Using Friction and Texture Data to Reduce Traffic Fatalities, Serious Injuries, and Traffic Delays

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ABSTRACT

In the United States, it has been estimated that inadequate highway pavement conditions contribute to 13,000 of the 43,000 annual highway fatalities. Poor pavement friction or surface texture increases total crashes and also contributes to wet-weather crashes, resulting in increased fatalities, more serious personal injuries, and significant traffic delays.

This issue is especially critical on two-lane roadways, because of generally lower geometric standards and more potential conflicting movements, particularly at curves, intersections, and steeper grades. Also, work zone crashes result in 1,300 fatalities annually, and transition areas are particularly critical. Ramps on freeways are also potential high accident locations. Thus, it is important to compare the friction demand assumed during design with the friction/texture actually provided at the site being investigated.

This paper discusses recent efforts in the United States by the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) to address this issue. It summarizes information obtained from international sources, particularly recent safety scans that have been conducted, and notes the experience of the U.K. and Austroads. Additionally, this paper describes current efforts in the U.S. to develop computerized analysis tools and to implement Road Safety Audits. It also identifies a number of relevant studies either completed or underway.

The current U.S. emphasis on pavement preservation presents an outstanding opportunity to improve the pavement condition and surface characteristics in order to reduce accidents and pavement-related noise. Technological advances in data collection, storage, and analysis make it possible to provide information to improve engineering decisions. Two examples of improved procedures are given. The first is a procedure adopted for texture and friction requirements on airfield pavements. The second example is the recent improvement in the Texas Wet-Weather Accident Reduction Program to reduce data collection and analysis costs and to reduce the number of crashes and fatalities.

Finally, some conclusions and recommendations are provided to develop safer roads. The emphasis is on providing better information on the effect of texture and friction on reducing accidents, so that more cost-effective engineering decisions can be made.

1. INTRODUCTION

In recent years, there has been a major effort initiated by the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) to improve highway safety in the United States. Safety management systems were first mandated by the Intermodal Surface Transportation Efficiency Act of 1991, and while these systems were made optional in 1995, the FHWA prepared updated guidelines for their development in 1996 (1). These activities were followed by the development of the AASHTO Strategic Highway Safety Plan in 1998 (2). However, while all States were working on developing safety management systems in 1995, only about 40 percent of the States continued to develop or enhance their systems in 2003 (3). This is important because it has been estimated that poor pavement conditions contribute to 13,000 of the 43,000 annual highway deaths.

This paper discusses recent efforts in the United States by the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) to address this issue. It summarizes information obtained from international sources, particularly recent safety scans that have been conducted, and notes the experience of the U.K. and Austroads. Additionally, this paper describes current efforts in the U.S. to develop computerized analysis tools and to implement Road Safety Audits. It also identifies a number of relevant studies either completed or underway.

Finally, some conclusions and recommendations are provided to develop safer roads. The emphasis is on providing better information on the effect of texture and friction on reducing accidents, so that more cost-effective engineering decisions can be made.

2. AASHTO STRATEGIC HIGHWAY SAFETY PLAN

In 1998, NCHRP 17-18 was established to support national implementation of the AASHTO Strategic Highway Safety Plan (4). However, in December 2003, a national meeting was held in Washington DC to begin a new, coordinated effort to significantly alter the nation's worsening highway death and injury picture. This new effort was launched to lower the nation's highway fatality rate to 1.0 per 100 million vehicle miles of travel by 2008 (compared to the fatality rate of 1.48 per 100 million vehicle miles of travel recorded in 2003). Thirty lead States were enlisted to test drive the Strategic Safety Plan and Process. An additional 10 States have now joined this effort. The goal is to save 9,000 lives a year by 2008. Currently, there are about 43,000 deaths, 3 million injuries, and 6 million crashes annually in the U.S. with an estimated associated cost of $230 billion. These numbers are considered unacceptable. Detailed information about the AASHTO Strategic Highway Safety Plan, the Integrated Safety Management Plan, and the "Tools for Life" (created to facilitate implementation) are all available at http://safety.transportation.org.

These new statewide efforts focus on six elements related to highway safety: drivers, vehicles, special users, highways, emergency medical services, and management. Key emphasis areas and corresponding strategies are listed under each element. In all, the AASHTO plan identifies 22 emphasis areas and more than 90 strategies for reducing the number and severity of crashes, saving lives, and lowering the number of injuries. Three tools are available to facilitate and accelerate implementation: Integrated Safety Management Process, Guidelines for Implementation, and Self-Assessment.

The Integrated Safety Management Process (ISMP), NCHRP Report 501, has been produced to aid in developing a comprehensive safety plan in each jurisdiction (5). This tool outlines the 10 steps involved in establishing an ISMP in their states. The ISMP stresses integration at all levels. During implementation, it continues across the '4-E's'—enforcement, engineering, education, and emergency services—and across safety agency and jurisdictions.

Under the NCHRP 17-18 project, 13 of the 22 implementation guides for the emphasis areas have been developed. Eight additional guides will be published in 2005. NCHRP Report 500, Volume 6: Run off the Road, Volume 7: Horizontal Curves, and Volume 12: Signalized Intersections identify that increased skid resistance of the pavement surface is a potential countermeasure (6). However, very little guidance on how to implement this recommendation is provided.

The Self-Assessment Tool lists each emphasis area and strategy included in the plan. It enables users to assess the degree to which recommended strategies are already being implemented and to identify safety concerns that require greater emphasis.

3. HIGHWAY SAFETY DATA BASES IN THE UNITED STATES

One of the early data base efforts was conducted by The Traffic Records Committee formed in the early 1970s to assist the National Safety Council in supporting the traffic accident reduction and prevention goals of the Traffic Safety Division. In 1996, a National Agenda for the Improvement of Highway Safety Information Systems was published (7). This committee has been renamed the Association of Transportation Safety Information Professionals (ATSIP), but the goals remain the same. The 31st Traffic Records Forum, July 31-August 4, 2005, to be held in Buffalo, New York, will once again showcase state-of-the-art projects that improve the collection, quality, and application of safety data. A "Best Practices Challenge of 2005" has been developed to share the benefits these projects offer with other traffic records experts.

In 2003, the Model Minimum Uniform Crash Criteria Guideline, *Improving Crash Data for Safer Roadways*, was updated (8). However, there remains a need to develop an integrated data base that ties the accident data to detailed geometric data and to pavement condition data bases that include pavement surface characteristics such as texture and friction (9, 10, 11). AASHTO is developing the Transportation System Information Management System (TSIMS) to enable States to draw on the data resources of existing safety systems and create a data platform that can be shared by all stakeholders to advance the stat-of-the-art in safety data analysis.

One of the most comprehensive systems available in the U.S. is the Highway Safety Information System (HSIS). The HSIS is a multi-State safety database that contains accident, roadway inventory, and traffic volume data for a select group of States. The data from nine State (California, Illinois, Maine, Michigan, Minnesota, North Carolina, Ohio, Utah, and Washington State) roadway systems is used by FHWA staff, contractors, university researchers, and others to study current safety issues, direct research efforts, and evaluate the effectiveness of accident countermeasures (12). Detailed pavement condition and surface characteristics data (texture/friction) are not currently included in this system.

4. INFORMATION FROM INTERNATIONAL SOURCES

It has been estimated that there are 1.2 million highway-related deaths and 50 million serious highway-related injuries annually in the world. This is a significant problem in both developed and developing countries. Greater international cooperation is needed to address this problem. To take advantage of the experience of other countries, FHWA and AASHTO representatives have conducted about a dozen international scanning tours to discuss and observe some of the best safety-related practices used in other parts of the world.

The October 2004 Report, *Traffic Safety Information Systems in Europe and Australia*, is the most recent published document (13). 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. (14). The highway safety program elements of most interest were the route-based or area-wide safety improvement programs and the road safety audits.

One of the major International Scan technologies being implemented in the U.S. is The Road Safety Audit and Review Process (15). The United Kingdom, Australia, and New Zealand are leaders in refining and advancing the state of the practice (16). 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 (16). A recent U. S. report also identifies roadway safety tools for local agencies (17).

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A Preprint CD of the SURF 2004 Pavement Surface Characteristics Symposium is also available (18). 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 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 (19). 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.

Figure 1 shows the effect of skid resistance (SCRIM) and texture depth (mm SMTD) on the accident rate (19). 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. 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 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 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.

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								

Table 1. Revised site categories and investigatory levels (19).

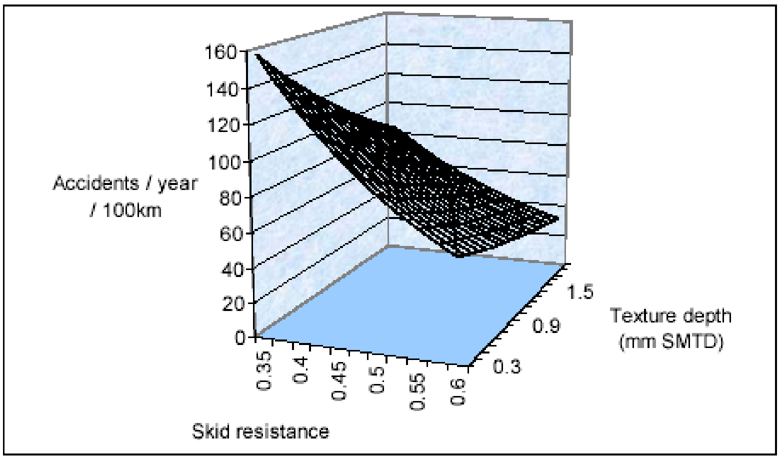

Figure 1. Accident model for skid resistance and texture depth on single carriageways (19).

In the April 2004 *Superior Materials International Scan* Report, the U.K. Highway Authorities Product Approval Scheme (HAPAS) concept was discussed (20). 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 RSA 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.

An OECD report, *Road Safety: Impact of New Technologies*, estimates that new technologies, including intelligent speed adaptation and collision avoidance systems, are being developed and could significantly reduce the number of people killed or injured by as much as 40 percent (21). However, improving pavement surface characteristics should not be delayed until these new technologies are implemented.

Infrastructure Safety was the heart of the 1st European Road Congress held in Lisbon in November of 2004. Three sessions addressed road safety from various angles (road design, accidentology, and construction technologies). A summary of the conference and all presentations delivered are available at http://www.europeanroadcongress.com. 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 (22).

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 (23). The Australian National Road Safety Action Plan 2005 and 2006 had 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 (24). 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 (23). 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.

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.

5. EFFORTS TO ADDRESS EFFECTS OF TEXTURE/FRICTION ON SAFETY IN THE UNITED STATES

5.1 GEOMETRIC DEMAND VERSUS TEXTURE/FRICTION

In the U.S., substantial research is underway on the geometric design of highways to improve safety (25). 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, etc.) throughout the pavement's service life. 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 and the *SafetyAnalyst* are two such tools under development or being enhanced by FHWA to aid in this effort (26). Updated information on FHWA's safety efforts can be accessed at http://safety.fhwa.dot.gov.

5.1.1 Interactive Highway Safety Design Model (IHSDM)

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.

5.1.2 SafetyAnalyst

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 (26).

5.2 ROAD SAFETY AUDITS

One of the most promising techniques being implemented in the U.S. is the Road Safety Audit (RSA). Iowa, New York, South Dakota, Pennsylvania, and South Carolina have developed programmed approaches for including proactive safety assessments. Kentucky, Maine, and Mississippi are others that have participated in audit training and are conducting RSA's. This is a 'Best Practice' that is being used by an increasing number of States to proactively address highway safety (16, 17, 27, 28). 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 at above-average accident rate sites and for improved guidelines on selecting the most cost-effective treatment.

5.3 TRAINING AND RESEARCH INITIATIVES

5.3.1 National Highway Institute (NHI) Training Courses

The National Highway Institute (NHI), the training branch of the FHWA, has several training initiatives that are new/updated/under development in FY 2004-2005, including:

- Course Number 151039, *Applying GIS & Spatial Data Technologies to Transportation*.
- Course Number 380071. *Interactive Highway Safety Design Model*.
- Course Number 380074. *Designing and Operating Intersections for Safety*.
- Course Number 380069. *Road Safety Audits and Road Safety Audit Reviews*.

5.3.2 National Cooperative Highway Research Program (NCHRP) Publications

The following recent NCHRP Synthesis of Highway Practice summarize a large number of safety related activities:

- Synthesis 291, *Evaluation of Pavement Friction Characteristics* (2000).
- Synthesis 295, *Statistical Methods in Highway Safety Analysis* (2001).
- Synthesis 321, *Road Safety Tools for Local Agencies* (2003).
- Synthesis 322, *Safety Management Systems* (2003).
- Synthesis 336, *Road Safety Audits* (2004).

Other Related NCHRP Synthesis of Highway Practice include:

- Synthesis 299, *Recent Geometric Design Research for Improved Safety and Operations* (2001).
- Synthesis 311, *Performance Measures of Operational Effectiveness for Highway Segments and Systems* (2003).
- Synthesis 330, *Public Benefits of Highway System Preservation and Maintenance* (2004).
- Synthesis 334, *Automated Pavement Distress Collection Techniques* (2004).

Related reports produced by the NCHRP include:

- NCHRP Report 486, *Systemwide Impact of Safety and Traffic Operations Design Decisions for 3R Projects*.
- NCHRP Report 500, *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan* (21 volumes are expected to be available in 2005).
- NCHRP Report 501, *Integrated Safety Management Process (ISMP).*
- NCHRP Report 523, *Optimal Timing of Pavement Preventive Maintenance Treatment Applications.*
- AASHTO NCHRP 17-18, *Tools for Life.*

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 (29, 30).

5.4 SAFETY BENEFITS OF PAVEMENT PRESERVATION PROJECTS

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) (31). Applying thin overlays or surface treatments are relatively low cost options, that if used to maintain or enhance the skid resistance of the pavement surfaces, can make a significant impact by reducing the 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. Effectively integrating pavement management, maintenance management, and safety management systems would provide the data needed to make more cost-effective decisions (29, 30). As noted above, the information being developed in the United Kingdom should help clearly demonstrate the value of the comprehensive road safety audit approach to the U.S.

5.5 UPDATED GUIDANCE ON TEXTURE/FRICTION BEING DEVELOPED

Three projects to develop enhanced guidance on using pavement surface characteristics to improve highway safety are underway in the U.S. The 1976 *AASHTO Guide for the Design of Skid Resistant Surfaces* is currently being updated under NCHRP Project 1-43 (32). 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, *Guidelines for PCC Surfacing Texturing,* are being developed. These guidelines will address the need for adequate friction and for low noise PCC surfaces (33). The preparation of a NCHRP Synthesis of Highway Practice 36-03, *Technologies for Improving Safety Data*, is just getting underway (34). These efforts will enhance available guidance on incorporating texture/friction information into the pavement design decision making process.

5.6 RECENT DEVELOPMENTS IN DATA COLLECTION AND ANALYSIS

In the past, there has often been a weak link between friction numbers and accident rates. One of these reasons was due to the widespread use of the ribbed tire to obtain friction numbers which masked the pavement surface drainage characteristics. Use of the blank tire would overcome this deficiency. Also, consideration of fixed-slip friction testers that allow continuous measurement, rather than the locked-wheel friction tester typically used in the U.S., should be given. 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 analysis capability. The advancements in global positioning systems and geographic based information systems allow various data bases to be tied together to allow 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 (30).

6. EXAMPLES FROM THE UNITED STATES

There are examples of recent developments in the U. S. where some of these concepts are being implemented. The Federal Aviation Administration (FAA) has implemented design specifications for airfield pavements that incorporate friction and texture. 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.

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6.1 Federal Aviation Administration (FAA) Airfield Surface Design 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 hot-mix asphalt (HMA) and portland cement concrete (PCC) airfield pavements and it provides specifications to implement the process (35).

6.2 Texas Department of Transportation Wet Weather Accident Reduction Program

The Texas DOT recently developed a new approach for safer highways using annual macrotexture surveys (with a specially developed laser) and periodic locked wheel skid trailer tests with a blank tire (non-standard rubber) at 50 mi/hr(36). 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 ± 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 (37). A January 2003 report on the value of their highway texture and friction related research estimated the following benefits for a 10 year period: (38)

- 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.

7. SUMMARY

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 saving 9,000 lives annually 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.

8. CONCLUSIONS AND RECOMMENDATIONS

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.

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