APPENDIX A. ANNOTATED BIBLIOGRAPHY


When American motorists talk about transportation problems, they generally key in on traffic. Snarled highways, epic commutes, and gridlocked business and commercial districts mar our suburban existence, weighting heavily upon our elected leaders, our policy-makers, and our families. Yet there’s a more costly problem to be addressed on America’s roads: motor vehicle crashes. In 2006, traffic crashes killed 42,642 people in the United States – about 117 deaths per day, and nearly 5 every hour. Most Americans would be surprised to learn the societal costs associated with motor vehicle crashes significantly exceed the costs of congestion. AAA commissioned this study to examine the costs of crashes to society. The study, along with recommendations for improvements, is designed to raise awareness of the importance of transportation investments, and provide policy-makers, departments of transportation, and the public with information on the magnitude of the safety problem.


Providing cost-effective, safe and smooth pavement surface is a priority for transportation agencies. The major challenge, however, is to provide a sustainable surface skid resistance for economy and preservation of superior safety, yet smooth enough for quiet and comfortable ride. Some advancement in smoothness indices and texturing methods has occurred as part of this balancing act between the pavement smoothness and surface friction. However, the sustainability issue of different surface textures has not yet fully addressed. There is also a need to develop comprehensive models that predict the short and long-term performances of different surface textures. This paper addresses the performance of concrete pavement surface textures using the Federal Highway Administration (FHWA) Long Term Pavement Performance Program (LTPP) data in GPS 3, 4 and 5. The analysis shows that tined/grooved textures maintain consistently higher skid resistance over time and concrete pavements surface friction is insensitive to ambient condition. Cumulative traffic passes was more sensitive to frictional performance than the cumulative axle loads. Two alternative models have also been successfully developed for prediction of concrete pavements long-term skid resistance as a function of texture type, cumulative traffic passes, speed, and concrete compressive strength. These models were shown to be statistically significant at 95% confidence levels with reasonable prediction accuracy.


Skid resistance has been the most important property of a surface layer in the UK for many years. It has been provided by the use of aggregate with high polished stone value and mixes designed with high texture. However, in recent years this traditional approach has been subject to investigation and the simplistic relationship between texture depth and polished stone value questioned. The polished stone value test has been found to be a ranking method dependant on the stressing conditions imposed during the tests i.e. vary the stress during testing and different aggregates will react in different ways to achieve a new equilibrium level. The German Wehner Schulze test is now proposed within Europe as a replacement to the polished stone value test. This method subjects either laboratory prepared asphalt samples or cores extracted from the pavement surface to simulated trafficking and measures change in skidding resistance with time. The method has been accepted by German contractors to predict performance of the mix. This paper details an investigation of the Werner Shultz equipment to assess UK asphalt surfacing mixes.

Researchers at Pennsylvania State University have developed a computer-based system that uses fuzzy logic to predict the risk of accidents on wet pavement. The system can help identify high-risk roads and indicate ways to improve their safety. When compared with probabilistic and nonlinear regression models, the fuzzy logic models not only were more accurate in predicting the risk of wet pavement accidents but also had the advantage of providing specific ways to decrease risk. Researchers hope that their work will help highway departments with limited resources decide which sections of road to focus on when doing improvements.


The purpose of this project was to identify techniques for improving the drainage of multi-lane highway pavements and to develop guidelines for implementing the most promising of these techniques. The drainage of highway pavement surfaces is important in the mitigation of splash and spray and hydroplaning. This study focused on improving surface drainage to reduce the tendency for hydroplaning. The main factor affecting the propensity for hydroplaning is the thickness of the water film on the pavement surface. Three general techniques were identified for reducing the water film thickness: controlling the pavement geometry, the use of textured surfaces to include porous asphalt surfaces and grooved surfaces, and the more effective use of drainage appurtenances. The prediction of the water film thickness is based on the use of the kinematic wave equation as a model to predict the depth of flow on pavement surfaces. Data supporting the model were obtained from the literature and from studies conducted to measure Manning’s n for a brushed concrete surface and for porous asphalt surfaces. Expressions for Manning’s n as a function of Reynold’s number were developed for Portland cement concrete, asphalt concrete, and porous asphalt surfaces. Full-scale skid testing was also conducted on grooved and brushed concrete surfaces and on porous asphalt surfaces; texture measurements were obtained for all of the tested surfaces (laboratory and field). The results have been integrated into an interactive computer program, PAVDRN. This interactive program allows the pavement design engineer to select values for the critical design parameters. The program then predicts the water film thickness along the line of maximum flow and determines the hydroplaning potential along the flow path. If the predicted hydroplaning speed is less than the design speed, the designer is prompted to choose from alternative designs that reduce the thickness of the water film.


This report provides background information for designers and users of braking slip measurement devices, with emphasis on topics related to the comparison and harmonization of friction measurement devices. It describes aspects of measuring braking slip friction on traveled surfaces, especially those found during weather changes on aerodrome movement areas during winter. In practice, all types of surfaces and conditions are encompassed, ranging from bare and dry to pavements covered with precipitation deposits, thus providing a year-around context. The mechanics of various combinations of the surface interaction mechanisms are discussed and a parallel case presentation of a force measuring and a torque measuring friction device highlights the difficulties of obtaining mechanical error-free measurements of braking slip friction in action. Also, the report presents models for the interaction between a braked tire and a surface, along with several approaches to harmonization of friction measuring devices and ways in which harmonized results could be used to predict aircraft braking-wheel performance. The report suggests normalized friction measurement devices and segmented runway condition maps to monitor friction at airports.


This paper presents a 5-year evaluation of nine test sections with varying textural characteristics. Nine test sections were constructed on I-70 near Denver, Colorado with varying textural characteristics. Texture depth, skid numbers at different speeds and their noise properties were measured and compared. Review of the acquired data revealed a definite relationship between speed, types of surface texture, and the magnitude of skid numbers. As speed increased, the skid numbers declined. This relationship was clearly more pronounced and consistent using the smooth tire. Longitudinal macrotexture and microtexture were the quietest surfaces. State standard transverse tining with 1-inch uniform spacing exhibited the highest noise level among all the test sections when measured with the microphone at the rear tire position. CDOT has adopted longitudinal tining as its preferred method of texturing.
concrete pavements since 1997. The results of this study indicated that longitudinal tining, in addition to possessing adequate frictional properties, provides lower noise than the CDOT’s standard transverse tining.


This report presents a 5-year evaluation and construction details of nine test sections with varying textural characteristics. Included in the report is an overview of the methodologies used to texture concrete pavement surfaces and a discussion of frictional attributes of various textures at different speeds and their impact on noise properties. Also included in the report are descriptions of texture-measuring devices and texture-installing equipment, a description of the state-of-the-art equipment used to acquire sound pressure levels, plus a thorough discussion of data acquisition/analysis. Frictional characteristics of the individual test sections were evaluated using the ASTM E 274 skid testing procedure. Ribbed-tire and smooth-tire friction tests were conducted to acquire skid numbers at three different speeds of 40, 50, and 65 mph (64, 80, and 105 km/h). To examine the noise properties of the test sections, noise measurements were acquired to acoustically assess the impact of various surface textures at three different locations: inside the test vehicle; 25 ft (7.6 m) from the center line [3 ft (0.9 m) away from the right shoulder); and near the right rear tire of the test vehicle, away from the exhaust pipe.


The third Action Plan identifies the main issues expected to influence road trauma levels in the foreseeable future, and sets out the priority areas for action in calendar years 2005 and 2006. The Action Plan was developed jointly by all Australian jurisdictions, with input from the National Road Safety Strategy Panel, which represents a broad range of organizations with a stake in road safety. It has been endorsed by Ministers of the Australian Transport Council (ATC). This new Action Plan deliberately builds on previous work, but also recognizes that changes in the Action Plans are needed to reflect recent developments and new information, and to anticipate actions that will influence road safety beyond 2010. An important aim of the Action Plan is to highlight the Safe System concept as an overarching framework for road safety intervention. The Safe System approach emphasizes the way different elements of the road transport system combine and interact with human behavior to produce an overall effect on total road trauma. The key components of the system are safer roads and roadsides (infrastructure), safer speeds and safer vehicles.


This guide provides systematic guidelines to asset managers, maintenance engineers and supervisors on the characteristics of road surfacings to assist in the process of selection of appropriate road surfacings for particular conditions. Companion Austroads publications provide detailed guides to the design and application of the various surfacings types. The guide provides detailed advice on:

- surfacing performance characteristics, which may influence the choice of pavement, and surfacings type;
- desirable performance characteristics of road surfacings and measures used for assessing the level of surface required;
- surfacing types;
- the selection of surfacings for new pavements;
- identifying and correcting deficiencies in existing pavements surfacings;
- the selection of surfacings for retreatments.

Detailed methodology is provided for the selection of surfacings for new pavements and also for pavement maintenance purposes.


These Guidelines provide information for road authorities to develop and implement a local response (throughout this document referred to as a local strategy) to manage the skid resistance of surfaced roads (i.e. both bituminous and concrete) within their network and introduces sixteen (16) key elements that need to be considered in the
development of such a strategy. The Guidelines also provide information on the basic principles of skid resistance, including surface friction, surface texture and the impact of road condition.


The Maryland State Highway Administration (SHA) owns and maintains 15,000 lane miles of mainline road network of which 98% is Hot Mix Asphalt (HMA) surfaced. The pavement friction survey includes collecting information on other roadway and pavement condition features such as traffic, location, test speed, date of testing, etc. The friction data in SHA’s database is managed by the Pavement Management Division, which is charged with receiving pavement condition data from the Exploration Division and maintaining the data. The pavement friction surveys in Maryland are conducted using the locked wheel pavement friction tester attached to a truck. The test vehicle used by SHA in the friction surveys is usually calibrated to conduct surveys at 40 mph. However due to speed limit restrictions and road usage, the test crew is sometimes forced to take readings at speeds less than prescribed by the manufacturer. Twenty percent (20%) of the friction values in SHA’s database were taken at speeds less than 38 mph. Currently at SHA, there is no correction applied to the friction numbers recorded at low speeds. The data that was used for this analysis was obtained from roadways located in six of the twenty-three counties in Maryland. The results of the analysis show that there is an inverse relationship between speed and friction values.


The results of a study aimed at investigating the effects of temperature and surface texture on the friction force developed at the tire-pavement interface during skidding are presented. Ten field sites representing a variety of asphalt pavements in the State of Ohio were selected for the study. Five laboratory briquettes made from the same materials used in the construction of the pavements were prepared for each of the sites. Skid resistance measurements were performed on the briquettes using a portable British pendulum tester. The friction force was considered to consist of two parts, namely, the wet adhesion and the hysteresis components. The adhesion and hysteresis components were measured separately using water and liquid hand soap as lubricants. To simulate the changes due to wear and aging of pavements, several cycles of mechanical polishing were conducted and the available contact area after polishing was determined using a digital image processing technique. Tests were conducted at five different temperatures. The hysteresis component of friction decreased with increasing temperature regardless of surface texture state. The adhesion component was more sensitive to surface texture effects. Hysteresis was found to account for the larger part of the total friction force. Combined friction decreased with increasing temperature on a polished surface; hence it is recommended that skid numbers obtained at any arbitrary temperature be normalized with respect to a value at a reference temperature, for example, 293 K (68°F).


The effective use of measurements of skid resistance requires that the measurements are accurately located. Traditionally linear referencing has been used to locate the measurements. The development of accurate GPS systems has offered the opportunity for more accurate referencing and this approach has been used together with GIS systems to present the measurements. However, software used to analyse the measurements and manage the data to produce maintenance treatment options associated with asset management plans, relies on linear referencing. Changes to this software would require a major investment. This paper shows how the accuracy of GPS referencing can be transferred to linear referencing thus gaining the benefits of GPS while maintaining the use of existing software systems. The paper describes the application of the approach in New Zealand and reports from pilot trials, the improvements in accuracy that can be expected. The paper concludes by describing the benefits that will accrue by implementing the approach and describing briefly the lessons learned from the trials to date.


Can the Sideways force Coefficient Resistance Investigation Machine (SCRIM) output data be utilized as a project tool? The annual SCRIM exception report for the New Zealand State Highways indicates at a network level that
specific lengths of road may have a loss of microtexture and macrotexture and thus need further investigation leading to remedial works. The Auckland region has traffic volumes of up to 200,000 vpd, as well as some topographically constrained alignments, exposes surfacing aggregate to the highest wheel tractive forces nationally. Monitoring of average Equilibrium SCRIM Coefficient results over treatment lengths of lengths 500m to 2 Km has produced credible trend information, which has lead to sustainable accident reduction.

The paper will describe how this approach has lead to timely intervention, a process of back calculation to better determine the PSV formula environmental factor and confidence with specific aggregate micro texture performance.


The purpose of NYSDOT’s Safety Appurtenance Program (SAFETAP) is to facilitate the inclusion of safety improvements in the Department’s simple resurfacing projects. The process of the implementation of SAFETAP involved explanatory discussions and negotiations, as well as some compromise with diverse agency interests before the program gained formal agency approval. The result has been the institutionalization of a major Department-wide program, which by systematically incorporating highway safety into hundreds of simple resurfacing projects will go a long way toward ensuring the continuation of sizeable accident reductions (which occurred in our state during the previous thirty-five years) into the next century.


The state of New York owns and maintains an enormous inventory of roadside appurtenances, including guide rail, signs, delineators, and drainage structures. Those roadside features exist for the convenience and safety of the motoring public. Historically, maintenance of roadside appurtenances has depended to a large degree on inclusion in the department's pavement resurfacing programs, particularly the previous resurfacing and preservation and ongoing resurfacing, restoration, and rehabilitation programs. Those resurfacing programs have been largely supplanted by the department's highly successful preventive maintenance paving (PMP) program. In fact, the share of miles of pavement being resurfaced each year under the PMP program has been increasing steadily since 1990 (from 44 to 72% of total miles resurfaced). Since the goal of the PMP program is limited largely to maintaining pavements, roadside appurtenances were not receiving the attention they required. The New York State Department of Transportation Safety Appurtenance program (an FHWA road safety audit pilot program) ensures that roadside appurtenances receive the attention they need under the PMP program in order to protect a sizable roadside investment and to ensure the safety of road users. The Offices of Engineering and Operations jointly proposed the plan that would involve maintaining existing safety features and adding appropriate, easily implementable, and low-cost safety treatments at PMP project locations either during construction or, more likely, after construction as part of a distinct but "linked" effort. Work not included in the PMP project could be undertaken by maintenance forces or under requirements type contracts (separate signing or guide rail contracts). The guiding principles behind the plan are that it not interfere with accomplishment of the primary goal of the PMP resurfacing program (pavement maintenance), that it not result in a reduction in the number of lane miles treated with PMP resurfacing, and that it not significantly delay or otherwise complicate the processing of PMP resurfacing projects. A regional road safety audit team (composed of staff from design, traffic, and maintenance areas) now reviews proposed PMP project locations for existing accident problems, based on an identified accident history or potential accident problems such as obvious, hazardous roadway features that can be readily identified during a field review, and recommends cost-effective improvements to address existing and potential accident problems. The design of the program, how it gained executive management approval, and some early program accomplishments are discussed. The initiative has proven successful not only because of its clearly defined benefits for two agency goals (highway maintenance and safety) but also because of the systematic process by which it was introduced to agency managers with sometimes conflicting needs and agendas.


New York State Department of Transportation's (NYSDOT's) Skid Accident Reduction Program (SKARP) identifies sections of pavement experiencing unusually high proportions of wet road accidents, friction tests them,
and treats those sections which are experiencing both high wet road crashes and low friction numbers. The treatment generally involves a 1 and 1/2" resurfacing, or a 1/2" microsurfacing, using non-carbonate aggregates (costing $20,000 per lane mile). Forty (40) locations treated under the Program have been evaluated. Based on the size and consistency of the differences in crash experience and friction numbers during each year before and following resurfacing at identified high wet road crash sites, it is concluded that the Program selection and treatment strategies are appropriate and effective. Percentages of wet road crashes (compared with total crashes) have remained consistently high during years before treatment, and consistently low following treatment. Particularly noteworthy, is that the percentages remained high during the before period even during years when the identified high wet road crash sites did not appear on the annual high wet road crash listing (suggesting a minimal effect of regression to the mean at identified high crash sites experiencing low friction numbers). "Before and After" accident analyses have shown that each year more than 740 annually recurring accidents are being reduced as a consequence of treatments undertaken at 40 sites between 1995 and 1997 on Long Island alone. Five hundred and forty (540) of those crashes were wet road crashes. Some simple empirically based tests for regression to the mean were undertaken (in addition to the above). A one year before/after study was performed for 20 of the test locations, which did not appear on the wet road crash listing during the one year before period. Results from that evaluation, the general consistency of percentages of wet road crashes in the before period, and previous empirically based findings regarding the effect of regression to the mean at untreated high accident sites, suggest crash modification factors for the SKARP program as follows: total crashes should be expected to decline by 20%, wet road crashes should be expected to decline by 60%, and severe (Fatal and injury) wet road crashes should be expected to decline by 70%. All but one of the 40 sites treated in this study involve intersections. Improving pavement friction at intersections experiencing high wet road crashes and low friction numbers, presents a relatively low cost improvement which should be expected to produce large crash reductions - particularly as regards severe (fatal and injury) crashes.


In March 2000, the Government announced a new set of casualty reduction targets for the year 2010 for Great Britain. A key element in the preparation of the new target was to forecast the number of casualties in 2010, taking account of any factors that might influence this number substantially. This report provides an account of progress up to 2004 and describes the casualty trends and what they suggest for the likelihood of achieving each of the targets. It updates the original analyses with data from 1999-2004 to re-assess the conclusions that were drawn about future casualty trends, and summarizes of the other investigations that have been carried out. The key target is for the number of people killed or seriously injured (KSI), with no separate target for the number killed. The number of deaths had tended to rise between 1998 and 2003, but fell by 8% in 2004. The changes in 2004 are analyzed in detail to see whether they are likely to signify a change in previously observed trends.


The purpose of this study is to provide a comparison of longitudinal diamond-ground and transverse-tined pavement surface texturing for newly constructed portland cement concrete pavement (PCCP). The study area is located along a test section of I-190 in Buffalo, New York. The two PCCP surface treatment types under evaluation are compared based on safety, noise, construction cost, service life, rideability, handling, and maintenance requirements. The initial evaluation is documented, as is the analysis of follow-up noise and skid resistance measurements conducted approximately one year later. Analysis of the initial testing indicates that the relative skid resistance of the experimental longitudinal diamond-ground surface is as good or better than that of the transverse-tined surface. The results of the noise analysis indicate that the longitudinal diamond-ground surface is 2 to 5 dB quieter depending primarily on the traffic vehicle mix. Noise and skid resistance measurements conducted one year later showed little change. Although less construction time was required for the transverse-tined pavement compared with that for the diamond-ground pavement, the actual cost difference is not quantifiable. However, a higher initial cost for longitudinal diamond grinding would likely be partially offset by an extended service life.
Macrotexture refers to variations in the road surface in the range 0.5 mm to 50 mm. It is generally believed to affect braking through the two mechanisms of hysteresis and the prevention of a water film. A literature review concluded that crash risk is greater at sites with low macrotexture, but studies differ as to the macrotexture values at which risk begins to increase. Limited work to date suggests that the relationship cannot be explained simply in terms of traffic flow. A pilot study of the relationship between macrotexture and crashes was undertaken by locating each crash on the macrotexture measurement record. The relationship was compared on the Great Eastern Highway, Western Australia, Princes Highway West, Victoria, and the Duke’s Highway, South Australia. In nearly all cases, there was an association between macrotexture and crashes, the exceptions being rural sites on the Princes Highway West, where the relationship was marginally significant, and urban sections on the Dukes Highway, where there was no association (but note there was very little urban road on this route). There was a significant association between low macrotexture and crashes at all rural intersection sites, but no association between low macrotexture and wet road crashes, nor between macrotexture and young driver crashes, and insufficient data to examine the relationship for heavy vehicles. The data were also examined for associations between macrotexture and young driver and heavy vehicle involvement. There was no significant association with young driver involvement. There was insufficient data to do formal testing for heavy vehicle involvement, but the pattern of the data suggests that low macrotexture was underrepresented at the sites of crashes involving heavy vehicles. The results agree with previous studies regarding the increase in risk with low macrotexture. The prospects for a surface management process based on macrotexture are therefore good, but further work is required before this is possible.


This paper reports an analysis of the relationship between road surface characteristics and crashes on undivided two-way roads in the state of Victoria, Australia. Surface condition data from multi-laser profilometer surveys was linked to geometry, traffic and crash data using GIS and the resulting tables analyzed to investigate the relationships. The three road surface characteristics were either uncorrelated or showed small enough correlations to disregard possible interactions among the variables. Crash rate was higher for road sections with low macrotexture; a power relationship provided a good fit to the data. Crash rate was also higher for roads where roughness was extreme, with a polynomial relationship providing a good fit to the data. No clear relationship emerged between rutting and crash rate. An economic analysis suggests that resurfacing sites with macrotexture of 1 mm SPTD or less would produce crash savings which would provide a very good return on the investment.
The frictional properties of pavement surfaces play an important role in highway safety. Pavement surfaces must ensure an adequate level of friction at the tire pavement interface to provide safe operation of vehicles. The Maryland State Highway Administration (MDSHA) routinely measures friction on State highways to assist with decision making associated with road maintenance management and to monitor network health against road condition targets detailed in the system preservation report published annually. The MDSHA uses the Friction Tester to monitor the micro-texture of the pavement aggregate during the service life of the pavement surface. Micro-texture is a measure of the degree of polishing of a road aggregate and is the main factor in determining the peak level of dry and wet friction provided by a pavement surface. Initial analysis of past friction information indicates a relationship between geometry, AADT, polish stone value and Friction Number. The MDSHA is attempting to better understand surface frictional requirements at approach to pedestrian crossing, traffic lights, etc. during wet weather and to establish minimum friction levels for different types of roadways based on accident data. This paper describes the MDSHA process in developing a design policy to improve pavement surface friction.


Identification of hot spots, also known as the sites with promise, black-spots, accident prone locations, or priority investigation locations, is an important and routine activity for improving the overall safety of roadway networks. There is an extensive literature focused on methods for the identification of "hotspots" (HS1D). A subset of this considerable literature has been dedicated to conducting performance assessments of various HS1D methods. A central issue in comparing HS1D methods is the development and selection of quantitative and qualitative performance measures or criteria. It is the contention of this paper that currently employed HS1D assessment criteria—namely false positives and false negatives—are necessary but not sufficient, and additional criteria are needed to exploit the ordinal nature of site ranking data.

With the intent to equip road safety professionals and researchers with more useful tools to compare the performances of various HS1D methods and to 'raise the bar' with regard to HS1D assessments, this paper proposes four quantitative HS1D evaluation tests that are to the authors' knowledge new and unique. These tests evaluate different aspects of HS1D method performance, including reliability of results, ranking consistency, and false identification consistency and reliability. It is intended that road safety professionals can apply these different evaluation tests in addition to existing tests to compare the performances of various HS1D methods and then select the most appropriate HS1D method to screen the road network to identify sites that require further analysis.

We demonstrate the five new criteria using three years of Arizona road section accident data and four commonly applied HS1D methods (Accident Frequency Ranking, Accident Rate Ranking, Accident Reduction Potential, and Empirical Bayes'-EB). The EB HS1D method reveals itself as the superior method in most of the five evaluation tests. In contrast, identifying hot spots using Accident Rate Rankings performs the poorest among the five tests. The Accident Frequency and Accident Reduction Potential methods perform similarly, with slight differences explained. We believe the four new evaluation tests offer insight into HS1D performance heretofore unavailable to analysts and researchers.


The present state-of-the-art locked wheel testers for roadway surface friction evaluation are fully automated. As with any testing using subject-driven, instrumented devices, the major concerns of the end usefulness of the resulting data are accuracy and precision. Although a level of uncertainty is always inherent to any measurement process, it must also be appropriately quantified or assessed. Therefore, the Florida Department of Transportation (FDOT) initiated the present field study to assess the level of precision of its own locked-wheel testers for field measurements. Friction measurements were acquired using four friction locked-wheel testers concurrently on a number of asphalt section sites. These test sections were randomly selected to include both open and dense graded surface mixtures. The collected friction data were first analyzed to determine the friction characteristics at each test.
location, in terms of a friction number at 40 mph using a standard ribbed test tire (FN40R). The results were then used as a basis for an evaluation of the repeatability and reproducibility of the friction units. In addition, the effects of pavement surface texture on friction measurements were assessed. This report presents a description of the testing program, the data collection effort and the subsequent analyses and findings.


The present state-of-the-art locked-wheel testers for roadway surface friction evaluation are fully automated. As with any testing using subject-driven instrumented devices, the major concerns of the end usefulness of the resulting data are accuracy and precision. Although a level of uncertainty is always inherent in any measurement process, it must also be appropriately quantified or assessed. Therefore, the Florida Department of Transportation (FDOT) initiated a field study to assess the level of precision of its own locked-wheel testers for field measurements. Friction measurements were acquired by using four friction locked-wheel testers concurrently on a number of asphalt section sites. These test sections were randomly selected to include both open- and dense-graded surface mixtures. The collected friction data were first analyzed to determine the friction characteristics at each test location, in terms of a friction number at 40 mph with a standard ribbed test tire (FN40R). The results were then used as a basis for an evaluation of the repeatability and reproducibility of the friction units. In addition, the effects of pavement surface texture on friction measurements were assessed. A description of the testing program, the data collection effort, and the subsequent analyses and findings is presented.

Clonch, D. 2006. “Ohio Department of Transportation Road Grip Tester Project.” Proceedings, GIS for Transportation Symposium. Columbus, OH.

The Ohio Department of Transportation (ODOT) has initiated a process to create a system that detects, records, reports, and disseminates informational data regarding low grip areas on roadway surfaces. A Road Grip Tester (RGT) system measures road surface friction by utilizing an existing hydraulic system to deploy and retract a wheel that is located in the front of the drive axle underneath the vehicle or using a wheel mounted to a tow hitch at the rear of the vehicle. In normal, dry conditions, a graphical display in the cab of the vehicle will show green lights (along with a corresponding numerical value). As the surface loses friction (e.g., wet or snowy conditions), more lights are displayed and the color changes from green to yellow; the numerical value changes (decreases) as well. As the road becomes snow covered, even more lights are displayed and the color changes to red. The numerical value decreases even further. The intent of the system is to serve as an early alert and advance notification system for road conditions before, during, and after a winter event. The RGT provides the ability to detect deteriorated pavement surface conditions associated with winter weather that are otherwise not visibly evident. The system provides information allowing ODOT maintenance forces to detect the presence of black ice on pavement surfaces and prompt immediate treatment where needed. It also provides real-time information to detect the rapidly changing conditions associated with winter maintenance activities.

Connecticut Department of Transportation (ConnDOT). “Enhancements to ConnDOT's Pavement Friction Testing Program.” (Research in Progress).

The objectives of the proposed research are to: (1) evaluate the effect of roadway geometry on friction measurements; (2) update friction number speed correction factors based upon pavement mix designs in use in Connecticut today with an upgraded friction tester (hardware and software); (3) research relationships between texture and friction; (4) evaluate the potential use of the International Friction Index in Connecticut; and, (5) implement the appropriate latest technology and procedures for pavement friction data request, collection and processing.


The skid resistance of a road is not constant and changes throughout the year, being at its highest in the late winter and at its lowest towards the end of the summer. Throughout the year the level will change depending on periods of rainfall and dry conditions. Highway Authorities must ensure that measurements of skid resistance are corrected to remove these seasonal effects so that maintenance treatments can be applied in priority regardless of when the survey work is undertaken. This paper describes the processes and procedure that Transit New Zealand have
introduced to minimize the seasonal effects. The paper also identifies the improvements that have been introduced since regular surveys were introduced in 1998 and those that are being considered for the future.


Three locked-wheel skid trailers, International Cybernetics Corporation (ICC) Model MOR 5041 and K.J. Law Models M 1270 and M 1290, were tested at three speeds on 14 test sections located in Greenville, North Carolina. The test sections included a heavy-duty surface course, polymer-modified heavy-duty surface course, rubber-modified heavy-duty surface course, heavy-duty surface course with carbon black, stone mastic with fibers, polymer-modified stone mastic, and large-stone surface course. Multivariate regression analysis of friction number versus speed for the three test vehicles was performed. Despite having been load cell calibrated 1 day before testing, the ICC MOR 5041 results were statistically different from those of the other skid trailers on all but one test section. The two K.J. Law skid trailers were statistically different from each other, either on intercept or slope, on more than half of the test sections. Each individual skid trailer provided repeatable results with a standard deviation of about 2 when testing was done at 64 km/h, with a higher standard deviation for testing at lower speed. The frictional resistance of the test sections was compared by ranking friction number at 64 km/h and rate of decline of friction number with speed. The best frictional performance was provided by the heavy-duty surface course and the large-stone surface course, and stone mastic with fibers and stone mastic with polymer were ranked poorest. None of the test sections had an average friction number less than 40, even when tested at 80 km/h.


The Washington State Department of Transportation (WSDOT) determines wet-pavement surface friction characteristics by conducting skid-tests in accordance with applicable AASHTO and ASTM standards. The results of the skid-tests are used in conjunction with other criteria to assist in selecting pavements for resurfacing (the primary criteria is wet-pavement accident rates). The paper examines literature from the United States and abroad on friction number guidelines for highways. On the basis of an analysis of the literature, a revised friction number guideline was developed. The new guideline is similar to those developed by other highway departments and is based on research conducted over the last 25 years.


Safety data provide the key to making sound decisions on the design and operation of roadways, but deficiencies in many States’ safety databases do not allow for good decision making. The Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), and the National Cooperative Highway Research Program (NCHRP) sponsored a scanning study of how agencies in the Netherlands, Germany, and Australia develop and use traffic safety information systems. That scan produced a report that included recommendations for advancing safety themes in the areas of strategy, efficiency, and utility. This current report is the result of a follow-on effort to build on the scan team’s final report and draft implementation plan by reviewing in detail the strategies suggested, providing action-related details to some of the critical strategies, and adding new strategies to help reach the team’s goals. Although strategies related to both crash data and other safety data such as roadway inventory and traffic volumes are included in this paper, more emphasis is placed on the latter because more effort has traditionally been spent on improving crash data. The five critical strategies detailed here include: (1) increase support for both safety programs and safety information systems from top-level administrators in State and local transportation agencies; (2) improve safety data by defining good inventory data and institutionalizing continual improvement toward established performance measures; (3) improve safety data by making it easier to collect, store, and use; (4) improve safety data by increasing the use of critical safety analysis tools, which themselves require good data; and (5) improve and protect safety data by storage and linkage with critical non-safety data. Discussion and action items are presented for each strategy, along with recommendations concerning which government agency potentially could be responsible for implementing the recommendation and a priority ranking of the proposed recommendations based on input from a review panel.

This synthesis will be of interest to pavement engineers, safety officers, and others interested in wet-pavement safety programs. Information is provided on the programs used by a number of agencies in gathering data and correcting areas of potential wet-weather accidents. Wet-pavement accidents continue to be of concern to highway agencies. This report of the Transportation Research Board summarizes agencies' programs in areas such as accident reporting, vehicle testing, friction testing, corrective actions for problem areas, and tort liability and gives some general guidelines for the content of a wet-pavement safety program.


The friction testing of runways in Australia is not common practice as the Australian regulatory body, CASA, only requirement regarding surface characteristics relates to surface texture. The recent modifications to the Manual of Standards (MOS) require some airports to implement friction testing from 2006. Friction testers throughout the world acknowledge that the machines have poor repeatability and calibration problems, which make their value as a tool of regulatory compliance questionable. However, it is the value as a maintenance tool for airport managers to utilize to determine frequency of rubber removal, which could potentially be of most benefit. The purpose of this project was to develop a methodology for the analysis of runway friction testing data so that airport engineers can have confidence in the results that the devices produce. In addition, the project took on a larger focus to assist other Australian airports with friction management in preparation for the new regulations in 2006.


The paper presents the results of a first attempt to combine detailed information on road geometry (horizontal curvature, gradient and cross-fall), road surface condition (roughness, rut depth, texture depth and skid resistance), carriageway characteristics (region, urban/rural environment, and traffic flow) and crashes. Such a study was only made possible because of annual surveys of the entire 22,000 lane-km of New Zealand’s State Highway network made with SCRIM since 1997, which involves simultaneous measurement of road condition and road geometry. Four subsets of road crashes were investigated: all reported injury and fatal crashes; selected injury and fatal crashes covering loss of control events; reported injury and fatal crashes occurring in wet conditions; and selected injury and fatal crashes occurring in wet conditions. One and two-way tables and Poisson regression modeling were employed to identify critical variables and the form of their relationship with crash risk. Particular emphasis was placed on quantifying the effect of skid resistance and texture depth on crash risk.


Highway engineers rely upon conventional skid resistance measurements in order to evaluate the level of a road's skid resistance. In France, such measurements are carried out using smooth tires under conditions of total sliding. The skid resistance assimilated by users may differ significantly due to the distinct nature of the tires as well as to the generalized use of antilock brake systems. Road tests conducted have shown that certain techniques yield different results whether focusing on this conventional skid resistance vs. the "treaded tire" skid resistance with variable sliding rates. The values of low-speed friction and average texture depth, both of which serve to explain quite well the conventional longitudinal skid resistance measurements, prove insufficient when it comes to predicting the level of skid resistance mobilized with antilock brake systems. Other indices in the area of macrotexture, and more specifically the density and angularity of indenters, play a vital role in the frictional force generation process at the tire/pavement interface.


A summary of research work conducted at LCPC over the past ten years on pavement surface microtexture will be presented. Progress has been made over the years in both measuring and characterizing such microtexture. The most recent microtexture descriptors have been integrated into a contact model for the purpose of computing a low-speed
friction coefficient. The contribution of the relationship between microtexture and low-speed friction in predicting skid resistance will then be approached. The variation in skid resistance with respect to speed will be displayed using a so-called "Stribeck" curve. The descriptive model of this curve clearly reveals the microtexture contribution. A validation procedure has been performed on a set of surfacing materials that spans use on roads exposed to traffic loads as well as test tracks. In conclusion, an assessment of the research to date on microtexture will be drawn and the avenues of subsequent research identified.


The Highways Agency has established 39 benchmark sites for long term study. The principal use of the benchmark sites is to provide a cost effective source of historical measurements of skid resistance across the network from which trends can be established to provide early warning of changes that may be required in policy. These sites have been surveyed by SCRIM three times a year, once in each of the three SCRIM periods (early mid and late) between May and September from 2002 up until 2005.

As expected the highest skid resistance for each site was given by the early runs in May/June, however, it was found that the skid resistance for the final run in the late period August/September had not recovered back to those of the early run and was often as low as or lower than the mid reading. This indicates that the August/September period is dryer than the May/June period whereas historically they have been considered similar. Therefore, in 2006, an additional survey run was included in late October and this was continued in 2007. It was found that the skid resistance for the addition very late run had recovered back to the values shown by the early survey.

It has also been found that the skid resistance for the 2006 and 2007 results are significantly lower than those from years 2002 to 2005; this suggests that the summer periods for 2006 and 2007 are dryer than they have been in the previous 4 years. These results may be indicating the effects of climate change on the skid resistance on the English road network. Although sites were selected that were not likely to be resurfaced for at least the first few years inevitably surface treatments have taken place and this has shown that the time for sites to reach a plateau skid resistance after being resurfaced is between 6 weeks and 6 months. Another interesting finding is that not all sites are affected by seasonal variation to the same extent; some sites are affected to a much greater degree than others are.


The Wehner Schulze (W/S) procedure, similarly to the Polished Stone Value (PSV) test, is designed to simulate accelerated wear on road surfacing materials and test the friction provided by the specimen before and after that wear. An important difference between the PSV test and the W/S procedure, however, is that the latter uses large, flat specimens that can be obtained from actual road surfaces, made in the laboratory from mixed materials or made in the laboratory as plates using aggregate alone. The test is carried out using a purpose-designed machine that is now available commercially. TRL Ltd operates one such machine on behalf of the Highways Agency who procured the device in 2005. The ability of the machine to test the skid resistance offered by a sample of the whole mixture used in a surface course rather than just its aggregate components is a major advantage. In some cases there is opinion that the performance of aggregate in roads is not sufficiently characterized by the PSV test, and this has led to the requirement for in situ trials to be carried out before an aggregate can be used extensively in a road network. TRL Ltd was commissioned by Tarmac Group to carry out initial investigations comparing aggregates with similar PSV, made into asphalt specimens, in the W/S machine. The work was carried out on an experimental basis, with the goal as much to expand understanding of the machine’s abilities when used with UK materials, as to define the performance of the range of asphalt samples used. Nevertheless, the results are interesting and similar experiments may eventually prove to be useful in determining expected in situ performance of new asphalt mixtures thus informing maintenance requirements on existing roads. This paper will describe the basic operation and principles of the W/S machine, and present some of the results and conclusions from the Tarmac experiment.
The French national road-building policy as regards skid resistance will be presented herein. The various circulars previously published and the primary rationale behind their successive replacement will also be recalled. The last circular issued, which dates from 2002, will be analyzed in detail; its adoption resulted from the research completed by a subgroup assembled as part of the National Surface Characteristics Working Group, which was created in 1991 by the French Highway Administration. This circular serves to establish specifications in terms of average texture depth with respect to the authorized speed for each type of pavement, pavement geometry and site layout. The general principles provided from this regulatory document are intended to successfully adapt, by means of choosing the appropriate wearing course, the skid resistance potential "supplied" with a demand based on the trio of variables: speed - site layout - pavement type.


This report was prepared by the OECD/ECMT Working Group on Achieving Ambitious Road Safety Targets. At its first meeting held on 9-10 March 2005, the Working Group discussed the importance of cross-country comparisons and targeted performance assessment in identifying the priority areas for implementation of effective measures and areas for possible improvements.

It was decided to present and publish an overview of the safety evolution of individual countries, based on information collected through a survey. The survey was sent to all 50 OECD/ECMT countries to collect information on road safety trends, recent road safety measures implemented; key road safety issues, measures planned to address these issues, targets set, and current results towards these targets. The responses to the survey are completed by other relevant data from other sources (e.g. IRTAD, ECMT statistics, and recent reports of the JTRC). This report includes a summary of road safety performance in OECD/ECMT countries. It presents an overview of road safety targets in OECD/ECMT countries, highlights the main road safety problems identified by member countries and provides some country comparisons.


This paper compares five techniques for identifying hazardous road locations. The five techniques embody different degrees of control for randomness in accident counts. They are tested by means of data for Norwegian roads. As a basis for the comparison, a hazardous road location is defined as any road location that has a higher expected number of accidents than similar locations due to local risk factors present at the location. The following five techniques for identifying hazardous road locations were compared:

1. Hazardous road locations are identified in terms of the recorded number of accidents during a specific period.
2. Hazardous road locations are identified in terms the observed accident rate (accidents per million vehicle kilometers) during a specific period.
3. Hazardous road locations are identified in terms of the combination of a critical count of accidents and an accident rate above normal during a specific period.
4. Hazardous road locations are identified in terms of the empirical Bayes estimate of the expected number of accidents at each location.
5. Hazardous road locations are identified in terms of the size of the contribution of presumably local risk factors to the empirical Bayes estimate of the expected number of accidents at each location.

Each of the criteria were applied to the upper 1 %, upper 2.5 % and upper 5 % of the distribution of sites according to the criterion (accident count, accident rate, etc). The diagnostic performance of the five techniques was assessed in terms of epidemiological criteria (sensitivity and specificity). The empirical Bayes technique was found to perform best according to the epidemiological criteria. It is concluded that hazardous road locations are most reliably identified by applying the empirical Bayes technique.


Until the mid-1960s, the United States was the world leader in traffic safety, but by 2002, the nation's ranking had dropped from 1st to 16th place in terms of deaths per registered vehicle. The author of this article, who is both a researcher and safety expert, argues that, if the focus of U.S. traffic safety policy would shift from vehicle factors to such road-user behaviors as speed, alcohol consumption, traffic law violation, and seat belt wearing, the number of fatalities could be reduced by half.


The ultimate objective of research in this problem area, dealing with the frictional coupling of the vehicle tire and the pavement surface, were to (1) determine pavement skid resistance requirements, (2) improve the reliability of skid resistance measurements, and (3) improve the ability to build and maintain highly skid resistant pavements. The specific objective of this project was the development of procedures for determining pavement skid resistance requirements for various classes of highways, taking into consideration such factors as driver and vehicle characteristics, traffic, weather, and highway geometry.


The determination of skid resistance requirements for any given set of roadway and traffic conditions is reported. The study focuses on wet pavement skidding accidents at intersections and curves. The feasibility of implementing these procedures was demonstrated in the field. A simplified version of the procedures was also developed. The three steps involved in the procedure for determination of skid resistance requirements are outlined. The system developed for measurement of longitudinal acceleration at intersections is based on the use of a series of event detectors to determine the time-position signature of a vehicle over some known distance, from which acceleration values can be computed. Data was collected for an average of 350 vehicles at each of 12 intersections. Controlled skid studies were conducted to determine the relationship between longitudinal acceleration and skid resistance requirements. A simplified intersection demand model (idm) for estimating skid resistance is desired. This is based on the apparent normality of distribution of observed deceleration values at the various distance intervals from the stop line of the 12 sites studied. The findings indicate a strong relationship between pavement skid resistance and locked wheel braking deceleration. Accelerations and speeds of vehicles braking at intersection are normally distributed and exhibit stable standard deviations. A relationship exists between average approach speed and skid resistance requirements. Considerably more extensive field evaluations are necessary to verify the applicability of the procedures.

This paper reports the results of reviewing the current information on pavement texture and its relationship to the skid resistance-speed gradient and to the available friction at selected speeds. The report discusses different methods of modeling the skid resistance and predicting it based on friction and texture measurements.


The purpose of this document is to provide guidance for State and local highway agencies in conducting skid accident reduction programs. This program shall provide that "there are standards for pavement design and construction with specific provisions for high skid resistance qualities." The HSPS No. 12 requires that each State have a "program for resurfacing or other surface treatment with emphasis on correction of locations or sections of streets and highways with low skid resistance and high or potentially high accident rates susceptible to reduction by providing improved surfaces." In discharging the responsibilities of FHWA, the Division Administrator should determine the acceptability of specification requirements and construction practices for placing, consolidating, and finishing both asphalt concrete and portland cement concrete pavements. Such determinations will rely on the highway agency to research, evaluate, and document the performance of the various aggregates, mix designs, and construction practices used.


A Road Safety Audit (RSA) is a formal safety performance examination of an existing or future road or intersection by an independent audit team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users. RSAs represent an additional tool within the suite of tools that currently make up a multidisciplinary safety management system aimed at improving safety.

The primary purpose of this guideline is to provide a foundation for public agencies to draw upon when developing their own RSA policies and procedures and when conducting RSAs within their jurisdiction. The availability of a consistent guideline is anticipated to lead to a better understanding of the core concepts of RSAs and to promote their use. These guidelines were developed by building upon experiences gained in the United States and in other countries. They are meant to present basic RSA principles, to encourage public agencies to implement RSAs, and to embrace them as part of their everyday practice. When used they should be tailored to suit local conditions.

The guidelines are divided into three main sections. Part A provides general information on RSA, information how to implement an RSA program and an overview of the RSA process. Part B describes the stages of an RSA, and different types of audits, including preliminary design, detailed design, construction, pre-opening, and RSA of existing roads. Part C describes RSA tools, namely prompt lists, and when and how to use them. Following the body of the guidelines, appendices that discuss approaches to road safety and the evolution of RSA are provided. Several case studies are also provided and a bibliography is included.


A State Department of Transportation (DOT) developed Strategic Highway Safety Plan (SHSP) is a new Federal requirement of SAFETEA-LU, 23 USC 148, and is a major part of the core Highway Safety Improvement Program (HSIP). This preview document has two purposes:

- To promote best practices and serve as interim guidance to State DOTs and their safety partners for the development and implementation of the State SHSP.
- To assist State DOTs in creating an SHSP that meets the requirements of SAFETEA-LU with the ultimate goal of reducing the number of highway fatalities and serious injuries on all public roads.

The purpose of this interim guidance in the format of this “Preview Document” is to provide the best available information in a timely manner. The US DOT is still analyzing and interpreting legislation and crafting additional guidance material to further enhance this guidance, particularly the sections on Implementing and Evaluating
SHSPs. In addition, FHWA is developing guidance on the HSIP reporting requirements of Section 1401 of SAFETEA-LU.


This Technical Advisory (1) issues information on state-of-the-practice for providing surface texture/friction on pavements and (2) issues guidance for selecting techniques that will provide adequate wet pavement friction and low-tire/surface noise characteristics. Specifically, the advisory provides answers to the following questions:

- What are the surface texture components that influence wet-weather friction?
- What is the background on pavement surface texture/friction?
- How is tire/pavement noise impacted by surface texture?
- What is the recommended level of surface texture on high-speed (50 miles per hour or greater) facilities?
- What techniques will provide surface texture for concrete and asphalt pavements?
- How is adequate texture provided on concrete pavements over the performance life of the pavement?
- What techniques will restore desired surface texture to in-service pavement surfaces?
- What factors should be considered when selecting pavement surface techniques or thresholds?
- What factors should be considered when evaluating new or innovative texturing methods for concrete pavement?


The objective of this project was not to develop a Guide for Pavement Friction, that would identify technologies, processes, and practices suited for designing, constructing, monitoring and maintaining pavements with good frictional characteristics. The objective of this project was to compile the current methods (procedures and acceptability criteria) and related regulations that are currently implemented and used by state and local jurisdictions to not only characterize pavement friction but also to qualify pavement condition.


Since 1980, Australia has gone from nearly 4.5 to 1.5 deaths per 10,000 registered motor vehicles. This compares to a change of 3.5 to 2.3 deaths per 10,000 registered motor vehicles in the United States over the same time period. In terms of traffic deaths as a function of population, Australia went from 22.5 deaths per 100,000 population in 1980 to fewer than 9 deaths per 100,000 population in 2003. From nearly identical rates in 1980, the Australian rate has fallen to a point where it is now a little more than half the U.S. rate. This report, which was undertaken through Austroads by Professor Ian Johnston, director of the Monash University Accident Research Centre, reviews Australia’s accomplishments in highway safety. It not only discusses the performance measures established, but also goes beyond the public data. It draws from interviews with politicians, senior agency staff, and others with firsthand knowledge of how the traffic safety strategies were put together and, above all, how they were implemented, often amid public controversy but with majority community support.


The Ohio Enhanced Crash Location Identification System (OECLIS) is a flexible crash analysis software system for identifying high hazard locations combining analysis factors such as crash frequency, rate, severity, the change in the crashes occurring at a location over time, etc. allowing for a comprehensive methodology to determine hazardous locations. OECLIS also allows the user to specify minimum crash thresholds, weighting factors, and other input criteria. Three years of crash data are used in conjunction with current signal, volume, and road inventory data files associating each location with its specific operating characteristics. Intersection and intersection-related crashes are examined to ensure each crash is identified with the correct priority roadway, cross-road name and log point. OECLIS first reduces the number of locations by comparing the number of crashes occurring at both intersection and section locations with pre-defined threshold values for frequency, creating pre-candidate locations. The intersection threshold is currently specified at 14 and the section threshold is currently specified at 20 crashes. OECLIS calculates the following values for each pre-candidate location:
Crash frequency – The number of crashes occurring at a location - (intersection).
Crash density – The number of crashes per mile occurring along a section of roadway.
Crash rate – The number of crashes occurring per million vehicle miles of traveled for a location.
Delta-change – The change in the number of crashes over time using the slope of the regression line to determine whether crashes are increasing or decreasing for a location over time.
Equivalent property damage only (EPDO) – The cost to society of a fatal crash, injury crash, and PDO crash normalized to a base of 1.0 for a PDO crash. The number of crashes by severity are multiplied by their respective values and then summed to determine a locations EPDO value.
Equivalent property damage only rate (EPDO rate) – Uses the standard rate equation with a base of 1 million and substitutes the EPDO value for the number of crashes in the equation.
Relative severity index (RSI) – The Relative Severity Index (RSI) represents the relative cost to society of a specific type of crash (head on, rear end, angle accident, etc.). The RSI for a location is the sum of the relative costs per crash divided by the total number of crashes for a location.

At least one of these calculated values must meet or exceed the threshold applicable for its matching criteria in order to remain as a candidate location. OECLIS then determines each location's rank with respect to each categorical value. OECLIS uses the hazard index method to determine overall ranking. A high hazard location list is developed for freeway and non–freeway locations separately. OECLIS calculates a priority index value for each location. ODOT specifies the weight given to the six categories to be included as factors for the final priority index calculations. The values for each location and method selected are multiplied by their corresponding weight value. Those products are then summed, giving the priority index value for that location. The resulting priority index values of all locations are then sorted to determine the priority hazard index rank for all location candidates.

From the 250 location high crash listing, the intersections and sections were then ranked based on fatalities and incapacitating injuries (freeways and non–freeway locations were ranked separately). An equation was developed for the combination of the fatalities and incapacitating injuries $= 2*\text{(# of fatalities)} + \text{(# of incapacitating injuries)}$. Since Ohio's Strategic Highway Safety Plan has a goal of reaching 1.0 fatality per 100 million vehicle miles of travel, the fatalities were given a weighting of two times that of an incapacitating injuries. From this ranked list (> the top 5% most severe safety needs were reported.


Take the proactive, cost-saving approach to improving roadway safety by implementing road safety audits (RSA). An RSA is the formal safety performance examination of an existing or future road or intersection by an independent multidisciplinary team. RSAs can be used in any phase of project development, from planning to construction, and on initiatives ranging from minor maintenance activities to mega projects. The Federal Highway Administration (FHWA) recently launched a new RSA Implementation Team that will be working with State and local transportation departments, tribal governments, and Federal land management agencies to provide guidance and assistance in implementing RSAs.

Under the 2005 Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), States are required to report at least 5 percent of the locations on their public roads that are exhibiting the most severe safety needs. This report must also include remedies, costs, and impediments to implementing improvements at each of these locations.


The lack of quality data that relates tire-pavement noise to the texture of concrete pavements has hindered the pavement community in both understanding the phenomena and finding ways to minimize its impact. The National Concrete Pavement Technology Center (USA), the US Department of Transportation Federal Highway Administration, and the American Concrete Pavement Association have formed a coalition to address this problem. Work to date includes the simultaneous measure of noise, profile (unevenness), friction, and texture from active roadways across the U.S. The intent is to first link tire-pavement noise to texture to friction, then attempt to measure the rate of change of these properties over time.
The data collection process has been categorized hierarchically. At the top are new construction sites employing conventional texture variations (e.g., tining, burlap drag) termed Type 1 New Construction. There are also sites including diamond grinding variations (Type 1 Grinding). For each of the Type 1 sites, full control is maintained over the types of textures, including their construction techniques. Extensive information is collected on the design, materials, construction, and climate during placement or grinding. A second level of experiments termed Type 2 includes existing projects with various types of surface texture, tested comprehensively for all surface characteristics over time. Finally, a third type of experiment includes an inventory of numerous sites, measured with noise and texture only (Type 3).

The fieldwork of this effort is well underway, with monitoring expected to continue for at least five years on an annual basis. The findings to date have been very significant, and have the potential to alter how concrete pavement surfaces are specified in the future.


Highway noise is one of the most pressing of the surface characteristics issues facing the concrete paving industry. This is particularly true in urban areas, where not only is there a higher population density near major thoroughfares, but also a greater volume of commuter traffic.

In 2004 and 2005, the Federal Highway Administration, Iowa State University, and the American Concrete Pavement Association initiated a five-year, multi-million dollar Portland Cement concrete Surface Characteristics Program. This program is administered through the National Concrete Pavement Technology Center located at Iowa State University. The purpose of the program is to determine the interrelationship among noise, friction, smoothness, and texture properties of concrete pavements.

This report addresses work conducted under Part 2 of the program. In Part 2, data were collected on 1,012 test sections totaling 240,000 ft., representing 395 unique pavement textures. This is the most comprehensive inventory of concrete pavement surface textures ever compiled. The inventory includes transverse and longitudinal tining, diamond grinding, various drag textures, grooving, exposed aggregate, shot peening, cold milling, and some asphalt pavements and surface treatments.

A preliminary analysis of the data has revealed a number of important findings. For example, relationships between texture and noise are beginning to emerge. These are not based on nominal texture dimensions, however, since a second finding is that nominal dimensions are rarely observed to be found in place. Friction and noise are also found to have no relationship, demonstrating that quieter concrete pavements can be achieved without compromising this important characteristic.


Skid resistance of a pavement surface is important for safety. Therefore the surface of a concrete pavement must have a roughness suitable for a high skid resistance but also for a low noise emission. These surface properties must be as durable as possible. In Germany there are various possible ways for producing surface textures in fresh and hardened concrete surfaces with high skid resistance. For noise-sensitive areas good results can be achieved by dragging a burlap or an artificial turf over the fresh concrete in the longitudinal direction. Also, good and durable skid resistance and low noise emission can be achieved on an exposed concrete surface. Surface grinding a hardened concrete can provide high skid resistance. The practical experiences in Germany for producing a concrete pavement surface with high skid resistance are described in the paper.


Variation in skid resistance and surface macrotexture measurements due to testing conditions such as tire, test vehicle speed, pavement grade, and hot-mix asphalt (HMA) design characteristics were analyzed in detail for different HMA surface mixtures at the Virginia Smart Road. The seven HMA wearing surface mixtures studied
include five different SuperPave™ mixtures, a stone mastic asphalt (SMA), and an open-graded friction course (OGFC). Mixture properties were measured from samples taken from each test section and compacted in the laboratory. The evaluation of the surface characteristics was based on measurements conducted using a locked-wheel trailer with the ASTM-specified ribbed and smooth tires. Macrotecture measurements were conducted using a laser profile measurement device. Statistical tests indicate that, for the mixes studied, the roadway slope has insignificant effect on skid number measurements. Friction measurements are dependent on the tire used, surface texture, age in service, and temperature of the surface. The dependence of skid numbers on the measurement speed also varies with the type of tire used and surface conditions during testing. The relationship between SN and speed can be appropriately modeled using both exponential (Penn State model) and linear models. Regression analysis was performed on specific mixture properties, including voids in the mineral aggregate, total voids in the mixture, percentage passing the number 200 sieve, and binder type and content. The analysis indicated that there is a significant influence of these parameters on the ribbed tire skid resistance measurements and laser profile mean texture depth. These properties, however, were not sufficient to develop accurate models as to their effect on the smooth tire skid resistance measurements.


This paper discusses an extensive investigation conducted to evaluate the texture and skid resistance properties of seven wearing surfaces used at the Virginia Smart Road. Variation in skid resistance and surface macrotexture measurements due to HMA design characteristics and testing conditions (tire, test vehicle speed, and grade) were analyzed. The mixtures studied include five different SuperPave™ mixes, a stone mastic asphalt (SMA), and an open-graded friction course (OGFC). The evaluation of the surface skid characteristics was based on measurements conducted using a locked-wheel trailer utilizing ASTM-specified ribbed and smooth tires. The macrotexture measurements were conducted using mainly a laser profiler. Statistical results indicated that, for the mixes studied, the roadway slope had insignificant effect on skid number (SN) measurements. Friction measurements, however, are dependent on the tire used, surface texture, age in service, and surface temperature. It was found that HMA design parameters affect pavement surface friction and texture. For the range of mixes studied, the mean profile depth (MPD) can be closely predicted based on the nominal maximum size (NMS) and VMA. Furthermore, the SN measured at 64 km/hr using the ribbed tire (SN(64)R) is mostly influenced by the NMS and VTM. The greater the NMS, the lower the ribbed tire skid number. On the other hand, other aggregate parameters and mixture properties have to be considered to accurately predict SN measured at 64 km/hr using the smooth tire (SN(64)S).


The main objective of the project is to establish a research program focused on enhancing the level of service provided by the roadway transportation system by optimizing pavement surface texture characteristics.


Different techniques for measuring pavement surface macrotexture and their application in pavement management are discussed. The main applications of surface macrotecture are to measure the frictional properties of the pavement surface and to detect hot-mix asphalt (HMA) construction segregation or nonuniformity. Since surface macrotexture can be measured quite efficiently using noncontact technologies and provides important information regarding pavement safety and HMA construction quality, this parameter may be included in the quality assurance or control procedures. Correlations between different measuring devices were investigated utilizing different HMA wearing surfaces. Excellent correlation was found between the circular track meter and sand patch measurements. In addition, the macrotexture determined using a laser profiler correlates well with that determined with sand patch measurements. Consistent with previous studies, it was found that the skid number gradient with speed is inversely proportional to the pavement macrotexture. However, there was a noticeable difference in speed dependency when smooth and ribbed tires were used. Oscillations in the percent normalized gradient with time due to seasonal variations were also observed. Macrotecture measurements hold great promise as tools to detect and quantify segregation for quality assurance purposes. A standard construction specification was proposed in a recent NCHRP study. However, the equation proposed for computing the nonsegregated estimated (mean) texture depth could not
be applied to the mixes studied. An alternative equation has been proposed, which estimates the surface macrotexture using the mix nominal maximum size and voids in the mineral aggregate. The study was based on the mixes used at the Virginia Smart Road. Further investigation using other mixes is recommended.

**Florida Department of Transportation. “Feasibility of Measuring Pavement Friction Characteristics at Higher Speeds for Added Safety.” (Research in Progress)**

The Florida Department of Transportation (FDOT) currently owns and operates four Pavement Friction Testing Units. Each consists of a tow vehicle, water tank, friction trailer, and mobile data processor. Friction measurements are obtained from the force induced on a locked test wheel as it is dragged over a wetted pavement surface. The mean friction number of the pavement section being tested is obtained from this test. Although the current FDOT friction testing program is fully functional, there are several areas that need to be addressed, most importantly safety while conducting the test. The current specified test speed of 40 mph is used on all state roadways, including primary, secondary, interstates, and toll roads. To maximize safety and minimize traffic disruption, friction testing is typically conducted on weekdays and sometimes at night. Nevertheless, there are still safety concerns related to potential conflicts with the motoring public on high-speed facilities. In order to properly address these safety concerns, it may be necessary to modify the current FDOT friction testing program to accommodate both advanced technologies and elevated testing speeds, comparable to the speed limit of the facility being tested. The objective of this project is to modify the existing standard test methods to allow for elevated test speeds.


This research investigates the feasibility of applying simple statistical models for forecasting road surface temperature at locations where RWIS data are available. Three commonly used modeling techniques are considered and those are time-series analysis, linear regression and artificial neural networks (ANN). A data set from a RWIS station is used for model calibration and validation. This paper describes the major findings with a specific focus on the generalization capability of the models. The analysis indicates that multi-variable and ANN are the most competitive technique with lowest forecasting errors.


This paper presents two statistical models for discriminating different types of road surface contaminants based on friction measurements and other road condition data. The first model is a disaggregate logit model which can be used to predict the probability that a road surface is covered by snow or in bare condition based on direct friction measurements and other available road weather data. The second model is an aggregate logit regression model that uses aggregated measures over a section of road as input to distinguish two sub snow cover states, namely, full snow cover and partial snow cover. The proposed models are calibrated using field data collected from a maintenance route in Ontario, Canada and show high discrimination power based on holdout data sets.


Traffic engineers continue to lay emphasis on the identification of crash causal factors on different functional classes of highways, in order to improve safety. The purpose of this study was to identify crash causal factors on two-lane highways and select countermeasures that could significantly reduce these crashes. The scope of the research was limited to two-lane highways in Virginia for the years 2001 to 2004.

The researchers identified 143 sites of five- to ten-miles highway segments, including proportional representatives from primary, secondary, rural and urban highways in each of the counties in Virginia, resulting in 10,000 crashes and over thirty variables. Police reports for all crashes along each site were extracted from VDOT’s crash database and relevant crash variables obtained. Traffic volumes and speed data along each site were obtained from VDOT publications. GPS data collected by the researchers for each site provided information on grading and curvature of the sites. The researchers also collected signing and speed limit data for each site.
The data were analyzed by highway classification (urban primary, urban secondary, rural primary, rural secondary) and collision type (rear-end, angle, head-on, sideswipe, run-off-the-road, deer, and other). Fault-Tree analysis was used to determine the critical fault path for each crash type and highway category to identify the causal factors and to quantify the probability of occurrence of those causal factors. Generalized linear models were then developed to predict crashes from the causal factors using the Negative Binomial distribution and then appropriate countermeasures selected.


Changes in pavement texture because of temperature, moisture, and polishing reduce the available friction for vehicles to perform routine maneuvers under normal operating conditions and thereby increase the potential for skid-related accidents. Optimization of texture and frictional properties at the mix design stage requires that specimens prepared in the laboratory accurately represent the pavement surface in the field. Initial findings from an investigation of the texture and frictional properties of specimens prepared in the Superpave gyratory compactor compared with field measurements are presented. In addition, the mix design properties that may be altered for increased friction are presented. The surfaces of the field specimens were different from their respective gyratory surfaces but were well correlated in the case of macrotexture measurements from the sand patch test. High correlation also was observed between field macrotexture and select mix properties, including the fineness modulus, voids in the mineral aggregate, percentage passing the 4.75-mm sieve, and bulk relative density. Poor correlation was observed between the British pendulum numbers recorded on unpolished field specimens and gyratory specimens, although the bottom gyratory surfaces best matched with field values. Preliminary results suggest the gyratory compactor orients the aggregate particles in a different manner from field compaction equipment. Further, the aggregate breakdown imposed by the gyratory compactor results in additional microtexture exposure not observed on newly compacted pavements in the field until trafficking removes the upper layer of asphalt cement from the coarse aggregate particles.


This paper presents results of an analysis of crashes on U.S. highways in poor road weather conditions. Dan Cohen provided crash tabulations for the seven-year period from 1995 to 2001 from National Highway Traffic Safety Administration (NHTSA) databases. The objectives of the analysis were to update a March 2001 report titled “A Preliminary Analysis of U.S. Highway Crashes Against an Exposure Index”, and to identify trends in the frequency of weather-related crashes.


The equipment and methods currently employed in France to evaluate the skid resistance characteristics of a pavement will be described. These characteristics are obtained by means of investigating both the microtexture and macrotexture of the pavement's wearing courses. The methods introduced along with associated instrumentation fully satisfy the needs of road infrastructure managers. The two international studies performed, i.e. PIARC (1992) and HERMES (2004) whose main results are summarized herein, enable understanding the relationships existing between the values output by these various instruments and have led to proposing a single index. Such an index would be beneficial, yet still not allow attaining adequate levels of repeatability and reproducibility. The primary rules when interpreting skid resistance measurements will be recalled, and the preferential fields of application for friction and texture measurements provided. The impacts of the European context on these devices will also be discussed.


For some years it has been suspected that new asphalt surfacings may have different skid resistance properties to surfaces that have been in service for some time. This is thought to be due to the presence of a film of bitumen binder on the new surface that is eventually removed by weathering and traffic. New types of surfacing introduced in the mid 1990s have led to concerns that the risk of early-life skid resistance problems, and the time that any effects last, may have increased. Research has identified physical phenomena that might lead to an increase in accident risk in some circumstances.
This paper summarizes the methodology and results of a study to investigate if a link could be observed between new surfacings and accident risk. The study used a combination of an analysis of accidents before and after resurfacing on the Highways Agency (HA) network, and collation and review of anecdotal comment from the HA’s Area Teams and Service Providers, and from other Highway Authorities. The findings from this study are generally consistent with the physical phenomena that have been measured on new asphalt surfacings. Neither of the approaches used in the study identified widespread problems with modern asphalt surfacings in their early life but there is evidence of a small increased accident risk in some circumstances.


This report documents the research performed under NCHRP Project 1-43. It describes the work activities undertaken in the study and presents the results of those activities toward the development of the Guide for Pavement Friction. The information provided in this report serves as the basis for many of the guidelines and recommendations contained in the Guide. The information will be of interest to highway materials, construction, pavement management, safety, design, and research engineers, as well as others concerned with the friction and related surface characteristics of highway pavements.

Using information collected through detailed literature reviews and survey/interviews with state highway agencies, this report discusses a variety of aspects regarding pavement friction. It describes and illustrates the importance of friction in highway safety, as well as the principles of friction, as defined by micro-texture and macro-texture. It identifies the factors affecting friction and examines the ways that friction can be measured (equipment and procedures) and expressed (Reporting indices). Most importantly, it presents valuable information on (a) the management of friction on existing highway pavements and (b) the design of new highway surfaces with adequate friction. This information focuses on techniques for monitoring friction and crashes and determining the need for remedial action, as well as identifying combinations of aggregate (micro-texture) and mix types/surface texturing methods (macro-texture) that satisfy friction design requirements.

The report includes various conclusions and recommendations based on the results of the study, and it features five appendixes containing supplemental information on friction.


This document provides guidance on the management of friction on existing pavements and on the design of new pavement surfaces with adequate friction. The overview of pavement friction includes discussion on importance and basic principles of pavement friction. The recommendations on developing the policies of the pavement friction management are provided, as well as the steps that should be taken in establishing the pavement friction management program by the state highway agencies. The friction design considerations include guidance on developing friction design policies and the project-level design guidelines.


Long-life concrete pavements require less frequent repair and rehabilitation and contribute to highway safety and congestion mitigation. The Federal Highway Administration, American Association of State Highway and Transportation Officials, and National Cooperative Highway Research Program sponsored a scanning study to identify design philosophies, materials requirements, construction procedures, and maintenance strategies used in Europe and Canada to build long-life concrete pavements. The scan team observed that concrete pavements in the countries visited are designed for 30 or more years of low-maintenance service life. The countries are responding to pavement-tire noise issues in urban areas by using exposed aggregate surface. Some use catalog designs for pavements and geotextiles as a separator layer between the cement-treated base and concrete pavement. Team recommendations for U.S. implementation include using two-lift construction to build pavements, developing pavement design catalogs, using better-quality materials in pavement subbases, paying greater attention to cement and concrete mixture properties, using a geotextile interlayer to prevent concrete slabs from bonding to the cement-treated base, and using exposed aggregate surfaces to reduce noise.
Relationship Between Skid Resistance Numbers Measured with Ribbed and Smooth Tire and Wet-Accident Locations


The Circular Texture Meter (CT Meter) is a laser-based device for measuring the mean profile depth (MPD) of a pavement at a static location. Both MPD measurements from the CT Meter and mean texture depth (MTD) measurements from the sand patch test were obtained in five random locations in each of 45 section of the 2000 National Center for Asphalt Technology (NCAT) Test Track. The NCAT Test Track provides a wide range of surface types including: coarse and fine dense graded Superpave mixes, Open Graded Friction Course (OGFC), Hveem mixes, Stone Mastic Asphalt (SMA) and Novachip. Testing indicated that CT Meter produced comparable results to the ASTM E965 Sand Patch Test. When open-graded mixtures were excluded, this study indicated that the offset was non-significant between CT Meter and sand patch test results.

Previously developed equations to predict macrotexture were found to be inadequate for the wide range of mix types and aggregate types found at the NCAT Test Track. An equation was developed to relate fineness modulus to macrotexture. This equation was validated with independent data collected by Virginia Transportation Research Council. Testing conducted as part of a mini round robin indicated that two readings should be averaged to represent a single CT Meter measurement. The within-lab coefficient of variation for the CT Meter is estimated to be 2.3 percent. The between-lab coefficient of variation for the CT Meter is estimated to be 4.2 percent. Both estimates are based on the average of two tests being reported as a single measurement. This indicates that the CT Meter is more variable than the sand patch test. However, less technician skill is required to operate the CT Meter.


Works Infrastructure Ltd manages the state highway network for Transit New Zealand in the Northland Region of New Zealand. The network is managed on a performance basis, using key performance measures to manage the delivery standards specified in the contract. Providing and maintaining an appropriate level of skid resistance is an important priority for network management. The Northland network is some 750 km in length and passes through a wide variety of terrain types and degrees of geometric difficulty. Heavy goods vehicle traffic levels are high in some sections, leading to rapid polishing of surface aggregates and a consequent rapid loss of skidding resistance, particularly in sections of terrain with corners of low radii. Experience has indicated that skid resistance levels on the network can not be assumed adequate simply based on a network survey performed once a year as the skid resistance, as measured by the SCRIM machine changes rapidly, depending on weather conditions and traffic loading. The recorded skid resistance is also affected by uncertainty associated with spatial referencing issues and the precision limits of measurement. This paper is a review of some of the various issues facing a network manager, such as:

- The background and development of test procedures.
- Aggregate quality and its polished stone value (PSV).
- The precision (repeatability and reproducibility) of the data.
- The uncertainty and interpretation of data used to interpret key performance measures.
- The locational accuracy of data collection.

The review described investigation and work, previously published and unpublished, relating to the network and illustrates the issues to be considered by a highway network manager when using key performance measure assessment techniques.


The measurement and assessment of skid resistance is routine on New Zealand’s state highway network. Some Local Authorities are now also investigating and implementing policies with respect to the skid resistance of their networks. Skid resistance is generally accepted to be a function of:

- The traffic volume and heavy goods vehicles over the life of the surfacing.
- The quality of the aggregate, determined by its polished stone value (PSV).
- The surface texture.
Texture, combined with the PSV, is desirable for high-speed skid resistance, however, within an urban environment, it is not so critical as suitable skid resistance can be achieved by specifying an appropriate aggregate PSV and selection of the surfacing type. Auckland City has recently investigated this approach, with respect to the PSV of aggregates used for asphalt and chip seal on its networks. The closure of a major quarry has necessitated recent changes in the sources of aggregate used in the region. The purpose of the investigation was to ensure network safety would not be compromised if materials from alternative sources, but potentially having a slightly lower PSV, were used. This paper describes an approach used to investigate potential issues related to the use of an alternative aggregate source. An assessment was undertaken using the AS/NZS 4360 “Risk Management” approach and an innovative method to develop a risk matrix table and assign hazard levels and scores to prioritise and identify high-risk sites.


This synthesis report will be of interest to pavement design, construction, management, and research engineers, highway safety officials, and others concerned with pavement friction characteristics. It describes the current state of the practice and discusses the methods used for evaluating wet pavement friction characteristics of new and restored pavements. This synthesis reviews models used for measuring and evaluating friction and texture, causes for friction changes over time, and aggregate and mix design to provide adequate friction. Also presented are construction and surface restoration practices for providing good pavement surface characteristics. In addition, considerations of noise and ride quality are discussed when compromise may be required.


The annoying noise frequencies produced from the tire/pavement interaction on some (usually transversely tined) Portland Cement Concrete (PCC) pavements have concerned both residents living nearby and motorists traveling over them. A Technical Working Group (TWG) was formed to investigate the problem by conducting a review of previous research and by evaluating the results of ongoing research in the United States. The goal of the TWG was to recommend PCC pavement surface textures that will reduce the annoying noise frequencies without compromising safety. Previous research determined that PCC surfaces constructed for speeds under 80 km/h need only a good microtexture for wet weather stopping. For speeds of 80 km/h or greater, a macrotexture is also needed to reduce the water film thickness and prevent hydroplaning. The exposed aggregate surfaced PCC pavements and the open-graded asphalt friction course pavements combine for the quietest and safest rides where premium textures are desired. Smoother pavements also result in a quieter ride. Wisconsin researchers, using narrow band frequency analysis techniques, have recently discovered how to objectively measure and analyze the annoying pure tones that create tire/pavement whining or lower frequency rumbling. Noise-reducing construction methods that work most effectively for new pavements are to randomly space (10 to 40 mm) the transverse tines/grooves, construct longitudinal tines/grooves (either according to AASHTO guidelines or to the Spanish plastic brushing method), or construct an exposed aggregate surface. Existing PCC pavements that produce an annoying noise should be retextured (diamond grooving, diamond or carbide grinding, or shotblasting) or resurfaced (PCC overlay or surface laminate, microsurfacing, or a dense- or open-graded asphalt concrete overlay). Further research needs to determine the relationship between friction numbers and wet weather accident rates and develop improved construction guide.


This interim advice note provides guidance to facilitate the effective application of the Skid Resistance Policy (HD28/04) by the Highways Agency and its Service Providers. It provides specific instructions and additional guidance about how to implement the Standard on trunk roads in England as well as introduces several changes to the standard itself. This advice is based on the results of consultation process and feedback provided by Service Providers and external consultants.


A three-year research program was initiated in 1978 at the Pennsylvania Transportation Institute by the U.S. Department of Transportation to investigate possible causes for seasonal and short-term skid resistance variations.
The primary objective is to determine the parameters that can be used to predict the influence of seasonal and short-term effects. Results concerning short-term, weather-related skid resistance variations are presented and discussed. Twenty-one test surfaces in State College, Pennsylvania, were selected for testing. The testing program includes daily skid measurements according to ASTM test method E274 and the collection of daily weather data. After the data are adjusted for long-term variations, the short-term residuals are regressed against rainfall and temperature parameters. The number of days since the last significant rainfall and the test pavement temperature are both found to be significant causes of short-term skid resistance variations. Further unexplained variations are attributable to measurement errors, particularly the lateral placement of the skid test trailer. The Pennsylvania results are supported by data collected in a similar study of 10 sites located in North Carolina and Tennessee (Federal Highway Administration Region 15).


The importance of surface texture characteristics to roadway safety was first recognized during the late 1940s and early 1950s when increases in traffic volumes and vehicle speeds resulted in increases in wet-weather crashes and fatalities. As a result, agencies conducted extensive research (including experimental projects around the country) to better understand and improve the surface conditions of Portland cement concrete pavement in wet weather conditions. As new surface texturing methods were tried and evaluated, pavement engineers recognized the corresponding influence of the texture (type, characteristics and quality) on tire-pavement interaction noise. Specifically, it was recognized that a general trade-off existed between friction and noise; i.e., surface textures with higher friction also tended to have greater tire-pavement noise. The noise associated with tire-pavement interactions has been a concern of pavement engineers for nearly 50 years, but it has received particular attention over the past decade. Although considerable information exists on the influence of surface friction characteristics on safety (surface friction and splash and spray) and tire-pavement noise, it is dispersed among numerous sources. This document identifies and summarizes key texture-related information and recommendations based on the current state of the practice. Specifically, this document provides a brief summary of texture-related research; introduces pavement texture nomenclature; discusses the measurement of texture, surface friction and tire-pavement noise; describes traditional and innovative texturing methods/techniques; summarizes respective conclusions pertaining to the influence of texture characteristics on surface friction, tire-pavement noise, and surface durability; and provides current state-of-the-art texture-related recommendations.


Crash reduction factors are used to identify and prioritize the most effective safety improvement measures, and prioritize and allocate available resources optimally for a highway safety improvement project. Simple before and after analysis accounts for the regression-to-the-mean bias. This research employs an Empirical Bias (EB) methodology that overcomes the regression-to-the-mean property that is encountered in traditional before and after analysis. Traffic, geometric and crash data for both the treatment and comparison sites were collected from Ohio in developing the crash reduction factors. Using data collected from Ohio, the EB methodology was applied in developing crash reduction factors for the following improvement categories: add a two-way left turn lane, install a median barrier, flatten slope and remove guardrail, remove or relocate a fixed object, flatten vertical curve, providing highway lighting and close median opening.


Statistics indicate that rain and wet pavement have more significant impacts on road safety than snow and ice. The effect of Wet Percent Time was found to be an important variable in wet accidents. Caltrans sponsored a two-year research project in 2006 to develop an updated Wet Percent Time table, as the current table was developed with data more than 30 years old. Historical hourly precipitation data of California reported by rain gauges were obtained from the five network data sources including CDEC, CIMIS, MESOWEST, NCDC, and the National Weather Service. Based on the density and distribution of available hourly precipitation data stations, an 11-year period (01/01/1995-09/30/2005) was chosen for this project. When available archived precipitation data were downloaded from various upstream weather data providers and uploaded to the WTI database, we followed three processes to check and improve the quality of the data: Reprocessing, Quality Control, and Missing data In-filling. To assure and
quantify the quality of the data used in this study, the statistical summaries were generated and the results were reviewed. Overall there were 1296 out of 1718 stations available from CDEC, CIMIS and MESOWEST for constructing the California Wet Percent Time table from 1995 to 2005, whereas 422 problematic stations were removed from the WTI database for either short duration of available data or large percent of erroneous and missing data. An improved method using the Zonal Statistics provided in the ArcGIS Spatial Analyst was tested and chosen for this project to produce a more accurate County-Average Wet Percent Time table.


This report provides information on best practices used in five areas in the country to enhance intersection safety. These practices focus on key elements of highway safety: safety management and comprehensive safety processes; traffic control devices for motorists, pedestrians and bicyclists; traffic operational practices; geometric design treatments; and enforcement practices and educational programs. The purpose of this document is to serve as an information and technology transfer tool on intersection safety practices used by State, regional and local transportation officials for the benefit of motorists, pedestrians and bicyclists.


The Illinois Department of Transportation (IDOT) uses two-wheeled friction testers to obtain a standard measurement of pavement surface friction under wetted conditions. A standard test is made at 40 mph in the left wheel path with a treaded tire. The test takes about 3 seconds. Torque on the trailer axle is measured for a 1-second interval. IDOT also performs a test in the right wheelpath with a smooth (treadless) tire. Treaded tire friction numbers are referred to as FNt and smooth tire numbers as FNs. Tests are made by alternating wheels as the trailer is towed along the roadway.


It’s true that US motor vehicle death rates have been trending downward for decades. Since the mid-1980s, the rate per registered vehicle has declined 43 percent. Traffic safety policies aimed at improving drivers and roadways have influenced this trend, but it’s a mistake to attribute all of the death rate reductions to such policies. More sophisticated analyses are required to get a clearer idea of what is behind the reductions, and new Institute research helps to identify the reasons.

The researchers focused on two factors that have influenced the driver death rate per registered vehicle over 20 years (1985-2004). One is how vehicle use patterns change as vehicles age. The other is vehicle design changes—the introduction over time of different types of vehicles and more crashworthy ones to replace vehicles that weren’t doing as good a job of protecting their occupants.


In Minnesota, concrete pavements are finished by dragging an inverted turf or a stiff-bristled broom longitudinally on the surface of freshly placed concrete pavements, right behind the paving machine. Prior to 1998, most concrete pavements were finished with a combination of the burlap-drag and transverse-tining. Subsequently those pavements were reconstructed and finished with current broom or turf drag. The study sought to ascertain if current texturing techniques resulted in higher wet weather accident events. A Minnesota Department of Transportation (Mn/DOT) study selected segments in the network where current texturing techniques replaced previous textures. Annual wet weather accidents data from the Mn/DOT database were analyzed. By examining annual wet weather accident counts, total accident counts and crash rates for a ten year period, current textures were compared to previous textures. The paper discusses how three statistical tools were used to compare wet weather accident data from previous texturing to data from current texturing. Statistical tools showed that current texturing practices did not cause an increase in the annual wet weather accidents and crash rates, as well as ratio of wet to dry weather accidents, in the chosen test sections.

Pavement friction testing is frequently conducted in accordance with the provisions outlined in ASTM E 274, "Standard Test method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire." The standard speed of testing in Florida is 40 mph (64.4 km/h). However, due to safety concerns related to testing on high-speed facilities, considerable attention has been focused in recent years on height-sensor based (non-contact) technology. Such sensors are potentially well suited for surveying the surface texture characteristics of pavement sections while operating at highway speeds. Although the height-sensor based technology has been available since the 1960s, it continues to mature.

A considerable amount of research has been conducted to gain further understanding on the factors affecting high-speed pavement surface surveying from both the analytical and experimental points of view. Still some problems have not fully been resolved, particularly in the interpretation of the measured data and selection of adequate sensing technology (or sensor designs). The Florida Department of Transportation (FDOT) initiated the present study to assess the feasibility of using high-speed, laser-based sensors to quantify the texture and friction characteristics of asphalt pavements. The main objective of this study is to provide for a safer, faster and more appropriate method of estimating pavement friction characteristics on high-speed facilities, ramps, and at other potentially hazardous sites. Further, it is also intended to provide for a means to obtain a measure of International Friction Index (IFI) in accordance with ASTM E 1960. This report presents a description of the FDOT testing program, the data collection effort as well as the subsequent analyses and findings.


Findings are presented from a research study conducted in Texas to determine the significance of seasonal variation in skid measurements. Six bituminous highway pavement sections, two each from three different climatic regions, were monitored over a period of more than 18 months. Monitoring included collection of wet pavement skid resistance data using a locked-wheel skid trailer that met the specifications of ASTM E 274. These measurements were made at biweekly intervals in two of the three climatic regions and at monthly intervals in the remaining climatic region. The necessary climatic data were obtained from nearby National Climatic Data Centers. The data obtained indicated that significant variation in skid numbers occurs from one day of measurement to another. The maximum variations observed were on the order of 10 to 12 skid numbers. Furthermore, there were strong indications that the variations occurred in response to changes in temperature and precipitation. Finally, three methods of normalizing the skid data to obtain the true mean skid number of the pavement were evaluated. The first of these was a linear regression model based on rainfall, temperature, and other variables. The second was a nonlinear regression model based on Julian calendar day only. The third approach examined the possibility of using multiple skid measurements to achieve a desired level of accuracy. The advantages and disadvantages of each method are discussed.


It has been acknowledged recently in the UK and New Zealand that setting single investigatory levels (IL’s) for each site category may not be the optimum management of risk since each site category is quite broad and individual sites, within a site category, can have very different conditions. Therefore, a range of IL’s has been recommended for each site category; the advantage of setting a range is that levels can be more closely aligned with particular risk for each individual site. Also, since the range is set out in the policy it removes the perceived risk to the Site Investigation Engineer, to move the IL away from the tabulated value in the specification. However, fundamental to this new approach is the correct assessment of the risk through the use of a site investigation process. In this paper, a risk assessment has been carried out on 35 category 2 or 3 sites situated in the Northland region. The assessment includes the results from the SCRIM survey, the effect of rain fall on the skid resistance, the results of a curve deficiency procedure, a full site investigation for each site and the wet crash data for the sites. Using all the information a comparative analysis of risk for each of the sites has been determined. The risk assessment has been used to assign individual investigatory levels and, using information from previous studies, an estimate in the benefits arising from crash reduction has been made. Using the cost associated with the crash reduction a benefit-cost analysis has been carried out taking into account the benefits obtained by crash reduction on one hand and the
cost of achieving the recommended IL on the other. Finally, the implications to local key performance measures have been discussed, along with the implications if the approach was adopted on a national basis.


Properly tined concrete pavements generally provide superior skid resistance compared to asphalt pavements. Skid resistance is a critical factor in many highway crash situations. However, no published studies exist that statistically compare the safety of concrete and asphalt pavement surfaces. The American Concrete Pavement Association (ACPA) is interested in exploring existing crash data sources that may be used in a statistically valid evaluation of concrete and asphalt pavement surface safety. This study was undertaken to assess the feasibility of using data contained in two publicly available datasets: the Highway Safety Information System (HSIS) and the Fatality Analysis and Reporting System (FARS). The assessment was based on the ability to compare crash frequency, crash rate, and crash injury severity as safety metrics. The HSIS contains crash and other relevant data from nine states: California, Illinois, Maine, Michigan, Minnesota, North Carolina, Ohio, Utah, and Washington. For each state, HSIS data consistently provides crash, vehicle, occupant, and roadlog files. Data from each state was assessed for its potential usage in a comparative study of concrete and asphalt pavement surface safety. The assessment indicated that data from all nine states can potentially be used for analysis of crash frequency and crash rates, after the necessary file merging operations. Injury severity analysis is possible, albeit with some limitations – either restricting it to injuries of drivers involved in single-vehicle crashes or relying on the characteristics of most severely injured occupant and the respective vehicle in the analysis. Alternatively, an indicator variable for injury/non-injury crashes may be used in the crash frequency models. Although FARS data initially appeared to have potential for use in a comparative study of concrete and asphalt pavement surfaces, its assessment showed that it is unlikely to be useful for an “apples-to-apples” safety comparison. The non-usefulness of FARS data for this study is due to absence of specific crash locations in the dataset and non-availability of crash exposure information on concrete and asphalt pavement surfaces. The following recommendations have emerged based on the assessment of HSIS and FARS data:

- Conduct crash frequency analysis of each of the nine states contained in the HSIS by using appropriate count data models (Poisson, Negative Binomial, Gamma, etc.).
- Using HSIS data for the nine states, conduct simple comparisons of crash rates as well as regression analysis of crash rates to obtain insights beyond those obtained by frequency analysis.
- Conduct injury severity analysis using the HSIS data with the understanding that findings from the analysis may be limited in scope.
- North Carolina, Minnesota, Ohio, and Maine databases in the HSIS appear to be good candidates if analyses are limited to only a few states.
- FARS data may not be pursued further for the purpose of comparing the safety of concrete and asphalt pavement surfaces because of non-availability of crash location and exposure information.

Data from only two states in the HSIS contain information on pavement roughness: North Carolina and Ohio. While the analyses of data from all states can reveal safety differences between concrete and asphalt pavement surfaces, the analyses of data from only these two states can potentially link the difference in safety to pavement roughness.


This report represents the second phase of a project sponsored by the Wisconsin DOT and the FHWA researching the texture and noise characteristics of Portland cement concrete (PCC) pavements. The team of Marquette University and the HNTB Corporation measured noise, texture and friction of 57 test sites in Colorado, Iowa, Michigan, Minnesota, North Dakota and Wisconsin. During 1997, new test sections were constructed in Wisconsin, including random transverse, skewed and longitudinally tined PCC pavements. Interior and exterior noise was measured on all 57 sites using the Fast Fourier Transform method with a Larson-Davis two channel real time acoustical analyzer. Subjective testing of interior noise was measured on 21 selected sections with 24 subjects with good hearing in a closed acoustical environment. Texture on all test sites was measured with the Road Surface Analyzer (ROSAN). Sand patch tests, a measure of surface texture, were also performed on most of the 22 test sections in Wisconsin. Highway noise cannot be characterized by one single type of noise measurement. For this
reason, conclusions were drawn using the data acquired from all of the different measurements. These include: exterior, interior, subjective, and prominent frequency noise analysis as well as texture characteristics. Some pavement textures exhibit a definite distinctive noise that is often described as “a whine”, and is exhibited as a prominent tone or discrete frequency also described as a “spike”. Generally, the longitudinal tined PCC and the Asphaltic concrete (AC) pavements exhibited the lowest exterior noise levels. The AC pavements and the longitudinally tined and random skewed PCC pavements and the European texture exhibit the lowest interior noise levels. ROSAN texture measurements were relied upon and proved invaluable in analyzing the reason why different textures exhibited different noise characteristics. The ROSAN mean profile depth (MPD) and estimated texture depth (ETD) correlated very closely with sand patch. There was good correlation between tining depth and width, using the ROSAN data, and some of the loudest transverse tined pavements had both greater depth and widths, but it could not be determined which was responsible for the greater noise. Spectral analysis of the ROSAN outputs was utilized to recommend the proper random pattern for transverse tining. The patterns were tested in 1999 and both subjective and objective analyses confirmed the lack of discrete frequencies.

Conclusions include that tining depths vary tremendously among the pavements constructed, even within a single test section, uniform tined pavements exhibit a discrete frequency or whine and should be avoided, transverse tined pavements with the deepest and widest textures were often the noisiest, longitudinal and random skewed tining (1:6 skew) can be easily built, eliminate discrete frequencies while substantially reducing noise levels, and random transverse tining must be carefully designed to eliminate discrete frequencies, but may not substantially reduce overall noise levels. When comparing different pavement textures with the same mean texture depth (approximately 0.7 mm) to that of uniform 25 mm, transverse tined PCC pavements, a well randomized transverse will result in a 1 to 3 dBA exterior noise reduction, a random skew 4 dBA, a longitudinal tined 4 to 7 dBA and an opened textured AC pavement 5 dBA, based on this study. Interior noise reduction were approximately half of the exterior reductions. Recommendations include improving the quality control over tine spacing depth and width, future research on wet pavement accidents and longitudinal tining and the relative effects of tining depth and width on tire pavement noise, and specific recommendation on when to use longitudinal, random skewed and random transverse tining. Long term monitoring of noise differences of these 57 test sections is recommended in order to determine if surface texture differences can be reflected in FHWA noise models.


One of the factors contributing to motor vehicle crashes is lack of sufficient friction at the tire-pavement interface. Although the relationship between surface friction and roadway safety has long been recognized, attempts to quantify the effect of pavement skid resistance on wet accident rates have produced inconsistent results. This thesis analyzes the relationships between skid resistance, accident, and traffic data for the state of Virginia. The correlation between wet skid resistance measured with a locked-wheel trailer using a smooth tire and wet accident rates is examined. Additionally, the influence of traffic volumes on accident rates is considered. The research used accident and skid data from the Virginia wet accident reduction program as well as from sections without pre-identified accident or skid problems. The wet accident data was aggregated in 1.6 km (1 mi) sections and divided by the annual traffic to obtain wet accident rates. The minimum skid number measured on each of these sections was then obtained and added to the database. Regression analyses indicated that there is statistically significant effect of skid resistance on wet accident rate; the wet accident rate increases with decreasing skid numbers. However, as expected, skid resistance alone does a poor job of modeling the variability in the wet accident rates. In addition, the wet accident rate also decreases with increasing traffic volume. Based on the data studied, a target skid number (SN(64)S) of 25 to 30 appears to be justified.


Municipal, state, and federal agencies in the United States that are responsible for traffic safety have used crash rates such as fatalities per 100 million vehicle miles traveled (VMT) as traffic safety performance measures. However, the appropriateness of using such rates as performance measures has not been examined empirically, although the rates have been made public.
This study examined 20 candidate crash rates (e.g., fatalities per million population and injury crashes per million registered vehicles) for an annual safety performance measure for Virginia using autoregressive error models and empirical data from 1971 through 2006. The study found that the injury rate per driver and the crash rate per VMT seem appropriate as long-term (1971-2006) and short-term (1995-2006) safety performance measures, respectively, for Virginia. Statistical uncertainty should be considered when these rates are used to measure safety performance.


This book presents a thoroughly scientific and practical approach to designing highways for maximum safety. Based on original research plus scrupulously collected data amassed over more than two decades in different continents by the main author, this important book originates vital criteria for safe design and shows you how best to achieve roads with the lowest possible accident risk and severity rates. In addition, this valuable and necessary resource gives you serious help coordinating safety concerns with important economic, environmental, and aesthetic considerations. Overall the book is an invaluable source of information for educators, students, scientists, highway agencies, and consultants in the field of highway design and traffic safety engineering.


This paper provides background information on pavement texture and its relationship to the skid resistance from period between late 60s and early 90s. It also discusses existing guidance regarding pavement friction/texture. The author emphasizes current friction/texture vs. accident research and implementation activities, providing comprehensive list of references on the issue. The following actions are recommended:

1. Develop a one day workshop to summarize the portland cement concrete (PCC) surface texturing research currently being completed in Wisconsin. This would emphasize efforts to reduce annoying tonal frequencies and total noise on PCC pavements for both the user and the adjacent residences. This would include implementation guides or aids to facilitate early technology transfer.

Attachment to the paper discusses effect of friction/texture on crash rates. While the direct relationship between skid numbers measured on the surface and wet-pavement crashes is questionable, the effect of texture depth on the crash rate has been proved to be significant by many studies both in the U.S. and overseas (U.K., Australia, New Zealand).


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.


The surface characteristics of pavements contribute to good functional performance. These characteristics are gaining in significance with the shift of focus from new construction and major rehabilitation to pavement preservation. Functional performance is determined by how well the pavement serves the user. Until now, riding comfort—a concept developed in 1957—had been the dominant concern. Today the greater need is to improve other important functional surface characteristics of pavements. The new pavement preservation technologies may enable researchers to develop guidelines for the functional surface characteristics of pavements that maintain ride comfort but also contribute to reductions in fatalities and injuries, as well as in highway noise.


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)], and aesthetics are not often specifically addressed. The purpose of this paper is to look at the functional characteristics of well performing paved highway surfaces. First, functional performance will be described. Secondly, the individual surface characteristics affecting functional performance will be discussed. Finally, recent innovative techniques and equipment to measure and evaluate these characteristics will be explained. Consideration of these factors by the engineering profession will help ensure that the highway user expectations are met on completed projects.


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.


Over a number of years the United Kingdom has published a series of guidance manuals and standards for Local Highway Authorities. These require Local Authorities to assess and manage the Skid resistance performance of their highway surfaces. The Road Death Investigation manual developed by the police has resulted in a new level of scrutiny of the LA’s skidding policy and its implementation.

By using a series of case studies from a range of LA’s this paper will outline the fundamental steps to be used in developing a practical skidding policy. This policy will be able to be managed by non-specialist engineers within the limited resources available to the LA’s. A summary of the current practice by LA’s on the use of warning signs is given.
The paper will consider the impact of the newly introduced SCANNER surveys and the use of technologically advanced computer systems, particularly in the areas of Global Positioning Systems, Graphical Information Systems and internet facilities. These systems combine to give fast and easy access to different data sets for efficient coordination. A demonstration of an automatic process that will give the engineer an early warning system of potential accidents at particular locations on the road network will be given.


The influence of the particle size distribution used in road surfacing mixes on both average macrotexture depth and skid resistance of pavements is described herein. It will then be shown how the nature of aggregates is able to influence the evolution in the pavement surface state when submitted to the effect of traffic-related polishing. Following a presentation of methods used for characterizing the level of aggregate polishing resistance, the correlation between this resistance and the trend in pavement skid resistance will be highlighted by results from recent experimental testing. Moreover, discussion will be provided on the aggregate selection criteria used for wearing courses.


Traffic accidents cause loss of life and property. Proper identification of accident causal factors is essential for composing countermeasures against traffic accidents and reducing related costs. However, two-lane rural roads have distinctive roadway characteristics compared with other types of roads. In order to find cost-effective countermeasures and prioritize roadway safety improvement plans, a better understanding of the relationship between accident risk and respective characteristics is necessary. This study focuses on accident analysis of two-lane rural road sections in Washington State. Six representative state routes (SRs), SR-2, SR-12, SR-20, SR-21, SR-97 and SR-101, are selected as study routes based on their location, length, accident history, and geometric characteristics. Along with six-year (1999-2004) accident data from the Highway Safety Information System (HSIS), roadway video image data and geographical information system data retrieved from Washington State Department of Transportation are employed in this study. Econometric modeling methods are utilized to identify accident causal factors and evaluate their impacts on accident risk. Poisson regression, negative binomial regression, and zero-inflated regression models were evaluated and negative binomial regression was found to be the most suitable form for modeling accidents on two-lane rural roads. In addition to modeling all-type accidents, a rear-end accident risk model is also developed since rear-end accidents are the most frequent accident type on all routes. Findings from this study not only help identify accident causal factors, but also provide valuable insights for developing countermeasures against two-lane rural road traffic accidents.


Because of the evident advantages associated with the smooth tire for the measurement of pavement friction, many highway agencies have become interested in the smooth tire. Pavement friction is the result of tire–pavement interaction. Because of the differences between ribbed and smooth tires, experiences with the ribbed tire may not apply to the smooth tire. Therefore, it is of great importance to evaluate those issues associated with the use of the smooth tire in network pavement inventory friction testing, such as variations in the friction testing system, seasonal friction variations, spatial friction variations, and temporal friction variations. The Indiana Department of Transportation (InDOT) has been using the smooth tire in the network pavement inventory friction test program since 1996. Large amounts of friction data have been obtained in the InDOT friction test track and network pavements. This paper presents the variations in the friction measurements obtained with the smooth tire because of testing system errors and seasonal and temperature effects. The paper also presents the spatial and temporal variations in the friction measurements. It was thought that the results provided in this paper would be useful for highway agencies for determination of test cycle, test spacing, and friction corrections for their network pavement inventory friction testing programs.

This study investigated many important issues associated with pavement surface friction testing, in particular using the smooth tire. This study utilized 3-D FEM program to investigate the fundamental friction phenomenon in light of energy dissipation during friction process. It was demonstrated that the pavement friction depends on many factors such as test tire, test speed, surrounding conditions, pavement surface texture, and pavement type. A great amount of friction data has been collected to investigate variations involved in pavement friction measurements. System variations depend on the features of the pavement surface. The standard deviations due to system errors are usually less than 5. The smooth tire tends to provide greater variations than the ribbed tire. As air temperature increases, the friction number does not necessarily decrease. No consistent relations were identified between friction measurements and test seasons. Seasonal friction variations are negligible. The largest lateral variation is 16 with the smooth tire on a State road. The State and U.S. roads tend to produce greater directional variations than the interstates. Driving lane usually has lower friction than other lanes. The greatest lateral variation arose due to the effect of wheel track. Longitudinal friction variations depend on traffic distribution, pavement type, and surrounding conditions. Friction measurements taken at 1.0-mile spacing can provide realistic network pavement friction information. Pavement frictions on interstates decreased faster than those on State and US roads. The Indiana Department of Transportation (INDOT) conducts pavement inventory friction tests every year on interstates and every three years on State and US roads. The force transducers should be calibrated every month and the whole system performance verified every week to identify potential significant performance changes. A minimum of 3 to 5 test runs must be conducted for system verification. The standard smooth tire is recommended for INDOT network pavement inventory friction tests. In general, the friction number measured with the ribbed tire is greater than that with the smooth tire. However, the differences decrease as the surface texture becomes rougher. The average friction difference is about 20 on highway pavements. Friction test speed should be determined in light of the traffic conditions. Test speeds of 30 mph, 40 mph, and 50 mph are recommended for network pavement inventory friction testing. Determination of the minimum friction requirement should consider its impact on wet-pavement accidents and agency's budgets. Taking into account the minimum friction requirement recommended by NCHRP Report 37 and the differences between the ribbed and smooth tires, a friction number of 20 with the smooth tire at 40 mph is recommended as the minimum friction requirement for network pavement inventory friction testing. It was found that this requirement is economically reasonable.


Questions concerning the effect of skid resistance on traffic accidents have been investigated in various research studies. Apart from separation of the influence of skid resistance from other influence factors, one of the main issues in all these studies has repeatedly been the quantifying of the correlation between skid resistance and accident occurrence. The goal was finding a threshold or minimum value for the skid resistance. Whereas elder studies show quantified correlations between skid resistance and accident occurrence, recent research results tended to put these in question. Based on a large data set regarding freeways and a pilot study regarding main roads the present study shows that it was not possible to identify any such relation between skid resistance and accident occurrence for either wet or dry pavements. It was not possible to formulate no quantifiable correlation in this regard. It could, however, be found that a systematic search for notable areas where very low skid resistance values with high accident frequencies by wet pavement coincide is extremely worthwhile, as it serves to identify individual, randomly distributed danger zones. These can then be subjected to more detailed investigations.


Highway safety is one of the most important issues in transportation. Intersections are the locations with higher traffic crashes as compared with other highway locations. To evaluate or assess the safety performance of an intersection, traffic crash analysis is the most popular method and has been used for a long history. However, traffic crash analysis is based on a lot of crash data, which needs to be accumulated through a long time period. Besides, sometimes, traffic crashes randomly happen with the impacts of human driving behavior. Therefore, without sufficient data and crash history, traffic crash analysis may not give an overall evaluation for the intersection safety performance. This paper introduces an approach to evaluate highway intersection safety performance. This approach
is fully based on the existing conditions of the intersection, including geometrics, channelization, sight distance, pavement surface conditions, traffic control devices, traffic signal timing and phasing, etc. The non-accident based approach is based on field survey to the conditions mentioned before. The approach will also result in a safety index to indicate the safety performance degree of the intersection. Meanwhile, corresponding countermeasures are ranked and recommended based on the cost-benefit analysis. The content of this paper is based on the research results from a part of a research project (entitled “Safety Design of Highway Intersections”) sponsored by China Department of Transportation. In this paper, the approach (called diagnostic approach) is practically applied to evaluate the safety performance of some intersections in Shan Dong Province and Jiang Su Province. Results from the real application indicate that the approach has good applicability and can be used by field safety engineers in real application. In addition, the approach is implemented into software with friend operational interface.


Road traffic safety has substantially improved in The Netherlands since it peaked in the mid 1970s, and especially after Phase I (1998-2002) of the Dutch road infrastructure redesign programme "Duurzaam Veilige Infrastructuur" (Sustainable Safe Infrastructure). Surprisingly, however, from 2003 to 2006 Dutch traffic safety has considerably further improved without any stimulating national programme. Aiming to assist further Dutch policy making of road traffic safety, the paper analyses the Dutch situation and explores potential factors that may have contributed to the traffic safety improvement in the past years. In addition, it investigates the use of a first-order, one-variable grey model, denoted as GM (1,1), to model traffic accident severity (in terms of fatalities) in The Netherlands for the period 2003-2006, and to forecast the trend of the reduction of fatalities in the years 2007 and 2008 (based on the data of the previous four years). Error analysis shows that the applied model has a high degree of reliability. Therefore, it is concluded that GM (1,1) is applicable for short-term forecasting of this type of problem.


Aggregate properties are one of the important factors that influence the asphalt pavement skid resistance. This paper presents a detailed analysis of aggregate texture and its relationship to pavement skid resistance. A new method is developed for the evaluation of aggregate resistance to polishing. This method relies on the Micro-Deval test as the mechanism for polishing aggregates and the Aggregate Imaging System (AIMS) for quantifying the change in texture due to polishing. The results show that the Micro-Deval test is an effective method for polishing aggregates within a short time. Also, the AIMS texture analysis is able to rapidly and accurately quantify the influence of polishing on texture. The verification of the new method was achieved through measuring the skid resistance of pavements constructed using three different aggregate sources and three different aggregate gradations. The skid resistance was found to be related not only to average aggregate texture, but also to the texture distribution within an aggregate sample. The developed method can be used in models for predicting the change in asphalt pavement skid resistance as a function of aggregate texture, mixture properties, and environmental conditions.


The study examined the safety impacts of improving pavement skid resistance using data from New York State. The New York Department of Transportation (NYDOT) runs a skid accident reduction program that identifies sections of pavement with a high proportion of wet-road accidents, friction-tests these locations according to ASTM E-274 using the ASTM E-501 Ribbed Tire, and treats those with both a high proportion (35-40%) of wet-road accidents and low friction numbers (<32). An empirical Bayes before after study was conducted of locations that were treated under this program. The results indicate that this can be a highly cost-effect safety treatment for both intersections and road segments that warrant skid resistance improvement because of a high frequency of wet road accidents and low friction numbers.


This scan, cosponsored by the American Association of State Highway and Transportation Officials (AASHTO), the National Association of County Engineers (NACE), and the Federal Highway Administration (FHWA), was conducted to document and disseminate information on good practices by State Departments of Transportation
Relationship Between Skid Resistance Numbers Measured with Ribbed and Smooth Tire and Wet-Accident Locations

(DOTs) and local agencies to integrate safety improvements into resurfacing and pavement restoration projects. Agencies have multiple objectives and limited resources. Programs and projects are developed to balance competing needs and limited funds. Integrating safety improvements into resurfacing is a resource-efficient method of pursuing infrastructure and safety goals. Resurfacing programs are not the only mechanism through which safety improvements are implemented. Further, resurfacing programs cannot be the means by which all existing highways are upgraded to meet all current criteria and standards related to geometry, traffic control, and safety appurtenances; however, incorporating selected, cost-effective safety improvements in resurfacing and restoration projects can provide extended public benefits. Attributes of successful programs include:

- The agency's resurfacing program is considered to be an element of its overall safety strategy.
- Agency leadership supports an integrated resurfacing-safety strategy.
- Funding of integrated safety improvements is recognized as an appropriate expenditure.
- Safety improvements are targeted and cost-effective.
- "Scope creep" does not interfere with timely resurfacing.

Integrated resurfacing-safety programs don't come into existence instantaneously. Successful programs are developed over time and may be akin to a journey that involves changing organizational paradigms and culture. The States and counties visited are all on a journey to the goal of well-integrated programs. Some agencies are further along than others. This report encompasses both how (i.e., process) integrated programs function and what is being accomplished (i.e., completed projects). It is written primarily for Federal, State, and local agency personnel in appointed and career executive positions, bureau and district/region managers that have a role in establishing direction and priorities within transportation agencies.


Nearly 25 percent of fatal crashes occur at or near a horizontal curve. Hence, addressing the safety problem at horizontal curves is one of 22 emphasis areas of the Strategic Highway Safety Plan prepared by AASHTO. Also, crashes at horizontal curves are a big component of the road departure crash problem, which is one of FHWA’s three focus areas. This publication was prepared to provide practical information on low-cost treatments that can be applied at horizontal curves to address identified or potential safety problems. The publication concisely describes the treatment, shows examples; suggests when the treatment might be applicable; provides design features; and where available, provides information on the potential safety effectiveness and costs. The treatments include:

- Basic traffic signs and markings found in the MUTCD.
- Enhanced traffic control devices.
- Additional traffic control devices not found in the MUTCD.
- Rumble strips.
- Minor roadway improvements.
- Innovative and experimental treatments.

The publication concludes with a description of maintenance activities that should be conducted to keep the treatments effective.

Midwest Regional University Transportation Center (MRUTC). “Incorporating Road Safety into Pavement Management: Maximizing Surface Friction for Road Safety Improvements.” (Research in Progress)

The objective of this research is to integrate road safety and pavement management strategies. Specifically, objectives include: (1) Determine the relationship between skid resistance and traffic safety; (2) Develop asphalt pavement mix design strategies that consider skid resistance as its primary measure of effectiveness; (3) Identify existing prediction models for skid resistance, propose modifications to models, and identify minimum skid resistance ranges to trigger the need for roadway maintenance; and (4) Incorporate skid resistance and safety in a pavement asset management tool. Traffic crashes and the associated injuries and fatalities continue to be a significant problem for transportation professionals. In 2001, 37,795 motor vehicle fatalities were reported in the United States as a result of over 6.3 million crashes (1). Over one-third of these crashes included personal injury to at least one of the vehicle occupants. The Region 5 states accounted for 6,360 of the 42,116 transportation fatalities in 2001, approximately 15 percent of the national total. Although numerous safety measures have been implemented in recent years, ranging from stricter safety laws and public awareness campaigns to roadway and
traffic control device improvements, total crashes and fatalities per year continue at unacceptable rates. Little has been done to incorporate safety into the pavement management and maintenance decisions that are made. Nevertheless, the results of numerous road crash investigations and statistical analysis have suggested that there is a relationship between crash frequency and pavement surface conditions. This relationship is not well understood. A vehicle that has lost contact with the pavement and entered a skidding maneuver is a safety hazard to drivers. High pavement skid resistance properties resulting in minimized skid lengths can be significant in reducing or eliminating the magnitude of a crash impact. Skid resistance can also be significant is keeping vehicles on the roadway during aggressive horizontal and lateral movements. The method used today for measuring resistance to skidding is measuring the friction provided by the surface to a typical tire traveling at a specified speed, under selected climatic and surface wetting conditions. There is a fair amount of variability within the specifics of these methods. It is well recognized that skidding is a phenomenon related to both the tire and surface characteristics. Normal load (weight), tire tread, temperature, and water all affect skidding. Thus it is essential to use standardized tires and conditions to compare resistance offered by surfaces to skidding.


The previous skid resistance standard was introduced was introduced into Scotland in 1994 since that time, major changes in the levels and type of traffic flow have occurred in Scotland. In particular, there has been a significant increase in traffic volumes, changes in the composition of the traffic with increasing numbers of four wheel drive sport utility vehicles, van like people carriers, and developments to the braking and suspension systems. Therefore, in 2003 Transport Scotland decided to review the current standards. As part of this review not only were the current investigatory levels considered but also the site categories were reviewed to determine if a number of new site categories including approaches to: Lay by’s, Bus Stops, on and off Slips and exits to garages, should be included in the standard.

By analyzing the accident rates and densities at different sites categories and at different skid resistances, it was possible to determine a set of optimum investigatory levels. It was found from this study that there was no justification for adding the new site categories. Benefit cost calculations were undertaken and it was found that there was economic justification for implementing a number of revised investigatory levels. The results were discussed with TRL who were commission by the Highway Agency to undertake a similar study for the English trunk roads and it was found that with few compromises a single standard could be established for England and Scotland and a revised standard HD28/04 was implemented in 2004.

A procedural manual was written with the aim to provide clear unambiguous procedures for Managing the Skid Resistance of the Road Surface on the Scottish Trunk road system. This manual was released in September 2004 and since then, there has been various changes made and it is anticipated the manual will be rewritten to incorporate these changes in 2008. It should be noted that there are some changes between the Scottish procedures and those used in England. The key points of the Scottish procedures are outlined in the paper.


No abstract available.


The determination of skid resistance requirements is reported. The study focuses on wet pavement skidding accidents at intersections and curves. The feasibility of implementing these procedures was demonstrated in the field. A simplified version of the procedures was also developed. The three steps involved in the procedure for determination of skid resistance requirements are outlined. The system developed for measurement of longitudinal acceleration at intersections is based on the use of series of event detectors to determine the time-position signature of a vehicle over some known distance, from which acceleration values can be computed. Data was collected for an average of 350 vehicles at each of 12 intersections. Controlled skid studies were conducted to determine the relationship between longitudinal acceleration and skid resistance requirements. A simplified intersection demand model (IDM) for estimating skid resistance is desired. This is based on the apparent normality of distribution of
observed deceleration values at the various distance intervals form the stop line of the 12 sites studied. The findings indicate a strong relationship between pavement skid resistance and locked wheel braking deceleration. Accelerations and speeds of vehicles braking at intersection are normally distributed; they exhibit stable standard deviations. A relationship exists between average approach speed and skid resistance requirements. Considerably more extensive field evaluations are necessary to verify the applicability of the procedures.


The American Association of State Highway and Transportation Officials (AASHTO) Strategic Highway Safety Plan identified 22 goals to pursue in order to significantly reduce highway crash fatalities. One of the plan’s hallmarks is to comprehensively approach safety problems. Goal 15 in the Strategic Highway Safety Plan is *Keeping Vehicles on the Roadway*, and Goal 16 is *Minimizing the Consequences of Leaving the Road*. Subsequently, three emphasis areas evolved from these two goals: (1) Run-off-road (ROR) crashes, (2) Head-on crashes, and (3) Crashes with trees in hazardous locations. ROR crashes involve vehicles that leave the travel lane and encroach onto the shoulder and beyond and hit one or more of any number of natural or artificial objects, such as bridge walls, poles, embankments, guardrails, parked vehicles, and trees. Reducing the likelihood that a vehicle will leave the roadway through roadway design (e.g., flattening curves or installing shoulder rumble strips) prevents deaths and injuries resulting from ROR crashes. To reduce the number of ROR fatality crashes, the objectives should be to keep vehicles from encroaching on the roadside, minimize the likelihood of crashing or overturning if the vehicle travels off the shoulder, and reduce the severity of the crash.


One of the hallmarks of the AASHTO SHSP is to approach safety problems in a comprehensive manner. The range of strategies available in the guides will ultimately cover various aspects of the road user, the highway, the vehicle, the environment, and the management system. Two guides in the NCHRP Report 500 series discuss intersections: this volume covers signalized intersections, and Volume 5 discusses unsignalized intersections. This implementation guide provides guidance to highway agencies that desire to implement safety improvements at signalized intersections and includes a variety of strategies that may be applicable to particular locations.

Signalized intersections are generally the most heavily traveled intersection types and are therefore a major element of the highway fatality and crash problem nationally. Signalized intersections are operationally complex, with many factors contributing to the potential safety problems. The intent of a signal is to control and separate conflicts between vehicles, pedestrians, and cyclists to enable safe and efficient operations. Operation of a signal itself, however, produces conflicts (e.g., conflicts between through vehicles that could lead to rear-end crashes). In addition, varying signal operations (timing and phasing) place demands on drivers that are not always met. While the focus of the strategies discussed in this guide is on reducing fatalities at signalized intersections, the implementation of many of these strategies will likely lead to an overall reduction in intersection crashes. The objectives and the related strategies for improving safety at signalized intersections are explained.


This digest identifies liability risks associated with sharing safety data among transportation agencies pursuant to Section 409 of Title 23, U.S.C.; identifies best practices; reviews the Pierce County, Washington v. Guillen decision and its potential impact on managing state liability risk; and describes strategies for overcoming the impediments to data sharing, specifically those related to liability. Transportation lawyers and risk management practitioners for the states, metropolitan planning organizations (MPOs), and transportation planning organizations may find this digest useful.

Based on a scan of U.S. universities, the study reveals to what extent core competencies for highway safety professionals are incorporated into existing safety curricula and suggests strategies to expand their application to a broader audience. The core competencies, developed under this project, will be useful to managers identifying the knowledge, skills, and abilities an organization as a whole requires, adjusting job descriptions and announcements, and working with other departments and managers to hire for these skills. Supervisors may also use the competencies to assess the level of the team’s skills and make recommendations for individual training and assignments. The competencies include: (1) understanding the management of highway safety as a complex multidisciplinary system; (2) understanding of and the ability to explain the history of highway safety and the institutional settings in which safety management decisions are made; (3) understanding the origins and characteristics of traffic safety data and information systems to support decisions using a data-driven approach to managing highway safety; (4) (a) demonstrating the knowledge and skills to assess factors contributing to highway crashes, injuries, and fatalities; (b) identifying potential contributing factors; (c) applying countermeasures to user groups or sites to reduce crashes and injuries; and (d) implementing and evaluating the effectiveness of the countermeasures; and (5) developing, implementing, and managing a highway safety management program.


In this annual report, Traffic Safety Facts 2003 – A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System, the National Highway Traffic Safety Administration (NHTSA) presents descriptive statistics about traffic crashes of all severities, from those that result in property damage to those that result in the loss of human life.


Traffic crashes and the associated injuries and fatalities continue to be a significant problem for transportation professionals. In 2001, 37,795 motor vehicle fatalities were reported in the United States as a result of over 6.3 million crashes (1). Over one-third of these crashes included personal injury to at least one of the vehicle occupants. The Region 5 states accounted for 6,360 of the 42,116 transportation fatalities in 2001, approximately 15 percent of the national total. Although numerous safety measures have been implemented in recent years, ranging from stricter safety laws and public awareness campaigns to roadway and traffic control device improvements, total crashes and fatalities per year continue at unacceptable rates. Little has been done to incorporate safety into the pavement management and maintenance decisions that are made. Nevertheless, the results of numerous road crash investigations and statistical analysis have suggested that there is a relationship between crash frequency and pavement surface conditions. This relationship is not well understood.

A vehicle that has lost contact with the pavement and entered a skidding maneuver is a safety hazard to drivers. High pavement skid resistance properties resulting in minimized skid lengths can be significant in reducing or eliminating the magnitude of a crash impact. Skid resistance can also be significant in keeping vehicles on the roadway during aggressive horizontal and lateral movements. The method used today for measuring resistance to skidding is measuring the friction provided by the surface to a typical tire traveling at a specified speed, under selected climatic and surface wetting conditions. There is a fair amount of variability within the specifics of these methods. It is well recognized that skidding is a phenomenon related to both the tire and surface characteristics. Normal load (weight), tire tread, temperature, and water all affect skidding. Thus it is essential to use standardized tires and conditions to compare resistance offered by surfaces to skidding.


This synthesis will be of interest to state transportation agency personnel, as well as to others who work with them in the area of safety. It provides information for state departments of transportation (DOTs) on new technologies for the acquisition, processing, and overall management of crash, roadway inventory, and traffic operations data. The objective was to summarize the current state-of-the-practice and state-of-the-art use of technologies for efficient and
Relationship Between Skid Resistance Numbers Measured with Ribbed and Smooth Tire and Wet-Accident Locations

effective collection and maintenance of data for highway safety analysis. Information is presented about the U.S. DOT developing new safety and analysis tools to help state DOTs identify safety problems and countermeasures to increase highway safety. States are limited in their abilities to make informed decisions about the allocation of scarce safety resources because many states lack the database elements and linkages between databases to compile the data sets required by the new safety analysis tools. This synthesis effort contains information received from three individual surveys, developed to gather state-level information about the core safety data areas--crash, traffic operations, and roadway inventory. These surveys yielded approximately 60 returns from 34 different state DOTs and, along with a literature review, Internet search, and follow-up telephone contacts and interviews, generated the information used in this synthesis.

Ohio Department of Transportation (ODOT). 2006. *Crash Base Rates for Intersections*. Final Report. Ohio Department of Transportation, Columbus, OH.

The objective of the study is to develop a process or processes to ensure intersection crashes are analyzed based on intersection geometrics, traffic control and environmental factors. The validity of the process will be established and intersection crash base rates will be developed by studying appropriate variables for intersection crashes. The project tasks include analyzing at least the following variables for their affect on intersection crash rates:

- Roadway categories such as 2-lanes; 4-lanes divided/undivided
- Types of intersections such as 3-legged, 4-legged and 5-legged intersections with different number of lanes in each approach and with or without left/right turn lane
- Types of traffic control such as 2-way stops, 4-ways stops, overhead flashes, traffic signal with left turn phases and with or without exclusive turn lanes
- Number of lanes per approach, lane width, shoulder width, angle of approach
- Posted speed limit
- Number of residential/business driveways within the influence of intersection
- Horizontal/vertical curve influence on crashes at various types of intersections within certain distances from intersection
- Population density within 1 mile of intersection
- Number of vehicles entering the intersection, and effect of truck ratio if any
- Type of crashes related to various types of intersections
- The above list is not meant to be exhaustive. It is provided to illustrate that the research approach is expected to be broad and inclusive of all pertinent variables.

Ohio Department of Transportation (ODOT). 2006. *Ohio’s Road Map to Fewer Fatalities*. Ohio Department of Transportation, Columbus, OH.

Safer highways are at the heart of Ohio’s Road Map to Fewer Fatalities – a comprehensive highway safety plan, which has been developed by safety advocates and citizens throughout Ohio. The document is a tool that outlines the greatest threats to highway safety and identifies new strategies designed to lower the number of crashes, injuries and deaths that occur each year on Ohio highways. This document is considered comprehensive because it asks government agencies and safety advocates to work across jurisdictional boundaries to address crash problems regardless of where they occur. The document represents a broad approach to improving highway safety by drawing upon engineering, enforcement and educational strategies to prevent crashes. It also strengthens the relationship with emergency response and health care professionals, who respond to crashes and rehabilitate the injured. Their input can add new insight into the human and financial costs of crashes, which may influence how we prioritize and attack crash problems. This document also serves to complement hundreds of existing programs, projects and initiatives that have been developed and funded by federal, state and local agencies to improve roadway safety throughout Ohio.

Ohio Department of Transportation. “Continuing Investigation of Polishing and Friction Characteristics of Limestone Aggregates in Ohio.” (Research in Progress)

Asphalt concrete pavements gradually lose their skid resistance, creating a serious safety concern, especially when pavements are wet. As the driving speed and the Average Daily Traffic (ADT) increases, the chances of having skid-related accidents also increase rapidly. Thus, the Federal Highway Administration (FHWA) has issued a Wet Skid Accident Reduction Program to encourage each state highway agency to minimize wet weather skidding
accidents by identifying and improving the sections of roadways with high occurrences of skid accidents and by developing new surfaces which would have adequate and durable skid resistance properties. The objectives of continuing investigation of polishing and friction characteristics of limestone aggregates in Ohio are to: (1) develop new accelerated polishing equipment for Superpave HMA to facilitate rapid simulation of wear and polish actions between the vehicle tires and asphalt pavement surface; (2) develop a complete test protocol to include sample preparation method, test sequence, data precision and bias analysis, and acceptance criteria; (3) develop recommended specifications for the new test methods; and (4) conduct training and transfer equipment to the Ohio Department of Transportation (ODOT) Bituminous Lab.


The project aim is to develop strategies and tools to help MRWA ensure that maintenance contractors provide appropriate levels of skid resistance throughout the network. Current skid resistance monitoring programs and investigatory levels used in Australia are derived from systems developed in the U.K. and these are unlikely to suit WA conditions. They have high cost implications in terms of monitoring, and in maintaining surfacings at inappropriately high skid resistance levels. The first part of the report addresses the development of investigatory levels for the British Pendulum Tester (BPT) since MRWA has BPT intervention levels incorporated into its Term Network Contract (TNC) specifications. Background information on the development of the Austroads and U.K. investigatory levels is provided. The second part of the report considers the desirability of replacing skid resistance investigatory levels with macrotexture levels for high speed roads. Several studies (U.K., Australia, France) all showed a strong correlation between accident rate and macrotexture. It is thought that high macrotexture permits increased levels of hysteretic (deformation) friction to be developed by vehicle tires thus permitting them to avoid accidents. A macrotexture requirement may be more effective in reducing accident rates on high speed roads (where the effect of hysteretic friction is greatest) than a skid resistance (SCRIM) requirement. It is recommended that MRWA consider adoption of the BPT values presented in the report and consider the adoption of a 1.0 mm macrotexture investigatory level for high speed roads.


Policy makers too often have chosen to ignore the efficacy of science-based highway safety countermeasures in favor of education-based efforts, which rarely change user behavior, according to the author of this article who is a leader in highway safety research. The author concludes that progress on road user issues, such as belt use, motorcycle helmet use, alcohol impaired driving, and speed, will depend on political action at the state level.


The use of grooving in pavement surface is a common approach to improve wet weather skid resistance and reduce hydroplaning risks. Field measurements have found transverse grooves effective in significantly improving skid resistance and reducing the occurrences of hydroplaning. On the other hand, despite reported wet-weather accident reduction effectiveness of longitudinal grooving, most experimental studies did not record any significant increase in the measured skid resistance of longitudinally grooved pavements. This paper presents an analytical study to evaluate the relative effectiveness of the two types of grooving in terms of their ability to reduce hydroplaning potential, and their respective skid resistance available at the onset of hydroplaning. The groove dimensions examined cover groove widths from 2 to 10 mm, groove depths from 1 to 10 mm, and center-to-center spacing from 5 to 25 mm. It is found that in terms of the ability to rise hydroplaning speeds (i.e. to lower hydroplaning risks) and skid resistance values, transverse grooving consistently produced much better results than longitudinal grooving. The simulation results confirm that for longitudinal grooving with dimensions within the practical ranges, there are only marginal improvements in both hydroplaning speed and skid resistance in the longitudinal directions. However, an analysis by the simulation model indicates that, unlike a smooth plane surface, which has the same skid resistance properties in all directions, longitudinally grooved pavements have significantly higher skid resistance as the skidding direction deviates from the true longitudinal direction. The quantitative simulation analysis suggests that this has the effect of enhancing traction to keep skidding vehicles within the roadway and to cut down wet-pavement accidents, a result that has been widely observed in field applications of longitudinal grooving.

The current means of predicting the skid resistance of a wet pavement and the speed at which hydroplaning would occur are based on empirical models or relationships derived from experimental studies. These models and relationships are applicable only for the conditions specified, and extrapolations beyond the applicability range of parameters (e.g. range of vehicle speeds, tire loads, tire inflation pressures, water-film thickness, types of tires and pavement surfaces) are not advisable. Such restrictions could be overcome by developing an analytical model derived based on theoretical considerations. An analytical model would also provide a more in-depth understanding of the relative influence of different parameters. This paper presents a three-dimensional finite-element model to predict wet-pavement skid resistance and hydroplaning speeds under different magnitudes of passenger car wheel load, tire inflation pressure, water-film thickness and vehicle speed. The analysis shows that hydroplaning speed increases (i.e. hydroplaning risk decreases) with wheel load and tire inflation pressure, but decreases with the depth of water-film thickness. The skid resistance measured in terms of skid number decreases as the sliding wheel speed or the water-film thickness increases, but increases with the magnitude of wheel load and is affected marginally by the tire inflation pressure. Within the normal passenger car operation range of each of the parameters, the hydroplaning is affected most by tire inflation pressure, followed by water-film thickness, and is least influenced by the wheel load; while the skid resistance is most influenced by wheel sliding speed, followed by water-film thickness and wheel load, and is least affected by the tire inflation pressure.


Traffic noise has become a major concern in the last decade and many states have been looking for solutions to reduce noise levels. Reducing noise levels by proper selection of surface type may provide an alternative to sound walls. California Department of Transportation (Caltrans) has been using different open-graded mixes to reduce highway noise levels and to improve wet weather driving conditions. Before placing more open-graded mixes, there is a need to identify their noise reduction properties, durability, and safety, and to compare these with other asphaltic mixes. In 2005, Caltrans initiated a long-term program to investigate and monitor field performance of different open-graded mixes and other commonly used asphalt surface mixes.

This paper summarizes part of the first-year measurements of relevant parameters from asphalt pavements with different surface mixes. It was found that open-graded mixes generally reduce the tire/pavement noise level, and the amount of reduction is correlated with air-void content and surface texture. However, the noise-reduction benefit may be lost with the increase of pavement age.


This study was conducted to develop base crash rates for intersections in Ohio. The models were developed for the following crash types: (1) injury crashes, (2) PDP crashes, (3) total crashes, (4) wet crashes, (5) night crashes, (6) rear-end crashes, (7) sideswipe crashes, (8) fixed object crashes, and (9) left turn crashes. The base crash rates models considered different type of traffic control for different type of intersection approaches (legs), such as signalized intersection legs and no control legs at one-, two-, three-, and four-way intersections. The variables included in the analysis were number of left turns, number of through lanes, population density, speed limit, and average daily traffic (ADT). A master database was prepared by using data available form ODOT and data manually extracted from photologs by the researchers. To evaluate the complex interaction among the dependent and independent variables, Automatic Interaction Detection (AID) technique was used. Finally, based on stepwise multiple regression technique, the regression equations were developed to determine statewide base crash rates.
Recognizing the importance of providing safe pavements for travel during wet weather, highway agencies have established programs to provide adequate pavement friction. The Federal Highway Administration Technical Advisory T 5040.17, Skid Accident Reduction Program, which was issued in 1980, provides guidance to State and local highway agencies in establishing a skid accident reduction program. The main purpose of a skid accident reduction program is to minimize wet weather skidding accidents by: ensuring that new surfaces have adequate and durable skid resistance properties, identifying and correcting sections of roadway with high skid accident incidence, and utilizing resources available for accident reduction in a cost-effective manner. This synthesis summarizes skid accident reduction programs/practices of several State and foreign highway agencies. The synthesis also presents an overview of the components of a comprehensive skid accident reduction program.

There is a perception that transportation professionals can do little about adverse weather effects because it is “Mother Nature”. Accordingly, most of the weather responsive strategies are reactive such as speed management, access control and other operational practices. In fact, particular weather factors should be considered during the design, perhaps even the project planning stages, to avoid large remedial costs. The objective of this study is to develop a pragmatic safety audit process and procedure in which roadway and weather-related issues can be addressed proactively.

The paper introduces the development of the road safety checklist with the emphasis on potential weather influence on highway safety. A total of five road safety audit checklists were developed for a series of stages from the project development to the project completion: Feasibility Stage; Preliminary Stage; Detailed Design Stage and Pre-Opening Stage. Consistency and usability were key elements in the checklists development. A quantitative method is also provided to assist auditors in evaluating the severity of road weather safety problems. Meanwhile, this paper proposes an approach to institutionalizing the road weather safety audit by incorporating the road safety audit procedure as part of the Facilities Development Manual (FDM), which is the departmental procedure guidance for the development of road projects in Wisconsin.

Current UK standards for skidding resistance and texture depth are based on studies carried out in the 1970s, which showed that low-speed skidding resistance depends upon the microtexture of the road surfacing, but as speed increases, the skidding resistance falls, depending on the texture depth. In 1995, the Highways Agency commissioned further research in order to reassess the earlier work, particularly the influence of texture on the relationship between high- and low- skidding resistance, for the wide range of surfacings now used on UK trunk roads. A K J Law T1290 Pavement Friction Tester (PFT) was purchased by the Highways Agency, for this new study. The equipment has been used to make measurements of locked-wheel friction over a range of speeds from 20 to 130 km/h. Measurements have been made on more than 130 sites covering a wide range of types of surfacing, levels of texture and skidding resistance. The report presents the results of the first phase of analysis, which show clearly the loss of friction with increasing speed and confirm that this is more marked for surfacings with low texture.
Relationship Between Skid Resistance Numbers Measured with Ribbed and Smooth Tire and Wet-Accident Locations

depth. Significant findings were that texture has a greater impact on loss of friction at lower speeds than previously thought and that the effect is similar for both random-textured and transverse-textured impermeable surfacings.

No abstract available.

This paper discusses the issues relating to the calibration and comparison of skid resistance measurement devices, particularly in fleet operation. It reviews UK experience of over fifteen years of controlling a fleet of SCRIM machines in use providing survey data for comparison with skid resistance standards of the national road network. This includes the approach taken to setting and applying acceptance criteria, and briefly compares this with the approach taken in some other European countries in relation to the devices that they use. The paper also discusses the problems of correlating devices that operate on different principles, drawing on UK experience with GripTester and the Pavement Friction Tester. Additionally, the paper discuss the practical experience gained from the recent HERMES project in Europe conducted by FEHRL (Forum of European National Highway Research Laboratories) that evaluated a proposed standard process for harmonization of friction measurement devices.

The project was sponsored by the Illinois Concrete Council and had the following goals: (1) research of previous work on vehicle safety aspects of pavement surface defects, particularly, rutting and washboarding, and (2) implementation of a testing program based upon the panic stop test and report of the results. The testing program was aimed (1) to show the relative behavior of several typical domestic sedans (Chevrolet and Buick), and (2) determine if the results obtained are consistent with previous results reported in the scientific literature.

This EI describes the Department’s Skid Accident Reduction Program (SKARP) component of safety related asset management activities. This program identifies wet road accident locations on state owned roadways and arterials, friction tests them, and treats those locations which are experiencing both wet road accidents and pavement friction below the Programmatic Design Target Friction Number (PDTFN). Each year, the Traffic Engineering and Highway Safety Division identifies high wet road accident locations on State owned roadways and arterials, and produces a Wet Road Accident Priority Investigation Location (PIL) listing. Locations on the Wet Road Accident PIL listing are friction tested by the Technical Services Division. The Wet Road Accident PIL listing, and the results of the friction tests, are both forwarded to the Regions for consideration in the Regions’ capital programming and Preventive Maintenance Paving activities.

Skid resistance is an important factor in a rational maintenance program for pavement surfaces. Therefore, the skid resistance of a road surface is monitored by maintaining skid resistance inventories; in addition, spot checks are made at high accident sites. The equipment, called the dynamic friction tester (DF tester), is a disc-rotating-type tester that measures the friction force between the surface and three rubber pads attached to the disc. The disc rotates horizontally at a linear speed of about 80 to 20 km/hr under a constant load, so the DF tester can measure the skid resistance at any speed in this range with a single measurement. At the same time, the results provide speed dependency of skid resistance that will be as close as possible to the results obtained by other testing modes. The DF tester can measure on flat as well as rutted surfaces, the depths of which are less than 6 mm. In that case, the coefficient of variation is found to be less than 10%. The long-term characteristics of the coefficient of friction were measured by the DF tester, the British pendulum tester and the mini-texture meter. The coefficient of friction increases moderately with the traffic service period (up to 35 weeks) and decreases with increasing speed. The test results showed a significant speed dependency on the coefficient of friction measured by the DF tester although
there was a high relationship between the coefficient of friction of the DF tester and the British pendulum number at each point and at each measuring speed. A weak relationship was found between the coefficient of friction and the sensor-measured texture depth values produced by the texture meter. Results of the Permanent International Association of Road Congresses experiment to compare and harmonize texture and skid resistance measurements indicate that the DF tester is capable of reporting the friction component (F60) of the international friction index using the friction coefficient at 60 km.


Questions concerning the effect of skid resistance on traffic accidents, particularly by wet pavements, have been investigated in various research projects for many years. Apart from separation of the influence of skid resistance from other influence factors, one of the main issues in all these studies has repeatedly been the quantifying of the correlation between skid resistance and accident occurrence. The goal was finding a threshold or minimum value for the skid resistance. Whereas elder studies show quantified correlations between skid resistance and accident occurrence, recent research results tended to put these in question.

Based on a large data set regarding freeways and a pilot study regarding main roads the present study shows that it was not possible to identify any such relation between skid resistance and accident occurrence for either wet or dry pavements. It was not possible to formulate no quantifiable correlation in this regard. It could, however, be found that a systematic search for notable areas where very low skid resistance values with high accident frequencies by wet pavement coincide is extremely worthwhile, as it serves to identify individual, randomly distributed danger zones. These can then be subjected to investigations that are more detailed.


This paper relates to an investigation into the performance of high skid resistant road surfaces with regard to the impact on traffic crash trends. This study built on previous work which investigated the total numbers of crashes and trends at specific sites. The investigation showed the high skid resistant treatments were effective in reducing the number of crashes, using up to 5 years of ‘before’ and up to 5 years of data ‘after’ placement.

The objective of this project was to investigate any trends for the types of crashes for ‘before’ and ‘after’ the high skid resistant surface was placed. The project investigated twenty-three high skid resistant treatments within Melbourne and Geelong, Australia. The investigation found the following trends in crashes:

- An overall reduction in crashes of 39% on the treated areas.
- High friction surface treatments were very effective reducing loss of control crashes on high speed curves with free-flowing traffic.
- High friction surface treatments appear to be more effective when placed on the approach and centre of signalized intersections compared to sites with the treatment on the approach only.
- The sites in the project showed a slight increase to more serious injury crashes, and the high friction surface treatments followed this trend.
- A minority of sites displayed an increase in crashes and a larger increase in severity of injury.
- Although the total number of crashes was reduced, the proportion of different types of crashes remained the same.
- The skid resistant treatments altered the wet/dry road accidents ratio, and reduced the number of wet road crashes.


The United Kingdom skid resistance policy was published in December 1987 as Departmental Standard HD15/87 and was applicable to all Trunk Roads and Motorways. The policy required the whole of the network to be monitored using a Sideway-force Coefficient Routine Investigation Machine, SCRM. The standard was innovative and introduced concepts of investigatory rather than intervention levels. At any location on the network where the skidding resistance became equal to or fell below the investigatory level, an investigation was required to determine
Relationship Between Skid Resistance Numbers Measured with Ribbed and Smooth Tire and Wet-Accident Locations

if treatment to improve its skidding resistance was justified. The recognition that the level of skidding resistance required to provide an equal risk of a wet road skid occurring would need to vary along a road depending on the geometry of the road and other factors. The varying characteristics were defined in terms of 13 SCRIM site categories e.g. dual carriageway no-event, single carriageway no-event, approach to major junction, bend of less than 250m, etc.

The aforementioned concepts have been proved and they remain features of the revised standard published as HD 28/04 in 2004. A major feature of the new standard is the greater range and detail of the advice included to guide those responsible for providing adequate skid resistance in the application of the standard. Clear advice and guidance is provided in setting investigatory levels and carrying out investigations to determine if treatment is required. This paper describes the development of the new standard, considers the main parameters to be considered when setting investigatory levels and carrying out site investigations and explains the costs and benefits that will accrue from its introduction.


Twenty years after the introduction of Standards for aggregates used in road surfacing materials and for in-service skid resistance, it is clear that these approaches have been widely adopted and have produced a number of benefits, including better skid resistance and an acceptably low level of claims arising from slippery surfaces. However, benefits in terms of accident reduction have not been quantified adequately, and so it is difficult to assess whether the anticipated benefits of these Standards are being delivered in practice. This paper reviews the extent to which these Standards have been successful, and identifies a need for better information to be gathered to facilitate monitoring of in-service skid resistance and to support quantification of accident benefits.


This report presents an overview of the major aspects of tire-pavement interaction as they relate to highway noise, safety, and economics. The many sources of sound in the highway environment are described and the perception and measurement of noise are discussed. The measurement of roadway friction and the impact of pavement texture on highway safety are described. Techniques for controlling sound form the highway environment are also discussed, including the use of noise walls and barriers and the management of pavement surface characteristics. The noise, safety characteristics and cost-effectiveness of traditional and newer concrete pavement materials and surface textures, including turf drag, longitudinal tining, exposed aggregate, porous concrete, diamond grinding and others, are described and documented through summaries of studies from around the world. Techniques for balancing noise, safety, economics and other factors in the selection of pavement surface type and texture are also reviewed.


This paper will describe the process whereby SCRIM data and the associated Investigation Levels (IL) derived from the joint Cornwall County Council (CCC) / WDM work (as set out in the complementary paper by Stephenson et al) are used to determine the default base level skidding resistance for the network; it will then deal with the process of validating, investigating and quantifying the true level of deficiency at a given location and present one possible method of establishing a prioritized list of sites for treatment and alternative means of managing the risk of wet weather skidding on a live highway network.

The paper will draw on the work undertaken within CCC’s Asset Team arising from the revision of SCRIM IL’s brought about by the authority’s response to the Highway Agency’s 2004 revision of HD 28; the subsequent impact on a predominantly unimproved rural network and the need to effectively manage risk in a period of restricted maintenance funding.

The growing use of GIS-based packages in planning practice is assisting in the development and implementation of methods that facilitate safety consideration in transportation planning. This paper presents a method of predicting safety for planning alternatives. Although applicable to large road networks, the method predicts crashes at the road facility level (intersections and segments), which makes it suitable to jointly evaluate modifications of the road network, changes in network traffic flows, and improvements in road geometry considered by planners. A complete set of crash prediction models were developed by the authors for seven types of road segments and four types of road nodes based on crashes reported on Indiana highways in 2003-2005. A mainstream research method has been used - Negative Binomial regression with a stepwise variable selection method with the AIC criterion. The obtained equations are transparent to transportation planners and allow efficient computations for large road networks.

The crash prediction equations have been implemented in the GIS-based planning package TransCAD as an add-on tool. The included in the tool calibration procedure allows a planner to search for optimal values of calibration factors if calibration of crash prediction models is needed.


Improving road safety through proper pavement engineering and maintenance should be one of the major objectives of pavement management systems. When pavements are evaluated in terms of safety, a number of factors related to pavement engineering properties are raised, such as pavement geometric design, paving materials and mix design, pavement surface properties, shoulder type, and pavement color and visibility. Each year there are voluminous annual reports on traffic accident statistics and discussions of such road safety issues as road safety modeling and pavement safety measurements and criteria. Although road safety may be considered a separate area, it should be incorporated into pavement management systems. The main pavement engineering relationships associated with road safety are identified, and the various aspects of road safety related to pavement management, such as pavement types, pavement surface macrotexture and microtexture, and pavement safety measurements, criteria, and evaluation methods, are discussed. A systematic approach is proposed for the coordination of pavement maintenance programs with road safety improvement and the incorporation or integration of safety management with pavement and other management systems. Finally, a list of possible remedial measures for road safety improvements associated with pavement maintenance activities is recommended.


Solving the U.S. highway safety problem is a task for everyone--local, state, and federal departments of transportation; legislative groups at all levels; national, state, and local safety organizations; insurance companies; citizen groups; utility companies; road contractors; and road users. It requires a concerted, collective will, the author maintains, citing ways to identify many problems and to apply simple and inexpensive corrections.


A major goal of the Long-Term Pavement Performance (LTPP) study is the development of recommendations for improving the design and construction of new and rehabilitated pavements to make them longer lasting. As part of the condition monitoring of the LTPP test sections, friction data are being collected on a regular basis at each test site. Friction data collection is the responsibility of the specific highway agency under whose jurisdiction the pavements are located. The LTPP data collection guidelines for friction data recommend using the ASTM E 274 (AASHTO T242) procedure as the preferred method for obtaining data. The ASTM E 274 procedure uses a locked-wheel skid tester in a trailer assembly. Friction test results are reported as Skid Numbers (SNs). This report provides an assessment of the availability, characteristics, and quality of the friction data collected as part of the LTPP study. Also, the availability of related pavement characteristics data was assessed. The report also contains recommendations for adjustments and refinements to current procedures for the collection of friction and related data. The LTPP database provides a one-stop source of reasonably good friction data collected in a systematic manner from a wide range of pavements subjected to a wide range of traffic loading and environmental conditions. The
friction data will be of use for analyzing why some pavement surfaces retain good friction characteristics with time and why some surfaces show rapid deterioration in friction over time.

**Transportation Pooled Fund Program.** Reducing Crashes at Rural Intersections: Toward a Multi-State Consensus on Rural Intersection Decision Support. Study TRF-5(086). Minnesota Department of Transportation, St. Paul, MN.

This research will build on recent advances in intelligent transportation systems (ITS) technology to address a significant public safety problem. Rural Intersection Decision Support focuses on enhancing the driver's ability to successfully negotiate rural intersections. It is a system which will use sensing and communication technology to determine the safe gaps and then communicate this information to the driver so that he or she can make an informed decision about crossing the intersection or entering a major road traffic stream. Our goal is to reduce crashes and fatalities at such intersections without having to introduce traffic signals which on high speed rural roads often lead to an increase in rear end crashes.

The State of Minnesota is already partner with California, Virginia and the FHWA in a pooled fund consortium (the Infrastructure Consortium) dedicated to improving intersection safety. Three research teams have been identified: The Intelligent Transportation Systems Institute at the University of Minnesota, the PATH (Partners for the Advancement of Transit and Highways) Program at the University of California's Berkeley campus, and the Virginia Tech Transportation Institute at Virginia Polytechnic. Each member of the consortium is tasked with addressing an aspect of intersection safety; Minnesota's efforts focus on the problem of rural intersection crashes.

The Minnesota objective is to develop a better understanding of the causes of crashes at rural intersections and then develop a toolbox of effective strategies to mitigate the high crash rate. Preliminary information seems to point to the driver's inability to correctly identify and select the gap needed for safe passage. Efforts proposed in this program address rural intersection crashes through the application of a suite of advanced surveillance technology, algorithms which predict vehicle and gap location, and driver interfaces designed to best provide necessary information to drivers at intersections. 'Low tech' solutions will also be considered. The main program emphasis is on the integration of these key components into an effective, affordable system. The study will focus on alternatives to traditional traffic signals as a means to decrease the frequency and severity of rural intersection crashes.


America’s economy and quality of life depend on a transportation system that functions well. As with other major infrastructure systems that support society—for example, water or electricity—the importance of the nation’s transportation system becomes apparent only when problems arise. The destruction caused by Hurricane Katrina in August 2005 demonstrated the vital importance of transportation in the response to natural disasters and in recovery, as well as in connecting regional economies to the nation’s. The loss of terminals, pipelines, railroad lines, and bridges along the Gulf Coast, for example, had an immediate impact on the energy supply nationwide. Perhaps transportation’s successes over the past century explain why it does not make the national list. Although the rate of population growth—and therefore of travel demand—is projected to slow in the coming years, the increase in population will amount to approximately 100 million by 2040. This could double the demand for passenger travel. Moreover, the added population will concentrate in selected states and regions, which will intensify the demand for transportation in these areas. Meanwhile, the U.S. population will become older and more diverse. With the emergence of China, India, and Mexico as major trading partners, international trade as a proportion of the gross domestic product (GDP) has almost doubled to more than 22 percent in little more than a decade. Truck and containerized shipments may double by 2025 as the globalization of the economy unfolds. Trade will become an increasingly important component of the U.S. economy, intensifying the demand for transportation.

With these considerations in mind, the Executive Committee of the Transportation Research Board of the National Academies has outlined the most critical transportation issues facing the nation in this first decade of the new century:

- Congestion: increasingly congested facilities across all modes.
- Emergencies: vulnerability to terrorist strikes and natural disasters.
- Energy and environment: extraordinary challenges.
Relationship Between Skid Resistance Numbers Measured with Ribbed and Smooth Tire and Wet-Accident Locations

– Equity: burdens on the disadvantaged.
– Finance: inadequate revenues.
– Human and intellectual capital: inadequate investment in innovation.
– Infrastructure: enormous, aging capital stock to maintain.
– Institutions: 20th century institutions mismatched to 21st century missions.
– Safety: lost leadership in road safety.

The Executive Committee of the Transportation Research Board of the National Academies has outlined these issues to focus attention on the most significant policy decisions facing the country and on the areas most in need of innovation.


TRB’s Transportation Research Record: Journal of the Transportation Research Board No. 1908 examines the use of a linear optimization model to maximize the safety benefits from highway improvements under specific budget constraints and types of crashes at signalized intersections with complete crash data. This volume of the TRR: Journal also explores the events leading to a sport utility vehicle rollover, as well as countermeasures for deer–vehicle crashes.


This Transportation Research Record contains 10 papers on the subject of statistical methods and crash prediction modeling. Specific topics discussed include the following:

– Bayesian Multivariate Poisson Regression for Models of Injury Count, by Severity.
– Calibration of Safety Prediction Models for Planning Transportation Networks.
– Comparison of Two Negative Binomial Regression Techniques in Developing Accident Prediction Models.
– Describing the Evolution in the Number of Highway Deaths by Decomposition in Exposure, Accident Risk, and Fatality Risk.
– Effects of Sample Size on Goodness-of-Fit Statistic and Confidence Intervals of Crash Prediction Models Subjected to Low Sample Mean Values.
– Use of Propensity Score Matching Method and Hybrid Bayesian Method to Estimate Crash Modification Factors of Signal Installation
– Using the Rural Two-Lane Highway Draft Prototype Chapter.


This Transportation Research Record contains 23 papers on the analysis and evaluation of safety data. Specific topics discussed include the following: assessing crash occurrence on urban freeways; crash estimation at signalized intersections; crash mitigation by variable speed limits; the relationship between real-time traffic surveillance data and rear-end crashes on freeways; real-time indicators of sideswipe crashes on freeways; a new approach to accident analysis of hazardous road locations; the influence of land use, population, employment, and economic activity on accidents; reanalysis of encroachment frequency data; rural expressway intersection characteristics; driver assistance systems evaluation by traffic simulation; estimating right-angle collision frequency at traffic signals; crash estimation at signalized intersections; in-vehicle data recorders; traffic signal warrants; intersections with potential for red light-related safety improvement; the severity of head-on crashes on two-lane rural highways; safety effect of daylight savings time; the safety effect of continuous shoulder rumble strips on rural interstates; experience with road diet measures; right turn from driveways followed by U-turn on four-lane arterials; linking databases for analysis of injury specifics and crash compatibility issues; safety of jug handle intersections; and the safety evaluation of the Stop Sign In-Fill program.

No abstract provided.


Tire-pavement friction and pavement surface texture are very important safety characteristics that need to be considered in pavement surface design and monitored throughout the life of the pavement. This paper compares friction measurements obtained with different equipment (three locked-wheel trailers with smooth and ribbed tires and one Dynamic Friction Tester) and at different speeds. Five tests in each lane at each speed were conducted on each of eight pavement sections with a wide range of surface textures. The paper also compared the relationship between friction and speed for the different pavement sections and devices and the International Friction Index values obtained using the different equipment and tires. The investigation showed that the repeatability of the various locked-wheel trailers evaluated was considered acceptable and that the reproducibility obtained with the same type of tire was also good at the various speeds considered. The correlation between the measurements using the locked wheel trailers with the smooth and ribbed tires did not correlate that well to each other, when all of the evaluated pavement surfaces were included in the analysis. In all cases the measurements obtained with the ribbed tire were higher than with the smooth tire. Finally, discrepancies in the IFI F60 values calculated for the different devices suggest that the original coefficients determined during the PIARC experiment may need to be adjusted for the device evaluated before the IFI can be implemented in the participating agencies.


The report of the 2005 National Road Maintenance Condition Survey (NRMCS) on the condition of roads and footways in England and Wales presents information on both the surface condition and structural condition of roads. Surface condition is measured using a visual survey of defects and machine based surveys of wet road skidding resistance and the English trunk road network. The structural survey uses a machine to measure the deflection of a road under a standard load. This document presents key results from the report.


When, in 1988, the UK Department of Transport first introduced requirements for skid resistance on its trunk road network, it introduced the concept of “investigatory levels” to be compared with measurements from routine skid resistance surveys. At the heart of this process was a link between the risks of wet skidding accidents occurring and the levels of measured skid resistance on the road. Initially, this was based upon a survey of a sample of the network at which the time was limited by survey capacity and computing power. The skidding standards have recently been revised and as part of this process, a new assessment of the link between accident risk and skid resistance has been made. This has involved a study of the whole Trunk Road network. This paper will review the historic background and then describe in more detail the recent study and its findings, how the results compare with the historic work and the changes that were shown to be appropriate for application in the revised standard introduced in August 2004.


The skid resistance policy for UK trunk roads has been reviewed after fifteen years of operation. As a result, a revision to the policy is being implemented in 2004, which is described in this paper. A key part of the review has been a re-examination of the link between skid resistance and accidents. This confirmed the importance of skid resistance but also the site specific nature of the effect. As a result of the advice on determining Investigatory Levels of skid resistance has been strengthened to promote better engineering judgment of skid resistance requirements and more robust investigation of sites where the skid resistance measurements are found to be below
the Investigatory Level. The review has also resulted in changes to the survey strategy, use of slippery road warning signs and on-going monitoring of the effectiveness of the policy.


The United Kingdom has implemented a policy to manage skid resistance and skidding accidents on its road network. This paper describes the results of the accident analysis, which has led to a revision of the site categories and investigatory levels and changes to the way that potential maintenance schemes will be evaluated. Information about pavement conditions, road geometry, and accident data was correlated to skid resistance information to produce a profile of accident risk. The study demonstrated that there is a wide range of accident risk present on sites within the same site category and that better procedures are needed to identify sites where accident risk could be reduced.


IAN98/07 was prepared to assist HA service providers in implementing the UK policy for managing the skid resistance on trunk roads effectively and, in doing so, to facilitate good record keeping, promote consistent and effective decision making and maximize the benefits by targeting maintenance to improve the skid resistance at those sites most likely to deliver safety benefits. The approach taken to developing the advice, combining the results of accident studies on the English trunk road network with a general knowledge of the factors influencing accident risk, is described in this paper.


No abstract available.


Doubtless, there is a strong correlation between road friction and accident risk. The problems arise when we demand a more detailed view of that correlation. The aim of the project behind this report was to gather information about the different friction methods in use and about published quantitative relations between road friction and accident risk. Regarding friction measurements, every country has instruments and methods of its own, and the friction values reported from different international investigations are therefore not directly comparable. Work on harmonization of friction measurements is in progress. Road friction is very important for traffic safety, but it is difficult to single out the effect of poor friction on the accident risk. Drivers adjust their driving behavior depending on many factors, e.g. the appearance of the road environment, the weather, the sound from the tires, and the sliding and skidding movements of the vehicle. For dry or wet bare roadway, however, the conditions are comparably homogeneous, and several studies show a dramatic increase in accident risk when the friction numbers decrease below certain threshold values. For winter circumstances there are few and unreliable estimations of the correlation between accident risk and friction.


Tests with four ground friction measuring devices—an electronic recording decelerometer, a GripTester, a runway analyzer and recorder, and a SAAB friction tester—were conducted on a variety of runway and taxiway winter-contaminated surfaces at Jack Garland Airport, North Bay, Ontario. These tests were part of a joint Transport Canada/Norsemeter winter runway friction program aimed at comparing, measuring, and understanding the effects of winter conditions on ground friction. Conditions included bare and dry from +2°C to -24°C, bare and wet, slush, smooth and rough ice, loose snow, medium-packed snow, and hard-packed snow at variable temperatures as recorded. For a given contaminant, one to five loops were run by each of the four devices. Correlations between the equipment are given for the various speeds, tires, and ambient temperatures, as well as for the various contaminants.

Analysis of the frictional properties of the tire-pavement interface provides useful information to minimize wet-weather accidents and aid state agencies in making better pavement management decisions. In this paper, the surface friction and texture properties of 12 asphalt pavement sections placed at the Virginia Smart Road pavement facility were studied over a 6-year time period. The surfaces investigated include five SuperPave™ mixes, an Open-Grade Friction Course (OGFC) and a Stone Matrix Asphalt (SMA) mix. The levels of friction and macrotexture of these pavement sections were compared and analyzed. Short-term (seasonal) and long-term (multi-year) variations of the surface characteristics were investigated in order to learn how the properties vary with temperature and time, which can be used to support asphalt mixture selection, determine the need for friction correction factors, and assess their suitability for use on the network pavement monitoring. The investigation confirmed that the environmental factors have a significant effect on the seasonal variation of friction. For all mixture types investigated, the friction measurements experienced variation within a year (short-term) and throughout several years (long-term). Both the friction number at zero speed [FN(0)] and percent normalized gradient (PNG) decrease in the summer and thus friction varies differently at low and high speeds. In the long term, the low speed friction increases first due to weathering of the asphalt film from the aggregate, and then starts to decrease, probably due to polishing and weathering. Macrotexture variations are almost unnoticeable within a year and small across 5 years. The measured texture depth initially decreases a little, and then starts a modest ascending trend. This is probably due to the loss of fines through weathering and/or washing by the rainfall.


This paper describes the approach of the Queensland Department of Main Roads (QDMR) to managing skid resistance on the State-controlled road network, as a means of improving road safety and reducing trauma associated with road crashes.

Queensland’s road traffic is concentrated in high rainfall sub-tropical and tropical Pacific coastal areas. QDMR developed a skid resistance management plan (SRMP) in response to studies of traffic crash histories around the world that have consistently found that, for wet road surfaces, a disproportionate number of crashes occur where the road surface has low surface friction.

Risk management is an integral aspect of the QDMR strategy for managing skid resistance. The QDMR strategy is based on a rational analytical methodology supported by field inspections and integration with related asset management decision tools. The aim is to make the probability of a crash with skid resistance or surface texture as a contributing cause uniform across the network, having regard to local circumstances such as traffic patterns and climate.

The QDMR SRMP defines the Department’s overall objective and central strategy for managing skid resistance, describes a corresponding suite of performance indicators, and describes specific actions including research and development necessary to achieve the overall objective.

The paper explains the SRMP in detail, and concludes that skid resistance should be a central aspect of asset management and performance reporting, and that implementation of the SRMP will reduce the incidence of crashes with low skid resistance as a contributory cause.


The durability of concrete pavement depends on its load bearing capacity and the performance properties of the surface texture during use. During wet weather conditions the textured surface should provide good tire grip for safety reasons. In recent years increased focus has been placed on the noise emitted by road traffic in Germany. Traffic and weather result in wear which changes the surface texture and affect the performance properties of the road surface. The durability of texture is especially dependent on the shape of the texture and the quality of the surface mortar, i.e. on the composition and the properties of the near surface concrete. Optimization of the surface
durability is essentially the task of concrete technology. Over the past years, extensive research work financed by the German Federal Ministry of Transport, Building and Housing represented by the Federal Highway Research Institute has been carried out in order to improve texture durability. A time accelerated assessment procedure for laboratory testing under simulated practice conditions was developed in order to systematically test texture durability. The changes of texture were recorded three dimensionally with a laser surface scanner, evaluated and expressed by means of geometrical parameters. In various test series, the effects of the texture shape and concrete composition on texture durability have been studied.


It is well understood that aggregate is rarely inert (either chemically or mechanically) and that its role in pavement construction is—or should be—far greater than that of a space occupier, as it was believed earlier. While such aggregate properties as soundness, durability, gradation, and bonding properties has become well recognized as important in controlling the aggregate performance, the skid resistance related characteristics are not so well understood. Although the evaluation of the skid resistance has a long history in U.S., establishing the standards based on the skid measurements remains to be a challenge. It occurs mostly due to poor repeatability of results obtained with locked-wheel trailers. Recently, two levels surface texture—microtexture and macrotexture—have been recognized as important factor affecting performance of the wet pavement in terms of skid resistance. Therefore, the texture measurements should be included in the skid evaluation procedure.

While the need in major surface rehabilitation increases rapidly, the cost effectiveness of the surface treatments becomes an issue. When pavement needs surface improvements, but is not structurally defective, the slurry seal placement appears to be fast and reliable technique to improve skid resistance and correct surface defects.


The use of 4.75mm asphalt mixtures is gaining popularity in the United States as an efficient paving alternative. These mixes are placed in thin lifts, thereby reducing the quantity and cost of materials, as well as construction time. Although there are many advantages associated with 4.75mm mixtures, there are some issues that must be considered prior to the placement of these mixes. 4.75mm mixtures are comprised primarily of fine aggregates that produce tight and smooth mixes, which could pose safety concerns related to surface friction.

The primary goal of this research effort was to determine what actions could be taken during the design of a 4.75mm Superpave asphalt mixture to improve its frictional performance. Specific tasks included 1) an investigation of variations in 4.75mm mix design properties with respect to the microtexture and macrotexture of the mixes, 2) an evaluation of the characteristics of the constituent aggregate materials in order to determine fine aggregate properties that can be used during design to improve the skid resistance of the resulting mixes, and 3) a relative comparison of the skid resistance of 4.75mm mixes with that of typical 9.5mm and 12.5mm surface mixes. Three aggregate sources were used to develop the Superpave mixtures. The British Pendulum Tester was used to quantify the microtexture of the mixes, and a modified laboratory sand patch test was used to quantify the macrotextre. A number of aggregate properties, including source and consensus properties were used to describe fine aggregate characteristics. The results indicate that, in general, both the microtexture and macrotexture of the 4.75mm mixes were relatively unaffected by the various mixture parameters. Aggregate source did produce a significant effect. Aggregate gradation affected the microtexture and macrotexture of the mixes such that a gap-graded blend could be used to increase skid resistance. Aggregate source and consensus properties can also be used to improve the frictional performance of mixes. Skid resistance can be improved by limiting the percent loss for durability and soundness of the fine aggregate, and by increasing the angularity of the fine aggregate. When compared to mixes composed of larger aggregates, the microtexture of the 4.75mm mixes was superior to that of the 9.5mm and 12.5mm mixes; although the 4.75mm mixes possessed limited macrotexture.

Overall, when fine aggregate properties are properly considered, 4.75mm Superpave mixes can be designed with adequate microtexture for use on low speed roadways, and in a manner that may partially compensate for the lesser macrotexture, thereby providing adequate skid resistance for high speed roadways.
In recent years, many Road Controlling Authorities have made concerted efforts to measure skid resistance in order to better understand how their asset are performing and to improve their decision making. Because of the prohibitive costs of skid testing measurements, usually only one ‘network level’ test are undertaken annually. This sampling period, while being reasonable for other pavement condition indicators, should be used with caution as a performance indicator of skid resistance. This paper discusses infrastructure asset management goals and the development in New Zealand (NZ) of the NZdTIMS system of predictive deterioration modeling. The paper then demonstrates that measured skid resistance varies significantly from month to month, week to week and even day to day, based on a number of external variables. The outcome being that it is very difficult to develop credible incremental deterministic prediction models for skid resistance. The paper then reports upon research that is currently being undertaken at the University of Auckland, New Zealand into the variability of road pavement skid resistance over time. The methodology includes the measuring and analyses of skid resistance with rainfall and contaminants in the field using the GripTester, SCRIM and the Dynamic Friction Tester (DFTester) and secondly by means of controlled laboratory experiments on prepared samples. The paper discusses the results of the experiments that were developed to try and simulate infield skid resistance variability. The research demonstrates the importance of understanding the significance of a single skid measurement as a ‘snapshot’ in time. This result must be qualified in the context of not only the method of measurement but an understanding of the surrounding local environmental factors in which the measurement was taken.

The “approximately sinusoidal seasonal” effect of low skid resistance in the summer and high skid resistance over the winter period is well known. This relates to the measurement of skid resistance in New Zealand by SCRIM over the summer period that is reported by Mean Summer SCRIM coefficient. However, the cause of this “approximately sinusoidal” effect is little understood. Recent research undertaken by the University of Auckland in the Northland transit New Zealand PSMC 002 Region and in Auckland clearly showed that the “approximately sinusoidal seasonal” effect of the variation in measured skid resistance is neither a repeatable, nor a predictable, phenomenon. Clearly, a better understanding of what causes the variation to occur is required. If the causal effects are known, this will enable better decision making by road managers, and will lead to more appropriate road management in terms of surfacing techniques and practices. This will ultimately lead to a safer road network for all road users.

The paper reports on Stage 1 of the project that developed a controlled laboratory experiment using the Dynamic Friction Tester (DFT), and an accelerated polishing machine to simulate in-field variation of measured skid resistance. The paper discusses the development of testing procedures, methodology and laboratory equipment and presents results to date in simulating the in-field polishing of road surface aggregates to equilibrium skid resistance levels to a range of high to low PSV aggregates. The experiments were undertaken on prepared chip sealed surface samples that were subjected to cycles of polishing and periodic skid testing.

Wisconsin Department of Transportation (WDOT). “Wet Pavements Crash Study of Longitudinal and Transverse Tined PCC Pavements.” (Research in Progress)

Since the late 1960s, the Federal Highway Administration and most states have favored transverse tines or grooves on concrete pavement as a safety measure offering greater skid resistance than would longitudinal measures parallel to the center line. Yet few studies have compared actual crash experience on both types of pavement. In the early 1990s, public concern about tire-pavement noise compelled a national investigation into issues of pavement texture, noise and safety, and recent research sponsored by WisDOT and FHWA has measured greater tire-pavement noise on transverse-tined highways than on longitudinally tined. Wisconsin researchers have also linked evenly spaced transverse lines to the highway “whine” found particularly objectionable by the public. The objective of this study is to clarify the relative safety characteristics of longitudinal- and transverse-tined pavements through an analysis of
actual crash data from Wisconsin and other states. Methods of research include gathering and evaluating information from various states on tining practices and creating a corresponding crash database, followed by analysis of safety performance of the tining methodology in wet and dry conditions. Expected benefits include evidence that neither type of texture has significant safety advantages over the other, which would allow texture choice based on tire-pavement noise, construction cost and other considerations, resulting in quieter roads.


This paper considers the prediction of skid resistance for differing types of UK thin surfacing materials in relation to mix properties such as aggregate type and size. This is based on different research projects that have been in response to meeting the needs for sustainable construction i.e. providing a safer and longer lasting pavement. The traditional UK requirement for high values of skid resistance and texture must now be viewed along with properties such as noise, fatigue, permanent deformation and rolling resistance. Using examples and case studies the paper considers the implication of combining these sometimes conflicting properties.


One of the benefits associated with the use of a pavement preservation program is improved safety characteristics. Improved safety can be realized in several ways. For instance, an agency with a pavement preservation program that includes the early application of preventive maintenance (PM) treatments can generally keep the road network in better condition for a longer period of time. As a result, the roads are relatively smooth, which reduces the cost of operating a vehicle and minimizes crashes associated with defensive driving to avoid potholes and other surface irregularities in the pavement. However, in addition to providing a smoother surface, PM treatments can be used to improve the surface characteristics associated with surface texture (friction) to reduce the likelihood of wet weather and dry weather crashes. In the United States and abroad, an increased emphasis is being placed on safety issues to reduce the number of fatal and serious injuries caused by crashes and the resulting traffic delays. However, the effect of microtexture and macrotexture on crash rates has not been quantified. Past studies have often shown a weak link between increased friction and reduced crash rates. Recently, there have been major advances in data collection and analysis capabilities that show promise for improving the ability of transportation agencies to better quantify the effectiveness of pavement preservation treatments on reducing crash rates by improving surface characteristics. For instance, it is now possible to collect continuous pavement macrotexture information at highway speeds. It is also possible to measure macrotexture under the tire during skid trailer friction testing. These technological advances will greatly enhance the ability of highway agencies to identify sites of potentially high accident rates and to proactively take preventive actions as part of a pavement preservation program. This paper focuses on the safety improvements that can be realized as part of a pavement preservation program. Specifically, the following areas are discussed in this paper:

- The use of network-level evaluations (including features such as pavement macrotexture and annual friction surveys) as a means of identifying pavement sections that could benefit from the use of certain PM treatments to enhance or restore friction values (such as microsurfacing, grinding and/or grooving, or chip seals).
- The development of safety investigatory levels based on microtexture and macrotexture data for various site categories.
- The incorporation of safety features into a pavement management analysis.

The application of these characteristics are demonstrated using examples from transportation agencies worldwide. For instance, the Texas Department of Transportation’s Wet Weather Accident Analysis Program is an example of the type of study used to illustrate the points raised. Internationally, work being conducted in the United Kingdom and New Zealand on continuous friction measurements and the use of the data to identify pavement sections where poor texture/friction may be contributing to higher than average crash rates are featured. Other examples, such as Australia’s recently established goal of achieving 19% of their 40% per capita accident reduction by providing safer roads is also documented.