly enhances the testing and analysis capability. The advancements in global positioning systems and geographic based information systems allow the various data bases to be tied together to enable more comprehensive evaluations. These advancements plus the increased data storage capabilities, faster computers, and enhanced analysis programs make procedures possible that were not practical just a few years ago (Larson, Scofield, and Sorenson 2004).

***Durability***. Recent technological advancements are greatly improving the quality and ease of making periodic pavement distress surveys. Hand-held computers have reduced data entry time and reduced errors for manual distress surveys. Automated distress surveys are getting increasingly reliable and results will soon be available in real time (McGhee 2004). Combined with software to generate graphical output and summary tables, this equipment will greatly reduce the time and cost of doing periodic distress surveys so that the rate of deterioration can be more easily determined and improved performance prediction models developed and refined. This will allow the development of improved recommendations for timing on pavement preservation activities to address both structural and functional performance.

Other high-speed, nondestructive evaluation techniques are available or under development that will help differentiate structural and functional distresses. For example, a rolling wheel deflectometer is under development and has been tested on CRCP (poor results) and on HMA pavements. This device allows continuous, high-speed network- and project-level evaluations of uniformity of structural strength by monitoring deflections. The University of Texas Rolling Dynamic Deflectometer (RDD) is a prototype device for slow speed (1 to 2 mi/hr) project level evaluations. It outputs deflections every 2 feet and joint load transfer efficiencies. It has been successfully demonstrated on PCC pavements.

Ensuring that there are no significant structural deficiencies will help provide more cost-effective functional surface treatments. As another example, Texas has developed a ground penetrating radar (GPR) device to be used as a practical screening tool for HMA pavements to help focus testing (nondestructive and destructive) on critical locations to aid in making better pavement preservation decisions (FHWA 2002c). Refinement to this technique will be required in order to make it address PCC pavement issues more effectively.

These tools will also help to evaluate the rate of deterioration so improved guidance on timing of preservation activities can be developed and will also help improve surface durability and reduce the need for frequent routine or reactive pavement maintenance activities. By improving the pavement condition and texture/friction, fatalities and serious injuries and resulting traffic delays will be significantly reduced.

Recent advancements in laser technology make possible improved ride quality statistics and also the evaluation of a number of other features. For example, it is now possible to measure macrotexture in accordance with ASTM E-1845 at highway speeds (Henry 2000). This capability allows the evaluation of the uniformity of the pavement texture on a continuous basis, and could minimize the need for network-level friction testing. With multiple sensors or the newly developed scanning lasers, it will also allow the improved evaluation of rutting, polishing of aggregate in and between the wheelpaths, raveling of surface aggregates, and segregation of the mixes during construction operations (FHWA 2001c). Improvements in laser technology are being made to more accurately quantify both transverse and longitudinal pavement surface textures.

The FHWA Office of Asset Management has a project underway to use pavement management systems (PMS) to evaluate the performance of Superpave mixes (Hudson et al. 2002). Because many states have adopted the Superpave system, it is important to verify that the planned benefits (including improved safety, durability, and longer service lives) are actually being achieved. This evaluation needs to include the functional performance (particularly texture/friction) as well as the structural performance of these mixes. This same approach can apply to PCC pavements. Also, it is proposed in the future to use the PMS to evaluate the effectiveness of warranty, guaranty, and performance-related specifications. These evaluations should help verify that PCC pavement safety and surface durability characteristics are improving and that they are cost effective.

***Ride Measurement and Evaluation.*** As noted above, there have been significant recent developments in evaluating ride comfort as a result of the FHWA Pavement Smoothness Initiative (Wolters and Grogg 2002; Grogg and Smith 2002; FHWA 2003a; Smith, Titus-Glover, and Evans 2002). This includes adopting the IRI as the standard measurement unit. Also, the use of lightweight laser profilers to monitor construction quality and to provide an initial value for monitoring long-term performance is a promising development that needs evaluation and refinement. Efforts are underway to develop bump specifications (including must-grinds or repairs) and to ensure that roughness does not result in dynamic loading by trucks that would increase the rate of pavement structural damage. A computer software program (ProVAL 2.5) is now available from FHWA to compare profile data taken at different times. Additional effort is underway to evaluate the effects of texture and joints on PCC smoothness. The effects of faulting and temperature curling and moisture warping on PCC smoothness are also being evaluated. The goal is an enhanced analysis capability to improve guidelines for constructing and maintaining smooth pavement surfaces.

***Pavement Texture Measurement and Evaluation (Friction and Noise).*** Very few specifications currently address texture or friction requirements (Jayawickrama, Prasanna, and Senadheera 1996; Anderson and Russell 2001; Hudson et al. 2002). Pavement texture is important to friction and noise properties of the pavement surface. The few states that do have guidelines typically address minimum friction values and not the desirable values that are needed for long-term performance or for the more critical individual site categories. It is believed that none had specific requirements on desirable and/or maximum noise levels for the various surface types. The most comprehensive annual evaluation of ride, texture, and friction evaluation equipment is conducted at the NASA Wallops Flight Facility (Wambold, Henry, and Yager 2004). A summary of a recent International Texture Workshop is also available (Avinor 2003).

Texture affects both noise and friction characteristics; these properties must be considered together in order to fully address highway users concerns (FHWA 2003a). It is also imperative that texture/friction be specifically addressed to reduce the current unacceptable level of almost 43,000 fatalities and 3 million injuries annually in highway crashes and to minimize the resultant traffic delays. It has been estimated that poor pavement conditions currently contribute to 13,000 deaths annually. A small but significant portion of the poor pavement condition is due to poor surface texture or friction characteristics.

Very little research in the U.S. has been conducted on the effect of texture on splash and spray. It has been estimated that up to 10 percent of the wet weather accidents are due to reduced visibility (particularly at night) caused by splash and spray (Hibbs and Larson 1996). Both the United Kingdom and South Africa have used equipment to quantify the amount of splash and spray from different pavement textures. This information would help determine desirable surface textures where this issue is a significant concern.

The U.K. has also developed equations to predict the noise on various pavement surfaces to within + or – 2 dB(A) 90 percent of the time and + or – 1 d(B)A

60 percent of the time. The input needed is pavement type, aggregate type, and macrotexture characteristics (Brian Ferne, personal communication, January 12, 2005).

Laser technology has now enabled the continuous measurement of macrotexture at highway speeds. This should enable researchers to develop cost-effective pavement texture guidelines that reduce fatalities and serious injuries and that also reduce noise impacts on both highway users and adjoining property owners.

Portable devices are also available to evaluate pavement texture (e.g., Circular Track Meter) and friction (e.g., Dynamic Friction Tester) values and to develop the International Friction Index (IFI) (Henry 2000). This equipment is being used by the AZ DOT, National Center for Asphalt Technology, and others for a variety of research studies. These are stationary devices that require lane closures for testing; however, they can provide a relatively quick comparison of the macrotexture of existing surfaces.

## Issues

***General.*** There are some general issues that are particularly important when considering the importance of texture and friction. In November 2004, a Workshop was held on *Optimized Surface Characteristics for Safe, Quiet, and Smooth Concrete Pavements*. This meeting was held to obtain feedback from the stakeholders on this portion of the Long-Term Plan for Concrete Pavement Research and Technology being developed for the FHWA (FHWA 2004b). This comprehensive plan addresses the specific research needs identified.

***Meeting Customer Expectations.*** It is considered important that customer expectations be addressed. The customers clearly want durable, safer, smoother, and quieter pavement surfaces. Current method type specifications do not guarantee that these expectations will be met on completed projects. Additional research is needed on end-result or performance-related specifications.

***Safety Benefits of Pavement Preservation.*** FHWA's current emphasis on pavement preservation presents an outstanding opportunity to improve highway safety by improving the surface condition of a large portion of the highway network in a relatively short time period (5 to 10 years) (Lemer 2004). Applying thin overlays or surface treatments are relatively low-cost options, which if used to maintain or enhance the skid resistance of the pavement surfaces, can make a significant impact by reducing fatalities, serious injuries, and traffic delays. Research is needed to help determine the cost effectiveness of significantly improving the texture/friction on a corridor or network basis, particularly on two-lane roads and four-lane expressways (at-grade intersections). Effectively integrating pavement management, maintenance management, and safety management systems would provide the data needed to make more cost-effective decisions (Larson, Scofield, and Sorenson 2003; Larson, Scofield, and Sorenson 2004). The information being developed in the United Kingdom to evaluate the effectiveness of road safety audits (discussed later) should help clearly demonstrate the value of this comprehensive safer road approach in the U.S. This same type of information could help quantify the safety benefits of pavement preservation to obtain management support and additional funding for the program.

**Focus on Safer Roads**

***Introduction.*** In the U.S., substantial research is underway on the geometric design of highways to improve safety (Fitzpatrick and Wooldridge 2001). This is important as there is a need to compare the friction demand assumed during pavement design with the cross slope, texture, and friction actually provided on the roadway surface at known critical sites (curves, intersections, approaches to work zone transitions, freeway ramps, and so on) throughout the service life of the pavement. Numerous AASHTO Guides address various aspects of this issue. The amount of the material available is so voluminous that computer-supported tools are being developed to help apply the results. The Integrated Highway Safety Design Model (IHSDM) and the *SafetyAnalyst* are two such tools under development or being enhanced by FHWA to aid in this effort (FHWA 2004c). Updated information on FHWA's safety efforts can be accessed at http://safety.fhwa.dot.gov.

IHSDM is a suite of software analysis tools for evaluating safety and operational effects of geometric design decisions on two-lane rural highways. IHSDM is available for downloading free of charge at www.ihsdm.org. The FHWA Geometric Design Laboratory within the Office of Safety R&D provides free technical support to IHSDM users. Ongoing research and development will enhance and expand the capabilities of IHSDM, in coordination with the Transportation Research Board's (TRB's) *Highway Safety Manual,* which is currently under development.

A software package with state-of-the-art tools, *SafetyAnalyst,* is being developed to correspond to the six main steps in highway safety management: 1) network screening to identify sites and corridors that hold the most potential for reducing crashes; 2) diagnosis of safety problems at specific sites; 3) selection of appropriate countermeasures; 4) economic appraisal of candidate improvements; 5) priority rankings for candidate improvements; and 6) before-after evaluations of safety improvement projects.

***International.*** A Preprint CD-ROM of the SURF 2004 Pavement Surface Characteristics Symposium is also available (WRA 2004). It provides an excellent summary of the world-wide state-of-the-practice, with the United Kingdom and New Zealand having the most proactive programs to monitor pavement surface characteristics in efforts to reduce highway fatalities and serious injuries. The European Road Federation CD-ROM, *Guidelines to Black Spot Management, Identification & Handling*, January 2003 is another example of information sharing from the international community (ERF 2003).

Additionally, the recent publication of the *Austroads Guide to the Management of Road Surface Skid Resistance* will provide further impetus to change. The Austroads guide strongly recommends that highway agencies have a policy to manage skid resistance (Austroads 2005). The Australian National Road Safety Action Plan 2005 and 2006 has a targeted 40 percent reduction in the national per capita fatality rate based on the estimated effects of known road safety measures. It was estimated that 19 percent of the 40 percent reduction proposed by 2010 should be attributed to safer roads (ATRSB 2005). In addition, the Austroads publication, *Guide to the Selection of Road Surfacings* (2003), provides typical texture depths for a range of commonly used surfacing types when new and indicative investigatory levels for texture depths for various site types are needed (Austroads 2005). This is an excellent approach and suggests that better engineering of the roadway [geometric and traffic engineering design, improving the pavement condition (absence of surface distresses), and improved texture and friction where appropriate] can contribute to about half of the expected reductions in fatal and serious injury accidents. Transit New Zealand has been able to demonstrate by its considerable commitment to, and investment in, the implementation of a skid resistance strategy on the state highway network (where all roads on the network are tested annually) has reduced crash rates in wet conditions by 30 percent. Crash savings estimated to total NZ$395 million are anticipated over the first 10 years of the strategy's implementation. (Austroads 2005)

The October 2004 Report, *Traffic Safety Information Systems in Europe and Australia*, is the most recent published international scan document (FHWA 2004d). It was noted that there is a trend in the U.S. and abroad that is resulting in a drop in crash documentation by law enforcement agencies. This affects both the quantity and quality of data available. The Scan recommended that the AASHTO Strategic Plan Goals 21 (improving information and decision support systems) and 22 (creating more effective processes and safety management systems) be revised and also that revised implementation strategies be developed for AASHTO adoption. A separate, more detailed, *Scan Technology Implementation Plan* document is being developed. However, there was very little emphasis in the Scan Report on the need for improved road surface properties to help enhance guidelines in this area. Only the Netherlands identified that road surface properties, such as roughness and surface friction, are missing.

The April 2003 Report, *Managing and Organizing Comprehensive Highway Safety in Europe*, reported on information from Sweden, Germany, the Netherlands, and the United Kingdom that has potential to significantly influence highway safety management and organization in the U.S. (FHWA 2003b). The highway safety program elements of most interest were the route-based or area-wide safety improvement programs and the road safety audits.

These international scans and safety related conferences have made a major contribution to exchange technical information on what works and what doesn't. The International Scan Reports and other safety related information are available at www.international.fhwa.dot.gov. Obviously, greater international cooperation in this area would be very beneficial.

***U.S. Efforts.*** Highway safety is AASHTO's and FHWA's number one priority. In 1998, AASHTO published a Strategic Highway Safety Plan, which outlines a comprehensive, strategic approach to reduce highway fatalities by 5,000 to 7,000 annually (AASHTO 1998). In order to help implement the Plan, NCHRP Project 17-18 (1998) has developed a major product, an Integrated Safety Management Process (ISMP), which will be pilot-tested in eight or more states.

In March 2005, the AASHTO Strategic Highway Safety Plan was revised and updated. It reflects the revised goal to reduce the nation's highway fatality rate from 1.5 deaths to not more than 1.0 deaths per 100 million miles traveled. It was noted that safety audit processes have the potential to reduce overall crashes 3 to 4 percent by improving design, construction, and maintenance processes from a safety standpoint. The initiative will develop model safety audit guidelines, demonstrate them in five states, evaluate the results, design enhancements, and disseminate the guidelines nationally. Additionally it was proposed to establish an ongoing performance measurement system to evaluate the cost-effectiveness of safety investments at both project and program levels. In addition, NCHRP plans to release an Implementation Guide that addresses collecting and analyzing safety data in late 2006.

***FHWA Safety Goals.*** The FHWA has also outlined an approach to highway safety. The FHWA Safety Focus Areas for FY 2004 included:

- Reduce roadway departure crashes.
- Reduce number of collisions at intersections.
- Improve pedestrian safety.
- Encourage states to:
  - adopt strategic and performance based goals.
  - implement data improvement programs.
  - identify priority improvement projects.

In December 2003, the U.S. Department of Transportation, AASHTO, The Governor's Highway Safety Association, and others adopted the goal of reducing highway deaths to a rate of 1.0 per 100 million vehicle-miles by 2008 (compared to the fatality rate of 1.48 recorded in 2003). This change was in response to an increase in fatalities and injury accidents.

Research results indicate that up to 70 percent of wet weather crashes could be prevented with improved texture/friction. Given that wet weather crashes represent about 14 percent of the total fatal crashes, this potentially could result in a 10 percent total reduction in fatal and serious injury crashes and also could significantly reduce travel delays. A recent New York study reported that at 40 intersections with high relative crash rates and low friction values, accidents were reduced an average of 61 percent when the PCC approaches were given a more skid resistant surface (Bray 2002). In the U.S., more than 3 million crashes occurred at intersections in 2002, causing nearly 9,000 fatalities and 1.5 million injuries (FHWA 2004d). Clearly, reducing wet weather accidents remains a high priority.

However, a little recognized fact is that 80 to 86 percent of total fatal crashes occur on dry roadways. In the past, most of the emphasis has been on wet weather crashes, with the friction (or macrotexture) on dry roadways often assumed to be adequate. However, increasing texture and friction has a significant effect on accident rates by reducing the stopping distance required for both wet and dry pavements. To provide safer roads, the effect of increasing texture/friction on reducing crashes on both wet and dry roadways must be considered.

***Friction and Texture Guidelines Development.*** Three projects to develop enhanced guidance on using pavement surface characteristics to improve highway safety are underway. The 1976 *AASHTO Guide for the Design of Skid Resistant Surfaces* is currently being updated under NCHRP Project 1-43 (2003). The updated guide is expected to be available in mid-2005 so it can be submitted to AASHTO for adoption. It is expected that the updated guide will provide more specific guidance on considering texture and friction during the pavement design process. Also, under NCHRP Project 10-67, *Texturing of Concrete Pavements,* new guidelines are being developed. These guidelines will address the need for adequate friction and for low noise PCC surfaces (NCHRP Project 10-67 2004). The preparation of a NCHRP Synthesis of Highway Practice 36-03, (2004), *Technologies for Improving Safety Data*, is just getting underway. These efforts will enhance available guidance on incorporating texture/friction information into the pavement design decision-making process.

While there is a tremendous amount of information available on the effect of various geometric design features, there is much less guidance currently available on defining desirable pavement surface characteristics that will help reduce the number of deaths, serious injuries, and resulting traffic delays (Larson, Scofield, and Sorenson 2003; Larson, Scofield, and Sorenson 2004).

None of the above AASHTO guidelines or FHWA goals specifically target the expected overall benefits of increased network texture/friction levels on reducing fatalities, injuries, and resulting traffic delays [although pavement skid resistance has been considered in the roadway departure, horizontal curves, and intersection implementation guidelines] (NCHRP 17-18(3) 1998). There also are no corresponding performance measures (i.e., average macrotexture depth that can be measured continuously at highway speeds or continuous friction measurements) to help monitor whether texture/friction levels on the network are being significantly increased during construction and maintenance activities. An analysis of friction and texture versus average accident rate by the major roadway classifications would more clearly demonstrate the benefit of increased texture and friction on reducing fatalities and serious injuries (Wallman and Anstrom 2001). The failure to have an accident reduction target goal based on building and maintaining safer roads (which includes improving the surface condition with adequate texture/friction) and establishing a corresponding performance texture/friction measure to monitor progress toward meeting that goal is a deficiency that needs to be addressed.

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***Road Safety Audits.*** One of the major International Scan technologies being implemented in the U.S. is The Road Safety Audit and Review Process (FHWA 1997). The United Kingdom, Australia, and New Zealand are leaders in refining and advancing the state of the practice (Wilson 2003). For example, over 10,000 road safety audits a year are conducted in the U. K. alone. The approach of monitoring, which is beginning to occur in the United Kingdom, should advance the state of road safety audit (RSA) benefit-cost project analysis. The crash data from the U.K. requirement to monitor RSA projects after 12 and 36 months should become key inputs to future analyses and to providing the benefits of the RSA, at least internationally (Wilson 2003).

Iowa, New York, South Dakota, Pennsylvania, and South Carolina have developed programmed approaches for including proactive safety assessments (RSAs). Kentucky, Maine, and Mississippi are others that have participated in audit training and are conducting RSAs. This is a 'Best Practice' that is being used by an increasing number of States to proactively address highway safety (Wilson and Lipinski 2004; Wilson 2003; NHI 2002; FHWA 2005). However, no specific guidance on using improved surface characteristics (texture and friction) to reduce the number of crashes is provided in the current implementation material. There is a critical need for research to demonstrate the benefits of applying skid resistant surfaces or treatments at above-average accident rate sites and for improved guidelines on selecting the most cost-effective treatment. Increased emphasis in the recently revised and updated AASHTO Strategic Highway Safety Plan should help address these issues.

***Noise Considerations.*** Pavement texture also affects noise. Reduced tire/pavement noise levels will benefit the highway users and adjacent property owners. Little emphasis has been placed on specifying desirable noise levels on noise-sensitive projects in urban areas. Therefore, there have been large variations in the noise levels of completed projects with little monitoring of as-constructed projects (FHWA 2003c). The Arizona Department of Transportation has one of the most comprehensive studies underway to evaluate pavement texture characteristics (both friction and noise) for representative surface types from about 200 pavement preservation test sections. They are also evaluating quieter PCC pavements by whisper grinding and thin overlays. It is expected that ranges of texture (and resulting friction and noise levels) will be developed for various surface treatments and thin overlays to help select the most cost-effective treatment for a specific project site.

States are encouraged to develop noise monitoring procedures on their networks and to incorporate that data into their pavement management systems. Noise performance predictions models could then be developed and refined using this data. In the future, this data would allow pavement surface type to be considered as a possible noise mitigation method. It would also help ensure that the lowest noise consistent with the state-of-the-practice is being provided.

The September 2004 Purdue Workshop developed *The Roadmap to Quiet Highways* (FHWA 2004f). This industry wide effort identified a comprehensive approach to address some of the technology gaps needed to implement a Quiet Highway program.

## Special PCC Considerations

From a durability standpoint, it is desirable to keep the original concrete pavement surface as long as feasible. This is made possible by the development and refinement of concrete pavement restoration techniques. After any minor structural deficiencies and surface defects are repaired, pavement retexturing is generally necessary. Diamond grinding and grooving and possibly carbide milling are techniques to restore the pavement texture. This technique addresses or affects all of the above functional performance objectives.

Diamond grinding has most frequently been used to restore the PCC ride quality. This procedure has been well documented. It has occasionally been used for this purpose on new pavement construction with mixed overall results.

If the technique is used after load transfer restoration to correct faulting on a durable pavement surface, it can result in an effective extension of pavement life of up to 20 years. However, if the coarse aggregate is polish-susceptible, the ride may significantly be improved but the average macrotexture depth and friction numbers may decrease rapidly, thereby increasing the relative accident risk. For this application, diamond grooving should be considered in addition to diamond grinding to increase the functional service life until some additional surface treatment may be needed.

If the purpose of the diamond grinding is to reduce the noise level, then additional research is needed to optimize the procedure. In Arizona, a recently constructed PCC pavement project with a randomized, transversely tined texture resulted in an objectionable tire pavement whine. It was diamond ground by the industry to reduce the noise and resulted in a significant noise reduction. However, it was still not as quiet as asphalt rubber friction courses on adjacent sections of pavement. The use of the "whisper grinding" approach developed in Belgium resulted in an additional decrease in noise of 4 d(B)A, which is very significant. Additional research is needed to optimize the texture provided to reduce the noise and to provide a durable, safe surface. The Arizona Department of Transportation is using State-of-the-Art Close Proximity noise-measuring equipment and a fixed-slip pavement friction tester to get continuous measurements to support their comprehensive evaluation effort (FHWA 2003c). The rapidly changing technology will economically provide significantly improved data to aid decision makers.

## Examples of Best Practice

***General.*** There are examples of recent developments where improved texture and friction data collection and analysis methods have been implemented. The most comprehensive example is the current activities in the United Kingdom which was initiated in 1989. The Federal Aviation Administration (FAA) has implemented design and maintenance specifications incorporating friction and texture measurements for airfield pavements that are similar to the U.K. approach. The Texas Department of Transportation has significantly revised their wet weather accident reduction program to enhance their data collection and analysis procedures to provide better information to decision makers. This is an example of how this same general approach can be effectively applied to a very large network.

***United Kingdom Practice.*** The recent publication in the United Kingdom of a revised Skid Resistance Policy based on 15 years of experience is an outstanding example of what can be done (Viner, Sinhal, and Parry 2004). The U.K. has established desirable, investigatory and minimum friction levels for paved highway surfaces. Table 1 shows the recently revised guidelines. The lightly shaded areas are considered appropriate for lower traffic volume facilities, whereas the darker boxes generally include a range of possible values depending upon conditions which are very site specific.

Table 1. Revised site categories and investigatory levels (Viner, Sinhal, and Parry 2004).

| Site category and definition | | Investigatory level at 50km/h | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 |
| A | Motorway class | | | | | | | | |
| B | Dual carriageway non-event | | | | | | | | |
| C | Single carriageway non-event | | | | | | | | |
| Q | Approaches to and across minor and major junctions, approaches to roundabouts | | | | | | | | |
| K | Approaches to pedestrian crossings and other high risk situations | | | | | | | | |
| R | Roundabout | | | | | | | | |
| G1 | Gradient 5 to 10% longer than 50m | | | | | | | | |
| G2 | Gradient >10% longer than 50m | | | | | | | | |
| S1 | Bend radius <500m – dual carriageway | | | | | | | | |
| S2 | Bend radius <500m – single carriageway | | | | | | | | |

Figure 1 shows the effect of skid resistance (SCRIM) and texture depth (mm SMTD) on the accident rate (Viner, Sinhal, and Parry 2004). Increasing the texture depth from 0.3 mm to 1.5 mm reduces the accident rate about 50 percent, and increasing the skid resistance from 0.35 to 0.6 reduces the accident rate about 65 percent. Where the texture depths are below 0.7 mm, the friction requirement is increased 0.05 to compensate. This is the best known data that clearly shows the expected benefits that increasing texture and friction can have on reducing the number of fatal and serious injury accidents. The Skid Resistance Policy, updated in 2004, also provides for annual Sideway Force Coefficient Routine Investigation Machine (SCRIM) and macrotexture surveys on the entire U.K. network. Sites with higher than average accident rates are reviewed annually to determine if low friction and/or texture values are likely contributing to the number of crashes; and, if so, appropriate actions are taken. There can be a large number of reasons for higher-than-average accident rates other than poor texture/friction as demonstrated by the Road Safety Audit process. The U.K. skid resistance approach is considered a Best Practice.

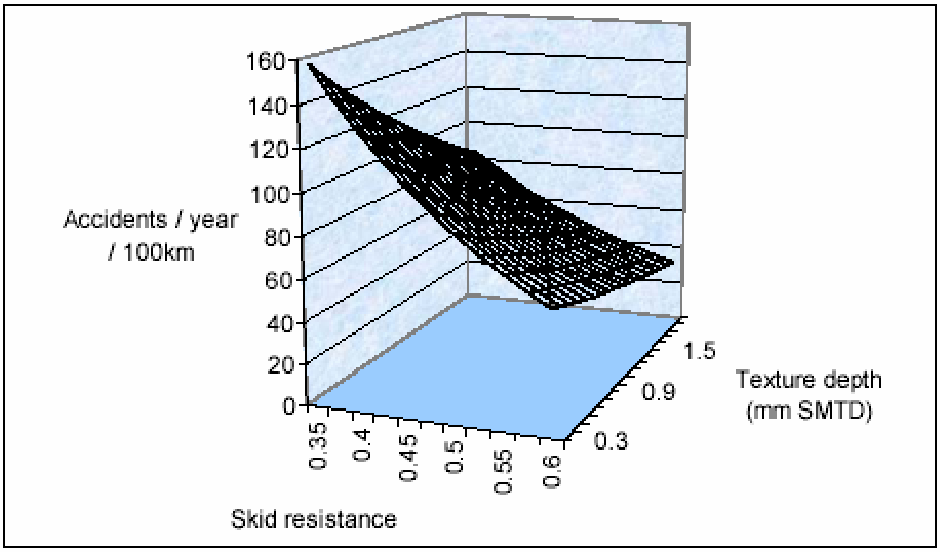


Figure 1. Accident model for skid resistance and texture depth on single carriageways (Viner, Sinhal, and Parry 2004).

In the April 2004 *Superior Materials International Scan* Report, the U.K. Highway Authorities Product Approval Scheme (HAPAS) concept was discussed (FHWA 2004e). The U.K. thin surface friction treatments (HAPAS approved) was believed to be one of the items with the most potential for the U.S. The comprehensive U.K. effort involving a formal skid resistance policy, approved thin surface friction treatments, and the road safety audit process to identify and correct potential accident locations is believed to be a major reason why the U.K. has one of the lowest accident rates in the world.

***Federal Aviation Administration Airfield Surface Specifications.*** The 1997 FAA Advisory Circular demonstrates an approach similar to that used in the U.K. for U.S. airports. It identifies desirable friction and texture values for both HMA and PCC airfield pavements and it provides specifications to implement the process (FAA 1997).

The FAA guidelines for skid-resistant airport pavement surfaces are considered a best practice example that could be modified to address various highway pavement classes. Friction and texture for new construction and for maintenance activities are addressed. This includes desirable friction and texture for new surfaces, maintenance planning (investigatory or warning) levels, and minimum acceptable levels.

***Texas Department of Transportation Wet Weather Accident Reduction Program.*** The Texas DOT recently developed an updated approach to provide safer highways by using annual macrotexture surveys (with a specially developed laser) and periodic locked wheel skid trailer tests with a smooth tire (non-standard rubber) at 50 mi/hr

(Behrens 1999). Macrotexture measurements are now made on 100 percent of the system during pavement management surveys. Texas tests friction on 25 percent of all roads (70,000 miles) annually except the Interstate system where 50 percent of the roads are tested. Friction testing is done every half mile. The mean profile depth, pavement type, and aggregate type are used to estimate friction every 80 feet within $\pm$ 6 friction numbers. The data are then summarized to obtain the average, maximum, minimum, and standard deviation of the estimated friction every 0.1 mile to evaluate variability (Carl Bertram, personal communication, August 5, 2004). A January 2003 report on the value of transportation research estimated the following benefits from their highway texture and friction related research for a 10-year period: (Texas DOT 2003)

- Pavement Surface Texture Measurement System: 12 lives saved, 1,100 accidents prevented, and $5,922,000 saved.
- Micro-Deval Aggregate Test: $1,495,000 saved.
- Alternate Polish Value and Soundness Specification Requirements (New Wet Weather Accident Reduction Program): 60 lives saved and 8060 accidents prevented.

This clearly demonstrates the significant benefits that can be expected from using new technology and analysis procedures to improve engineering decisions.

## Conclusions

Most of the efforts described in this paper do not specifically address the effect of increasing texture/friction on reducing both wet weather and total deaths and serious injuries and resulting traffic delays. It has been estimated that poor pavement conditions contribute up to 13,000 of the 43,000 annual highway-related deaths in the U.S. The current national emphasis on pavement preservation activities provides an outstanding opportunity to improve both the pavement condition and surface characteristics in a very cost-effective manner. Combined with known geometric design and traffic engineering improvements developed under the Road Safety Audit Process, the provision of better surface condition (few or no defects) and appropriate levels of texture and friction can make a significant contribution to accomplish the goal of reducing the fatality rate from 1.5 to 1.0 per 100 million vehicle miles of travel in 2008. The recent significant developments in data collection equipment and analysis procedures will make it possible to significantly improve engineering guidance to help reduce the number of deaths and serious injuries annually and also to reduce the resulting traffic delays.

It is recommended that the U.S. goal of reducing deaths and serious injuries by 2008 be modified to assign a portion of this reduction to providing safer roads:

- Minor geometric and traffic engineering improvements.
- Improved pavement condition and optimized texture and friction characteristics.

It is recommended that one or more of the States with HSIS data be encouraged to annually include a 100 percent macrotexture survey and a continuous friction survey in their database. This would allow the development of improved IHSDM and *SafetyAnalyst* models. One of the weakest links is the inability to compare friction demand assumed during design and actual pavement conditions at the sites being investigated so the cost-effectiveness of skid resistant surfaces or treatments can be evaluated. The enhanced data should also be used to document the benefits of pavement preservation projects and the Road Safety Audit Process.

Road Safety Audit Guidelines should be revised to include guidelines on desirable pavement surface characteristics. Typical values of texture and friction for typical wearing courses and thin friction courses or surface treatments and costs should be developed so the cost-effectiveness of more skid resistant surfaces can be evaluated.

End-result specifications for texture and friction levels should be developed to ensure desired levels are obtained during construction. Also, there is a need to develop predictive models for accident rate and noise levels and to develop monitoring procedures to validate/refine the models.

The revised and updated AASHTO Strategic Highway Safety Plan (particularly Part 6: Management) will address many of the above issues. Combined with the friction and texture guidelines being developed by NCHRP, significantly improved guidelines should be available to help ensure durable, safe, and quiet highways are provided the highway users.

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