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Assessment of Friction-Based Pavement Methods and Regulations

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ASSESSMENT OF FRICTION-BASED PAVEMENT METHODS AND REGULATIONS

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ARAN	Automatic Road Analyzer
ASTM	American Society for Testing of Materials
BMVBW	German Federal Ministry of Transport, Building and Housing (Now BMVBS)
BPN	British Pendulum Number
BPT	British pendulum tester
CSC	Characteristic SCRIM Coefficient
CSS	County Surveyors' Society
DfT	British Department for Transport
DFT	Dynamic friction tester
DOT	Department of Transportation
FGSV	Road Transport Research Association
FHWA	Federal Highway Administration
HSTS	High Speed Texture System
GFP	Good-Fair-Poor
IFI	International Friction Index
IL	Investigatory Level
IRI	International Roughness Index
LA	Los Angeles
MPD	Mean Profile Depth
MSD	Mean Segment Depth
MTD	Mean Texture Depth
NCHRP	National Cooperative Highway Research Program
PCI	Pavement Condition Index
PCR	Pavement Condition Rating
PRC	Pavement rutting condition
PSC	Pavement structural condition
PSI	Present Serviceability Index
PSR	Pavement Serviceability Rating
ROSANv	Road Surface Analyzer - vehicle-mounted
RMS	Root Mean Square
RN	Ride Number
RSP	Road Surface Profiler
SCRIM	Sideways Force Coefficient Routine Investigation Machine
SFC	Side force coefficient
SFN	Slip friction number
SN	Skid numbers
SP	Sand Patch
TFHRC	Turner-Fairbank Highway Research Center
TR	Texture Ratio
TRL	Transport Research Laboratory
UK	United Kingdom

1.0 Introduction

Pavement surface characteristics contribute to several important driving-related factors, among which are:

- Surface integrity, which can contribute to tire damage and/or reduced vehicle control due to suspension interaction with large scale road irregularities. This is also known as pavement distress.
- Pavement friction, for which a minimum must be provided to ensure sufficient traction for safe vehicle braking, cornering, lateral maneuvering and forward acceleration.
- Splash from heavy trucks and SUVs during wet driving conditions, for which a maximum allowable level is needed to prevent obscuring the visibility of other road users.
- Noise from pavement/tire interaction, for which a minimum is sought to prevent either hearing damage or a negative impact on residential property value.

The coarse texture, including grooving; the fine texture, including morphology, distribution and physical characteristics of the aggregate; the degree of porosity; and the interaction of the contacting surface with the tire compound and tread pattern all play a role in the latter three factors. Further, the top layer's resistance to wear and compaction, and the characteristics of the underlying structure also influence the durability of the pavement.

Future pavement design is expected to make use of tools to optimize this combination of factors as a function of the relative importance assigned to each one as well as for the economic road construction and maintenance. As such, State and local jurisdictions should have means to first monitor or estimate pavement characteristics, and second, to base decisions regarding actions required when certain values are measured or certain pre-established thresholds are exceeded.

To assist with these efforts and with the planning for future R&D needs, a compilation of the current methods (procedures and acceptability criteria) and related regulations used to characterize pavement friction and qualify pavement condition is needed.

The objectives of the project presented herein include:

1. Investigate procedures used to evaluate pavement conditions,
2. Determine the criteria, if any, used to qualify pavement conditions,
3. Identify, amongst those used, whether they are based on friction or not, and
4. Characterize the actions required based on the specific values of the criteria used.

As a first step, this report summarizes literature review findings from all relevant publications related to current practices of pavement condition evaluations. In particular, in 1999, NCHRP Synthesis 291, by J.J. Henry, surveyed many states and non-US agencies to compile information on methods used and associated threshold values. This study however did not include information of follow-on actions taken when threshold values are exceeded. All publications reviewed are listed in Appendix A.

As a second step, this report includes results from surveys and interviews conducted to gather additional information on current state-of-the-art used by the States and also on potential policies established to identify actions. Results from eight of the 9 candidate states selected for interviews and draft questions are included.
While most of this report is focused on US-based information, this report summarizes, as a final and third step, results from surveys and interviews conducted to gather information on processes and measures used by international agencies known to be proactive in the area of road friction monitoring.

1.1 Background

Pavement experts have the daunting task of designing and maintaining infrastructures which will provide a comfortable ride, maintain skid resistance, and minimize noise all while limiting the amount of tire wear and damage created when the rubber meets the road. Unfortunately, there is no pavement composite that will yield desirable results in all areas when it comes to comfort, wear, and safety. To increase skid resistance, the surface texture could be increased. However, increasing texture also increases the amount of tire damage and noise generation created by the rough surface. Better water run-off can be created by increasing the course-scale surface texture, but the trade off is a decline of skid resistance, particularly at lower speeds. Historically ride quality has dominated as the most important characteristic for road design and maintenance. As the cost of motor vehicle crashes within the United States continues to climb, it is expected that a greater emphasis will be placed on safety related pavement properties such as skid resistance.

Skid resistance has two major components: adhesion and hysteresis. When a tire is pressed into close contact with pavement surface particles, molecular bonds between the tire and the surface particles are formed. Adhesion results from the shearing of those bonds. The greater the number of bonds formed, the greater the energy required to break the bonds, and therefore better skid resistance. Hysteresis results from energy dissipation as the tire rubber is deformed when it passes across the asperities of a rough surface pavement. Again, the greater the energy dissipation of the moving tire, the better the skid resistance (Noyce, 2005).

Skid resistance is highly dependent on the surface irregularities of individual stone particles used in pavements and upon the larger irregularities of the overall road surface. The surface irregularity of individual particles is referred to as “fine-scale” or “microtexture”. “Course-scale” or “macrotexture” refers to the larger irregularities found between the particles that make up the pavement. Fine-scale texture and adhesion are the prevailing factors influencing skid resistance at speeds less than 30 mph.

At higher speeds, microtexture and adhesion still play a small role in skid resistance, however, macrotexture has a greater effect on maintaining skid resistance and on wet weather travel. Macrotexture affects hysteresis. Coarse-scale texture is created by voids between individual stone particles in the pavement mix. Voids are essential in providing a pathway for water to escape the road surface during wet weather. Initial macrotexture properties on a pavement surface are determined by a combination of size, shape and gradation of the coarse stone particles in the pavement. Over time, macrotexture properties degrade as individual aggregates become polished by tire wear, voids become clogged by dirt, sand, or oil, and as the individual stones become compacted by the weight of vehicles, particularly in the wheel paths.

Two other road surface texture properties contribute to the overall quality of a pavement surface: megatexture and roughness (unevenness). While micro and macrotexture are the heavy hitters for skid resistance, megatexture and roughness are the major players for ride quality. Megatexture describes the irregularities that result from rutting, potholes, major joints and cracks, and surface stone loss. Megatexture is known to play a small role in providing skid resistance, but, it plays a dominant role in rolling resistance and in the noise levels created by the tire-road interactions. Roughness refers to surface irregularities larger than megatexture – like those really big potholes, or that annoying washboard effect felt that makes a Sunday drive feel more like a day on rough seas. Rough surfaces can cause extensive vehicle operating costs. Figure 1 shows examples of each of the four categories of surface texture.

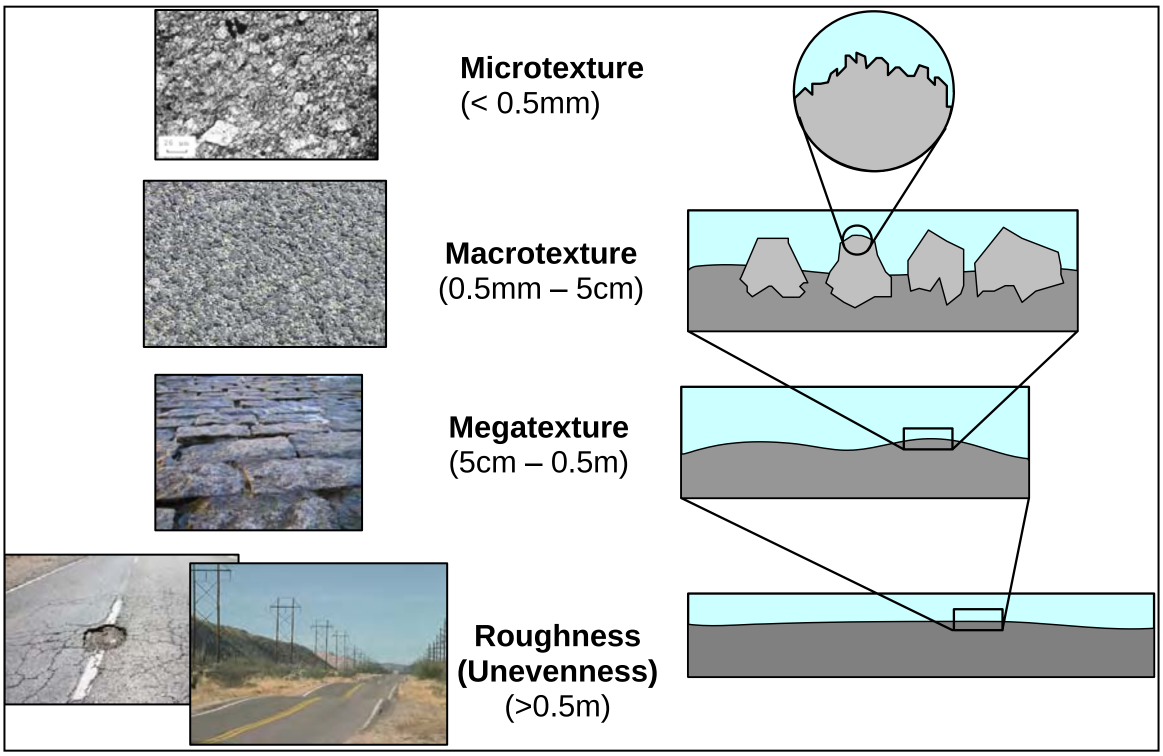

Figure 1. Representation and examples of surface textures: microtexture, macrotexture, megatexture, and roughness.

Microtexture, macrotexture, megatexture, and roughness are defined by texture wavelengths in units of meter. As in freshman physics, texture wavelength is the length of the wave having periodic oscillation as measured from the same point along the wave (crest-to-crest, trough-to-trough). Unlike freshman physics where the periodic oscillations were smooth and well-defined curves, profiles of pavement surfaces reveal a complex pattern containing layers of multiple wavelengths of varying amplitudes. Figure 2 shows a typical bituminous road surface profile as collected with a profilometer over a distance of 100 meters.

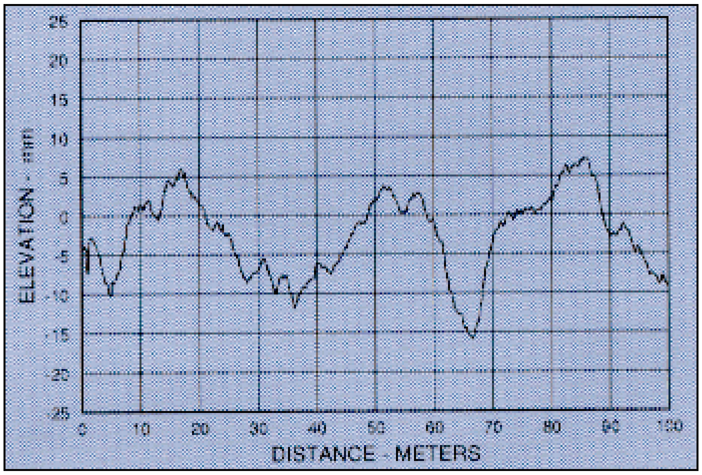

Figure 2. Typical bituminous road surface profile (Hegmon, 1993)

The larger amplitudes are generally associated with longer wavelengths. Here, the maximum amplitudes are about 20 mm. When the long wavelengths are removed by filtering down to maximum amplitudes of about 10 mm, the shorter wavelengths created by surface texture features becomes more apparent as shown in Figure 3. (Hegmon, 1993)

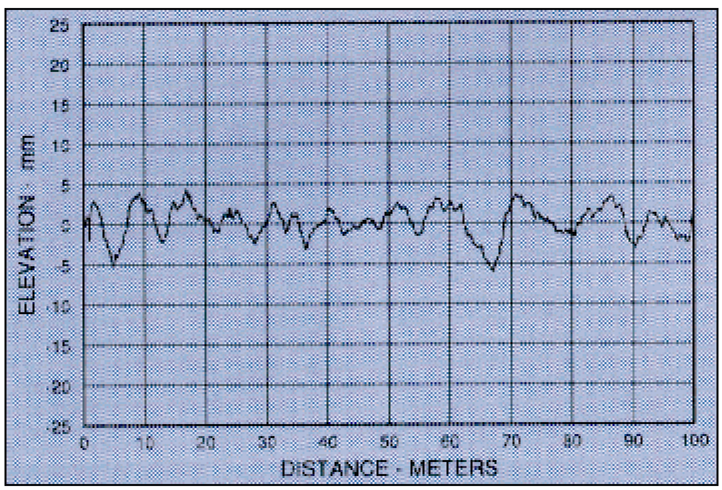

Figure 3. Surface from Figure 2 with long waves filtered out. (Hegmon, 1993)

Surface texture wavelengths have been shown to influence surface texture characteristics. Microtexture wavelengths fall between 10^{-6} and 10^{-4} meters. Macrotexture wavelengths range from about 10^{-4} to 10^{-2} m. (Recall that microtexture describes the surface irregularities of the individual particle and macrotexture describes the course-scale texture created by differences of course stone particle size and voids.) Megatexture and roughness wavelengths range between 10^{-2} to 10^{-1} m and 10^{-1} and 10^{1} m, respectively (Noyce, 2005).

Figure 4 defines each of the four textures in terms of texture wavelength and reports the influence of each on pavement surface characteristics. The degree of influence upon the characteristics varies and is indicated in the figure by degree of shading. For example, wet pavement friction is highly influenced by microtexture due to the influence of the surface irregularities of the individual particles on adhesion between the rubber tire and the particles. Wet pavement friction is only moderately affected by megatexture – those surface irregularities caused by potholes, cracks, ruts and major joints. (Noyce, 2005; Henry, 2000).

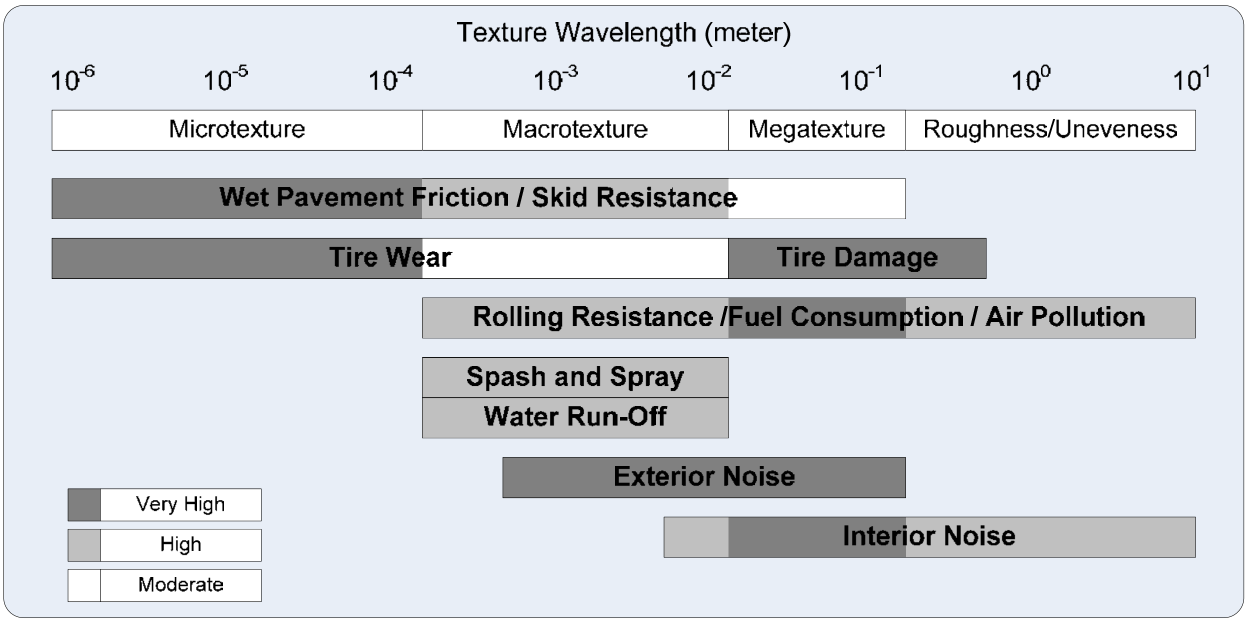

Figure 4. Influence of Texture Wavelength on Surface Characteristics (Adapted from Henry, 2000; Noyce, 2005).

Growing concerns over a State's legal liability place increasing demands on highway engineers to maintain highway surfaces that provide a measure of safety, as witnessed in the Missouri law suit of 2000 (Noyce, 2005). The challenge for pavement management engineers will be to find accurate, reliable, and cost effective measures to evaluate pavement surface conditions, including skid resistance and to use that information to prioritize highway maintenance projects.

2.0 Procedures Used to Evaluate Pavement Conditions

In general, the procedures currently used to evaluate pavement conditions can be broken into two categories; qualitative and quantitative. Qualitative measurements are typically based on a subjective visual observation of the road surface. Those observations may be made at highway speeds over large sections of roadway or they may be taken at discrete points of interest in pavement condition studies. Quantitative measurements, as with qualitative subjective measurements, may also be taken either at discrete points of interest or at highway speeds. However, the pavement characteristic of interest is measured, i.e. quantified, by some physical means, rather than by qualitative assessments.

Amongst factors listed in Figure 4, friction/skid resistance, splash & spray, and tire damage have the greatest potential to directly affect the vehicle's safe operation when traveling on roadways. These factors are highly or very highly influenced by nearly all surface features of all wavelength ranges, i.e. microtexture, macrotexture and megatexture. However, the literature mostly chooses to refer to microtexture, macrotexture, friction/skid resistance, and pavement distress as both quantitative and qualitative measures which can be used to assess pavement conditions.

The literature reveals that an abundant number of tests have been developed to study each type of pavement characteristics, and information is readily available. To avoid duplication of efforts, this report focuses on the techniques most commonly used and only includes a brief description of these techniques. Appendix B contains a thorough list of test methods developed and used to evaluate pavement conditions.

2.1 Microtexture

Microtexture is a function of the surface irregularities of individual aggregates in the pavement mix, and influences pavement friction at low speeds. The relationship between increasing aggregate polishing through wear and decreasing skid resistance has long been acknowledged among pavement experts. As such, numerous methods have been developed to quantify an aggregate's resistance to polishing. A survey conducted by J.J. Henry (2000) for the National Cooperative Highway Research Program shows that the LA abrasion test is the method of choice for most states when determining aggregate polishability. Table 1 shows the individual results for each of the thirty states.

Table 1. Aggregate Evaluation (Henry, 2000)

Agency	Mixture Evaluation	Aggregate Polishability
Alaska		LA abrasion
Arizona		LA abrasion
Arkansas		PSU reciprocating
Florida		LA abrasion
Hawaii		LA abrasion
Illinois		Variable speed tester
Kansas		LA abrasion
Kentucky		LA abrasion
Louisiana	BPT	AASHTO T-96
Maryland		Br. Wheel/LA abrasion
Massachusetts		LA abrasion
Michigan		MI wear index
Minnesota		LA abrasion
Mississippi		LA abrasion
Missouri		LA abrasion
Nebraska		LA abrasion
New Jersey	BPT	British wheel
New Mexico		LA abrasion
North Carolina		LA abrasion
Oklahoma		LA abrasion
Oregon		LA abrasion
Pennsylvania	BPT	LA abrasion
Rhode Island		LA abrasion
South Carolina		LA abrasion
Texas		British wheel
Utah	BPT	British wheel
Virginia		LA abrasion
Washington		LA abrasion
Wisconsin		LA abrasion
Wyoming		LA abrasion

In Europe, the British Wheel method is more commonly used. The LA abrasion and the British Wheel testers assess rather different aspects of the aggregate; resistance to polishing from contact against a rubber tire (British Wheel), and resistance to degradation via attrition due to abrasion, impact and grinding in a ball-mill-like test against the aggregate itself and steel spheres (LA abrasion).

2.2 Macrotexture

Macrotexture is a function of the size of the aggregates used in a pavement mix, and its effect on friction increases as speed increases (McDaniel, 2003). Macrotexture is also known to affect the amount of splash and spray on wet pavements as well as noise generated. A variety of methods have been developed to measure macrotexture characteristics of the roadway surfaces. They are mostly based on measuring the depth or the volumetric flow.

Mean Profile Depth (MPD) is one of the most common macrotexture measures. The test methods used to obtain the MPD include the sand patch test, circular texture meter, and automated road analyzer system (e.g., ARAN). The sand patch tester and circular texture meter evaluate small areas, typically a circular test area of 10-cm (~4-in) diameter for the sand patch and 80-cm (31.5-in) diameter for the circular texture meter. Automated road analyzer systems employ advanced laser scanning equipment coupled with pattern recognition software to continuously evaluate the mean profile depth of miles of roadway surfaces (Watson, 2003).

Macrotexture influences the amount of splash and spray generated on wet pavement by affecting the rate at which water is channeled away from the roadway surface during wet driving conditions. To characterize the channeling rate of macrotexture, an Outflow Meter (a transparent ~4-in diameter cylinder with a rubber annulus) is placed on the pavement surface. A known volume of water is placed in the cylinder. The time needed for the water to escape through the channels and voids in the pavement surface, thus volumetric flow, give an indication of the surface texture and porosity below the contact surface (McDaniel, 2003).

J.J. Henry reports that of the forty-two United States agencies that responded to his 2000 survey, only five states reported measuring macrotexture. By contrast, fifteen of twenty-eight non-U.S. agencies reported measuring macrotexture routinely (Henry, 2000). Table 2 lists the states that reported measuring macrotexture and how the data were used.

Table 2. Use of Texture Measurements among U.S. Agencies (Henry, 2000)

State	Routine Survey	Construction	Pavement Management
Louisiana	●		
Minnesota		●	
Mississippi	●		●
Pennsylvania			
Virginia	●		●
NASA	●	●	●
France	●	●	●
Hungary	●	●	
Japan		●	
Morocco		●	
The Netherlands		●	
New South Wales		●	
New Zealand	●	●	
Ontario		●	
Portugal		●	●
Quebec	●	●	●
Saskatchewan		●	
Slovakia		●	
Slovenia	●		
South Australia	●	●	●
United Kingdom	●	●	●
Victoria	●		●

2.3 Friction/Skid Resistance

The relationship between friction and highway safety has long been known and accepted among the world's highway authorities. Microtexture and macrotexture are of importance in particular for their known influence on friction. A variety of methods exist to directly or indirectly assess friction of pavement surfaces. Methods described previously in sections 2.1 and 2.2 yield surrogate measures of friction. Additional methods also exist to directly measure friction or skid resistance, either at a localized site or for a larger section of roadway.

The two most common site specific tools to measure friction are the British pendulum tester (BPT) and the dynamic friction tester (DFT).

The British pendulum tester is limited to low speed frictional measurements. The BPT is a portable device that measures the frictional properties of a road surface or laboratory specimen in contact with a rubber slider. The value obtained, the British Pendulum Number (BPN), is a measure of the energy absorbed when the rubber slider contacts the test surface during the swing of a pendulum. Because the sliding speed is low, approximately 10 km/hr (~6 mph), the BPN is related to the microtexture of the test surface.

The dynamic friction tester provides the frictional properties of the road surface as a function of speed. The DFT measures the friction continuously as a circular array of three rubber pads spins to a stop from an initial high speed of 80 km/hr (50 mph). As such the DFT provides values indicative of both macrotexture and microtexture. The DFT is also a portable device which can be used on a road surface or test panel. When combined with mean profile depth data, DFT measurements can be used to calculate the International Friction Index, IFI (McDaniel, 2003).

There are four primary methods used to obtain full-scale field measurements of skid resistance along highway sections. They are:

- Side Force,
- Variable Slip,
- Fixed-Slip, and
- Locked-Wheel.

All four methods use one or two full-scale test tires and apply water at a controlled rate to the pavement surface to obtain wet pavement friction values. They are typically completed at or near highway speeds. In all except the locked-wheel devices, measurements are taken continuously (Kuttesch, 2004).

Side Force – Side force is related to vehicle control in a curve. The two most commonly used devices to measure side force are the SCRIM (Sideways Force Coefficient Routine Investigation Machine) and the MuMeter. To measure the side force coefficient (SFC), pressure on the test wheel is created by setting the wheel at a yaw angle to forward motion. On the SCRIM machine the yaw angle is 20 degrees to forward travel. The yaw angle on the MuMeter is 7.5 degrees. The SCRIM can be operated continuously at speeds up to thirty miles per hour (Summers, 2004). Both the SCRIM and the MuMeter were developed in Great Britain, and while the SCRIM is the most common tool used to evaluate SFC among many non-U.S. agencies, it is not used in any of the fifty states. And, of the thirty nine states responding to Henry’s 2000 survey, only Arizona used the MuMeter to measure side force coefficients on its highway system. However, Arizona reported plans to change to a fixed slip friction tester.

Variable Slip – Slip is related to tire-road characteristics under the action of anti-lock brake systems. Variable slip devices are used to determine the slip friction number (SFN) by measuring the frictional force on a tire as it is taken through a set of pre-determined slip ratios at speeds ranging from zero up to test speed. Whereas the SCRIM and MuMeter measure a side force coefficient, the slip friction number is a measurement of the longitudinal frictional force divided by the vertical force on the test tire (Kuttesch, 2004), hence the longitudinal friction coefficient.

Fixed Slip - Fixed-slip devices measure the friction in a manner related to vehicles with anti-lock brakes. The frictional force in the direction of motion between the tire and pavement is measured as a vertical load is applied to the test tire while a constant slip of ten to twenty percent is maintained, typically by skewing the tire about its axis of rotation to create a fixed yaw angle (Kuttesch, 2004).

Locked Wheel - The locked-wheel method was developed to measure friction under emergency braking conditions for vehicles without anti-lock brakes. The locked-wheel method differs from the side-force and fixed-slip method in that the slip speed is equal to the vehicle speed (100% slip), preventing the wheel from being able to rotate. Locked-wheel devices are used by all fifty states making them the most commonly used device to evaluate friction. Because of the extreme wear caused on the test tire, the locked-wheel test can only be conducted for one second at a time (Kuttesch, 2004).

Despite the availability of methods to measure friction/skid resistance, setting threshold limits has yet to become standard practice among highway agencies (Kuttesch, 2004).

2.4 Pavement Distress

Pavement distress ratings in one form or another are used by every state to prioritize highway pavement projects according to limited highway budgets. The criteria or pavement characteristics used to evaluate pavement distress as well as the equipment and procedures vary widely. All states include rutting, cracking, raveling and patching in their pavement distress rating. Some states also include ride quality and/or splash and spray ratings. In many states, the ratings are based on visual observations gathered while traveling at relatively high speed, a highly subjective technique. However, some states such as Maine and Iowa have transitioned from visual survey to using sophisticated digital imaging coupled with GPS monitoring and pattern recognition software to eliminate subjectivity while evaluating pavement distress.

3.0 Criteria Used to Qualify Pavement Conditions

One of the challenges facing the United States highway maintenance agencies is to establish standardized criteria to be used by each state to quantify pavement conditions. Each state is responsible for determining which pavement properties to evaluate and what methods to use in that evaluation. All states collect a Pavement Condition Index (PCI) rating based on pavement distress and ride quality. However, a survey of the lower forty-eight states revealed that skid resistance was also measured and used as a rating system. States fell into five general classifications based on their guidelines for evaluating skid resistance, primarily related to aggregate properties (Road Engineering Journal, 1997). This section discusses the two primary criteria used to qualify pavement conditions, namely the Pavement Condition Index and friction/skid resistance ratings.

3.1 Pavement Condition Index (PCI)

Even though all fifty states collect a PCI rating, the type of data collected and the methods used to collect that data vary significantly. Four case studies follow to illustrate the wide variety of pavement data collection among the states. They are: Louisiana, Washington State, Oregon, and Maine.

In summary, although all methodologies are based on the same principles, they all differ from each other and there are no straight-forward correlations known. For example, depending on the methodology, some ratings will change as a function of road type (urban versus rural) while others will be depending on the pavement type (flexible versus rigid pavement).

3.1.1 Case Study 1:
Louisiana – Combination of pavement distress and ride quality

The Louisiana Department of Transportation uses a Pavement Condition Rating (PCR) system obtained by combining ride quality and pavement distress data.

Ride quality is collected using a Mays Ride Meter profilometer. The data collected are used to determine the vertical motion of a vehicle caused by irregularities in the pavement surface. The data are reported in inches per mile.

Pavement distress data is based on visual evaluations of standard pavement distress patterns: cracking, raveling, and patching. A subjective estimation of the severity and extent of those distress patterns is assigned by the survey team. Pavement distress rating values in Louisiana are road type dependent. Rural roads showing no distress receive a rating of twenty-five while urban roads with the same condition only receive a rating of twenty. Roads with total distress receive a rating of zero. (Shah, 1987)

3.1.2 Case Study 2: Washington State – Combination of structural condition, pavement rutting and surface roughness

To monitor their highway system conditions, Washington State looks at pavement structural condition (PSC), pavement rutting condition (PRC), and surface roughness.

Structural condition is based on a visual evaluation of typical pavement distress patterns; cracking, raveling, and patching. A subjective estimation of the severity and extent of distress is used to assign the pavement distress rating and assess structural condition. Washington State weighs the effect of pavement distress differently for flexible versus rigid pavements in the calculation of an overall PSC value.

The second component in Washington State's pavement evaluation plan is to monitor pavement rutting conditions. As do most other states, a profilometer is used to determine the extent of rutting.

Because there are numerous methods available for measuring ride quality, Washington State has adopted the International Roughness Index (IRI) to standardize roughness measurements across the state. The IRI is a mathematically-defined statistic of the profile in the wheel path of a road surface and is representative of the vertical motion a vehicle experiences in response to the pavement surface (WSDOT, 1994).

3.1.3 Case Study 3: Oregon – Qualitative Good-Fair-Poor visual ratings

Oregon uses two different pavement condition evaluation systems, one for national highways and one for non-national highways. For interstates and national highways, pavement distress surveys similar to the methods used by Washington State are used to evaluate pavement condition. The surveys are conducted by engineering student interns following an extensive week-long workshop for training. Non-national highways are evaluated using a more subjective "windshield survey" of overall pavement conditions at highway speeds by full-time ODOT employees. The overall pavement condition is then given a Good-Fair-Poor (GFP) rating. No specific pavement distress information is collected (Oregon DOT, 2004).

3.1.4 Case Study 4: Maine – Quantitative digital video-based evaluation system

Unlike either Louisiana or Washington State, the state of Maine bases pavement condition ratings entirely on quantitative analysis of pavement surface conditions. An ARAN (Automated Road Analyzer, Section 2.2) is used to collect continuous digital video data of the road surface and GPS data at highway speeds. The ARAN collects information on:

- Shim qualities

- Gradient and slope of the surface
- Rut depth
- Radius of curvature
- Road smoothness
- Right-of way data

Unlike other states, Maine's DOT is able to quantitatively evaluate the severity and extent of pavement distress by analyzing the digital video images with WiseCrax, a pattern recognition software package.

Maine estimates that prior to implementation of ARAN with WiseCrax, only 4% of the highway network was being evaluated and that pavement condition rating was being applied to the entire network. With automated data collection and processing, the state of Maine can now sample 100% of the road surveyed. Pavement management engineers attribute more efficient use of highway funds with such automated PCR capabilities (Watson, 2003).

3.2 Friction Ratings and Skid Resistance

As early as 1967, the National Cooperative Highway Research Program sponsored a program to develop minimum friction levels for rural highways. As a result, the U.S. Department of Transportation provided tentative skid resistance requirements (skid numbers, i.e. SN) to the States based on ribbed (R) tire locked-wheel friction tests as a function of mean traffic speed (V). The tentative minimum skid numbers proposed in 1967 are shown in Table 3.

Table 3. Tentative Minimum Skid Numbers (Kuttesch, 2004)

Mean Traffic Speed, V (mph)	Skid Number	
	SN_V	SN_{40}
0	60	-
10	50	-
20	40	-
30	36	31
40	33	33
50	32	37
60	31	41
70	31	46
80	31	51

SN_V – Skid Number measured at speed V (mph)
SN_{40} – Skid Number at equivalent speed 40 mph

By 1977, five states had developed their own recommended minimum skid numbers based on limited studies of their highway surfaces. Table 4 lists these states and their minimum skid number recommendations which have been adjusted to the skid number value at equivalent speed of 64 km/h measured by a ribbed tire (R) (e.g., SN(64)R).

Table 4. Proposed Minimum Skid Values (from Kuttesch, 2004)

State	Minimum Friction Values, SN(64)R or $SN_{40}R$
Arizona	29
Kentucky	40
Tennessee	40
Texas	38
Virginia	30

$SN_{40}R$ ~ SN(64)R – Skid Number equivalent speed 40 mph (64 km/h) measured by a ribbed tire

According to a survey of the lower forty-eight states conducted in 1996, nearly half of the State Departments of Transportation did not have any guidelines for specific surface friction (Kuttesch, 2004).   Among those that did, their guidelines fell into five general classifications. Table 5 lists the five categories and the number of states falling into each classification (Henry, 2000)

Table 5. Use of Skid Resistance in Asphalt Concrete Pavement Evaluation (Henry, 2000)

Guidelines		Number of States
I	No specific guidelines to address skid resistance	14
II	Skid resistance accounted for through mix design	9
III	General aggregate classification procedures are used	7
IV	Laboratory evaluation of aggregate frictional properties	18*
V	Incorporate field performance in aggregate qualification	4*

** Four states reported using both items IV and V, resulting in fifty-two responses.*

A complete list of each state and their response is given in Appendix C. Among the states that reported using surface friction in pavement design, most do so by controlling the quality of the aggregates, i.e. surface macrotexture, as measured using the tests listed in Table 1.

4.0 Corrective Measures Based of Pavement Condition Ratings

Budgets associated with most publicly funded projects are insufficient to accomplish every task needed. Because of this, the data collected by states on pavement conditions has historically been used to prioritize road maintenance projects within a set budget, but not to establish threshold values at which point mandatory corrective measures would be required.

4.1 Skid Resistance and Texture

The United Kingdom is well known for its position as a world leader in establishing threshold values for skid resistance and texture depth (Lawson, 2005). However, despite this leadership, the UK uses established values to trigger further investigation of the pavement surface, but not to require remediation. The UK's Skid Resistance Policy sets a friction threshold established to represent desirable, investigatory and minimum friction levels for a variety of site categories (Table 6). Threshold values are based on SCRIM values and texture depths. The shading differentiates the general traffic levels, with dark shading representing roads carrying significant traffic loads and light shading representing low traffic levels.

Table 6. Investigatory Friction Levels Established in the UK (HD28/04).

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

Light shading – Roads with low traffic levels
Dark shading – Roads with significant traffic loads

The UK uses an annual survey schedule to reduce the effects of seasonal variations on friction levels (CSS Guidance Note, 2005). However, sites with higher than average accident rates are reviewed more frequently to determine if low friction and/or mean profile depth values contribute to accident rates. When either low friction or mean profile depth have been found, hence potentially contributing to higher accident rates, corrective measures are required (Sinhal, 2005).

In 2000, twenty states reported measuring skid resistance on newly constructed or restored surfaces. However, only four states reported using minimum allowable friction values for newly constructed and restored pavement surfaces (Henry, 2000). Those states and their threshold friction numbers are given in Table 7.

Table 7. Minimum Allowable Friction Values for New Construction and Restored Surfaces (Henry, 2000)

State	Minimum Friction Level ($SN_{40}R$)
Maine	35
Minnesota	45
Washington	30
Wisconsin	38

When it comes to monitoring pavement surface conditions on existing roadways rather than new surfaces, states that collect skid or friction numbers typically use that information to provide recommendations, not to call for mandatory actions. Table 8 lists the typical skid number and corresponding recommendations (Noyce, 2005).

Table 8. Typical Skid Resistance Value Ranges and Corresponding Recommendations (Noyce, 2005)

Skid Number	Recommendations
< 30	Take measures to correct
≥ 30	Acceptable for low volume roads
31 - 34	Monitor pavement frequently
≥ 35	Acceptable for heavily traveled roads

Ten states and Puerto Rico reported having intervention levels for friction (Henry, 2000). They are listed in Table 9 along with threshold friction level for intervention. However, no information was reported in the open literature on intervention actions taken when friction values fell below the thresholds listed. These States therefore comprise the basis of the list for interviews.

Table 9. Friction Intervention Levels (Henry, 2000)

State	Measure Used	Interstate/ Motorway	Primary	Secondary	Local
Arizona	MuMeter value	34	34	34	
Idaho	$SN_{40}S$	>30	>30	>30	
Illinois	$SN_{40}R$	>30	>30	>30	
Kentucky		>28	>25	>25	>25
New York		>32	>32	>32	>32
South Carolina		>41	>37	>37	
Texas		>30	>26	>22	
Utah		>30-35	>35	>35	
Washington		>30	>30	>30	>30
Wyoming		>35	>35	>35	

S – Smooth tire; R – Ribbed tire

In recent years, states where winter weather driving conditions are of concern have begun to incorporate SALTAR instrumentation with their snow plows. SALTAR systems measure skid resistance in real time as a means to effectively disperse salt, brine or salt/sand mixtures on the road surfaces. This is the first known application of friction data in real time used to take immediate corrective actions, albeit temporary actions, and only applicable to the snow/ice-contaminated road conditions. States known to use the SALTAR system include Iowa, Michigan, and Minnesota (Noyce, 2005).

4.2 Slippery When Wet Warning Signs

There has been much discussion regarding the effectiveness of slippery-when-wet warning signs. The United Kingdom evaluated the effect of slippery-when-wet postings on driver behavior. The test site was a straight section of roadway followed by a curve and was known to have good skid resistance. Slippery-when-wet signs were posted just before the bend. Driver behavior was monitored before and after the sign was erected. The study found the warning signs did not have a statistically significant effect on driver behavior (Sinhal, 2005).

Regardless of the effect of warning signs on driver behavior, posting slippery-when-wet signs provides a defense against litigation in wet weather accidents (Sinhal, 2005). In 2000, the state of Missouri was found liable for failure to warn the public of hazardous wet pavement conditions resulting in a traffic fatality. In this case, the judge ruled that Missouri's DOT had the responsibility to improve skid resistance and/or warn motorists of slippery conditions (Noyce, 2005). Despite the Missouri ruling, no evidence was found in the literature of States requiring the posting of slippery-when-wet signs as determined through either reduced friction measurements or by increased wet weather accidents.

4.3 Present Condition Rating

The most commonly used tool among states to determine pavement surface restoration or remediation is the Present Condition Rating (PCR) system or a system similar to it. While most states use the rating systems to prioritize projects, some states are adopting threshold values for surface restoration.

Ohio's DOT bases its present condition ratings based on the visual observations of pavement distress by trained raters. As an example, Table 10 lists pavement types and the recommended rehabilitation levels based on PCR values used by Ohio. However, in Ohio, even though structural defects are included in the PCR rating, if the structural defect score is greater than 25, that pavement section is considered for rehabilitation regardless of the overall PCR rating (Ohio DOT, 1999).

Table 10. Pavement Deterioration Model 101-1 (Ohio Department of Transportation Pavement Management Publication Section 101-1.)

RIGID PAVEMENT		
Minor Rehabilitation:		
	All Overlays with and without Repairs	PCR = 96.0 - 3.7(AGE)
	CPR	PCR = 96.2 - 7.0 (AGE)
New Rigid Pavement & Unbonded Concrete Overlay		PCR = 99.1 - 0.9 (AGE)
FLEXIBLE PAVEMENT		
Minor Rehabilitation		
	Non-Structural Overlay with Minimal Repairs	PCR = 98.1 - 3.3 (AGE)
	Non-Structural Overlay with Repairs	PCR = 98.6 - 3.8 (AGE)
	Structural Overlay with Minimal Repairs	PCR = 98.3 - 3.3 (AGE)
	Generic Minor Rehabilitation (all of the above)	PCR = 98.0 - 3.3 (AGE)
Major Rehabilitation		
	Fractured Slab Technique	PCR = 98.0 - 3.4 (AGE)
	New Flexible Pavement	PCR = 99.5 - 2.0 (AGE)
COMPOSITE PAVEMENT		
Minor Rehabilitation		
	Non-Structural Overlay with Minimal Repairs	PCR = 96.1 - 4.0 (AGE)
	Non-Structural Overlay with Repairs	PCR = 96.1 - 3.8 (AGE)
	Structural Overlay with Minimal Repairs	PCR = 96.1 - 4.3 (AGE)
	Structural Overlay with Repairs	PCR = 96.1 - 3.3 (AGE)
	Generic Minor Rehabilitation (all of the above)	PCR = 96.0 - 3.7 (AGE)
New Composite Pavement		PCR = 99.6 - 3.3 (AGE)

4.4 Pavement Serviceability Index

Another widely used tool for evaluating the need for pavement restoration is the Pavement Serviceability Rating (PSR). The PSR serves as a pavement performance parameter by which the pavement condition is rated. Defined as "to serve traffic," the PSR is a rating of surface roughness or riding comfort. Rating is on a scale from 0, for impassable, to 5, for perfect. The Present Serviceability Index (PSI) is based on the relationship between PSR values and measurable pavement attributes. In Ohio, the design serviceability loss is the amount of serviceability the Ohio Department of Transportation will tolerate losing before requiring rehabilitation of the pavement surface. Design serviceability loss is defined as the difference between the terminal serviceability and the initial serviceability (Ohio DOT, 1999). Table 11 lists the design serviceability loss criteria used in the state of Ohio for two types of road surfaces: rigid/composite and flexible.

Table 11. Maximum Design Serviceability Loss Allowable
(Ohio Department of Transportation Pavement Design Concepts Publication 200-1)

SERVICEABILITY FACTORS		
	RIGID / COMPOSITE	FLEXIBLE
Initial Serviceability	4.2	4.5
Terminal Serviceability	2.5	2.5
Design Serviceability Loss	**1.7**	**2.0**

4.5 Correlations between Accident Rates and Pavement Conditions

In December 2003, a new effort was launched under the AASHTO Strategic Highway Safety Plan to significantly reduce the nation's worsening highway death and injury rates. The new effort was aimed to lower the nation's highway fatality rate to 1.0 per 100 million vehicle miles of travel by 2008 from the 2003 fatality rate of 1.48 per 100 million vehicle miles (Larson, 2005). As part of that effort, thirty states were recruited to take part in the Strategic Safety Plan and Process. By 2005, an additional ten states had joined the effort.

As part of the Strategic Safety Plan, the Indiana Department of Transportation incorporates crash rates and traditional pavement condition assessments when considering highway improvement projects. For example, at sites where the predominant crash scenario is rear-end collision, the recommended safety improvement project would be to either improve pavement friction (if it less than the design standard) or to install rumble strips in the roadway pavement. While rear-end is the only crash type leading to pavement condition-related actions, Table 12 shows the specific recommended safety improvement projects considered by INDOT on the basis of crash data.

Table 12. Default Safety Improvement Projects Considered by INDOT (Labi, 2005)

Road Environment Factor		Recommended Safety Improvement Project
Roadway Deficiency	Left shoulder width	• Widen left shoulder if less than design standard (2 ft or 4 ft)
	Right shoulder width	• Install 6 ft right shoulder if not existent • Widen right shoulder if less than design standard (2 ft or 4 ft)
	Lane width	• Widen roadway lanes if less than design standard (1 ft or 2 ft)
	Median width	• Widen roadway median width if less than design standard
	Access control	• Change access control from none to partial control
	Horizontal alignment	• Realignment of horizontal curves
	Vertical alignment	• Realignment of vertical grades
Predominant Crash Pattern	Off road	• Install 6 ft outside shoulder if not existent • Widen right shoulder if less than design standard (2 ft or 4 ft) • Install guard rail • Install rumble strips on outside shoulder
	Head on or opposite direction side-swipe	• Widen roadway lanes if less than design standard (1 ft or 2 ft) • Install non mountable Median for two-lane road • Install rumble strips on inside shoulder if present
	Same direction side-swipe	• Install 6 ft right shoulder if not existent • Widen right shoulder if less than design standard (2 ft or 4 ft) • Widen roadway lanes if less than design standard (1 ft or 2 ft)
	Rear end	• Improve pavement friction if less than design standard • Install rumble strips in roadway pavement
	Night Crash	• Install or improve pavement markings • Install or improve roadway lightening

5.0 Summary of Literature Review Findings

In summary, findings of the literature review are:

- The 2000 J.J. Henry survey contains a wealth of information related to practices used for assessing pavement conditions, including some information specifically on friction-based pavement methods. However, this report did not include information related to policies, regulations and follow-on actions required when pavement friction values were found below given thresholds.

- At this time, no findings are available in the open literature on a key National Cooperative Highway Research Program (NCHRP) project, “1-43: Guide for Pavement Friction”. The objective of this research project is to develop a Guide for Pavement Friction, for consideration and adoption by AASHTO, in an effort to replace the outdated 1976 AASHTO “Guidelines for Skid Resistant Pavement Design”. As detailed in the project description, the new guide takes into consideration frictional characteristics, performance of pavement surfaces, tire-pavement noise and other relevant issues.

- There are a myriad of methods used to assess pavement conditions, some based on microtexture assessment, some based on macrotexture assessment, some based on friction value measurements, some based on human observations, etc. All methods provide the user with its own road assessment values, which are mostly used to prioritize road maintenance projects according to funds available. As such, most follow-on actions are a recommendation, but not a requirement, for maintenance activities. Nearly no follow-on actions such as sign posting are dictated by specific values of friction values.

- Some have attempted to correlate findings obtained from different methods, but limited correlations could be found. The large number of methods and practices used makes the task of finding a universal correlation unlikely successful. To complicate matters, some methods are also based on subjective assessments.

- Most pavement condition rating methods are based on the assessment of surface features, as a surrogate measure of friction.

- There are no national guidelines on the assessment of surface friction, or on the follow-on actions required when friction thresholds are exceeded. Each user may or may not value such guidelines if their current practice is satisfactory to them.

6.0 Candidate Interviewees and Survey Questions

6.1 Selection of Candidate Interviewees

The survey plan was developed to interview a maximum number of nine state highway agencies to remain in compliance with the paperwork reduction act of 1995 without seeking exemption from OMB review of Agency Information Collection. The nine states were carefully selected to maximize the response rate as well as the value of the information collected.

Several criteria were taken into consideration for the selection, including:
- Findings from NCHRP-sponsored 1999 survey (Henry, 2000), and
- Recommendations by Mr. Swanlund, FHWA Senior Pavement Engineer, including traffic volumes.

Findings of the NCHRP-sponsored survey of 1999 (Henry, 2000) address several issues related to pavement characterization of relevance and interest to the current project, and in particular, provide a thorough assessment of states, agencies or government practices. However, not only was the survey conducted nearly seven years ago, but also it did not include actions to be taken upon measuring road condition exceeding established thresholds. These findings qualified each state agency in one of five categories for incorporating aggregate properties and/or skid resistance in guidelines for pavement evaluations (Appendix C):
- Category I: No specific guidelines to address skid resistance. However, frequent field testing conducted to assure skid numbers remained acceptable.
- Category II. Skid resistance accounted for through mix design. Frequent skid field tests conducted to assure adequate skid resistance.
- Category III. General aggregate classification procedures used to control quality of aggregates used and thereby provide adequate skid resistance. Skid field testing employed to assure adequate skid resistance over time.
- Category IV. Evaluate aggregate frictional properties using laboratory test procedures. Only aggregates meeting specifications in laboratory tests qualified for use in highway pavement systems.
- Category V. Both laboratory test and field results used to decide classification of aggregate and its appropriateness for road pavement systems.

A preliminary list of States was established using the Henry (2000) NCHRP-sponsored survey (Table 13, columns 3 – 4). With recommendations from FHWA, the traffic volumes of candidate states as well as the distribution of roadway type (highway, urban, rural) were taken into consideration (Table 13, columns 11 – 12). States with high traffic volumes were preferred. Finally, additional pre-existing knowledge and experience with working with selected states were taken into consideration. In summary, nine states were identified as shown in column 2 of Table 13. These states were thought of as good representatives of the high traffic volume states while being somewhat evenly distributed amongst the five categories defined by the NCHRP survey (Henry, 2000).

Table 13. Identification of Nine Candidate States (Bold font indicates final selection)

State	Selected as Interviewee	Friction-based intervention levels	Texture measurements	JJ Henry Categories					FHWA experience	Traffic Volumes 1/	% Urban Roadway
				I	II	III	IV	V			
Arizona	**Yes**	**x**			●					**57,336**	**70%**
California	**Yes**			●					**yes**	**328,917**	**80%**
Florida							●			196,444	82%
Georgia						●				112,620	61%
Idaho		x		●						14,729	39%
Illinois	**Yes**	**x**				●				**109,135**	**71%**
Kentucky	**Yes**	**x**					●		**yes**	**47,322**	**42%**
Maryland	**Yes**			●					**yes**	**55,284**	**75%**
Michigan							●			103,326	69%
Mississippi			x				●			39,431	39%
New York	**Yes**	**x**					●		**yes**	**137,898**	**71%**
Oregon					●				yes	35,598	54%
Pennsylvania							●			108,070	64%
Puerto Rico		x								-	-
South Carolina		x					●			49,551	35%
Texas	**Yes**	**x**					●		**yes**	**231,008**	**64%**
Utah		x					●			24,696	70%
Virginia	**Yes**		**x**			●				**78,877**	**61%**
Washington	**Yes**	**x**			●				**x**	**55,673**	**71%**
Wyoming		x		●						9,261	29%

1/ Annual Vehicle Miles - Functional System Travel (2004 FHWA estimates)

6.2 Survey Questions

The purpose of this survey is to collect information on procedures currently used by highway agencies to:

- Evaluate pavement conditions, including the methods and criteria, if any, used to qualify pavement conditions,
- Identify whether criteria used to evaluate pavement condition are based on friction or not,
- Characterize actions required based on the specific values of the criteria used.

As such, survey questions (Appendix D) were developed and organized in the following sections:

- Section A sought background information on the respondent.
- Section B was designed to ask general questions about friction measurements. For example, question Q2 states “Does your agency use any type of friction measurement (e.g., conduct regular surveys of the friction of your network)?”. If the respondent answered no, questions from Sections C through E’ were skipped and the respondent was directed to Section F. If the respondent answered positively, he/she was asked to answer questions from Sections C through E’.
- Section C questions were focused on measuring devices used.
- Section D targeted information related to the use of the data collected by the agencies.
- Section E questions investigated guidelines, procedures, threshold values and actions which may be taken by the agencies.
- Section E’ questions were designed to inquire about regulations and policy. For example, respondents were asked in Q 32 whether or not their agency had policies or regulations for friction measurements.
- Section F questions were developed for respondents who reported not collecting friction measurements.
- Finally, Section G questions were added to gain general information related to noise and spray from all respondents.

7.0 Survey Results

7.1 Survey Response Rates

Each of the nine states selected for participation on Task 2003E1, "Assessment of Friction-Based Pavement Methods and Regulations," was contacted after careful identification of qualified personnel at each department based upon recommendations of Mark Swanlund, FHWA Senior Pavement Engineer; authors of pavement and/or friction research available in the open literature; and participants in national committees related to skid resistance and/or pavement design.

Initial contact with each state was conducted by email with the survey attached. They were asked to then both complete and return the survey, or to identify the appropriate person within their department to respond. Eight out of nine states responded to the survey. Virginia was the only state in which the initial contact responded. All eight other states referred the survey to departments responsible for evaluating friction numbers. California passed the survey to several people within their transportation department and ultimately did not provide a contact within the timeframe for inclusion within this report.

Seven out of the eight states responding to the survey chose to fill in the survey and return it either by email or by fax. In all seven cases, the respondent reported that they had contacted others within their department for additional information to ensure accuracy in their reporting, particularly when responding to question 16, "what do you do with the data collected," and to the questions in section E related to guidelines/policies for threshold values and follow-up actions. Only one state, New York, chose to respond to the survey by way of telephone interview. Follow-up phone interviews for clarifications were made with six out of the seven states who had returned their surveys. Illinois could not be reached for clarification of their responses.

With the exception of the Washington State participant, those responding to the friction survey reported that they were unfamiliar with other data collected to assess pavement conditions. Their responses to question 7, "what other measures does your state use to evaluate pavement conditions" and questions 16, "what is done with the data collected", were based on the respondent's best knowledge which may or may not be accurate with respect to their state's current practices. In order to obtain accurate information on pavement assessment not related to friction, a separate survey would need to be conducted.

7.2 General Observations

Despite limited sampling and answers based on job duties or area of expertise of each respondent (e.g., aggregate specialist vs. pavement management supervisor), general trend observations can be made.

- All States surveyed generally indicated that there were too many variables to establish regulations for friction levels (Q33).
- Nearly all States surveyed (except Kentucky, which declined to comment) follow the FHWA requirements for friction monitoring programs (Q31).
- Responses regarding the establishment of National guidelines for friction measurement methods and criteria were mixed. Most felt roads were too site-specific for National guidelines (Q30).
- There seemed to be a general desire to have full length coverage from some non-contact, high speed measurement method (Q26), but most states surveyed did not know what they would do with more or better data from additional characterization tools (Q27).
- The two most cited criteria used in addition to friction reading to initiate or prioritize road maintenance were accident frequency and road/ride quality (Q23).
- Among the States surveyed, a wide range of minimum Skid Numbers were found at which a “concern” is triggered (from 24 to 35) (Q19, Q20).
- Most States surveyed use friction measurements from accident sites and to diagnose/prioritize for road repairs (Q3).
- There appeared to be considerable “experience”, via discretion or visual inspection, used to prioritize road maintenance actions, thus some qualitative and subjective component was included (Q6).
- All States surveyed had other measures besides friction to evaluate pavement conditions (but not necessarily prioritize actions). These measures appeared to be driven by the road users such as IRI and ride quality, (Q7).
- Most States use the ASTM E-274 locked wheel test, and considered it the be “standard” and reliable. Some adjusted for speed (for which a method exists), but none for temperature (Q8 – Q13).
- Among the States surveyed, those that archived their friction data and subsequently used it were concerned with relating materials (aggregate) and durability (Q16, Q17).
- Most States surveyed had no current effort in monitoring spray. While noise was a concern, less than half of the States reported having noise-related regulations. Most thought a standard for noise could be implemented (Q41 – Q45).

7.3 Results Trends

This section details trends in interviewee responses received question by question. Compilations of all detailed responses are included in Appendix E.

Results of Sections A and B – Background and general questions about friction measurements

All survey participants reported that their job was related to pavement condition evaluation. Every state responding to the survey reported that they conducted friction testing, although the methods used, frequency of testing, and how the data were used varied widely.

Only three states reported using friction measurements as a quality control measure. Of those, Kentucky reported they test the polish value of the aggregate before the aggregate source qualifies as an approved vendor. Each of the eight states reported using friction data for research purposes. Seven states used friction testing to diagnose the condition of specific sites. When asked whether friction data were used to monitor the condition of the road networks, four states responded “yes,” three states responded “no,” and one state, Kentucky, responded “yes and no.” When asked for clarification, Kentucky reported using friction data to monitor the condition of road networks for research purposes only. Six states reported conducting regular friction surveys on their road networks, but, the percentage of roads tested varied from less than ten percent per year to one hundred percent per year. Six states reported testing friction at accident locations. All eight states responded “no” when asked if they used friction measurements for winter maintenance.

The percentage and frequency of testing varied among states. The breakdown for percentage of roadway system tested for friction and the frequency of testing is shown in Table 14. Of the seven states responding to these questions, six reported testing 100% of their interstate roadways no less often than every three years. Only New York reported fewer than ten percent of their road network was tested annually. The low percentage was attributed to the high number of miles within their road network. Kentucky reported 100% of interstate network was tested initially after pavement was laid down. Testing then drops off as the road reaches 10 million cumulative traffic counts. Primary, secondary and local roads are reported to be tested in the same manner if they met average daily traffic count requirements for friction testing.

Table 14. Percentage of roadway network and frequency of friction testing.

	100% annually	100% biennially	100% three year cycle	100% four year cycle	Additional testing on “As Requested” basis
Interstate	2	3	1	0	3
Primary	2	2	0	2	3
Secondary	2	2	0	1	4
Local Roads	2	0	0	0	3

The criteria for testing friction on an as needed basis are reported in Table 15.

Table 15. Responses to Question 6:
"If tested on an as-needed basis, what criteria are used to determine if a roadway qualifies for friction monitoring?"

State	By request	Visual inspection which suggests friction may be low.	Higher than usual wet accident rate	Other
Arizona	X	X		
Virginia			X	
Maryland	NA			
Texas	Discretion of TxDot pavement engineer or other district manager.			
New York	Discretion of District Pavement Managers Discretion of Traffic & Safety Department	X	X	Inventory testing sites as determined by geology
Washington	NA			
Illinois	X		X	New Surfaces
Kentucky	X			New Surfaces

All but one state reported that they were not the appropriate person to respond to question seven, "What other measures besides friction does your state use to evaluate pavement condition?" They reported that non-friction related information was obtained through a different department within their state's DOT. However, the respondents gave answers to the best of their knowledge. A separate survey would need to be sent to the respective highway department in order to obtain more accurate information regarding other pavement condition evaluations.

Table 16. Responses to Question 7:
"Besides friction, what other measure(s) does your state use to evaluate pavement conditions?"

State	Cracking	Flushing	Roughness	Rutting	Patching	Ride Quality	IRI
Arizona	X	X	X	X	X		
Virginia	X			X		X	X
Maryland	X			X		X	
Texas				X		X	X
New York			X				
Washington	X	X	X	X	X	X	X
Illinois			X				X
Kentucky	X		X	X	X	X	X

Results of Section C – Questions about measuring devices used

The most commonly reported operating mode for friction on roadway networks was the locked wheel with seven out of eight states reporting this as the mode of choice for production testing. Virginia reported using the locked wheel method for production and the dynamic friction variable slip operation mode for research. Arizona reported using a fixed slip operation mode device. Seven out of eight states used the ASTM E-274 trailer as the tester of choice. Their reasons for using the E-274 ranged from it being the device used historically in that state to it being considered as the most likely instrument to yield friction numbers that would be obtained by the average vehicle traveling on that roadway. Arizona preferred using the Dynatest Highway Slip Friction Tester due to its ease of use.

Of the seven states preferring to use the ASTM E-274 trailer, only three states reported using the ASTM E-524 smooth tire. Virginia used the smooth tire test for all of their friction testing; Texas and Illinois used the smooth tire for limited testing, mostly for research. Six states reported using the ASTM E-501 ribbed tire. Washington State reported a recent change from the ASTM E-524 smooth tire to the ASTM E-501 ribbed tire due to the low life expectancy of smooth tires when taking friction measurements.

The most common test speed used among the eight responding states was 40 mph. Texas reported testing at 50 mph and Arizona reported testing at 60 mph. Concerns for the safety of their survey teams traveling below the speed limit prompted the increase. A state-by-state summary of test conditions is given in table 17.

Table 17. Responses to Questions 11 & 12:
"What test speeds does your agency use for the friction surveys?" and
"What is the spatial frequency and sample length of your friction testing?"

State	Test Speeds	Samples/Mile	Sample Length
Arizona	60 mph*	1	200 ft
Virginia	40 mph	3	1 second
Maryland	40 mph	3.33	Per ASTM E 274
Texas	50 mph	2	~ 100 ft
New York	40 mph**	10	Per ASTM E
Washington	40 mph	1	Per ASTM spec
Illinois	40 mph	up to 10	0.1 mi and greater
Kentucky	40 mph	5 minimum	147 feet

* When possible, otherwise, 40 mph.
** Higher speeds for higher speed roads or by request.

Washington State was the only state to report making adjustments for temperature variations. Maryland reported they were currently evaluating this option based on their research showing environmental conditions to have a more significant influence on friction number than any other variable. While Kentucky limits testing to ambient temperatures between 40 and 90 degrees F, they do not make adjustments to friction number results based on temperature.

Virginia was the only state to report making adjustments for seasonal variations when reporting friction numbers. Again, Maryland reported they were currently evaluating this option based on their research. Kentucky limited testing to between July 1 and mid-November, but they do attempt to correlate the time of year to the friction data they collect. New York reported testing seasonal variations in some cases, using the data collected for research purposes only.

Five states reported making adjustments for speed when collecting friction numbers. While the other three states reported they did not make adjustments for speed, it was unclear as to whether that was because they never tested at any other speeds, or, if they did test at other speeds, they did not make adjustments in the reported friction data.

Arizona was the only state to report using other friction measuring equipment in the past. They reported changing from the Mu-Meter to the Dynatest Highway Slip Friction Tester in 2000. Six out of the eight states were familiar with other friction measuring equipment. How they had become familiar with the other equipment was widely varied. Those results are reported in Appendix E.

Results of Section D – Questions about the use of the data collected

There was wide variation among the states as to what was done with the friction and other data that were collected when evaluating pavement conditions. The results are summarized in Table 18. The individual responses for each state are reported in Appendix E.

Table 18. Summary of responses to question 16:
"What do you do with the friction and other data collected?"

How state uses the data	Friction Data	Other Data
Pavement Decisions	6	4
Safety Analysis	3	0
Accident Investigation	1	0
Research	4	3
Identify and confirm skid-resistance deficiencies	2	0
New Pavement Design	0	2

All eight states responded "yes" when asked if they recorded and archived friction data. Seven of those states reported using a database archive system. During follow up phone calls, the respondents were asked if they were able to perform queries on their databases in order to identify possible links between such things as aggregate property and friction number. Three states reported they queried their database in order to track trends, three used queries to evaluate performance of aggregates. However, most of the states sorted their data according to milepost or global positioning satellite and did not try to track trends. Two states reported storing the data until it was a need to review them, usually based on a regional director's request for data pertaining to a particular milepost location.

When asked what the respondent would like to do with the data collected, two additional states reported they would like to be able to use it to track trends, and three additional states said they would like to see it used to evaluate the performance of various highway mixes. The individual responses for each state for question 17 "Do you record and archive friction data?" are reported in Appendix E.

Results of Section E – Questions about guidelines, procedures, threshold values and actions

Six states reported having guidelines for friction measurements (Q18) as shown in the table below. The lack of guidelines in Maryland and Illinois was explained by the lack of regional or national direction coupled with a lack of resources for Maryland, and by an undefined need in Illinois.

Table 19. States responding "Yes" to Questions 18: "Does your agency have guidelines for friction measurements?"

State	What are the guidelines?
Arizona	1. Test at each milepost for ~ 200 ft. 2. Measure wet. 3. Measure at 60 mph
Virginia	Copy being sent by snail mail (from Jerry Garrison)
Texas	ASTM procedures with at least one test per 0.5 mile section.
New York	ASTM procedures for test method. No policy to dictate frequency of testing nor percentage of highway system to be tested.
Washington State	Skid Accident Reduction Program requires skid numbers to be considered in development of appropriate solutions to address both accident and potential accident locations.
Kentucky	Sources of polish resistant aggregate source list must maintain a satisfactory performance level. Sources not on the list must display a satisfactory level by test sections to be added. Performance or sources will be based on pavement friction skid testing, and will be accordance with ASTM E 274. Skid numbers resulting from this test will be evaluated in the range of $6x10^6$ to $10x10^6$ cumulative traffic.

Similarly, 6 states reported having established threshold values of friction measurements. As shown in the table below, the investigatory levels differ from state to state. All six states reported subsequently re-testing and monitoring the friction numbers. Three states reported

posting slippery-when-wet warning signs, and some states stated that the friction numbers were used to prioritize remedial/restorative pavement projects.
Texas, which reported not having established threshold values of friction measurements, stated that they did not use specific threshold values but rather a statewide mean/standard deviation because of the influence of site conditions on the values. Illinois reported using guidelines for smooth and treaded tires rather than threshold values of friction measurements.

Table 20. States responding "Yes" to Questions 19 and 20:
"Does your agency have established threshold values of friction measurements?" and "Does your agency have established follow-up actions based on friction measurements?"

State	What are the guidelines?	Follow-up actions based on friction measurements
Arizona	Desired = 43+ "Point of concern" <35	Biennial review of areas below 35 to see if remedial action is appropriate. Post "S W W" signs when <35 verified, also prioritize for remedial actions
Virginia	SN40S<24 = Investigatory SN40S<20 = Intervention	Initial activity: erect warning signs As soon as practical: determine deficiency and restore skid-resistance
Maryland	Category 1 (<35) Category 2 (35-39) Category 3 (40+)	Poor friction roadway sections are combined with high accident locations to develop a friction improvement candidate list.
New York	SN40S<32 = Investigatory	Friction measurements are used in conjunction with accident data when prioritizing road projects.
Washington	SN40S<26 SN40S range of 26 to 30	Determine if conditions warrant posting of Slipper-When-Wet signs and implement solutions Repeat friction testing for accuracy and possible decline of FN. Determine if conditions warrant posting Slippery-When-Wet signs should be posted.
Kentucky	Values are highly confidential and given only to the vendor supplying the aggregate used in the mix.	Retest. If numbers are still low, field personnel checks out site to determine if further action is required.

Five states knew of policies developed or implemented regarding specific follow-up actions given friction numbers. The policies, as described by the respondents, are listed in the table below for each state. When asked if it would be beneficial to implement a policy, the three states which reported not knowing of any existing policy did not believe it would be beneficial because of the risk of liability (Arizona), because of the variability of the data on conditions (Texas), or because of the structure of their agency (Illinois).

Table 21. States responding “Yes” to Question 21:
"Do you know of any policy developed or implemented in your state regarding specific follow-up actions to be taken, given particular friction readings?”

State	Description of the policy
Virginia	Slippery-When-Wet signs are posted when friction levels drop to “Intervention” levels.
Maryland*	We are in the process of formalizing the policy. A friction improvement list is developed, but appropriate treatments have not been established.
New York	Implements FHWA Skid Accident Reduction Program (2002).
Washington State	Washington State’s Skid Accident Reduction Program (1994).
Kentucky	Possible follow-up actions include: de-slicking, possible overlay, coring the road to check the aggregate.

*Responded “yes & no”

Answers to question Q22 designed to gain information on other intervention method(s) used for readings other than threshold values were very varied and are listed in the table below.

Table 22. Responses to Question 22:
"What other intervention method(s) does your agency use for readings other than the threshold value?”

State	Answer
Arizona	Each site is considered for an appropriate action from “Do nothing” to “Do overlay”
Virginia	Nothing specific – monitoring encouraged
Maryland	Friction readings are used in the project level decisions for pavement rehabilitation strategy and material selection for pavement surface.
Texas	Depends on site conditions
New York	1. “PIL” investigation of location by Department of Traffic & Safety 2. Inventory testing of sites as determined by geology 3. Test-by-request
Washington State	Each site is considered for an appropriate action ranging from posting Slippery-When-Wet sign to taking immediate corrective action.
Illinois	Advise the Districts of the potential for friction problems when numbers are approaching guideline values.
Kentucky	Monitor the aggregate source for quality. See how it performs on other sites containing the same mix design.

The most common criterion used to initiate or prioritize road maintenance actions besides the friction readings was the accident frequency (five states).

Table 23. Responses to Question 23: "Are there other criteria besides the friction readings that are used to initiate or prioritize road maintenance actions?"

State	Response
Arizona	Each site is considered in context.
Virginia	High wet-to-dry accident ratio triggers more testing than inventory findings
Maryland	Percentage of wet accidents at a location Ride quality Cracking Rutting Other distresses
Texas	District practitioners have final say, but distress, ride, deflection, and other factors are considered.
New York	Accident frequency & type of accident (i.e. roll-over accident) Engineer requestor (i.e. monitor new surface, product evaluation, research)
Washington State	High accident location High accident corridor
Illinois	High accident locations
Kentucky	Determination made by Operations and Pavement Management Branch.

Despite the fact that most states (six) reported that their current practices suited their needs, seven states commented on possible deficiencies in the procedure(s). The most common suggestion for improvement was to find a way to measure microtexture data in conjunction with friction data, preferably through laser-based methods. Responses to Q27 revealed that six states would favor additional tools, specifically, as mentioned previously, high-speed texture-base methods. Additional details are tabulated in Appendix E.

Half of the states reported knowing of other agencies with established policies, previously developed guidelines, threshold friction values and associated follow-up actions. One state mentioned Texas, while Texas identified three European nations. When asked to compare their current practice with others known to them, two states reported being above average, three reported being comparable (average), one reported being below average as a result of lack of personnel and funding, and two were uncertain.

The majority of the states (six) did not think that national guidelines including methods used, criteria and follow-on actions should be developed and implemented because of too much variability associated with site-specific conditions. Some states were favorable to national guidelines on methods but not on follow-up actions.

Results of Section E' – Questions about regulations and policy

Seven states responded to the questions in section E Prime. Kentucky declined comment citing possible liability issues. Of the seven states responding, six states reported using the FHWA Wet Accident Reduction Program as the applicable legislative or regulatory basis for their friction monitoring program. Washington State reported they had developed their own Skid Accident Reduction Program, initiated in their state in 1994. It was interesting to note that although six states reported using the same FHWA program as the basis for their friction monitoring, four states reported having a policy or regulations for friction monitoring and the other two states did not.

When asked whether or not friction levels should be regulated, all seven states responded with a definitive "No." When asked why not, each state replied, "Too many variables affect friction to be able to regulate friction values." Additional comments related to why friction should not be regulated are included in Appendix E.

Results of Section G – Questions related to spray and noise

The responses for the survey questions relating to spray generation and noise reduction, questions 41 through 45, are summarized in Table 24. Kentucky's respondent did not know of any splash or noise testing but since type of testing would not have fallen under his department's jurisdiction, he felt saying "not sure" was more accurate based on his knowledge. Had this been an option on the survey, other states reporting "no" may have also responded "not sure" instead.

Table 24. Responses to Questions 41 through 45: "Splash/Spray and Noise"

State	Regulate spray generation and visibility reduction?	Quantify amount of spray?	Measure highway noise?	Regulations or corrective measures related to noise?	Standard for measurement of noise?
Arizona	No	No	Yes	Yes	Yes
Virginia	No	No	Yes	Yes	Yes
Maryland	No	No	No	No	No
Texas	No	No	No*	No*	No*
New York	No	No	No**	No	No
Washington	No	No	Yes	Yes	No***
Illinois	No	No	No	No	No
Kentucky	Not Sure	Not Sure	Not Sure	Not Sure	Not Sure

**Texas reports that they may start measuring noise at some point in the future. They report they are working on getting a standard measurement of noise.*
*** New York has measured highway noise in the past for research purposed only.*
**** Washington State is in the process of purchasing the OBSI equipment, which they would like to see become the standard for measuring noise.*

8.0 International Surveys and Interviews

8.1 Selection of Agencies

The literature search conducted for the National survey efforts of this project showed that the United Kingdom, Germany and France have comprehensive pavement assessment and management systems among the European countries, thus they are good candidate countries for conducting surveys and interviews. With subsequent discussions with international road safety experts, the Team chose to focus efforts on the United Kingdom and Germany. Further, according to 2004 crash statistics[1], these two nations had among the lowest per capita fatality rates in the world for highly motorized countries (5.3 and 7.1 for the UK and Germany, respectively, compared with 14.5 for the U.S.).

8.2 Survey Questions

The survey questions for international agencies (Appendix F) were adapted from the survey questions developed for the U.S. State surveys. The purpose of the surveys was essentially identical, i.e., to collect information on procedures currently used to:

- Evaluate pavement conditions, including the methods and criteria, if any, used to qualify pavement conditions,
- Identify whether criteria used to evaluate pavement condition are based on friction or not,
- Characterize actions required based on the specific values of the criteria used.

As such, survey questions were organized in the following sections:

- Section A sought background information on the respondent.
- Section B was designed to ask general questions about friction measurements.
- Section C questions were focused on measuring devices used.
- Section D targeted information related to the use of the data collected.
- Section E questions investigated guidelines, procedures, threshold values and actions which may be taken.
- Section E' questions were designed to inquire about regulations and policy.
- Section F questions were developed for respondents who reported not collecting friction measurements.
- Finally, Section G questions were added to gain general information related to noise and spray.

[1] www.driveandstayalive.com/info%20section/statistics/stats-multicountry-percapita-2004.htm

8.3 Survey Results:
Pavement Assessment in the United Kingdom

8.3.1 Background on the United Kingdom

The United Kingdom is often considered to be on the leading edge in the development and implementation of pavement practices. Among the practices which set the UK apart from many industrialized nations is the implementation of policies such as the HD28/04[2] policy and the CSS Guidance Note[3] on Skidding Resistance.

In the UK, while the overall responsibility for roads falls under the authority of the Department for Transport (DfT), roads are administered and maintained on two levels: Trunk Roads and Local Roads. The Trunk Road System is the UK's primary divided highway system, i.e. main highways. Trunk Roads carry the bulk of the traffic between major cities and regional centers and include most motorways. They are predominantly purpose-built or upgraded high-quality roads designed and maintained to carry heavy and fast traffic. Local roads range from major routes between smaller cities (including some roads that were once trunk roads) through to single-track country lanes and cul-de-sacs on housing estates.

- Trunk roads are managed separately in the four UK countries by Highways Agency in England, the Scottish Executive in Scotland, the Welsh Assembly in Wales and the Department of the Environment in Northern Ireland. These overseeing organizations are executive agencies of the Department for Transport with responsibilities to maintain the trunk road network. Although they have their own arrangements for managing and organizing the maintenance of the asset, including skid resistance, they generally collaborate to set common standards and specifications. A significant document for skid resistance measurement, the Design Manual for Roads and Bridges (DMRB), was jointly authored by these agencies.
- Local roads are managed by local authorities in accordance with high level principles set by the DfT and with help from recommendations of best practices for skid resistance standards and for road maintenance provided by the County Surveyors' Society (CSS). Local authorities range from small Unitary authorities covering one small town or city area, through County Councils which cover larger geographical areas with several towns and cities included. The major agglomerations such as Manchester, Birmingham and Liverpool have their own Transport Executives; while London has its own group "Transport for London" covering the whole range of routes. The majority of local authorities adopt the CSS practices. The DfT principles provide some guidance for managing skid resistance, but do not set specific requirements, resulting in varying practices used by local authorities.

One of the primary organizations providing guidance to the UK government for the development of design guidelines and standards for roadway friction and pavement maintenance is the Transport Research Laboratory (TRL). The TRL, formerly a part of the UK government,

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[2] HD28/04, adopted August 2004
[3] CSS Guidance Note, Revised May 2005

conducts research in all areas related to transportation safety. TRL not only conducted the research but also drafted the British Department for Transport's Design Manual for Roads and Bridges section on Pavement Maintenance Assessment (HD28/94) and the recently revised HD28/04. In addition to vehicle and passenger safety, TRL has a dedicated group devoted to research and development in the area of pavement characteristics. TRL both conducts and funds research on pavement materials and on characterization of pavement material and surface properties. In collaboration with an equipment manufacturer, WDM, Ltd., TRL has developed pavement surface characterization methods and equipment, in particular the SCRIM and SCRIMTEX, now widely accepted and utilized devices. In light of the breadth of the TRL involvement in the area of pavement research, characterization and management, the project team conducted the surveys with TRL staff.

Prior to discussing results from the surveys conducted, the following sections highlight elements of both the HD28/04 policy for trunk roads and the CSS Guidance Note on Skidding Resistance for local roads, specifically: establishment of investigatory levels (IL), measurement of of skidding resistance, site investigations, posting of warning signs, and remedial actions.

Policy for Trunk Road System (HD28/04)

Setting Investigatory Levels: HD28/04 specifies investigatory levels, i.e. skid resistance values at which pavements should be further investigated (i.e., site investigations) for potentially less than acceptable friction conditions. Investigatory levels are defined for different categories of sites as a range of values rather than an individual number to allow for flexibility in the pavement evaluation of various sites within the same category. For example, skid resistance in the high end of the IL range can be used to sites where the risk of skidding accidents is potentially higher. Table 25 shows investigatory levels for each site category.

Table 25. Site Categories and Investigatory Levels used in the UK for road assessment and maintenance decisions (light gray: low traffic level;

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

Light gray = low traffic level *Dark grey: high traffic level*

Measurement of Skidding Resistance: Skid resistance surveys on trunk roads are conducted using the Sideway-force Coefficient Routine Investigation Machine (SCRIM).

When HD28/04 was finalized in 2004, the measuring frequency was changed from the Mean Summer SCRIM Coefficient (MSSC) survey to the Single Annual Survey (SAS) method. Figure 5 compares the data collection intervals and time periods of the MSSC and SAS methods.

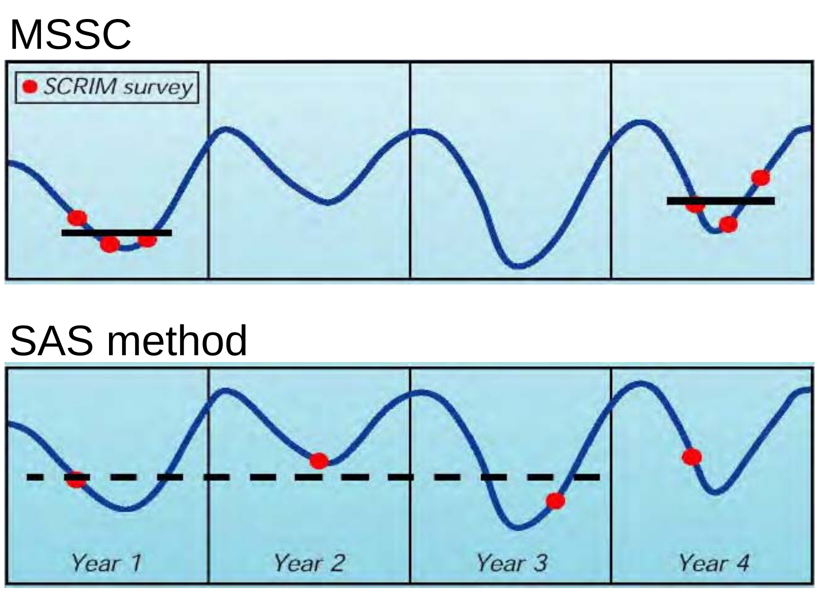

Figure 5. Mean Summer SCRIM Coefficient (MSSC) and single annual survey (SAS) method

- In the MSSC method, one third of the network was surveyed three times each year to account for seasonal variations and calculate the mean summer SCRIM value.
- In the SAS method, the survey timing is rotated through the early, middle, and late survey periods of the May 1st to September 30th test season in successive years, rather than in a given year.

The SAS method introduces a mean to correct for the effects of seasonal variation in skid resistance both from year-to-year and within individual years. The UK shows that the benefits of the SAS method include:

- Reduced interval between measurements,
- Minimization of the year-to-year variation in skid resistance, and
- Reduced survey costs through efficient organization and central management of surveys.

The UK claims that the SAS method results in earlier and more reliable identification of sites with skidding resistance below specified levels, and in accident reductions by earlier maintenance.

Since 2004, all SCRIM devices in the UK measure the vertical load applied to the test wheel. Research showed that the results obtained with the standard 200-kg load applied to the test tire could be affected by the tendency of the test vehicle to lean slightly to the left or right at bends and roundabouts.

Test speeds for the SCRIM were increased in HD28/04 from 20 km/hr to 50 km/hr in response to concerns for the safety of the SCRIM operators.

Site Investigations: When skid resistance of a given pavement section falls within or below the IL range, site investigations are conducted using accident data or other means of accident analysis. Site investigations are prioritized on the basis of the amount by which the skid resistance is below the Investigatory Level.

HD28/04 defines the required actions as a result of site investigations. Required actions include some form of treatment if:

- The number of accidents observed is higher than average for the type of site being considered; or
- The proportion of accidents in wet conditions or involving skidding is higher than average for the type of site being considered.

Given the nature of the site and its traffic volume, the condition of the pavement at the measured skid resistance or below might yield a higher accident risk compared with other sites in the same category. In this case, preventative treatment is justified to pre-empt a potential increase in accident or risk.

Warning Signs: As in HD28/94 published 10 years earlier, HD28/04 requires warning signs to be erected at sites where the need for treatment to improve skid resistance has been identified following a site investigation. However, revisions in HD28/04 specified that such warning signs must be removed when corrective measures have been implemented in order to avoid a proliferation of signs that would undermine the effectiveness of such warning signs. As such, posting of warning signs is only a temporary solution in the UK.

Remedial Actions: HD28/04 emphasizes that the most appropriate form of treatment be identified for each treatment length of a site investigation, with sites prioritized as follows:

- Where the skid resistance is at least 0.05 Characteristic SCRIM Coefficient (CSC) units below the Investigatory Level,
- Where low skid resistance is combined with low texture depth, and/or
- Where the accident history shows there to be a clearly increased risk of wet or skidding accidents.

At all other sites, HD28/04 states that prioritization of remedial action take into account other maintenance requirements, a comparison of the estimated accident saving and the cost-effectiveness of treatments.

Policy for Local Roads (CSS Guidance Note)

Setting Investigatory Levels: The authority for local pavement officials to use their judgment when setting Investigatory Levels was significantly expanded in HD28/04. In assigning Investigatory Levels, local authorities are instructed to consider whether there are any circumstances where it would be appropriate to deviate from the Investigatory Levels set for trunk roads, which may include accident and traffic statistics or local changes to road geometries. For example, local authorities may assign a lower Investigatory Level to urban roads with a speed limit of 30 mph or less when evidence from skidding accident statistics justify such a reduction.

Local authorities are also encouraged to reassess Investigatory Levels at “suitable intervals.” It is suggested that Investigatory Levels are reassessed every three years, as well as upon significant changes to a site such as the installation of traffic lights, pedestrian crossings or when the layout of road markings are altered.

While widely accepted that surface texture depth plays an important role in skid resistance at moderate to high speed, the UK authorities are encouraged to consider the influence of texture depth on speeds as low as 30 mph. Texture depth as measured using data collected through SCANNER surveys should be considered in setting local Investigatory Levels. Local authorities may decide to increase the Investigatory Level on roads having a low texture depth.

Measurement of Skidding Resistance: Local authorities are given the option of using either a SCRIM or a GripTester for road network and localized investigations.

- As of 2005, SCRIM measurements are to be taken at highway speeds.
- When authorities decide to use the GripTester, they have to either convert Grip Numbers to SCRIM values, or, convert Investigatory Levels from SCRIM to Grip Numbers.
- The Portable Skid Resistance Tester, also known as the British Pendulum Tester, may be used for detailed investigation of a local area or site, but, it may not be used for network assessment as its correlation with SCRIM values is poor at best.
- Network skidding resistance assessment is confined to the period between May 1 and September 30.

- Local authorities have more flexibility in the frequency of testing than do the trunk road authorities. Whereas the trunk road authorities have amended their test regime to an Annual Survey of the whole trunk road network once a year, frequency of testing for local roads is addressed in the Annual Survey with the Benchmark method. With this method, Benchmark sites are selected and tested three times every year, spread through the testing season. The whole of the network is tested once in every year. The Benchmark site results are used to reduce the seasonal variation of skid resistance.

Site Investigations: It is recommended that all sites having a skid resistance at or below the Investigatory Level should be investigated as soon a practicable in accordance with HD28/04 and at sites where wet or skidding accident levels have increased.
One of the objectives of a site investigation is to determine whether or not the site category Investigatory Level is appropriate for that particular site. If not, then the local authority is encouraged to consider adjusting the Investigatory Level as deemed appropriate.

Warning Signs: Where the skid resistance is substantially below the Investigatory Level, slippery road warning signs should be to be erected as a matter of urgency. In other cases, "Slippery Road" signs are to be erected as soon as practicable at all locations where a site investigation has shown the need for treatment to improve skid resistance. Similarly to HD28/04, signs are to be removed as soon as skid resistance levels have been restored.

Remedial Actions: Remedial actions are to be taken where skidding resistance is determined as being substantially below the Investigatory Level. Such remedial actions must be prioritized as a relatively urgent task when there are indications that such action is likely to reduce the risk of accidents. Priority is given using the same criteria as set in HD28/04. Local authorities are encouraged to consider measures beyond surface treatments when remedial actions are required.

Innovations on the Horizon for Skid Resistance Monitoring in the UK?

The UK continues to be innovative in its approach to maintaining safe highways. With HD28/04's adoption, the UK moved toward adopting a range of IL values instead of a single value for each site category. Kennedy *et al.*(2005) reported that both the UK and New Zealand were evaluating this option to move away from a single skid resistance Investigatory and Threshold value for site categories to use a range of skid resistance values for each site category. This approach was anticipated to result in more efficient and more effective use of pavement management resources, allowing authorities to remove some sites from the pool of sites identified for investigation each year, and allowing effort to be concentrated on sites where improvements are required. Alternatively, sites presenting a greater risk of skidding accidents than average for the particular site would justify a higher Investigatory Level.

No documentation was found to support whether or not there had been any studies of sites within the UK to investigate how such a change might affect pavement management strategies. Kennedy (2005) presented the findings of a 35 site detailed investigation within New Zealand concluding that such a shift was highly cost effective based on the reduction of traffic accidents.

8.3.2 Survey Results

Complete survey responses are found in Appendix G. Highlights of the UK survey responses in combination with initial literature findings and follow-up telephone/e-mail communications follow:

- The UK government implemented guidelines in 1994, subsequently revised in 2004, for maintenance of the major highways. Organizations within each of the four UK countries participated in the development, implementation and deployment of the guidelines. Separate, yet similar, guidelines were developed by an independent council (CSS) for agencies responsible for maintaining local roads. Local authorities are free to implement the guidelines.

- As far as legal requirements, each highway authority has a statutory duty "to maintain the highway", although to an unspecified standard. As such, should there be litigant claims against the authority for not properly doing its job of maintaining safe roads, it is up to the Courts to decide what is reasonable.

- Ranges of skid resistance values, i.e. Investigatory Levels, are used to trigger further site investigations, based on guidelines outlined in the HD28/04 policy.

- The policy was recently revised to allow for ranges of IL rather than single values, hence allowing for consideration of site-specific factors.

- English researchers have studied many types of friction measuring equipment, but have settled on SCRIM for pavement assessments, and guidelines were developed using the SCRIM as measurement device.

- Highway agencies use the SCRIM device or the GripTester for pavement monitoring. If a GripTester is used, the agency must convert IL values accordingly.

- Friction data from road surveys are stored and processed by a pavement management system. Sites for investigation are identified and tracked.

- Site investigations include the application of “risk factors”, providing both flexibility for selecting remedial actions as well as the ability to include experience.

- Noise is measured but not regulated in England.

- No UK regulations exist for spray limits nor do standards for quantification of spray.

8.4 Survey Results:
Pavement Assessment in the Federal Republic of Germany

8.4.1 Background on the Federal Republic of Germany

Limited information was found in the open literature on the pavement assessment practices of the Federal Republic of Germany. Based on the limited public data, Germany seems to monitor fewer performance indicators than other European nations, restricting its efforts to pavement deterioration, durability, and friction. Table 26 shows a comparison of performance indicators of interest among five European nations. As detailed later, interviews revealed that the technical specifications for friction measurements and for threshold values for minimum skid resistance are detailed in documents owned by the Road Transport Research Association (FGSV). Unfortunately, translated documents were not available.

Table 26. Performance indicators of interest for selected European countries (FHWA, 2003).

	Spain	Germany	Denmark	Sweden	U.K.
Deterioration (longitudinal, transverse, alligator cracking, potholes)	●	●	●	●	●
Durability (raveling, joints)	●	●	●	●	●
Friction	●	●	●		●
International Roughness Index (IRI)	●		●	●	
Longitudinal evenness			●		●
Transverse profile and drainage of surface water			●		●
Rutting			●	●	●
Instability/structural			●		
Crossfall	●		●	●	
Texture					●

The German pavement management approach differs from the UK approach. The German Federal system requires the pavement construction contractor to pass a minimum skid resistance acceptance test four to eight weeks after the road is first opened to traffic. The construction contractor is also responsible for meeting minimum standards within the first four years after construction, also under warrantee. Since the skid resistance is known to decrease over time due to polishing, the minimum required skid resistance at four years is slightly lower than the initial acceptance standards. At the same time, the initial values are set somewhat high. As shown in Table 27, the skid numbers specified vary with speed limit, but not with road type or traffic considerations. This is in contracts to the British system, where, for example, proximity to pedestrian crossings and approaches to intersections play a large role in selecting investigatory levels.

After four years, the responsibility for maintaining the skid resistance level of the roads reverts to the government:

- The Federal government is responsible for major highways (Autobahn and Bundesstraβe), and
- Each State or municipality is responsible for the local roads.

Table 27. Skid numbers for Germany

Speed limit (km/hr)	Minimum Skid Number		
	Final Acceptance 4-8 weeks after first traffic	After four years	Road monitoring for pavement management
80	0.43	0.40	0.32
60	0.48	0.45	0.37
40	0.53	0.49	0.42

In a general road construction circular number 27/1996, the Federal Ministry of Traffic, Construction and Housing (BMVBW, now BMVBS) requested the state road authorities to perform roadway condition registration and rating on a regular basis in future and use the obtained data for route-specific maintenance planning as part of an improved maintenance strategy. As such, the carriageways of interstate highways and roads are registered and rated annually in terms of their longitudinal and transverse evenness, traction and superficial damage. The federal government bears the costs of these surveys insofar as they constitute entrepreneur services and owns the obtained data. Interstate tasks are performed by the federal/state coordination group for condition registration and rating. This effort is managed by the BASt.

Similarly to the British TRL, the German BASt is a research organization that performs and coordinates the research and analysis on pavement and highways to provide specifications, standards and guidelines to the German Federal Ministry of Transport, Building and Housing. As a technical and scientific institute responsible to the Federal Ministry of Transport, Building and Housing, its main purpose is to promote the advancement of road systems and provide the BMVBW (now BMVBS) with scientifically verifiable specifications, standards and guidelines for making decisions on technical and traffic-related issues pertaining to such road systems. To fulfill this responsibility, the Federal Highway Research Institute performs independent research, coordinates research projects on behalf of the Federal Ministry of Traffic, Construction and Housing, and evaluates the results obtained in each case. The BASt is in close collaboration with the Road and Transportation Research Association (Forschungsgesellschaft für Straßen- und Verkehrswesen), the DIN German Institute for Standardization (Deutsches Institut für Normung), the German Institute for Construction Technology (Deutsches Institut für Bautechnik), the German Road Safety Council, (Deutscher Verkehrssicherheitsrat), competent state highway authorities, universities, associations and the highway industry. Another task is to act as scientific adviser to the state highway authorities which administer federal interstate highways and autobahns on behalf of the federal government. Staff members of the BASt were selected for the surveys.

Methods of pavement assessment
All major roads are monitored in their entirety every four years with a sideways force, fixed slip smooth tire measurement system (similiar to the SCRIM®, but manufactured in Germany). Data are collected continuously, and divided into 100-meter sections for inclusion as batches for a computer-aided Pavement Management System (PMS) and for planning the maintenance of interstate roads. Each section is taken into consideration for acceptance. The smaller roads are measured over 30 percent of their length.

Actions when skid resistance falls below the minimum
When the values decrease below the value set in the regulations, the road must be either re-surfaced, or a reduction in speed limit is instituted, the latter being a temporary measure until the former can be implemented. The minimum skid number values for the sixteen German States are the same, except for Bavaria, where they are 0.03 higher.

8.4.2 Survey Results

Complete survey responses are found in Appendix G. Highlights of the German survey responses in combination with initial literature findings and follow-up telephone/e-mail communications follow:

- Although a wide variety of pavement surface characteristics are studied and measured, at present, only skid resistance is regulated as a standard for roads maintenance.

- Across all 16 German States, a single measurement method is used, and 100 percent of the major roads are monitored. This method uses a device similar to the British SCRIM (20° skew angle, fixed slip).

- The pavement construction contractor is responsible for meeting the skid resistance standards set by the BMVBS upon initial installation in a final acceptance test and for the first four years, under a warrantee system. After four years, the government takes responsibility.

- Noise is also measured and regulated in Germany.
- No German regulations exist for spray limits nor do standards for quantification of spray.

9.0 Final Remarks

Most States interviewed expressed concerns over the risk of liability. The fear of being liable will most likely be the highest obstacle in the development of guidelines, threshold values, and associated follow-on actions for friction-based assessment of road surface conditions. A review of international agencies who have been successful in developing and implementing friction-based methodologies would be of value to shed light in potential solutions for overcoming such obstacles.

Although general trends can be observed in practices of the surveyed States, the States exercise discretion in the implementation of their practices. States have somewhat extended experience with measuring SN.

States appear to be more comfortable with texture measurements as a means to assess pavement conditions rather than friction measurements. There may be a trend of moving towards implementation of methodology related to roadway texture. As such, it may be most valuable for national guidelines to be implemented for texture measurements rather than friction measurements. In particular, recommendations on parameters, properties, methodology, interpretation, use and acceptance criteria may be more feasible at this time.

Although they were not part of the "Assessment of Friction-Based Pavement Methods and Regulations" survey conducted on behalf of the NTRCI in cooperative agreement with the FHWA, the following points became apparent throughout the course of this study:

- None of the states surveyed were willing to openly discuss minimum acceptable friction numbers as related to remedial actions for their state due to possible liability issues. When asked why they thought European countries were able to specify acceptable friction levels and remedial actions for pavements below the acceptable limit, the respondents reported they believed that due to the increase of litigation within the European courts, those countries were likely to move away from specification of acceptable friction levels to adopt a more general "investigation" approach.
- Kentucky has a pro-active approach to tightly controlling aggregate properties by way of testing aggregates before approving the aggregate vendor for bidding on highway projects. The results of the testing are very tightly controlled and shared only with the quarry supplying the aggregate. Although they appear to be ahead of the curve when it comes to being able to control friction through careful selection of aggregates, they are unwilling to publish their research findings due to the potential for litigation.
- Maryland has a firm belief that friction is impacted more by environmental conditions than by any other factor. They are currently in the process of developing a three phase program which will:
  - Assess aggregate properties
  - Tie aggregate properties to friction numbers

- Incorporate aggregate property research into pavement design, including site specific design.

Many states reported through this survey that there was no good way of measuring microtexture over roadway networks. This came as a surprise following the literature review findings where the ARAN automated road analyzer, coupled with WISECRAX software was touted as the solution to gathering pavement microtexture data at highway speeds. Because WISECRAX depends on grayscale to analyze digital images of the road surface, it cannot distinguish between a pothole and road-kill. As a result, the data obtained from this system are suspect. Throughout this survey, other states referred to Texas as being the leader in the development of a high-speed laser-based texture measuring device capable of collecting microtexture data simultaneously with friction data. However, Texas reports difficulties with the development of such a system. Battelle is in a unique position to take on this technical challenge. Battelle's has a collection of experts in all fields related to this type of project- electronics to optics to materials to data analysis and programming, ready to take on this challenge.

Conclusion to International practices

- UK paves the way with its "risk-related" model for pavement maintenance:
  - Skid number Investigatory Levels identify sites for follow-up.
  - Risk assessment allows flexibility in prioritizing actions to be taken.
  - Traffic situations play large role in minimum skid numbers and in risk assessment.

- Rigid German road friction responsibilities set in concrete:
  - High level for minimum skid number must be met upon initial installation and acceptance testing.
  - Skid numbers decrease to levels comparable with UK for in-service road monitoring and pavement management after four years.
  - Skid number minimum values based only on speed limits.
  - Temporary solution adopted with reduction in speed limits until remedial action can be implemented.

- The US should work closely with key stakeholders in the UK to understand the key elements allowing the implementation of their policies, hence identifying ways to avoid obstacles perceived in the United States. Of particular notice from this effort are:
  - The acceptance and use of a single method for skid resistance measurements (SCRIM) on major roads.
  - The recognition for the need of a range of investigatory levels, rather than a rigid single value.
  - The decision to post signs temporarily at sites for which investigations revealed the need for resurfacing.

References

CSS Guidance Note: Skidding Resistance. May 2005. http://www.cssnet.org.uk/members/committees/engineering/groups/highways-management/Highway-Condition-Assessment/activities/CSS 20Skidding 20Resistance 20Guidance 20Note.pdf

FHWA, "Asphalt Pavement Warranties - Technology and Practice in Europe", FHWA Report FHWA-PL-04-002, November 2003

HD28/04 "Pavement Design and Maintenance, Pavement Maintenance Assessment." Part 1. HD28/04 Skid Resistance. http://www.archive2.official-documents.co.uk/document/deps/ha/dmrb/vol7/section3/hd2804.pdf

Hegmon, R.R., "A Close Look at Road Surfaces." Federal Highway Administration, Public Roads On-Line. http://www.tfhrc.gov/pubrds/summer93/p93su4.htm

Henry, J.J., "Evaluation of Pavement Friction Characteristics." National Cooperative Highway Research Program (NCHRP) Synthesis 291. 2000.

Kennedy, "Allocating Skid Resistance Investigatory Levels on the Basis of Risk Analysis", http://www.surfacefriction.org.nz/downloads/PDFs/session 203/3 Kennedy Allocating Skid Resistance FP.pdf. 2005

Kuttesch, J.S., "Quantifying the Relationship between Skid Resistance and Wet Weather Accidents for Virginia Data." Thesis Submitted to Faculty of Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 2004. http://scholar.lib.vt.edu/theses/available/etd-10312004-081948/unrestricted/Kuttesch_ThesisFinal.pdf

Labi, S., Lamptey G., Sinha K.C., "Investigating the Sensitivity of Optimal Network Safety Needs to Key Safety Management Inputs." Presented at 84th Annual Meeting Transportation Research Board, Washington, DC, January 2005.

Larson, R.M., "Using friction and texture data to reduce traffic fatalities, serious injuries, and traffic delays." First Inaugural International Conference on Surface Friction, Christchurch, New Zealand, May 1-4, 2005. Available on-line at www.surfacefriction.org.nz/

McDaniel, R.S., "Identification of Laboratory Techniques to Optimize Superpave HMA Surface Friction Characteristics." Phase I: Final Report SQDH 2003 – 6, HL 2003 – 19, October 2003. http://ntl.bts.gov/lib/24000/24600/24637/SQDH2003-6_Final_Report.pdf

Noyce, D.A., Bahia, H.U., Yambo, J.M., Guisk, K., "Incorporating road safety into pavement management: Maximizing asphalt pavement surface friction for road safety improvements." Midwest Regional University Transportation Center, Traffic Operations and Safety (TOPS) Laboratory. April 2005.

Ohio Department of Transportation, Pavement Design Concepts. January 1999. http://www.dot.state.oh.us/pavement/Pubs/Sect200.pdf

Ohio Department of Transportation, Pavement Management. January 1999. http://www.dot.state.oh.us/pavement/Pubs/Sect100.pdf

Oregon Department of Transportation Final Report. 2004 Pavement Condition Report, http://highway.odot.state.or.us/cf/otms/pavement/Reports/2004 20Condition 20Report 20Internet 20Version 20Final.pdf

Road Engineering Journal, “Forty-Eight State Survey Showed Pavement Skid-Resistance Evaluation Varied Considerably.” 1997 hppt://www.usroads.com/journals/rej/9706/re970603.htm

Shah, S.C., “An integrated pavement data management and feedback system (PAMS).” Research Report 195 Project Number 79-IG, Louisiana Department of Transportation and Development, 1987. http://www.ltrc.lsu.edu/pdf/2005/report_195.pdf

Sinhal, R., “The Implementation of a skid policy to provide the required friction demand on the main road network in the United Kingdom.” November 9, 2005. http://www.surfacefriction.org.nz/downloads/PDFs/session 201/1 20 20SINHAL 20R 20-20The 20implementation 20of 20a 20skid 20....pdf

Summers, C.J., The Idiots’ Guide to Highways Maintenance. http://www.highwaysmaintenance.com/skidtext.htm

WSDOT, Washington State Department of Transportation. “A guide for local agency pavement managers.” 1994. http://www.wsdot.wa.gov/fasc/EngineeringPublications/Manuals/StreetwiseGuide.pdf

Watson, R., “The New World of Pavement Management – Efficient and Effective.” http://www.maine.gov/newsletter/sept2003/new_world_of_pavement_management. htm

Appendix A

Bibliography of Literature Reviewed

1. CSS Guidance Note: Skidding Resistance. May 2005. http://www.cssnet.org.uk/members/committees/engineering/groups/highways-management/Highway-Condition-Assessment/activities/CSS 20Skidding 20Resistance 20Guidance 20Note.pdf
2. Federal Highway Administration, "The highway performance monitoring system (HPMS)." Accessed November 11, 2005 http://www.fhwa.dot.gov/ohim/nahpms.html
3. Flintsch, G.W., Luo, Y., Al-Qadi, I.L. "Analysis of the Effect of Pavement Temperature on the Frictional Properties of Flexible Pavement Surfaces." Presented at Transportation Research Board, Washington, DC., January 2005.
4. Flintsch, K.K. McGhee, "High speed texture measurement of pavements." Final report to Virginia Transportation Research Council, 2003.
5. Florida Department of Transportation State Materials Office, "Flexible Pavement Condition Survey Handbook." April 2003. http://www.dot.state.fl.us/statematerialsoffice/administration/resources/library/publications/researchreports/PavementResearch/2003flexhandbook.pdf
6. Florida Department of Transportation, FDOT-814, Executive Summary, July 2001. http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_SMO/FDOT_814.pdf
7. Florida Department of Transportation, Flexible Pavement Design Manual, Section 6.4.3, 2005. http://www.dot.state.fl.us/PavementManagement/pcs/FlexiblePavementDesignManual2005.pdf
8. "Forty-Eight State Survey Showed Pavement Skid-Resistance Evaluation Varied Considerably." Road Engineering Journal. 1997 hppt://www.usroads.com/journals/rej/9706/re970603.htm
9. Hegmon, R.R., "A Close Look at Road Surfaces." Federal Highway Administration, Public Roads On-Line. http://www.tfhrc.gov/pubrds/summer93/p93su4.htm
10. Henry, J.J., "Evaluation of Pavement Friction Characteristics." National Cooperative Highway Research Program (NCHRP) Synthesis 291. 2000.
11. Jackson, N.M., C. Holzschuler. "Measuring pavement friction characteristics at variable speeds for added safety." http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_SMO/FDOT_DO2022.pdf
12. Kennedy, C., M. Haydon, J. Donbavand., "Allocating Skid Resistance Investigatory Levels on the basis of Risk Analysis." First Inaugural International Conference on Surface Friction, Christchurch, New Zealand, May 1-4, 2005. Available on-line at www.surfacefriction.org.nz/, http://www.surfacefriction.org.nz/downloads/PDFs/session 203/3 20 20KENNEDY 20C 20- 20Allocating 20Skid 20Resistance 20... 20FP.pdf
13. Kentucky Department of Transportation, "Kentucky Highway Rating System." Report KTC-02-30/SPR-256-01-1F. 2003. http://ntl.bts.gov/lib/23000/23700/23772/KTC_02_30_SPR_256_01_1F.pdf
14. Kuennen, T., "Creating friction where rubber meets the road." *Better Roads* October 2003.
15. Kuttesch, J.S., "Quantifying the Relationship between Skid Resistance and Wet Weather Accidents for Virginia Data." Thesis Submitted to Faculty of Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 2004.

http://scholar.lib.vt.edu/theses/available/etd-10312004-081948/unrestricted/Kuttesch_ThesisFinal.pdf

16. Labi, S., G. Lamptey, K.C. Sinha, "Investigating the Sensitivity of Optimal Network Safety Needs to Key Safety Management Inputs." Presented at 84th Annual Meeting Transportation Research Board, Washington, DC, January 2005.
17. Larson, R.M., "Using friction and texture data to reduce traffic fatalities, serious injuries, and traffic delays." First Inaugural International Conference on Surface Friction, Christchurch, New Zealand, May 1-4, 2005. Available on-line at http://www.surfacefriction.org.nz, http://www.surfacefriction.org.nz/downloads/PDFs/session%201/3%20%20LARSON%20R%20-%20%20Using%20friction%20and%20texture%20....pdf
18. Maine Department of Transportation, Automatic Road Analyzer (ARAN). http://www.maine.gov/mdot/systems_management/aran.php
19. Maine Department of Transportation, Automatic Road Analyzer Data Options (ARAN). http://mainegov-images.informe.org/mdot/systems_management/images/arandata.jpg
20. McDaniel, R.S., "Identification of Laboratory Techniques to Optimize Superpave HMA Surface Friction Characteristics." Phase I: Final Report SQDH 2003 – 6, HL 2003 – 19, October 2003. http://ntl.bts.gov/lib/24000/24600/24637/SQDH2003-6_Final_Report.pdf
21. McDaniel, R.S., W.D. Thornton, "Field Evaluation of a Porous Friction Course for Noise Control." Presented at Transportation Research Board, Washington, DC., January 2005.
22. Noyce, D.A., Bahia, H.U., Yambo, J.M., Guisk, K. "Incorporating road safety into pavement management: Maximizing asphalt pavement surface friction for road safety improvements." Midwest Regional University Transportation Center, Traffic Operations and Safety (TOPS) Laboratory. April 2005.
23. Ohio Department of Transportation, "Pavement Condition Rating System." 2004. http://www.dot.state.oh.us/pavement/files/2004 20PCR 20Manual.pdf
24. Ohio Department of Transportation, Pavement Design Concepts. January 1999. http://www.dot.state.oh.us/pavement/Pubs/Sect200.pdf
25. Ohio Department of Transportation, Pavement Management. January 1999. http://www.dot.state.oh.us/pavement/Pubs/Sect100.pdf
26. Oregon Department of Transportation Final Report. 2004 Pavement Condition Report, http://highway.odot.state.or.us/cf/otms/pavement/Reports/2004 20Condition 20Report 20Internet 20Version 20Final.pdf
27. Oregon Department of Transportation. "Highway Performance Monitoring System (HPMS)." http://www.oregon.gov/ODOT/TD/TDATA/tsm/hpms.shtml#Data_Summaries Accessed December 2, 2005.
28. Owen, M.T. and Donbavand, J., "There's a Fraction, too Little Friction", ", Conference on Surface Friction, Christchurch, New Zealand, May 1-4, 2005. Available on-line at http://www.surfacefriction.org.nz, http://www.surfacefriction.org.nz/downloads/PDFs/session%201/2%20%20OWEN%20M%20-%20Theres%20a%20Fraction%20too%20little%20Friction%20....pdf
29. "Pavement Design and Maintenance, Pavement Maintenance Assessment." Part 1. HD28/04 Skid Resistance http://www.archive2.official-documents.co.uk/document/deps/ha/dmrb/vol7/section3/hd2804.pdfProving Ground Support Program/Pavement Friction. http://tti.tamu.edu/inside/cdv/cpg/skid.stm

30. Prowell, B.D., D.I. Hanson, “Evaluation of Circular Texture Meter for Measuring Surface Texture of Pavements.” Presented at 84th Annual Meeting Transportation Research Board, Washington, DC, January 2005.
31. Roe, P.G. and Sinhal, R., “How do you Compare? Correlation and Calibration of Skid Resistance and Road Surface Friction Measurement Devices”, Conference on Surface Friction, Christchurch, New Zealand, May 1-4, 2005. Available on-line at http://www.surfacefriction.org.nz, http://www.surfacefriction.org.nz/downloads/PDFs/session%205/1%20%20ROE%20P%20-%20How%20do%20you%20compare%20paper%20....pdf
32. Roe, P.G. and Sinhal, R., “Recent Developments to the SCRIM Measurement Technique in the UK”, First Inaugural International Conference on Surface Friction, Christchurch, New Zealand, May 1-4, 2005. Available on-line at www.surfacefriction.org.nz/, http://www.surfacefriction.org.nz/downloads/PDFs/session%208/Part%201/4%20%20ROE%20P%20-%20Recent%20developments%20to%20the%20SCRIM%20....pdf
33. Seiler-Scherer, L., “Is the correlation between pavement skid resistance and accident frequency significant?” Conference Paper Swiss Transport Research Conference, Monte Verita, Ascona, March 2004. http://www.strc.ch/pdf_2004/Seiler_SkidResistance_STRC_2004.pdf
34. Shah, S.C., “An integrated pavement data management and feedback system (PAMS).” Research Report 195 Project Number 79-IG, Louisiana Department of Transportation and Development, 1987. http://www.ltrc.lsu.edu/pdf/2005/report_195.pdf
35. Shuo, L., Zhu, K., Noureldin, S., Harris, D., “Identifying Friction Variations with the Standard Smooth Tire for Network Pavement Inventory Friction Testing.” Presented at Transportation Research Board, Washington, DC., January 2005.
36. Sinhal, R., “The Implementation of a skid policy to provide the required friction demand on the main road network in the United Kingdom.” First Inaugural International Conference on Surface Friction, Christchurch, New Zealand, May 1-4, 2005. Available on-line at www.surfacefriction.org.nz/, http://www.surfacefriction.org.nz/downloads/PDFs/session 201/1 20 20SINHAL 20R 20-20The 20implementation 20of 20a 20skid 20....pdf
37. Smadi, O.G., Z.N. Hans, T. Maze. “Iowa Pavement Management Database: Integration and Delivery.” Report to Center for Transportation Research and Education, 1999. http://www.ctre.iastate.edu/pubs/conferences/ipmpdata.pdf
38. Summers, C.J., The Idiots’ Guide to Highways Maintenance. http://www.highwaysmaintenance.com/skidtext.htm
39. Transportation Research Center, “Performance Evaluation of Louisiana’s Superpave Implementation Projects Utilizing the Superpave Shear Tester.” Research Project 98-1B, Louisiana November 1998.
40. Viner, H.E., Singhal, R. and Parry, A.R., “Linking Road Traffic Accidents with Skid Resistance – Recent UK Developments”, First Inaugural International Conference on Surface Friction, Christchurch, New Zealand, May 1-4, 2005. Available on-line at www.surfacefriction.org.nz/, http://www.surfacefriction.org.nz/downloads/PDFs/session%201/4%20%20VINER%20H%20-%20Linking%20road%20traffic%20accidents%20....pdf

41. Washington State Department of Transportation. “A guide for local agency pavement managers.” 1994. http://www.wsdot.wa.gov/fasc/EngineeringPublications/Manuals/StreetwiseGuide.pdf
42. Watson, R., “The New World of Pavement Management – Efficient and Effective.” http://www.maine.gov/newsletter/sept2003/new_world_of_pavement_management. htm
43. Wisconsin Department of Transportation, “WISDOT Pavement Management System. (Adapted from WISDOT, 1999)”. (http://training.ce.washington.edu/WSDOT/state_information/11_pavement_management /wsdot_pms.htm Accessed December 2, 2005.

Appendix B

Test Methods used to Evaluate Pavement Conditions

Name	Background	Measures	ASTM / Other standard	Friction-Based?	Actions Required	Comments
ICC International Cybernetics Corporation	Developed by private company	Proprietary texture estimate	NA	No	None	
MGPS	Developed by FHWA	Mean profile depth	E1845	No	None	
Volumetric: Sand patch	Traditional	Mean texture depth	E965	No	None	
CTMeter	Developed by Nippon Sangyo Co. of Japan	Mean profile depth and root mean square	NA	No	None	Profilometer
Skid Trailer	Multiple Sources	Drag Force		Yes	Depends on State Agency Policies	
British Polishing Wheel	Multiple Manufacturers	Aggregate Properties	D3319	yes	None	Polish value correlation between aggregate type and friction: high value = good friction, low value = poor friction
Mohs hardness	Multiple Manufacturers	Aggregate Properties		Yes	None	Rough grains or mix of mineral texture will resist polishing and maintain good wet--weather frictional properties
British Portable Skid Resistance Tester (BPT / Pendulum Tester)	Multiple Manufacturers	Skid Resistance Value (SRV)	BS EN 13036-4 : 2003		None	Pendulum apparatus used to obtain British Pendulum Number (BPN). Used as an indirect measure of microtexture.
SCRIM: Sideways Force Coefficient Routine Investigation Machine	Multiple Manufacturers	Sideways Force Coefficient (SFC)	BS 7941-1: 1999	Yes	Depends on Agency Policies	Developed in Great Britain. Yaw of 20 degrees. Water applied to pavement at controlled rate. Sensitive to microtexture but not affected by macrotexture.
Mu-Tester	Multiple Manufacturers	Sideways Force Coefficient (SFC)	ASTM-E670	Yes	Depends on State Agency Policies	Developed for airport runways applied to highways. Water applied to pavement at controlled rate. Sensitive to microtexture but not affected by macrotexture.

Name	Background	Measures	ASTM / Other standard	Friction-Based?	Actions Required	Comments
Fixed-Slip Devices	Multiple Manufacturers	Brake Slip Numbers (BSN) using Slip data		Yes	Depends on State Agency Policies	Measures friction observed by vehicles with anti-lock brakes. Water applied to pavement at controlled rate. Sensitive to microtexture.
Variable Slip Devices	Multiple Manufacturers	Slip Friction Numbers (SFN)	ASTM E1859	Yes	Depends on State Agency Policies	(Longitudinal friction force)/(Vertical force) as test tire observes predetermined set of slip rates to determine SFN from zero to test speed. Results presented in graphical format.
Locked Wheel Devices	Multiple Manufacturers	Skid Number (SN) Friction Number (FN)	ASTM E 274 ASTM E 524 ASTM E 510	Yes	Depends on State Agency Policies	Most common method used in US. Used in all 50 states. Developed to measure friction under emergency braking conditions for vehicles w/o anti-lock brakes. Measures @ slip speed = vehicle speed. Water applied to pavement. Disadvantage: test time = 1 sec. Noncontinuous measures might result in missing low friction spots.
PFT: Pavement Friction Tester	Multiple Manufacturers	Locked Wheel Principle (friction between wheel and pavement)	E274	Yes	Depends on State Agency Policies	Standard apparatus for testing road friction in USA
Griptester	Multiple Manufacturers	Grip Number	BS 7941-2: 2000	Yes	Depends on Agency Policies	Gears down third wheel to measure road surface resistance.
Selcom, Optiocator 64kHz laser system	LMI Technologies	Friction Number	E 274; E 501; E 524; E 1845; E 965	Yes	None	Obtains MPD (Mean Profile Depth) info at higher speeds. However, correlations between MPD and FN are weak
Circular Track Polishing Machine	Multiple Manufacturers	Aggregate Polish?		No	None	After 8 hrs of polishing, the friction can be measured using British Pendulum or Variable Speed Friction Tester

Name	Background	Measures	ASTM / Other standard	Friction-Based?	Actions Required	Comments
Variable Speed Friction Tester (VST)	Multiple Manufacturers	Pendulum type friction		Yes	Depends on State Agency Policies	Better results than British Pendulum due to locked-wheel smooth rubber tire instead of rubber slider. Also employs water stream with adjustable flow rates.
Dynamic Friction Tester (DFT)	Multiple Manufacturers	Friction	E1911	Yes	Depends on State Agency Policies	Direct measurement of surface friction. Measures changes in friction as the disk slows - speed dependency of surface friction. DFT is effected by micro/macro textures. DFT + MPD measurements can be used together to determine International Friction Index.

Appendix C

Results of 48-State survey of Skid Resistance Evaluation

The categories for incorporating aggregate properties and/or skid resistance in guidelines for pavement evaluations are listed below:

Category I: No specific guidelines to address skid resistance. However, frequent field testing conducted to assure skid numbers remained acceptable.

Category II. Skid resistance accounted for through mix design. Frequent skid field tests conducted to assure adequate skid resistance.

Category III. General aggregate classification procedures used to control quality of aggregates used and thereby provide adequate skid resistance. Skid field testing employed to assure adequate skid resistance over time.

Category IV. Evaluate aggregate frictional properties using lab test procedures (AIR, PV, Moh's, Petrographic Analysis, AWI) Only aggregates meeting specs in lab tests qualified for use in highway pavement systems.

Category V. Both laboratory test and field results used to decide classification of aggregate and its appropriateness for road pavement systems.

State DOT	Category I	Category II	Category III	Category IV	Category V
Alabama				X	
Arizona		X			
Arkansas			X		
California	X				
Colorado	X				
Connecticut	X				
Delaware			X		
Florida				X	X
Georgia			X		
Idaho	X				
Illinois			X		
Indiana				X	
Iowa				X	
Kansas			X		
Kentucky				X	X
Louisiana				X	
Maine		X			
Maryland	X				
Massachusetts	X				
Michigan				X	
Minnesota				X	
Mississippi				X	

State DOT	Category I	Category II	Category III	Category IV	Category V
Missouri	X				
Montana		X			
Nebraska		X			
Nevada	X				
New Hampshire		X			
New Jersey				X	
New Mexico	X				
New York				X	
North Carolina	X				
North Dakota	X				
Ohio	X				
Oklahoma				X	
Oregon		X			
Pennsylvania				X	X
Rhode Island	X				
South Carolina				X	
South Dakota		X			
Tennessee				X	
Texas				X	X
Utah				X	
Vermont		X			
Virginia			X		
Washington		X			
West Virginia			X		
Wisconsin				X	
Wyoming	X				

Appendix D

Survey Questions

NATIONAL TRANSPORTATION RESEARCH CENTER, INCORPORATED

COOPERATIVE AGREEMENT #DTFH61-03-X-00030
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

TASK 2003E1
"ASSESSMENT OF FRICTION-BASED PAVEMENT METHODS AND REGULATIONS"

SURVEY QUESTIONS

APRIL 14, 2006

PURPOSE OF THIS SURVEY

This is a survey to collect information on procedures used by highway agencies to:

- Evaluate pavement conditions, including the methods and criteria, if any, used to qualify pavement conditions,
- Identify whether criteria used to evaluate pavement condition is based on friction or not,
- Characterize actions required based on the specific values of the criteria used.

Agency: ____

Name of respondent: _________________________________

Title: ____

Phone: ___________________ Fax: _____________________

e-mail: ____

SECTION A - BACKGROUND

Q1. Is your job related to pavement condition evaluation?

Yes _____ No _____

SECTION B - GENERAL QUESTIONS ABOUT FRICTION MEASUREMENTS

Q2. Does your agency use any type of friction measurement (e.g., conduct regular surveys of the friction of your network)?

Yes _____ (continue to Q3 page 3)
No _____ (go to Q34 on page 10)

Q3. What are the friction measurements used for?

- to evaluate the quality of newly constructed or repair sections (QC) Yes / No
- to study the conditions of specific sites for research Yes / No
- to diagnose the condition of specific sites and determine the appropriate remedies [not restricted to winter maintenance] Yes / No
- to monitor the condition of a road network for pavement management Yes / No
- to conduct regular surveys of the friction of your network Yes / No
- to measure friction at accident locations Yes / No
- for winter maintenance Yes / No
- Other. Explain ____

Q4. If you conduct regular surveys of the friction of your network, please indicate what percentage of each of the following roadway system is tested:

	%
Interstate	
Primary	
Secondary	
Local Roads	

Q5. Are these roadway systems tested on a regular pre-determined frequency (annually, every two years) or on an as-needed basis:

	Annual	**Biennial**	**As-needed**
Interstate			
Primary			
Secondary			
Local Roads			

Q6. If tested on an as-needed basis, what criteria are used to determine if a roadway qualifies for friction monitoring?

____
____
____
____

Q7. Besides friction, what other measure(s) does your state use to evaluate pavement conditions (e.g., roughness, smoothness…) ?

____
____
____
____

SECTION C – QUESTIONS ABOUT MEASURING DEVICES USED

Q8. What type(s) of friction measuring equipment does your agency use?
If you use more than one type of device, can you please specify which device is used for what purposes? (i.e. for large scale pavement condition monitoring vs. for research)?
____

Operational Mode:
- Side Force _______
- Variable Slip _______
- Fixed Slip _______
- Locked Wheel _______
- Slider _______
- Other ____________________

Tester Type:
- ASTM E-274 Trailer ________
- Mu-Meter ________
- SCRIM ________
- Griptester ________
- Other ____________________

Q9. Why does your agency use this (these) device(s)?
____
____

Q10. If applicable, what type of test tire does your agency use for the surveys?

- ASTM E-524 (smooth) ________
- ASTM E-501 (ribbed) ________
- Other ______________________

Q11. What test speeds does your agency use for the friction surveys?
____
____

Q12. What is the spatial frequency and sample length of your friction testing?

- Samples per mile ___________
- Sample length ___________

Q13. Do you adjust for temperature, seasonal and speed variations?

Temperature: Yes _____ No _____
Seasonal Variations Yes _____ No _____
Speed Yes _____ No _____

Q14. Have you used other friction measuring equipment in the past?

Yes _____ No _____

If yes, which one, when and where?
____
____

Q15. Are you familiar with any other friction measuring equipment?

Yes _____ No _____

If yes, which equipment and how did you become familiar with it (agency tested it, other agencies use it etc…)
____
____

SECTION D – QUESTIONS ABOUT THE USE OF DATA COLLECTED

Q16. What do you do with the data collected?

Friction data? ____
____
Other data? ____
____

Q17. Do you record and archive friction data?

Yes _____ No _____

If yes, how do you archive the data? ___________

If yes, what do you do with the archived data? ___________

If yes, what would you like to do with the archived data? ___________

SECTION E – QUESTIONS ABOUT GUIDELINES, PROCEDURES, THRESHOLD VALUES AND ACTIONS

Q18. Does your agency have guidelines for friction measurements?

Yes _____ No _____

If yes, what are these guidelines? Can we obtain a copy? _________________________
____
____

If no, why not? ____
____
____

Q19. Does your agency have established threshold values of friction measurements?

Yes _____ No _____

If yes, what are these threshold values? _______________________________________
____
____

If no, why not? ____
____

Q20. Does your agency have established follow-up actions based on friction measurements?

Yes _____ No _____

If yes, what are these follow-up actions? _______________________________________
____
____

If no, why not? ____
____

Q21. Do you know of any policy developed or even implemented in your state regarding specific follow-up actions to be taken, given particular readings of friction?

Yes _____ No _____

If yes, what are these policies? ____
____
____

If no, do you think it would be beneficial to develop and implement such policies? Please explain ____
____

Q22. What other intervention methods does your agency use for readings other than the threshold value? For example, when value is slightly below the threshold, is something less involved recommended?
____
____
____

Q23. Are there other criteria besides the friction readings that are used to initiate or prioritize road maintenance actions? (e.g., accident frequency at a given location)
____
____
____

Q24. Do you think your current practice(s) provide you with what you need?

Yes _____ No _____

Q25. Based upon your experience, do you think there are any possible deficiencies in the current procedure?

Yes _____ No _____

Q26. What do you think should be done to correct them? ______________________________
____
____

Q27. Would you need additional tools? If so, which ones would you find useful and how would they be useful?

Yes _____ No _____
____
____

Q28. Do you know of other agencies that have established policies, developed guidelines, threshold friction values and associated follow-up actions based on friction measurements?

Yes _____ No _____

If yes, which ones?

____

____

Q29. How does your practice(s) compare with other states' practices?

____

____

Q30. Do you think there should be national guidelines including methods used, criteria and follow-on actions?

____

____

SECTION E' – QUESTIONS ABOUT REGULATIONS AND POLICY

Q31. In general terms, explain the applicable legislative or regulatory basis or requirements for your friction monitoring program?

____
____
____

Q32. Does your agency have policies or regulations for friction measurements?

Yes _____ No _____

If yes, could you share info with us? ____
If no, why not? ____
____

Q33. Do you think friction levels should be regulated?

Yes _____ No _____

Explain ____
____

Continue to Q41

SECTION F – QUESTIONS IF YOUR AGENCY DOES NOT USE FRICTION MEASUREMENTS

Q34. Do you think that the use of friction measurement could be useful to your state?

Yes _____ No _____

Q35. Why does your agency not conduct regular surveys of the friction of your network (i.e. use any type of friction measurement)? (i.e. cost, not needed, other means are used, technology tested to date is not ready)

Q36. What do you think it would take to implement friction monitoring by your agency?

Q37. What does your agency do to characterize road surface conditions (smoothness, texture?)

Q38. How does your practice(s) compare with other states' practices?

Q39. Do you know of other agencies that have established policies, developed guidelines, or established threshold friction values and associated follow-up actions based on friction measurements?

Yes _____ No _____

If yes, which ones? ____________________

Q40. Do you think there should be national guidelines including methods used, criteria and follow-on actions?

SECTION G – OTHER QUESTIONS

Q41. Does your state regulate the amount of spray generation and visibility reduction related to the pavement surface characteristics (microtexture or macrotexture)?

Yes _____ No _____

Q42. Does your state have a standard practice to quantify the amount of spray or is there any qualitative measure for evaluation of spray generation?

Yes _____ No _____

Q43. Is highway noise being measured in your agency ?

Yes _____ No _____

Q44. Are there any regulations or corrective measures related to noise?

Yes _____ No _____

Q45. Is there a standard for measurement of noise?

Yes _____ No _____

Thank you for your time!

Appendix E

Compilation of Results Obtained from the 9-State survey

Section B - General questions about friction measurements

Table E1 Responses to Question 2, "Does your agency use any type of friction measurement?"

State		
Arizona	Yes	
Virginia	Yes	
Maryland	Yes	
Texas	Yes	
New York	Yes	
Washington State	Yes	
Illinois	Yes	
Kentucky	Yes	

Table E2 Responses to Question 3, "What are the friction measurements used for?"

State	**Evaluate quality of newly constructed or repair sections (QC)**	**Study conditions of specific sites for research**	**Diagnose condition of specific sites and determine appropriate remedies**	**Monitor condition of road network for pavement management**	**Conduct regular surveys of friction**	**Measure friction at accident locations**	**Winter maintenance**	**Other**
Arizona	No	Yes	Yes	Yes	Yes	Yes	No	
Virginia	No	Yes	Yes	No	Yes	Yes	No	
Maryland	No	Yes	Yes	Yes	Yes	Yes	No	
Texas	No	Yes	Yes	Yes	Yes	Yes	No	Evaluation and classification of aggregate
New York	No	Yes	Yes	No	No	Yes	No	
Washington State	Yes	Yes	No	Yes	Yes	No	No	
Illinois	Yes	Yes	Yes	No	No	Yes	No	
Kentucky	Yes	Yes	Yes	Yes & No	Yes	No	No	Evaluation of aggregates and pavements for their non-polishing capabilities.

Table E3 Responses to Question 4, "What percentage of each category of roadway system is tested?"

State	Interstate	Primary	Secondary	Local Roads
Arizona	100%	100%	100%	0%
Virginia	100% (33%/yr)	100% (25%/yr)	Spec Request	Spec Request
Maryland	100%	100%	100%	100%
Texas	50%	25%	25%	0%
New York	<10 %*	<10 %*	<10 %*	By Request
Washington State	100%	100%	100%	0%
Illinois	N/A	N/A	N/A	N/A
Kentucky	100%**	100%**	100%**	100%**

**Reported that low percentages were due to high number of miles in road network.*
*** Kentucky reported 100% of interstate network is tested initially after pavement is laid down. Testing drops off as road reaches 10 million CTC (cumulative traffic ?). Primary, secondary and local roads would be tested in the same manner if they met ADT (average daily traffic) requirements.*

Table E4 Responses to Question 5, "With what frequency are friction measurements taken?"

State	Interstate	Primary	Secondary	Local Roads
Arizona	Biennial *	Biennial*	Biennial*	Never
Virginia	3-yr cycle	4-yr cycle	As requested	As requested
Maryland	Annual	Annual	Annual	Annual
Texas	Annual	Annual	Annual	NR
New York	As-needed	As-needed	As-needed	As requested
Washington State	Biennial	Biennial	Biennial	Never
Illinois	N/A	N/A	N/A	N/A
Kentucky	Annual*	Annual*	Annual*	Annual*

** Reported that friction measurements are taken on "as-needed" basis in addition to regularly scheduled testing.*

Table E5 Responses to Question 6, "If tested on an as-needed basis, what criteria are used to determine if a roadway qualifies for friction monitoring."

State	By request	Visual Inspection which suggests friction may be low.	Higher than usual wet accident rate	Other
Arizona	X	X		
Virginia			X	
Maryland	NA			
Texas	Discretion of TxDot pavement engineer or other district manager.			
New York	Discretion of District Pavement Managers Discretion of Traffic & Safety Department	X	X	Inventory testing sites as determined by geology
Washington State	NA			
Illinois	X		X	New Surfaces
Kentucky	X			New Surfaces

Table E6 Responses to Question 7, "Besides friction, what other measure(s) does your state use to evaluate pavement conditions?"

State	Cracking	Flushing	Roughness	Rutting	Patching	Ride Quality	IRI
Arizona	X	X	X	X	X		
Virginia	X			X		X	X
Maryland	X			X		X	
Texas				X		X	X
New York			X				
Washington State	X	X	X	X	X	X	X
Illinois			X				X
Kentucky	X		X	X	X	X	X

Section C – Questions about measuring Devices used

Table E7 Responses to Questions 8 & 9, "What type of friction measuring equipment does your agency use?" and "Why does your agency use this (these) device(s)?"

State	Operational Mode	Tester Type	Test Tire	Reason for using
Arizona	Fixed Slip	Dynatest Highway Slip Friction Tester	ASTM E-1551 (Smooth Tread Tire)	Ease of use
Virginia	Variable Slip Locked Wheel	ASTM E-274 Trailer Dynamic Friction Tester	ASTM E-524 (smooth tire)	E-274: Production Tester DF Tester: Research
Maryland	Locked Wheel	ASTM E-274	ASTM E-501 (Ribbed Tire)	"Network & project level testing"
Texas	Locked Wheel	ASTM E-274	ASTM E-524 (smooth tire) ASTM E-501 (Ribbed Tire) occasionally, as needed	Consistency with historical data; also similarity to laser-based texture measurements
New York	Locked Wheel	ASTM E-274	ASTM E-501 (Ribbed Tire)	Considered to be most accurate, more like real world conditions. Promoted by FHWA
Washington State	Locked Wheel	ASTM E-274	ASTM E-501 (Ribbed Tire)	Been the device of preference for 20+ years. Switched to ribbed tire b/c smooth tire did not hold up to friction tests.
Illinois	Locked Wheel	ASTM E-274	ASTM E-524 (smooth tire) ASTM E-501 (Ribbed Tire)	They were perceived as the best available at the time of acquisition to meet Illinois' needs
Kentucky	Locked Wheel	ASTM E-274	ASTM E-501 (Ribbed Tire)	Consistency, satisfied with results

Table E8 Responses to Questions 11 & 12, "What test speeds does your agency use for the friction surveys?" and "What is the spatial frequency and sample length of your friction testing?"

State	Test Speeds	Samples/Mile	Sample Length
Arizona	60 mph*	1	200 ft
Virginia	40 mph	3	1 second
Maryland	40 mph	3.33	Per ASTM E 274
Texas	50 mph	2	~ 100 ft
New York	40 mph**	10	Per ASTM E
Washington State	40 mph	1	Per ASTM spec
Illinois	40 mph	up to 10	0.1 mi and greater
Kentucky	40 mph	5 minimum	147 feet

** When possible, otherwise, 40 mph.*
*** Higher speeds for higher speed roads or by request.*

Table E9 Responses to Questions 13, "Do you adjust for temperature, seasonal and speed variations?"

State	Temperature Variations	Seasonal Variations	Speed Variations
Arizona	No	No	No
Virginia	No	Yes	Yes
Maryland	No*	No*	Yes
Texas	No	No	No
New York	No	No**	Yes
Washington State	Yes	No	Yes
Illinois	No	No	Yes
Kentucky	No***	No***	No

**Maryland is currently evaluating this option because their research has shown that environmental conditions have a significant influence on friction number.*
***New York had tested Spring vs Autumn seasonal variations in some cases. The information gathered was used for research purposed only.*
**** Kentucky limits testing to ambient temperatures between 40 deg F and 99 deg F. All friction tests are completed between July 1 and mid-November.*

Table E10 Responses to Question 14"Have you used other friction measuring equipment in the past?"

State	Other friction measuring equipment used in past?	Type	Dates Used
Arizona	Yes	Mu-Meter	1972-2000
Virginia	No		
Maryland	“not in the past 7 years”		Through 1998 or 1999
Texas	No		
New York	No		
Washington State	No		
Illinois	No		
Kentucky	No		

Table E11 Responses to Question 15, "Are you familiar with any other friction measuring equipment and if so, how did you become familiar with it?"

State	Type of equipment	How did you become familiar with it?						
		Through survey consultant	Open Literature	Vendor	Pavement Conference	Trade Show	Committees	Research Center
Arizona	Skid Car w/locked wheel	X						
Virginia	Variable Slip (Norsemeter/ROAR) Fixed Slip (Griptester, Runway Friction Tester) Side-force friction measuring systems				X			
Maryland					X		X	
Texas	Scrim MuMeter Griptester		X					
New York	British Pendulum Tester Griptester Saltar Mu-Meter			X				
Washington State	Not familiar with other friction measuring equipment							
Illinois	Not familiar with other friction measuring equipment							
Kentucky	British Polishing Wheel							X

Section D – Questions about the use of data collected

Table E12 Responses to Questions 16 (friction data), "What do you do with the friction data collected?"

State	Pavement Management Decisions	Safety Analysis	Accident Investigation	R & D	Identify/Confirm skid-resistance deficiencies
Arizona	X	X	X		
Virginia					X
Maryland	X			Build performance models	
Texas	X (Through district and local agencies)				
New York		X		X	
Washington State	X	X			X
Illinois	X (Through district and local agencies)			Review performance of various pavement surfaces	
Kentucky	X			X	

Table E13 Responses to Questions 16 (other data), "What do you do with the other data collected?"

State	Pavement Management Decisions	Pavement Design	R&D
Arizona	X	X	
Virginia	NR	NR	NR
Maryland			Develop performance measure reports
Texas	X	X	
New York	NR	NR	NR
Washington State	X		X
Illinois	X (Through district and local agencies)		Review performance of various pavement surfaces
Kentucky	NR	NR	NR

Table E14 Responses to Questions 17, "Do you record and archive friction data?"

State	Record and archive friction data?	Archive method	What is currently done with archived data?	What would you like to do with the archived data?
Arizona	Yes	Database	Stored	"Use it"
Virginia	Yes	HTRIS*	"as little as possible"	Update Wet-Accident Reduction Program, Track skid resistance performance of various mixes Create objective non-polishing source-aggregate approval process
Maryland	Yes	Database	PM decisions Build performance models	NR
Texas	Yes	Database	Track Trends	Evaluate performance of specifications, materials, and treatments
New York	Yes	Database	Information is given to requesting agency	Allow requesting groups to query info for research purposes (by aggregate, road type, road geometry) and to be able to correlate GPS data with data collected.
Washington	Yes	Database; Hardcopy; Pavement Management System	Track Trends particularly for pavement wear and durability	No suggestions
Illinois	Yes	NR	Review for pavement performance evaluations	No suggestions
Kentucky	Yes	Database	Annual evaluation of aggregate sources and pavements and pre-qualification of aggregate sources	No suggestions

**HTRIS – DOT pavement inventory system*

Section E – Questions about guidelines, procedures, threshold values and actions

Table E15 States responding “Yes” to Questions 18, "Does your agency have guidelines for friction measurements?”

State	**What are the guidelines?**
Arizona	1. Test at each milepost for ~ 200 ft. 2. Measure wet. 3. Measure at 60 mph
Virginia	Copy being sent by snail mail (from Jerry Garrison)
Texas	ASTM procedures with at least one test per 0.5 mile section.
New York	ASTM procedures for test method. No policy to dictate frequency of testing nor percentage of highway system to be tested.
Washington State	Skid Accident Reduction Program requires skid numbers to be considered in development of appropriate solutions to address both accident and potential accident locations.
Kentucky	Sources of polish resistant aggregate source list must maintain a satisfactory performance level. Sources not on the list must display a satisfactory level by test sections to be added. Performance or sources will be based on pavement friction skid testing, and will be accordance with ASTM E 274. Skid numbers resulting from this test will be evaluated in the range of $6x10^6$ to $10x10^6$ cumulative traffic.

Table E16 States responding “No” to Questions 18, "Does your agency have guidelines for friction measurements?”

State	**Reasons given for no guidelines for friction measurements.**
Maryland	Do not have any regional or national direction coupled with limited resources.
Illinois	Currently in the process of reviewing their Friction Program and will subsequently determine if guidelines are necessary.

Table E17 States responding "Yes" to Questions 19 and 20, "Does your agency have established threshold values of friction measurements?" and "Does your agency have established follow-up actions based on friction measurements?"

State	What are the guidelines?	Follow-up actions based on friction measurements
Arizona	Desired = 43+ "Point of concern" <35	Biennial review of areas below 35 to see if remedial action is appropriate. Post "S W W" signs when <35 verified, also prioritize for remedial actions
Virginia	SN40S<24 = Investigatory SN40S<20 = Intervention	Initial activity: erect warning signs As soon as practical: determine deficiency and restore skid-resistance
Maryland	Category 1 (<35) Category 2 (35-39) Category 3 (40+)	Poor friction roadway sections are combined with high accident locations to develop a friction improvement candidate list.
New York	SN40S<32 = Investigatory	Friction measurements are used in conjunction with accident data when prioritizing road projects.
Washington State	SN40S<26 SN40S range of 26 to 30	Determine if conditions warrant posting of Slipper-When-Wet signs and implement solutions Repeat friction testing for accuracy and possible decline of FN. Determine if conditions warrant posting Slippery-When-Wet signs should be posted.
Kentucky	Values are highly confidential and given only to the vendor supplying the aggregate used in the mix.	Retest. If numbers are still low, field personnel checks out site to determine if further action is required.

Table E18 States responding "No" to Questions 19 and 20, " Does your agency have established threshold values of friction measurements?" and "Does your agency have established follow-up actions based on friction measurements?"

State	Reasons why no threshold values of friction measurements.
Texas	Not specific number, but statistically: based on statewide mean and standard deviation. There is no single "acceptable" skid test value. Site specific conditions are too variable and too predominant.
Illinois	Currently use guidelines of 15 for smooth tire and 30 for treaded tire. However, these are guidelines and not threshold values. Illinois is currently reviewing these numbers to ascertain appropriate guidelines for Illinois pavement. Illinois has a de-centralized IDOT and allows each District Office to determine appropriate follow-up for their individual district.

Table E19 States responding "Yes" to Question 21, "Do you know of any policy developed or implemented in your state regarding specific follow-up actions to be taken, given particular friction readings?"

State	Description of the policy
Virginia	Slippery-When-Wet signs are posted when friction levels drop to "Intervention" levels.
Maryland*	We are in the process of formalizing the policy. A friction improvement list is developed, but appropriate treatments have not been established.
New York	Implements FHWA Skid Accident Reduction Program (2002).
Washington State	Washington State's Skid Accident Reduction Program (1994).
Kentucky	Possible follow-up actions include: de-slicking, possible overlay, coring the road to check the aggregate.

*Responded "yes & no"

Table E20 States responding "No" to Question 21, "Do you know of any policy developed or implemented in your state regarding specific follow-up actions to be taken, given particular friction readings?" and "Do you think it would be beneficial to develop and implement policy regarding follow-up actions?"

State	Comment
Arizona	"It would be a clear liability so it would be counter productive."
Texas	Site specific conditions are too variable and too predominant.
Illinois	Because IDOT is a decentralized department, they can only recommend follow-up activities.

Table E21 Responses to Question 22, "What other intervention method(s) does your agency use for readings other than the threshold value?"

State	
Arizona	Each site is considered for an appropriate action from "Do nothing" to "Do overlay"
Virginia	Nothing specific – monitoring encouraged
Maryland	Friction readings are used in the project level decisions for pavement rehabilitation strategy and material selection for pavement surface.
Texas	Depends on site conditions
New York	1. "PIL" investigation of location by Department of Traffic & Safety 2. Inventory testing of sites as determined by geology 3. Test-by-request
Washington State	Each site is considered for an appropriate action ranging from posting Slippery-When-Wet sign to taking immediate corrective action.
Illinois	Advise the Districts of the potential for friction problems when numbers are approaching guideline values.
Kentucky	Monitor the aggregate source for quality. See how it performs on other sites containing the same mix design.

Table E22 Responses to Question 23, "Are there other criteria besides the friction readings that are used to initiate or prioritize road maintenance actions?"

State	Response
Arizona	Each site is considered in context.
Virginia	High wet-to-dry accident ratio triggers more testing than inventory findings
Maryland	Percentage of wet accidents at a location Ride quality Cracking Rutting Other distresses
Texas	District practitioners have final say, but distress, ride, deflection, and other factors are considered.
New York	Accident frequency & type of accident (i.e. roll-over accident) Engineer requestor (i.e. monitor new surface, product evaluation, research)
Washington State	High accident location High accident corridor
Illinois	High accident locations
Kentucky	Determination made by Operations and Pavement Management Branch.

Table E23 Responses to Questions 24, 25, and 26, "Current Practices"

State	Do you think your current practices provide you with what you need?	Based upon your experience, do you think there are any possible deficiencies in the current procedures?	What do you think should be done to correct current procedures?
Arizona	Yes	Yes	Better coverage
Virginia	No	Yes	High-speed texture screening Tools may reduce need for full-scale skid testing. IFI should be implemented
Maryland	Yes	Yes	Establish a link between aggregate material properties and friction number Identify rehabilitation strategies for a given set of site conditions.
Texas	Yes	Yes	We would like to go to 0.1-mile, non-contact, laser based texture in left and right wheel path.
New York	Yes	No	N/A
Washington State	Yes	Yes	Investigate the use of a ASTM E-524 because of its capability to more accurately assess microtexture. Look into the work being conducted by Texas on the use of lasers for determining texture.
Illinois	No	Yes	Acquire additional friction data to review pavement surface performance
Kentucky	Yes	Yes & No	Comparison testing at 20 mph vs 40 mph and 40 mph vs 60 mph is slated to begin

Table E24 Responses to Question 27, "Would you need additional tools? If so, which ones would you find useful and how would they be useful?"

State	Would you need additional tools?	What tools would you find useful?	How would those tools be useful?
Arizona	Yes	Tools for texture measurements	Would give full length coverage and allow us to focus better on potential low friction sites
Virginia	Yes	A reliable, functioning high-speed texture-measuring system.	Would be capable of accurately and cost-effectively measuring surface microtexture
Maryland	Yes	A tool which would establish a link between geological properties of the aggregate to friction number – perhaps a database or some sort of computer model.	Would be useful to have model for pavement design engineers.
Texas	Yes	Non-contact laser based device to measure texture	Greater precision and greater density of measurements
New York	Yes	Newer software for data collection (currently using DOS data collection software) New skid trailer: Current ASTM trailer purchased in 1992.	Improve data collection/sorting capabilities. Less time spent on equipment repairs would allow more for more data collection.
Washington	No		
Illinois	Yes	Calibration Sites Courses for Test Equipment	No response
Kentucky	No		

Table E25 Responses to Question 28, "Do you know of other agencies that have established policies, developed guidelines, threshold friction values and associated follow-up actions based on friction measurements?"

State	Response	If yes, which ones?
Arizona	Yes	Many states have but we don't keep a list
Virginia	Yes	Florida and Texas
Maryland	No	
Texas	Yes	United Kingdom, Norway, Sweden
New York	Yes	For collecting frictions: Municipalities within New York, other states but doesn't know which ones. For follow-up actions: not aware of any other agencies.
Washington State	No	
Illinois	No	
Kentucky	No	

Table E26 Responses to Question 29, "How does your practice(s) compare with other states' practices?"

State	Response
Arizona	Similar – biggest difference is type of tester we use.
Virginia	"We're better than most"
Maryland	"Above average b/c of our network level data collection and the fact that we use data to make decisions."
Texas	"not really sure"
New York	"Large highway system prevents 100% testing." "Issues are usually not friction, they are road geometry & high speed."
Washington State	"Not Sure"
Illinois	"In recent years, our testing has been limited, due to personnel and funding limitations, and therefore we acquire comparatively less friction data than many other states."
Kentucky	"Average but can be improved upon." Will be conducting comparison tests at pre-determined sites using Tennessee's skid rig.

Table E27 Responses to Question 30, "Do you think there should be national guidelines including methods used, criteria, and follow-on actions?"

State	Response
Arizona	No
Virginia	Yes, see preliminary findings of NCHRP 1-43
Maryland	Yes – national guidelines are needed coupled w/local calibration for regional material properties and climate. Guidelines are desperately needed to have a consistent measuring procedure across all agencies and devices. Everyone needs to be able to speak the same language and numbers.
Texas	No, but I'm a big advocate of national "one-size-fits-all" guidelines.
New York	Yes – for methods used, ASTM provides good guidelines. However, the ASTM guidelines need to be upgraded to account for new technologies/materials/conditions. No-for threshold criteria and follow-on actions.
Washington State	No. Each state has a different procedure. Guidelines should only apply to data collection and analysis. Criteria for follow up actions and definition of those follow up actions should be left to the states.
Illinois	No. Seasonal/temporal, precipitation and other variations within each state may have great impact on friction data.
Kentucky	No. Different weather, climate might dictate different guidelines. More freezing and thawing, etc.

Section E' – Questions about regulations and policy

Table E28 Responses to Question 31, "In general terms, explain the applicable legislative or regulatory basis or requirements for your friction monitoring program."

State	Response
Arizona	FHWA Policy
Virginia	We adhere to FHWA requirements to operate a Wet Accident Reduction Program
Maryland	FHWA direction to have a pavement management system and monitor the condition of the network.
Texas	FHWA requirement for providing skid-resistant surface, & wet weather accident reduction program.
New York	FHWA Skid Accident Reduction Program (2002)
Washington State	Washington State Skid Accident Reduction Program (1994)
Illinois	FHWA requirement for providing skid-resistant surface, & wet weather accident reduction program.
Kentucky	Declined comment.

Table E29 Responses to Question 32, "Does your agency have policies or regulations for friction measurements?"

State	Response	Policy/Regulation for Friction Measurements
Arizona	Yes	We follow FHWA requirements.
Virginia	Yes	See Virginia's WARP user's guide (being sent?)
Maryland	No	"I do not know."
Texas	No	We test for our own benefit in managing the highway system.
New York	Yes	FHWA Skid Accident Reduction Program (2002)
Washington State	Yes	Washington State Skid Accident Reduction Program (1994)
Illinois	No	
Kentucky	No response	Declined comment.

Table E30 Responses to Question 33, "Do you think friction levels should be regulated?"

State	Response	Why or why not
Arizona	No	Too many variables.
Virginia	No	Far too many variables Many state have different aggregate sources – polish resistance inconsistent
Maryland	No	Testing and measurement procedures need to be established, but regulating friction levels would be a challenge.
Texas	No	"No way", measurements do not describe wet weather safety or accident risk.
New York	No	Too many variables that effect friction Liability issues
Washington State	No	Each state has a different procedure. Guidelines should only apply to data collection and analysis. Criteria for follow up actions and definition of those follow up actions should be left to the states. For example, a friction number that may be adequate for a state with lower traffic volumes may not meet the needs of a state with higher traffic volumes.
Illinois	No	Seasonal/temporal, precipitation and other variations within each state may have great impact on friction data.
Kentucky		Declined comment.

Section F – Questions if your agency does not use friction measurements

Not applicable

Section G – Questions about spray and noise

Table E31 Responses to Questions 41 through 45, "Splash/Spray and Noise"

State	Regulate spray generation and visibility reduction?	Quantify amount of spray?	Measure highway noise?	Regulations or corrective measures related to noise?	Standard for measurement of noise?
Arizona	No	No	Yes	Yes	Yes
Virginia	No	No	Yes	Yes	Yes
Maryland	No	No	No	No	No
Texas	No	No	No*	No*	No*
New York	No	No	No**	No	No
Washington State	No	No	Yes	Yes	No***
Illinois	No	No	No	No	No
Kentucky	Not Sure	Not Sure	Not Sure	Not Sure	Not Sure

**Texas reports that they may start measuring noise at some point in the future. They report they are working on getting a standard measurement of noise.*
*** New York has measured highway noise in the past for research purposed only.*
**** Washington State is in the process of purchasing the OBSI equipment, which they would like to see become the standard for measuring noise.*

Appendix F

International Survey Questions

NATIONAL TRANSPORTATION RESEARCH CENTER, INCORPORATED

COOPERATIVE AGREEMENT #DTFH61-03-X-00030
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

TASK 2003E1
"ASSESSMENT OF FRICTION-BASED PAVEMENT METHODS AND REGULATIONS IN THE UNITED KINGDOM"

SURVEY QUESTIONS

JUNE 28, 2006

PURPOSE OF THIS SURVEY

This is a survey to collect information on procedures used by highway agencies to:

- Evaluate pavement conditions, including the methods and criteria, if any, used to qualify pavement conditions,
- Identify whether criteria used to evaluate pavement condition are based on friction or not,
- Characterize actions required based on the specific values of the criterion used.

Agency: ____

Name of respondent: ______________________________

Title: ____

Phone: ___________________ Fax: _____________________

e-mail: ____

SECTION A - BACKGROUND

Q1. Is your job related to pavement condition evaluation?

Yes _____ No _____

SECTION B - GENERAL QUESTIONS ABOUT FRICTION MEASUREMENTS

Q2. Does your agency use any type of friction measurement (e.g., conduct regular surveys of the friction of your network)?

Yes _____ (continue to Q3 page 3)
No _____ (go to Q34 on page 10)

Q3. What are the friction measurements used for?

- To evaluate the quality of newly constructed or repair sections (i.e. Quality Control) Yes / No
- To study the conditions of specific sites for research Yes / No
- To diagnose the condition of specific sites and determine the appropriate remedies [not restricted to winter maintenance] Yes / No
- To monitor the condition of a road network for pavement management Yes / No
- To conduct regular surveys of the friction of your network Yes / No
- To measure friction at accident locations Yes / No
- For winter maintenance Yes / No
- Other. Explain ____

Q4. If you conduct regular surveys of the friction of your network, please indicate what percentage of each of the following roadway system is tested:

United Kingdom	%
Trunk Road	
(Primary)	
2 Lane Carriageway	
(Secondary)	
B Roads	
(Local Roads)	
"C", "D", and "U"	

Q5. Are these roadway systems tested on a regular pre-determined frequency (annually, every two years) or on an as-needed basis:

United Kingdom	Annual	Biennial	As-needed
Trunk Road			
(Primary)			
2 Lane Carriageway			
(Secondary)			
B Roads			
(Local Roads)			
"C", "D", and "U"			

Q6. If tested on an as-needed basis, what criteria are used to determine if a roadway qualifies for friction monitoring?

Q7. Besides friction, what other measure(s) does your agency use to evaluate pavement conditions (e.g., roughness, smoothness…)?

SECTION C – QUESTIONS ABOUT MEASURING DEVICES USED

Q8. What type(s) of friction measuring equipment does your agency use?
If you use more than one type of device, can you please specify which device is used for what purposes? (i.e. for large scale pavement condition monitoring vs. for research)?

____

		Device	Purpose
Operational Mode:	Side Force	________	______________________________
	Variable Slip	________	______________________________
	Fixed Slip	________	______________________________
	Locked Wheel	________	______________________________
	Slider	________	______________________________
	Other	________	______________________________

		Device	Purpose
Tester Type:	ASTM E-274 Trailer	________	______________________________
	Mu-Meter	________	______________________________
	SCRIM	________	______________________________
	Griptester	________	______________________________
	British Pendulum Tester	________	______________________________
	Dynamic Friction Tester	________	______________________________
	Variable Slip Tester	________	______________________________
	Other	________	______________________________

Q9. Why does your agency use this (these) device(s)?

____
____

Q10. If applicable, what type of test tire does your agency use for the surveys?

ASTM E-524 (smooth) ________
ASTM E-501 (ribbed) ________
Other ________________________

Q11. What test speeds does your agency use for the friction surveys?

____
____

Q12. What is the spatial frequency and sample length of your friction testing?

Samples per kilometer ____________
Sample length ____________

Q13. Do you adjust for temperature, seasonal and speed variations?

Temperature:	Yes _____	No _____
Seasonal Variations	Yes _____	No _____
Speed	Yes _____	No _____

Q14. Have you used other friction measuring equipment in the past?

Yes _____ No _____

If yes, which one, when and where?

____

____

Q15. In 1995, PIARC published all skid resistance and texture measuring equipment in use throughout Europe. Has your agency added any additional equipment for measuring friction either for large scale pavement conditioning or research since 1995?

If yes, please list the equipment and what it is used for. ______________________________

____

____

Q16. Are you familiar with any other friction measuring equipment?

Yes _____ No _____

If yes, which equipment and how did you become familiar with it (agency tested it, other agencies use it etc…)

____

____

SECTION D – QUESTIONS ABOUT THE USE OF DATA COLLECTED

Q17. What do you do with the data collected?

Friction data? ____
____
Other data? ____
____

Q18. Do you record and archive friction data?

Yes _____ No _____

If yes, how do you archive the data? ___________

If yes, what do you do with the archived data? ___________

If yes, what would you like to do with the archived data? ___________

SECTION E – QUESTIONS ABOUT GUIDELINES, PROCEDURES, THRESHOLD VALUES AND ACTIONS

Q19. Does your agency have established guidelines for friction measurements?

Yes _____ No _____

If yes, what are these guidelines? If yes, please attach a copy of those guidelines. (If available on the web, a website is acceptable.) ___________________________________
____

If no, why not? ____
____
____

Q20. Does your agency have established investigatory levels (levels dictating follow-up action) based on friction-measured results?

Yes _____ No _____

If yes, are the values site specific or roadway category specific? ___________________
____

If yes, does your agency use a single threshold value or a range of values? ___________
____

If yes, please attach those threshold values.

If no, why your agency does not have established Investigatory Levels? _____________
____
____

Q21. Does your agency have established threshold values of friction measurements?

Yes _____ No _____

If yes, are those values site-specific or roadway-category specific? __________________
____
____

If yes, Does your agency use a single threshold value or a range of values? ___________
____

If yes, What are your threshold values? (If site specific, please include a table.)
____
____

If no, why your agency does not have established threshold values of friction measurements? ____
____

Q22. Does your agency have established follow-up actions based on friction measurements?

Yes _____ No _____

If yes, ____
____
____
____

If no, why not? ____
____

Q23. Do you know of any policy developed or even implemented in your country regarding specific follow-up actions to be taken, given particular readings of friction?

Yes _____ No _____

If yes, what are these policies? ____
____
____

If no, do you think it would be beneficial to develop and implement such policies? Please explain ____
____

Q24. What other intervention methods does your agency use for readings other than the investigatory levels? For example, when value is slightly below the threshold, is something less involved recommended?

____
____
____

Q25. Are there other criteria besides the friction readings that are used to initiate or prioritize road maintenance actions? (e.g., accident frequency at a given location)

____
____
____

Q26. Do you think your current practice(s) provide you with what you need?

Yes _____ No _____

Q27. Based upon your experience, do you think there are any possible deficiencies in the current procedure?

Yes _____ No _____

Q28. What do you think should be done to correct them? ______________________________
____
____

Q29. Would you need additional tools? If so, which ones would you find useful and how would they be useful?

Yes _____ No _____

____
____

Q30. In your opinion, what countries do the best at establishing policies and guidelines for maintaining adequate skid resistance on their roadways?

____
____
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____
____

Q31. How does your practice(s) compare with other countries' practices?

____
____

SECTION E – QUESTIONS ABOUT REGULATIONS AND POLICY

Q32. In general terms, explain the applicable legislative or regulatory basis or requirements for your friction monitoring program?
____
____
____

Q33. Does your agency have policies or regulations for friction measurements?

Yes _____ No _____

If yes, could you share info with us? ________________________________
If no, why not? ____
____

Q34. Do you think friction levels should be regulated?

Yes _____ No _____

Explain ____
____

Continue to Q42 (page 12)

SECTION F – QUESTIONS IF YOUR AGENCY DOES NOT USE FRICTION MEASUREMENTS

Q35. Do you think that the use of friction measurement could be useful to your Country?

Yes _____ No _____

Q36. Why does your agency not conduct regular surveys of the friction of your network (i.e. use any type of friction measurement)? (i.e. cost, not needed, other means are used, technology tested to date is not ready)

____

____

____

Q37. What do you think it would take to implement friction monitoring by your agency?

____

____

____

Q38. What does your agency do to characterize road surface conditions (smoothness, texture?)

____

____

____

Q39. How does your practice(s) compare with other EU nations' practices?

____

____

Q40. Do you know of other agencies that have established policies, developed guidelines, or established threshold friction values and associated follow-up actions based on friction measurements?

Yes _____ No _____

If yes, which ones? ____

____

____

Q41. Do you think there should be national guidelines including methods used, criteria and follow-on actions?

____

____

SECTION G – OTHER QUESTIONS

Q42. Does your state regulate the amount of spray generation and visibility reduction related to the pavement surface characteristics (microtexture or macrotexture)?

Yes _____ No _____

Q43. Does your state have a standard practice to quantify the amount of spray or is there any qualitative measure for evaluation of spray generation?

Yes _____ No _____

Q44. Is highway noise being measured in your agency ?

Yes _____ No _____

Q45. Are there any regulations or corrective measures related to noise?

Yes _____ No _____

Q46. Is there a standard for measurement of noise?

Yes _____ No _____

Thank you for your time!

NTRCI

NATIONAL TRANSPORTATION RESEARCH CENTER, INCORPORATED

COOPERATIVE AGREEMENT #DTFH61-03-X-00030
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

TASK 2003E1
"ASSESSMENT OF FRICTION-BASED PAVEMENT METHODS AND REGULATIONS IN GERMANY"

SURVEY QUESTIONS

JUNE 28, 2006

PURPOSE OF THIS SURVEY

This is a survey to collect information on procedures used by highway agencies[4] to:

- Evaluate pavement conditions, including the methods and criteria, if any, used to qualify pavement conditions,
- Identify whether criteria used to evaluate pavement condition are based on friction or not,
- Characterize actions required based on the specific values of the criterion used.

Agency: ____

Name of respondent: ___________________________________

Title: ____

Phone: ____________________ Fax: ______________________

e-mail: ____

SECTION A - BACKGROUND

Q1. Is your job related to pavement condition evaluation?

Yes _____ No _____

SECTION B - GENERAL QUESTIONS ABOUT FRICTION MEASUREMENTS

Q2. Does your agency use any type of friction measurement (e.g., conduct regular surveys of the friction of your network)?

Yes _____ (continue to Q3 page 3)
No _____ (go to Q34 on page 10)

Q3. What are the friction measurements used for?

- To evaluate the quality of newly constructed or repair sections (i.e. Quality Control) Yes / No
- To study the conditions of specific sites for research Yes / No
- To diagnose the condition of specific sites and determine the appropriate remedies [not restricted to winter maintenance] Yes / No
- To monitor the condition of a road network for pavement management Yes / No
- To conduct regular surveys of the friction of your network Yes / No

[4] Note: We are not sure if there a single Federal system or if there are variations from State to State within Germany. For example, if the answers from practices in Bavaria might be different from those in Schleswig-Holstein or Saxony, then please indicate the responses for your region, and we will follow up with surveys for the other regions, as applicable.

- To measure friction at accident locations Yes / No
- For winter maintenance Yes / No
- Other. Explain ____

Q4. If you conduct regular surveys of the friction of your network, please indicate what percentage of each of the following roadway system is tested:

Germany	%
Autobahn	
Bundesstrassen *(Primary)*	
Autostrasse *(Secondary)*	
Local Roads	

Q5. Are these roadway systems tested on a regular pre-determined frequency (annually, every two years) or on an as-needed basis:

Germany	Annual	Biennial	As-needed
Autobahn			
Bundesstrassen *(Primary)*			
Autostrasse *(Secondary)*			
Local Roads			

Q6. If tested on an as-needed basis, what criteria are used to determine if a roadway qualifies for friction monitoring?

____
____
____
____

Q7. Besides friction, what other measure(s) does your agency use to evaluate pavement conditions (e.g., roughness, smoothness…)?

____
____
____
____

SECTION C – QUESTIONS ABOUT MEASURING DEVICES USED

Q8. What type(s) of friction measuring equipment does your agency use?
If you use more than one type of device, can you please specify which device is used for what purposes? (i.e. for large scale pavement condition monitoring vs. for research)?

____

	Device		Purpose
Operational Mode:	Side Force	_______	____________________________
	Variable Slip	_______	____________________________
	Fixed Slip	_______	____________________________
	Locked Wheel	_______	____________________________
	Slider	_______	____________________________
	Other	_______	____________________________

	Device		Purpose
Tester Type:	ASTM E-274 Trailer	_______	____________________________
	Mu-Meter	_______	____________________________
	SCRIM	_______	____________________________
	Griptester	_______	____________________________
	British Pendulum Tester	_______	____________________________
	Dynamic Friction Tester	_______	____________________________
	Variable Slip Tester	_______	____________________________
	Other	_______	____________________________

Q9. Why does your agency use this (these) device(s)?

____

____

Q10. If applicable, what type of test tire does your agency use for the surveys?

ASTM E-524 (smooth) ________
ASTM E-501 (ribbed) ________
Other ______________________

Q11. What test speeds does your agency use for the friction surveys?

____

____

Q12. What is the spatial frequency and sample length of your friction testing?

Samples per kilometer ___________
Sample length ___________

Q13. Do you adjust for temperature, seasonal and speed variations?

Temperature:	Yes _____	No _____
Seasonal Variations	Yes _____	No _____
Speed	Yes _____	No _____

Q14. Have you used other friction measuring equipment in the past?

Yes _____ No _____

If yes, which one, when and where?

____

____

Q15. In 1995, PIARC published all skid resistance and texture measuring equipment in use throughout Europe. Has your agency added any additional equipment for measuring friction either for large scale pavement conditioning or research since 1995?

If yes, please list the equipment and what it is used for. ____________________________

____

____

Q16. Are you familiar with any other friction measuring equipment?

Yes _____ No _____

If yes, which equipment and how did you become familiar with it (agency tested it, other agencies use it etc…)

____

____

SECTION D – QUESTIONS ABOUT THE USE OF DATA COLLECTED

Q17. What do you do with the data collected?

Friction data? ____
____
Other data? ____
____

Q18. Do you record and archive friction data?

Yes _____ No _____

If yes, how do you archive the data? ___________

If yes, what do you do with the archived data? ___________

If yes, what would you like to do with the archived data? ___________

SECTION E – QUESTIONS ABOUT GUIDELINES, PROCEDURES, THRESHOLD VALUES AND ACTIONS

Q19. Does your agency have established guidelines for friction measurements?

Yes _____ No _____

If yes, what are these guidelines? If yes, please attach a copy of those guidelines. (If available on the web, a website is acceptable.) ________________________________
____

If no, why not? ____
____
____

Q20. Does your agency have established investigatory levels (levels dictating follow-up action) based on friction-measured results?

Yes _____ No _____

If yes, are the values site specific or roadway category specific? ___________________
____

If yes, does your agency use a single threshold value or a range of values? ___________
____

If yes, please attach those threshold values.

If no, why doesn't your agency does not have established Investigatory Levels? ______
____
____

Q21. Does your agency have established threshold values of friction measurements?

Yes _____ No _____

If yes, are those values site-specific or roadway-category specific? _________________
____
____

If yes, does your agency use a single threshold value or a range of values? ___________
____

If yes, what are your threshold values? (If site specific, please include a table.)
____
____

If no, why doesn't your agency does not have established threshold values of friction measurements? ____
____

Q22. Does your agency have established follow-up actions based on friction measurements?

Yes _____ No _____

If yes, what are these follow up actions?
____
____
____
____

If no, why not? ____
____

Q23. Do you know of any policy developed or even implemented in your country regarding specific follow-up actions to be taken, given particular readings of friction?

Yes _____ No _____

If yes, what are these policies? ____
____
____

If no, do you think it would be beneficial to develop and implement such policies? Please explain ____
____

Q24. What other intervention methods does your agency use for readings other than the investigatory levels? For example, when value is slightly below the threshold, is something less involved recommended?
____
____
____

Q25. Are there other criteria besides the friction readings that are used to initiate or prioritize road maintenance actions? (e.g., accident frequency at a given location)
____
____
____

Q26. Do you think your current practice(s) provide you with what you need?

Yes _____ No _____

Q27. Based upon your experience, do you think there are any possible deficiencies in the current procedure?

Yes _____ No _____

Q28. What do you think should be done to correct them? ______________________________

____

____

Q29. Would you need additional tools? If so, which ones would you find useful and how would they be useful?

Yes _____ No _____

____

____

Q30. In your opinion, what countries do the best at establishing policies and guidelines for maintaining adequate skid resistance on their roadways?

____

____

____

____

____

____

____

Q31. How does your practice(s) compare with other countries' practices?

____

____

SECTION E – QUESTIONS ABOUT REGULATIONS AND POLICY

Q32. In general terms, explain the applicable legislative or regulatory basis or requirements for your friction monitoring program?

____

____

____

Q33. Does your agency have policies or regulations for friction measurements?

Yes _____ No _____

If yes, could you share info with us? ____

If no, why not? ____

____

Q34. Do you think friction levels should be regulated?

Yes _____ No _____

Explain ____

____

Continue to Q42 (page 12)

SECTION F – QUESTIONS IF YOUR AGENCY DOES NOT USE FRICTION MEASUREMENTS

Q35. Do you think that the use of friction measurement could be useful to your Country?

Yes _____ No _____

Q36. Why does your agency not conduct regular surveys of the friction of your network (i.e. use any type of friction measurement)? (i.e. cost, not needed, other means are used, technology tested to date is not ready)

____
____
____

Q37. What do you think it would take to implement friction monitoring by your agency?

____
____
____

Q38. What does your agency do to characterize road surface conditions (smoothness, texture?)

____
____
____

Q39. How does your practice(s) compare with other EU National practices?

____
____

Q40. Do you know of other agencies that have established policies, developed guidelines, or established threshold friction values and associated follow-up actions based on friction measurements?

Yes _____ No _____

If yes, which ones? ____
____
____

SECTION G – OTHER QUESTIONS

Q41. Does your country regulate the amount of spray generation and visibility reduction related to the pavement surface characteristics (microtexture or macrotexture)?

Yes _____ No _____

Q42. Does your country have a standard practice to quantify the amount of spray or is there any qualitative measure for evaluation of spray generation?

Yes _____ No _____

Q43. Is highway noise being measured by your agency ?

Yes _____ No _____

Q44. Are there any regulations or corrective measures related to noise in your country?

Yes _____ No _____

Q45. Is there a standard for measurement of noise in your country?

Yes _____ No _____

Thank you for your time!

Appendix G

Results from the International Surveys

Section B - General questions about friction measurements

Table G1 "Q2 – Does your agency use any type of friction measurement?"

Country	Response
Germany	Yes
United Kingdom	Yes

Table G2 "Q3 – What are the friction measurements used for?"

Country	Evaluate quality of newly constructed or repair sections (QC)	Study conditions of specific sites for research	Diagnose condition of specific sites and determine appropriate remedies	Monitor condition of road network for pavement management	Conduct regular surveys of friction	Measure friction at accident locations	Winter maintenance	Other
Germany	Yes	Yes	Yes	Yes	Yes	Yes	No	
United Kingdom	Yes	No	Yes*	Yes*	Yes*	No	Yes	* Friction measurements are made for these purposes in the UK but not by us

Table G3 "Q4 – What percentage of each category of roadway system is tested?"

Country	Interstate	Primary	Secondary	Local Roads
Germany	100%	100%	~ 30%	~ 30%
United Kingdom	100%	Unknown*	Unknown**	Unknown**

** Some local authorities test regularly – others not at all.*
*** Probably very low.*

Table G4 "Q5 – With what frequency are friction measurements taken?"

Country	Interstate	Primary	Secondary	Local Roads
Germany	4-yr cycle	4-yr cycle	As needed	As needed*
United Kingdom	Annual	Annual	Biennial	As-needed*

** Depends on local highway administration*

Table G5 "Q6 – If tested on an as-needed basis, what criteria are used to determine if a roadway qualifies for friction monitoring."

Country	By request	Visual Inspection which suggests friction may be low.	Higher than usual wet accident rate	Other
Germany	X			Note 1
United Kingdom				No response given

Note 1. Final acceptance test by road construction contracts

Table G6 "Q7 – Besides friction, what other measure(s) does your agency use to evaluate pavement conditions?"

Country	Cracking	Roughness	Rut Depth	Texture	Other	Edge Roughness
Germany		X		X	Note 1	
United Kingdom	X	X	X	SMTD	Note 2	Local Roads only

Note 1. Surface monitoring with high speed vehicle (pictures).
Note 2. 3m, 10m, 30m longitudinal profile variance.

Section C – Questions about measuring Devices used

Table G7 "Q8, Q9 and Q10 – What type of friction measuring equipment does your agency use?" and "Why does your agency use this (these) device(s)?"

Country	Operational Mode	Tester Type	Test Tire	Reason for using
Germany	Slider Side Force	-British Pendulum Tester* -Other: Side force principal (like SCRIM) road monitoring and acceptance test	Other: Motorbicycle tire	- Decision to use the side-force principle in the 1980's because of the ability of long distance measurements
United Kingdom	-Side Force** -Fixed Slip -Locked Wheel -Slider	ASTM E-274 Trailer SCRIM Gripstester British Pendulum Tester	ASTM E-524 ASTM E-501 Other: Standard SCRIM and Gripstester tire	- SCRIM – robust, defined, procedures and standards available -ASTM trailer – high speed effects and dry testing, i.e. capability of observing other relevant effects

** Laboratory work, measurements after accidents*
*** Research and site investigation. Also used SCRIM on trunk roads and some local roads for network monitoring, but not by us.*

Table G8 "Q11 and Q12 – What test speeds does your agency use for the friction surveys?" and "What is the spatial frequency and sample length of your friction testing?"

Country	Test Speeds	Samples/Mile	Sample Length
Germany	Autobahn - 80 km/hr Buudesstraβe - 60 km/hr In cities, villages – 40 km/hr		100m
United Kingdom	Routine testing: 50-80 km/hr Research testing: 20-120 km/hr		10m for SCRIM surveys

Table G9 "Q13 – Do you adjust for temperature, seasonal and speed variations?"

Country	Temperature Variations	Seasonal Variations	Speed Variations
Germany	Yes	No	Yes
United Kingdom	No	Yes	Yes

Table G10 "Q14 – Have you used other friction measuring equipment in the past?"

Country	Other friction measuring equipment used in past?	Type	Dates Used / Where
Germany	Yes		Stuttgarter Reibuugsmesses
United Kingdom	No		

Table G11 "Q15 – Has your country added any additional equipment for measuring friction either for large scale pavement conditioning or research since the 1995 PIARC publication?"

Country	Response
Germany	n/a
United Kingdom	No

Table G12 "Q16 – Are you familiar with any other friction measuring equipment and if so, how did you become familiar with it?"

Country	Type of equipment	How did you become familiar with it?						
		Through survey consultant	Open Literature	Vendor	Pavement Conference	Trade Show	Committees	Research Center
Germany	Fixed slip (Griptester)	X						
United Kingdom	Have been involved in European research -HERMES experiment							X

Section D – Questions about the use of data collected

Table G13 “Q17 – What do you do with the data collected?”

Country	Response
Germany	Used for pavement management, research on new surfaces and to improve surfaces Other data: roughness for pavement management
United Kingdom	Our organisation processes the data on a site by site basis depending on the research or investigation being carried out. For routine monitoring (other organisation) the data will be loaded onto a pavement management system

Table G14 “Q18 – Do you record and archive friction data?”

Country	Record and archive friction data?	Archive method	What is currently done with archived data?	What would you like to do with the archived data?
Germany	Yes	No information	Look for trends especially to compare the different types of pavement construction.	No information
United Kingdom	Yes	Network data storage for low volume. Plus dedicated multiple disk drive system for large volume data.	No information	No information

Section E – Questions about guidelines, procedures, threshold values and actions

Table G15 “Q19 – Does your agency have guidelines for friction measurements? If yes, what are these guidelines? If no, why not?”

Country	Responses
Germany	No (Agency), but FGSV **(Foredeuugs Gesellschaftfor Straβen used Verkekrswesen eV, Wesslinges Straβen 17, 50999 Kólu, Germany)** does have technical specifications
United Kingdom	Yes, See Design Manual for Roads and Bridges, Volume 7, Part 3 HD28 “Skid Resistance”

Table G16 "Q20 – Does your agency/country have established investigatory levels (levels dictating follow-up action) based on friction-measured results? If yes, are these values site specific or roadway specific? If yes, does your agency use a single threshold value or a range of values? If not, why not?”

Country	Responses
Germany	Yes. Roadway category specific values. Single value is used. Different value for pavement management and acceptance test are included in the FGSV papers.
United Kingdom	Yes. Combination of both site and roadway specific values. Range of values is used.

Table G17 "Q21 – Does your agency have established threshold values for friction measurements? If yes, are these values site specific or roadway category specific? If yes, does your agency use a single threshold value or a range of values? If not, why not?""

Country	**Responses**
Germany	Yes. Roadway specific. Single threshold depending on use and road category (FSGV papers).
United Kingdom	No. No definition of level at which a road from "safe" to "dangerous". It should always be based on a risk assessment

Table G18 "Q22 – Does your agency have established follow-up actions based on friction measurements? If yes, what are they? If no, why not?"

Country	**Follow-up actions based on friction measurements**
Germany	No. These belong to the authority of countries.
United Kingdom	Yes. See reference above for UK trunk roads. Some local authorities adopt a similar system but with different investigatory levels.

Table G19 "Q23 – Do you know of any policy developed or implemented in your country regarding specific follow-up actions to be taken, given particular friction readings? If yes, what are they?"

Country	**Description of the policy**
Germany	Yes. FGSV policies, TP + ZTV asphalt; ZTV concrete
United Kingdom	See Q22

Table G20 "Q24 – What other intervention method(s) does your agency use for readings other than the investigatory levels?"

Country	**Responses**
Germany	Speed limits
United Kingdom	n/a

Table G21 "Q25 – Are there other criteria besides the friction readings that are used to initiate or prioritize road maintenance actions?"

Country	**Response**
Germany	Yes. Accident frequency.
United Kingdom	History of accidents taken into account (see reference); Also assessment of potential conflicts at site

Table G22 Responses to Q26, Q27 and Q28, "Current Practices"

Country	Do you think your current practices provide you with what you need?	Based upon your experience, do you think there are any possible deficiencies in the current procedures?	What do you think should be done to correct current procedures?
Germany	No	No	n/a
United Kingdom	Yes	Yes	Audits of the bodies implementing the standards to ensure correct implementation. More information about link between skid resistance and accidents on local roads.

Table G23 "Q29 – Would you need additional tools? If so, which ones would you find useful and how would they be useful?"

Country	Would you need additional tools?	What tools would you find useful?	How would those tools be useful?
Germany	Yes	Texture	n/a
United Kingdom	n/a	n/a	n/a

Table G24 "Q30 – In your opinion, which countries do the best at establishing policies and guidelines for maintaining adequate skid resistance on their roadways?"

Country	Response
Germany	Germany
United Kingdom	U.K.

Table G25 "Q31 – How does your practice(s) compare with other countries' practices?"

Country	Response
Germany	Difficult to compare because of variety of measurement systems in Europe
United Kingdom	We are more proactive at managing the risk of skidding accidents

Section E' – Questions about regulations and policy

Table G26 "Q32 – In general terms, explain the applicable legislative or regulatory basis or requirements for your friction monitoring program."

Country	Response
Germany	ZTV – ZEB; FGSV in implementation
United Kingdom	Highway authorities have a statutory duty to maintain the highway. The standard to be maintained is not specified and this is established via the courts.

Table G27 "Q33 – Does your agency have policies or regulations for friction measurements?"

Country	Response	Policy/Regulation for Friction Measurements
Germany	Yes	When friction values fall below accepted value, that section must either be replaced or the speed limits must be adjusted.
United Kingdom	n/a	

Table G28 "Q34 – Do you think friction levels should be regulated?"

Country	Response	Why or why not
Germany	Yes	For road safety
United Kingdom	n/a	n/a

Section F – Questions if your agency does not use friction measurements

Not applicable

Section G – Questions about spray and noise

Table G29 "Q42 to Q46 – Splash/Spray and Noise"

Country	Regulate spray generation and visibility reduction?	Quantify amount of spray?	Measure highway noise?	Regulations or corrective measures related to noise?	Standard for measurement of noise?
Germany	No	No	Yes	Yes	Yes
United Kingdom	No	No	Yes (research purposes only)	n/a	n/a