

2012

Investigating the Feasibility of Integrating Pavement Friction and Texture Depth Data in Modeling for INDOT PMS

Rebecca S. McDaniel

Purdue University, rsmcdani@purdue.edu

Karol J. Kowalski

Warsaw University of Technology, k.kowalski@il.pw.edu.pl

Recommended Citation

McDaniel, R. S., and K. J. Kowalski. *Investigating the Feasibility of Integrating Pavement Friction and Texture Depth Data in Modeling for INDOT PMS*. Publication FHWA/IN/JTRP-2012/33. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2012. doi: 10.5703/1288284315037.

JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY



INVESTIGATING THE FEASIBILITY OF INTEGRATING PAVEMENT FRICTION AND TEXTURE DEPTH DATA IN MODELING FOR INDOT PMS

Rebecca S. McDaniel

Technical Director
North Central Superpave Center
Purdue University
Corresponding Author

Karol J. Kowalski

Assistant Professor and Scholar of Foundation for Polish Science
Warsaw University of Technology

SPR-2936

Report Number: FHWA/IN/JTRP-2012/33

DOI: 10.5703/1288284315037

RECOMMENDED CITATION

McDaniel, R. S., and K. J. Kowalski. *Investigating the Feasibility of Integrating Pavement Friction and Texture Depth Data in Modeling for INDOT PMS*. Publication FHWA/IN/JTRP-2012/33. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2012. doi: 10.5703/1288284315037.

CORRESPONDING AUTHOR

Dr. Rebecca S. McDaniel
Technical Director
North Central Superpave Center
Purdue University
(765) 463-2317, ext. 226
rsmcdani@purdue.edu

JOINT TRANSPORTATION RESEARCH PROGRAM

The Joint Transportation Research Program serves as a vehicle for INDOT collaboration with higher education institutions and industry in Indiana to facilitate innovation that results in continuous improvement in the planning, design, construction, operation, management and economic efficiency of the Indiana transportation infrastructure.
https://engineering.purdue.edu/JTRP/index_html

Published reports of the Joint Transportation Research Program are available at: <http://docs.lib.purdue.edu/jtrp/>

NOTICE

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views and policies of the Indiana Department of Transportation or the Federal Highway Administration. The report does not constitute a standard, specification or regulation.

1. Report No. FHWA/IN/JTRP-2012/33	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Investigating the Feasibility of Integrating Pavement Friction and Texture Depth Data in Modeling for INDOT PMS		5. Report Date November 2012	
		6. Performing Organization Code	
7. Author(s) Rebecca S. McDaniel and Karol J. Kowalski		8. Performing Organization Report No. FHWA/IN/JTRP-2012/33	
9. Performing Organization Name and Address Joint Transportation Research Program Purdue University 550 Stadium Mall Drive West Lafayette, IN 47907-2051		10. Work Unit No.	
		11. Contract or Grant No. SPR-2936	
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.			
16. Abstract <p>Under INDOT's current friction testing program, the friction is measured annually on interstates but only once every three years on non-interstate roadways. The state's Pavement Management System, however, would require current data if friction were to be included in the PMS. During routine pavement condition monitoring for the PMS, texture data is collected annually. This study explored the feasibility of using this pavement texture data to estimate the friction during those years when friction is not measured directly. After multiple approaches and a wide variety of ways of examining the currently available data and texture measuring technologies, it was determined that it is not currently feasible to use the texture data as a surrogate for friction testing. This is likely because the lasers used at this time are not capable of capturing the small-scale pavement microtexture. This situation may change, however, with advances in laser or photo interpretation technologies and improved access to materials data throughout the INDOT pavement network.</p>			
17. Key Words friction, texture, macrotexture, microtexture, pavement management		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 26	22. Price

EXECUTIVE SUMMARY

INVESTIGATING THE FEASIBILITY OF INTEGRATING PAVEMENT FRICTION AND TEXTURE DEPTH DATA IN MODELING FOR INDOT PMS

Introduction

The Indiana Department of Transportation (INDOT) Research Division has had a network pavement friction testing inventory program to detect potential slippery pavements on all interstates, state routes and US highways for many years and has worked to continually refine and update the program. The Research Division annually conducts approximately 6,700 lane-miles of friction testing using the ASTM E274 towed friction trailer. When friction levels below a so-called friction flag value are measured, the district is informed and the site is visited to determine if remediation is needed; this is often called an investigatory level.

The inventory friction test results have been utilized by the districts in planning their annual pavement maintenance and resurfacing activities. However, the network inventory friction test results have not yet been integrated in the INDOT Pavement Management System (PMS). While interstates are tested annually, the inventory friction testing on the US and state roads is conducted every three years, i.e., only one-third of the US and state roads can be tested each year. Consequently there is no timely and accurate friction information on two-thirds of the US and state roads, making incorporation of this data in the PMS impractical. In addition, there are no temporal models available to forecast future friction numbers. Without predictive models, it is impossible to plan future work based on anticipation of future poor friction.

Pavement surface texture data is part of the data collected at the network level for PMS purposes. This is data that has not been utilized due to the lack of models to correlate it to pavement friction or distress types (such as raveling, stripping or disintegration). This project investigated whether it is feasible to use this network level texture data with the inventory friction data, and perhaps other readily available information, to provide realistic pavement friction information at the network level. An alternate option would be to identify a minimum texture level that could be used to signal the possibility of decreasing friction; this could potentially be used as a simple screening tool to identify locations that warrant a more detailed examination, similar to the way the friction flag value is currently used.

Findings

- Potential models to predict friction based on surface texture measurements were examined to determine if they could be implemented with the currently available equipment and data. No models that could accomplish the objectives were identified because of limitations in the equipment and lack of readily available mixture and aggregate information on a network level.
- Next, the available friction and texture data were analyzed in a variety of ways to determine if a minimum texture value

could be identified that would give some assurance that adequate friction would be provided. No clear texture limit could be identified. Although there were some cases where pavements with low friction values also had low textures, there were many more pavements-of a given type, road classification, district, approximate traffic level, etc. -that had much higher friction levels. Using a given texture level as a flag value or screening level would result in a large number of "false positives," as shown in Figure 4.6 of this report, and would create a great deal of investigatory effort to determine if a real friction issue existed on those pavements.

- In addition, selected pavements were examined to determine if changes in texture over time could signal that friction issues might be developing. There was no clear trend that would predict incipient friction issues based on changes in texture.
- Lastly, a few pavements that were suspected of having experienced a loss of friction over time were examined to explore whether there was also a loss of texture that could signal the loss of friction. No relationship was observed between loss of friction and change in texture.
- In conclusion, at the present time and with the data that is readily available, it is not feasible to incorporate friction in the pavement management system through use of the texture data collected during routine condition monitoring with the Pathway van. The available data was analyzed in a variety of ways, and no reliable, or even remotely definitive, relationships could be found to identify pavements that might demonstrate inadequate friction because of low texture. It is theorized that this lack of a correlation, or minimum texture value to provide adequate friction, is at least in part because the current texture measurements are of the macrotexture only and the significant effects of microtexture are not being captured. Future advances in laser technology, however, may make measuring microtexture feasible. This concept could be revisited in the future.

Implementation

At the present, it is not feasible to incorporate management of pavement friction in the PMS through the use of the pavement texture data collected during routine pavement condition monitoring. INDOT should remain open to consideration of future technological advances that may make it feasible to quantify the effects of pavement microtexture at highway speeds. The Office of Research and Development is ideally suited to continue to search for feasible technologies.

For spot testing for forensic analysis or for testing in places where the towed friction trailer cannot operate safely, it would be possible to measure friction and texture using the Dynamic Friction Tester (DFT) and Circular Texture Meter (CTM) as outlined in other research, as these values have been correlated with the towed friction trailer data. The CTM is particularly well suited to forensic analyses since its data can be analyzed to separate the effects of micro- and macrotexture, which helps to identify the causes of low friction. The North Central Superpave Center has this equipment and expertise in its use and would be available to assist with spot investigations.

CONTENTS

1. INTRODUCTION	1
1.1 Literature Review	1
2. PROBLEM STATEMENT	3
3. OBJECTIVES	3
4. FINDINGS AND DELIVERABLES	3
4.1 Research Approach	3
4.2 Relationships Explored.	5
4.3 Possible Explanation for Lack of Correlation.	9
5. CONCLUSIONS	10
6. RECOMMENDATIONS FOR IMPLEMENTATION	10
REFERENCES	10
APPENDIX A. Exploration of Change of Texture over Time	13

LIST OF FIGURES

Figure	Page
Figure 1.1 ASTM E274 towed friction trailer (a) rear view (b) side view	1
Figure 1.2 The Dynamic Friction Tester (DFT)	2
Figure 1.3 The Circular Texture Meter (CTM)	2
Figure 4.1 Relationships between F60 determined using DFT/CTM and towed friction trailer with (a) ribbed tire and (b) smooth tire	4
Figure 4.2 Texture vs. friction—all roads with paired friction and texture data, 2008	5
Figure 4.3 Texture vs. friction—concrete roads in 2008	6
Figure 4.4 Texture vs. friction—asphalt surfaces in 2008	6
Figure 4.5 Texture vs. friction—asphalt interstate surface only, 2008	6
Figure 4.6 Texture vs. friction with friction flag value and potential minimum texture reading	7
Figure 4.7 Texture vs. friction—asphalt US route surfaces only, 2008	7
Figure 4.8 Texture vs. friction—asphalt state routes only, 2008	8
Figure 4.9 Change in texture over time, I-64	8
Figure 4.10 Change in friction over time, I-865	9
Figure 4.11 Effects of micro- and macrottexture on surface friction at various speeds	10

LIST OF TABLES

Table	Page
Table 4.1 Friction Numbers over Time, I-64	9
Table 4.2 Range of Left Wheel Path Textures over Time, I-865	9

1. INTRODUCTION

In 1980, the Federal Highway Administration issued a technical advisory encouraging all highway agencies to develop a skid accident reduction program to reduce the frequency of wet weather skidding accidents. That advisory was superseded in 2010 by a new advisory on Pavement Friction Management (1). The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, known as SAFETEA-LU, called for agencies to develop Highway Safety Improvement Programs to address high risk rural roads, railway-highway grade crossings and other safety issues as well as wet-weather accident reduction. Consequently, pavement friction management can be considered one component of a Highway Safety Improvement Program.

The Indiana Department of Transportation (INDOT) Research Division has had a network pavement friction testing inventory program to detect potential slippery pavements on all interstates, state routes and US highways for many years and has worked to continually refine and update the program. The Research Division annually conducts approximately 6,700 lane-miles of friction testing using the ASTM E274 towed friction trailer (2). The towed friction trailer is shown in Figure 1.1. When friction levels below a so-called friction flag value are measured, the district is informed and the site is visited to determine if remediation is needed; this is often called an investigatory level.

The inventory friction test results have been utilized by the districts in planning their annual pavement maintenance and resurfacing activities. However, the network inventory friction test results have not yet been integrated in the INDOT Pavement Management System (PMS). While interstates are tested annually, the inventory friction testing on the US and state roads is conducted every three years, i.e., only one-third of the US and state roads can be tested each year.



Figure 1.1 ASTM E274 towed friction trailer (a) rear view (b) side view.

Consequently there is no timely and accurate friction information on two-thirds of the US and state roads, making incorporation of this data in the PMS impractical. In addition, there are no temporal models available to forecast future friction numbers. Without predictive models, it is impossible to plan future work based on anticipation of future poor friction. If the inventory friction testing reveals low friction numbers, the districts act immediately to correct the situation; temporal models are needed to anticipate these conditions before they occur.

Pavement surface texture data is part of the data collected at the network level for PMS purposes. This is data that has not been utilized due to the lack of models to correlate it to pavement friction or distress types (such as raveling, stripping or disintegration). This project investigated whether it is feasible to use this network level texture data with the inventory friction data, and perhaps other information, to develop models that will allow friction considerations to be managed in the PMS along with other factors.

1.1 Literature Review

The results of other research projects suggest that it should be possible to develop models to relate pavement friction to surface texture that would allow INDOT to take maximum advantage of the friction and texture data that it is currently collecting. These models should allow friction to be included in the PMS so that decisions to rehabilitate a pavement due to lower than desired friction numbers would be made on the same basis as rehabilitations for other reasons, such as ride quality. This will help to ensure that friction is managed and optimized network wide.

Adequate friction is needed to maintain control of a vehicle in all conditions, but is typically a greater concern in wet weather conditions, when water on the pavement surface can reduce the effectiveness of the tire-pavement interface to resist skidding. In the worst case, there can be enough water on the surface that the tire actually rides on a film of water, not on the pavement surface. This dangerous condition, called hydroplaning, can result in the loss of control of the vehicle.

Wet weather pavement friction is provided through two primary attributes of the pavement surface. The microtexture is the fine-scale texture of the aggregate particles themselves, usually defined as less than 0.5 mm. Microtexture determines the friction of the pavement surface at low speeds. Macrottexture is larger scale texture, on the order of 0.5 to 50 mm, provided between the aggregate particles. Macrottexture provides channels through which surface water can flow, providing surface drainage and improving the contact between vehicle tires and the pavement. This texture helps to decrease the chances for a vehicle to hydroplane in wet weather. In general, as the speed of the vehicle increases, the friction decreases, but the rate at which it decreases depends on the pavement

macrotexture and how quickly water can be forced out of the tire-pavement interface. Higher macrotexture allows for more rapid drainage of the water and therefore a higher friction value (3,4).

Microtexture can be measured in the field or the laboratory using devices such as the British pendulum and the Dynamic Friction Tester (DFT). The British pendulum has been used for many years, but the results are typically more variable than with the newer DFT. The DFT uses three rubber sliders on a spinning disk that are lowered to the pavement surface (see Figure 1.2). A water spray douses the surface during the test, so that wet friction is measured as with the ASTM towed friction trailer. Friction between the pavement and the sliders causes a gradual decrease in the speed of rotation of the disk, which is correlated to the coefficient of friction. The DFT records the pavement friction as the wheel slows, providing a measure of the friction and the speed gradient, or speed dependency, of the friction value. The ability of the DFT to measure at low speeds allows a strong correlation to be established between the DFT and the microtexture of the pavement (5).

There is currently no way to conduct high speed microtexture measurements for network level analysis (5). Correlations may be possible, however, based on the predominant aggregate type in the pavement surface (6). Microtexture can decrease as the aggregates exposed on the surface are polished by traffic. Alternatively, some aggregate particles can be dislodged by traffic, exposing new aggregates to the surface and maintaining or temporarily increasing the microtexture (5).

Macrotexture can also be measured in a number of ways (7). The historical method is the sand patch method, which involves spreading a certain volume of Ottawa sand or glass beads over the surface of the pavement in a circular manner. On a pavement with high macrotexture, the sand will fill the surface voids

and not spread as far as it will on a pavement with less texture. The sand patch method is simple and common, but is subject to fairly high variability and is quite time consuming. Also, only an average texture can be obtained; there is no way to determine anything about the nature of the texture (amount or spacing of voids, positive or negative texture, etc.) (8).

The Circular Texture Meter (CTM), shown in Figure 1.3, is another way to measure the pavement macrotexture. The CTM uses a laser on a rotating arm to measure the profile of a circle 800 mm (31.5 in.) in circumference. The vertical resolution of the CTM is 3 μm (0.12×10^{-3} in.). The CTM profile can be analyzed to determine more about the nature of the texture. One advantage of this method is that eight separate arcs of the circle can be analyzed. This allows determination of the texture in the direction of traffic and perpendicular to traffic, which could be useful in some situations, such as when analyzing tined or grooved concrete. The CTM is also very fast and less variable than the sand patch test. Previous research has demonstrated strong correlations between the two tests (9). The CTM and DFT are designed to work together, measuring the same footprint.

There are other stationary means of measuring macrotexture, including the outflow meter, grease patch and stylus devices, but none are superior to the CTM (7). There are also high speed devices, such as the Pathway vehicle used under contract by INDOT. McGhee and Flintsch (10) compared the CTM to high-speed, dynamic texture measuring equipment. The high-speed systems included the ICC system manufactured by International Cybernetics Corporation and the MGPS system, which is a commercial version of the FHWA's road surface analyzer (ROSAN). The devices were used on 22 surfaces at NASA's Wallops Flight Facility and seven surfaces on Virginia's Smart Road. McGhee and Flintsch found the results from the CTM and sand patch test to demonstrate "remarkable agreement." They also report that the CTM results

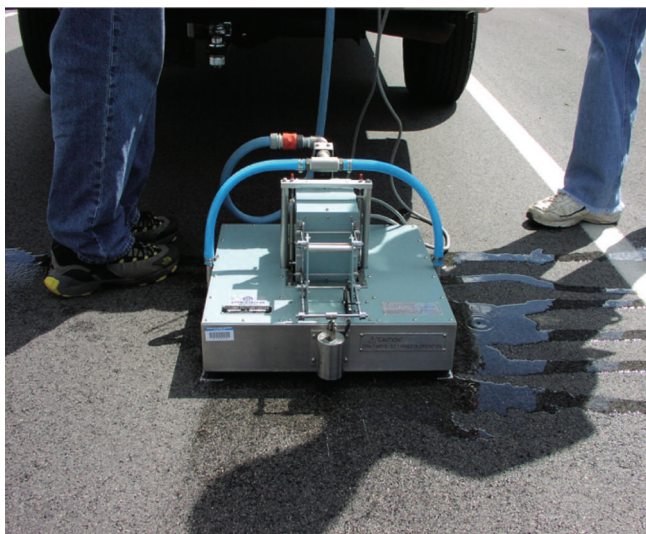


Figure 1.2 The Dynamic Friction Tester (DFT).



Figure 1.3 The Circular Texture Meter (CTM).

were highly correlated to the two high-speed measuring systems (10).

Measuring the microtexture or macrotexture alone is not sufficient to predict the friction level, as indicated by a number of previous studies. Yager and Bühlmann (8) note that macrotexture is very important in assessing the drainage characteristics of runways, but add that macrotexture alone cannot define the frictional properties of a pavement. Both properties are important. Kulakowski and Harwood (11) reported that as little as 0.025 to 0.23 mm (0.001 to 0.009 in) of water on the surface can lead to a friction decrease on the order of 20–30% of the dry friction, which underscores the importance of macrotexture to drain this water away.

Kandhal and Parker noted that, because of the complexities and many interrelated factors involved in frictional resistance of an asphalt pavement, “a test that measures only the microtexture of the coarse aggregate may not be an efficient means of evaluating suitability for polish and friction resistance” (12). Jayawickrama et al. (13) also noted the importance of assessing both micro- and macrotexture. They stated that an ideal design system should account for differences in both pavement qualities.

Doty (14) reported in a comparison of friction to surface texture, as measured by the sand patch test and outflow meter, that there was a general trend of higher friction with increasing texture depth for a variety of surface types including open and dense graded asphalt, sealed surfaces and polished and grooved PCC. Surface texture alone, however, did not yield strong enough relationships to establish a minimum texture depth criterion for use as a specification limit.

Many researchers have expended considerable effort attempting to correlate one measurement, typically aggregate microtexture, to pavement friction using statistical regressions with traffic and other factors (15,16), spectral power densities of the surface (17,18), and even fuzzy-set mathematics (19). Prasanna (6) pointed out that correlations can be improved by relying on more than one measured parameter and developed a software program for Texas that utilizes different regression equations depending on the predominant aggregate type.

As noted before, INDOT’s friction inventory program utilizes the ASTM E-274 towed friction trailer, which measures the wet pavement friction. INDOT routinely uses the blank or bald test tire on the trailer. Studies have shown that the friction measured with the bald tire is related to both the micro and macrotexture of the pavement (20,21). The ribbed tire INDOT previously used essentially provides its own macrotexture and is therefore more sensitive to the microtexture of the aggregates. When using the smooth tire alone, it is not possible to separate the effects of the micro and macrotexture. However, since the macrotexture is related to the speed gradient, or change in friction versus speed, testing at two or more different speeds would allow estimation of the macrotexture.

This is not practical on a network level, however, since it would significantly increase the time needed to complete the testing.

This study attempted to find a way to relate the surface texture, obtained from the Pathway van during routine pavement conditioning monitoring, to estimate the pavement friction during the “off years” when direct friction measurements are not conducted.

2. PROBLEM STATEMENT

Pavement distresses, ride quality, friction and structural capacity are key pavement condition items considered by a PMS. There is a need to develop sound models that will enable INDOT to predict and evaluate pavement friction from the collected network data.

3. OBJECTIVES

The overall objective of this research project is to explore the feasibility of developing sound friction and texture depth models for the INDOT PMS to provide realistic pavement friction information at the network level based on the friction data provided by the existing friction testing program and the surface texture data provided by the existing INDOT PMS. The original concept for this study was to:

1. Develop models to establish correlations between the locked wheel tester and the DFT and CTM devices;
2. Develop models to establish the correlations between pavement friction and surface texture; and
3. Develop models to predict temporal variations of surface texture in different types of pavement under selected conditions.

An alternate option would be to identify a minimum texture level that could be used to signal the possibility of decreasing friction; this could potentially be used as a simple screening tool that could be used to identify locations that warrant a more detailed examination, similar to the way the friction flag value is currently used.

4. FINDINGS AND DELIVERABLES

This section of the report describes the original proposed approach to address the objectives, changes to the planned approach and the findings.

4.1 Research Approach

The original concept behind this project was to use the International Friction Index (IFI) as a means to relate texture and friction. The IFI was developed in Europe to harmonize friction measurements made in various countries. The IFI allows friction to be measured using any of a number of different devices, then the results are reported in common measurement terms. Over 50 different texture and friction measuring

devices were compared in the European harmonization project (5). The IFI consists of the speed constant (S_p) and the friction number (F_{60}). The speed constant is a function of the pavement macrotexture and can be defined by the following equation:

$$Sp = a + b \cdot TX$$

where TX is the pavement macrotexture and a and b are constants depending on how the macrotexture is measured (7).

The friction number (F_{60}) is defined as:

$$F_{60} = A + B \cdot FRS \cdot e^{-\frac{S-60}{S_p}} + C \cdot TX$$

where FRS is the measurement of the friction at slip speed S, S_p is as defined above, TX is the macrotexture measurement and A, B and C are constants based on how the friction was measured. For smooth tires, the constant C is zero (7).

The original concept for this project was to relate friction measurements from the towed friction trailer to the DFT measurements, which were used in another study to evaluate the frictional properties of a variety of asphalt mixtures. Companion measurements with the CTM and high speed Pathway van were expected to yield a relationship between the different texture measurements that would in turn allow development of a model to estimate changes in surface friction based on changes in texture as a surrogate for yearly friction measurements.

This was to be accomplished, in part, by frequent DFT/CTM measurements on the INDOT Test Road and correlation of those measurements with the data from the towed friction trailer and the Pathway van. Frequent measurements of pavement friction and texture were made on the INDOT Research test road to serve as the basis for establishing correlations. INDOT routinely verifies the calibration of the friction system using the test road, which includes hot mix asphalt, smooth concrete and tined concrete surfaces. This verification is done nearly every week during the testing season from March or April to November. DFT/CTM measurements were conducted repeatedly

on days when the calibration of the friction trailers was performed on the test road, so that companion results taken under similar climatic conditions would be available. These measurements were used to establish correlations between the towed friction trailer results and the IFI determined with the DFT/CTM. This correlation was then used to develop a relationship between the towed friction trailer friction flag value and the DFT/CTM results (22), as illustrated in Figure 4.1.

The advantage of this relationship is that the DFT and CTM can be used in situations where the towed friction trailer cannot be used, such as curves, ramps and intersections. Use of these stationary devices is not recommended on a network level due to the need for traffic control and comparatively longer testing times (vs. the towed trailer), but they could be used for special investigations or project level testing.

For the present study, it was also planned to measure the texture with the Pathway van on the test road, however, this effort was not as successful as expected. During one of Pathway's visits to Indiana, the van was brought to the test road and measuring texture was attempted. Because of the short length of the test road, however, and the speed at which the van operates, it was not possible to reliably determine where the texture readings were being taken so that they could be correlated with the CTM measurements. This was especially true on the concrete sections, where roughly half the test road length is tined and the other half is slick.

A similar approach was planned for testing on in service pavements. That is, the researchers attempted to coordinate with Pathway so that actual pavements could be tested both by Pathway and with the CTM at close to the same time. The Pathway schedule for testing in the state is very dynamic, so this coordination proved unsuccessful. Field measurements were taken with the towed friction trailer and the DFT/CTM, which helped to verify the correlation with the friction flag value, but collecting Pathway texture data at the same time could not be accomplished.

Since these direct correlations were unsuccessful, the friction deterioration model developed under SPR-2413, *Identification of Laboratory Techniques to Optimize*

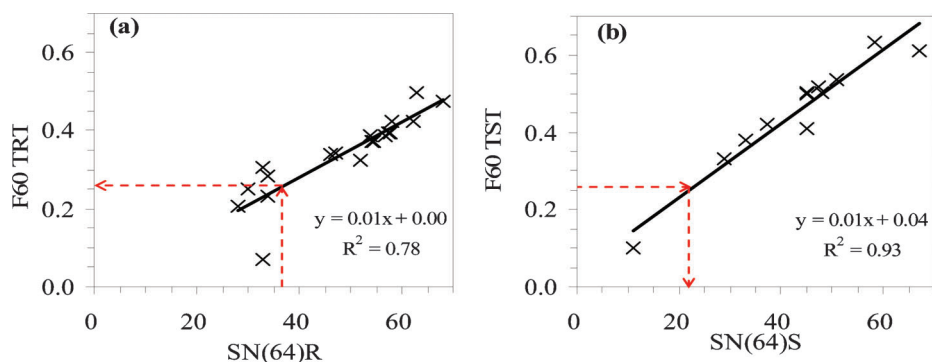


Figure 4.1 Relationships between F60 determined using DFT/CTM and towed friction trailer with (a) ribbed tire and (b) smooth tire (22).

Superpave HMA Surface Friction Characteristics, was examined to see if it could be used to relate changes in texture to changes in friction (23). This was not found to be a feasible approach, however. This model requires knowledge of the aggregate type, size (nominal maximum aggregate size, NMAS) and gradation; traffic volume and a transfer function to estimate the IFI F60 value. The transfer function consists of a set of equations with six parameters. While information about the aggregate and pavement mixture properties and traffic are possible to obtain, the data is not readily available in one consolidated database. This situation may improve in the future, making use of that model feasible for asphalt pavements; a similar model would need to be developed for concrete pavements. At the current time, implementation of this type of model is not feasible, given the availability of the required data and the complexity of the transfer function.

Since these approaches to modeling had not proven to be feasible or successful, other ways to examine the relationship between friction and texture were explored, as will be explained in the next section.

4.2 Relationships Explored

Since the modeling efforts appeared to be unsuccessful, historical data from the Pathway van and towed friction trailer was examined to determine if a relatively simple texture screening level could be established. A report by the Transport and Road Research Laboratory in the UK, for example, determined that accident risk increases when the texture level is below 0.70 mm using the sensor-measured texture depth determined using a high-speed texture meter (24). Another study in North Carolina suggested that tined concrete pavements should have macrotexture greater than or equal to 0.08 in. and asphalt pavements should have macrotexture greater than or equal to 0.04 in. to reduce wet weather accidents (25). Note that these

values cannot be applied universally because of differences in the measurement techniques; they are offered as illustrations of a possible approach to managing texture.

Mr. William Flora provided the research team with a data set from 2008 where friction test results and texture data were available at the same location. This data set included roughly 400 pairs of friction and texture data on asphalt and concrete roadways ranging from state routes to interstates. This data was plotted and examined to determine if low texture values could be related to low friction values, for example. In the following figures, the texture data collected in the left (TEXLe) and right (TEXRe) wheel paths is shown. In most cases, the textures at a given location are fairly similar in the different wheel paths, and neither wheel path has consistently higher texture than the other.

A plot of the combined data set is shown in Figure 4.2; no minimum texture value that relates to low friction is obvious in this combined data set; below the friction flag value of 20, the textures range from about 0.01 to 0.05 in. Other roadways with textures in this range had much higher friction values.

Figures 4.3 and 4.4 show the data for concrete and asphalt pavements separately, since the textures of these pavement types are typically very different. Videologs of the pavements were examined to identify the surface type. There are only about 40 points of comparison for concrete pavements and all but six were on interstate pavements. Again, however, there is no minimum texture depth for the concrete pavements that suggests adequate friction will be provided. The pair of readings with the lowest friction value, near the flag value of 20, has some of the highest texture readings, between 0.045 and 0.05 in., as shown in Figure 4.3. Figure 4.4, for all the asphalt pavements, does not show a clear minimum texture reading either.

The data for the asphalt pavements was further subdivided to try to indirectly consider different

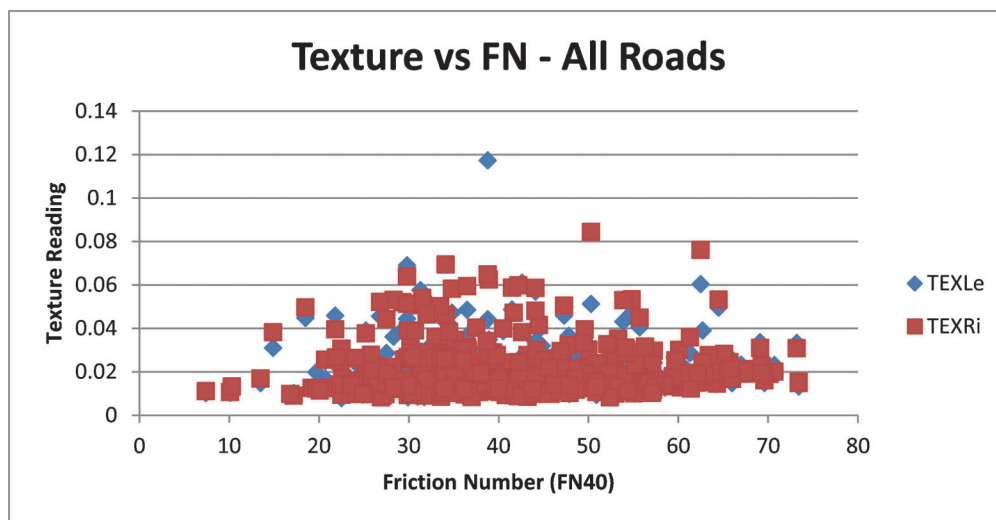


Figure 4.2 Texture vs. friction—all roads with paired friction and texture data, 2008.

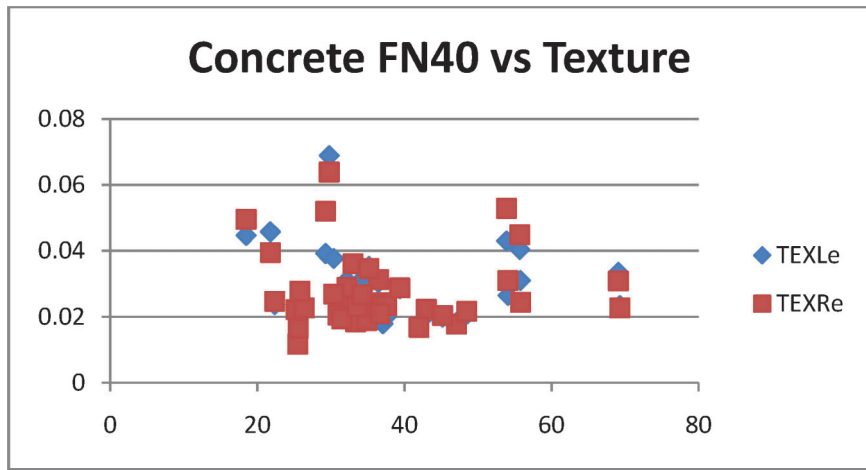


Figure 4.3 Texture vs. friction—concrete roads in 2008.

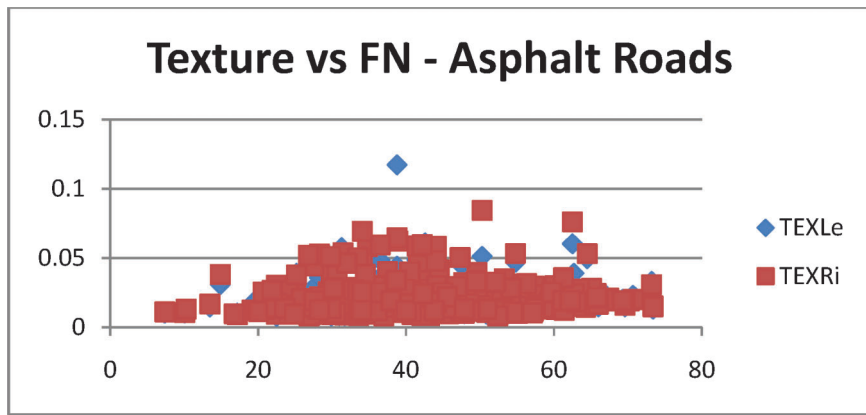


Figure 4.4 Texture vs. friction—asphalt surfaces in 2008.

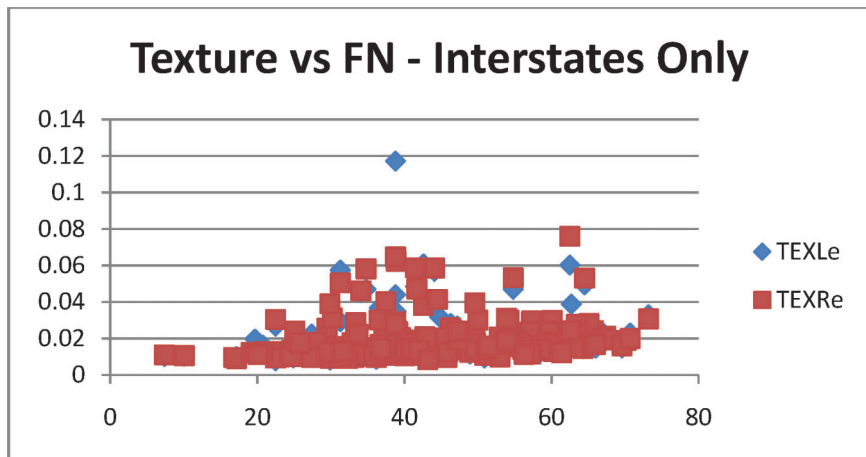


Figure 4.5 Texture vs. friction—asphalt interstate surface only, 2008.

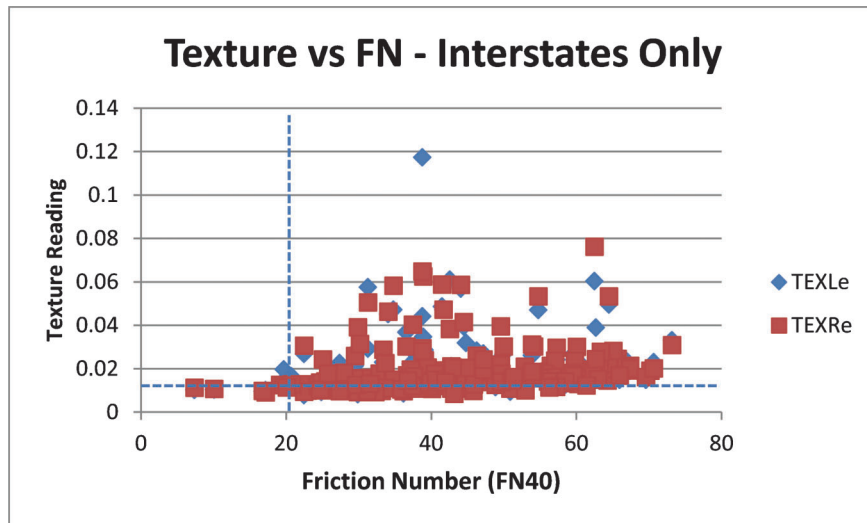


Figure 4.6 Texture vs. friction with friction flag value and potential minimum texture reading.

aggregate types. Since higher volume roadways have different aggregate requirements, the data was separated by roadway classification, as shown in Figures 4.5 through 4.7. Interstates would be expected to have slag or slag dolomite blends in the surface mixes, which would be expected to have higher microtexture than many mixtures used on lower volume roadways.

At first glance, Figure 4.5 looks promising. All of the roadway sections with friction values below 20 have relatively low texture at around 0.01 in. Further consideration, however, shows that any attempt to use this texture reading as a screening tool or flag value would result in flagging a large number of pavements with similar textures but much higher friction levels, some as high as 60 or higher. This is illustrated in Figure 4.6, where dotted lines have been added at the friction flag value and the potential minimum texture depth of approximately 0.01 in.

In Figure 4.7, for US Routes, the single site with a friction level below the friction flag value has a relatively high texture reading compared to the other US routes.

Figure 4.8 shows a situation similar to that with the interstates. While the two locations with low friction have textures below 0.02 in., so do a large number of other sites. Use of 0.02 in. as a flag value would result in a large number of “false positives”—projects with low texture but acceptable or even high friction.

The data was also examined using traffic volumes, but there were still no clear distinctions between acceptable and insufficient textures. Similarly, there were no appreciable differences between districts (geographical areas).

Since all of the analysis above was based on one year’s data, 2008, additional data was requested from and provided by William Flora. This data was provided

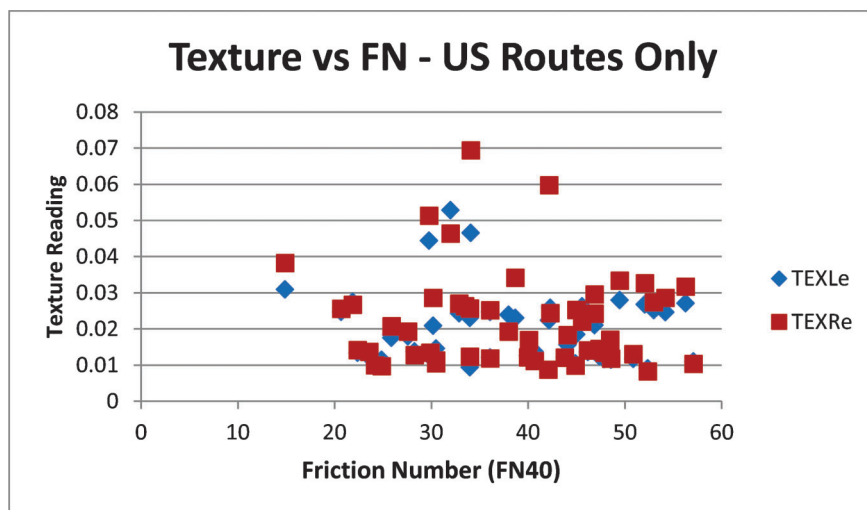


Figure 4.7 Texture vs. friction—asphalt US route surfaces only, 2008.

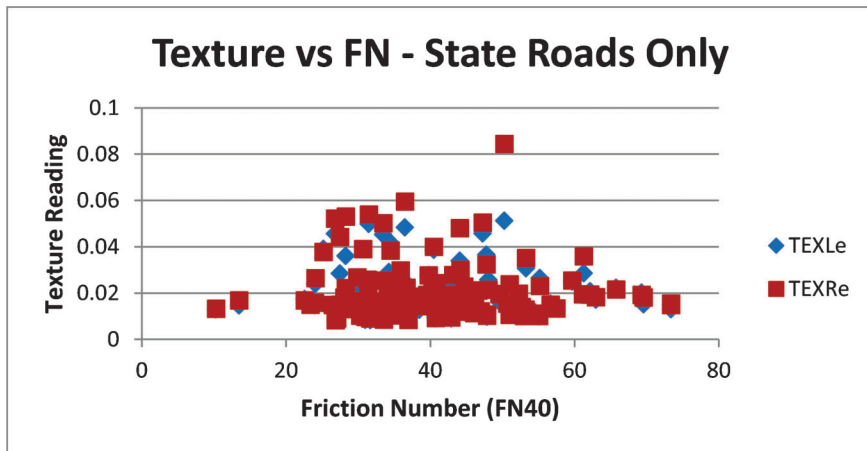


Figure 4.8 Texture vs. friction—asphalt state routes only, 2008.

in an Access database with hundreds of thousands of lines of data. The researchers identified about 16 sites where data had been collected in multiple years to see if changes in surface texture from one year to the next might signal a change in friction. These sites were mostly interstate sites since friction data there would be collected every year. The idea was that if trends existed showing that changes in texture could be related to changes in friction on the interstates where the annual friction data is available, non-interstate routes would then be examined to see if the trends held. Two non-interstate sites where the data was available were also examined.

The first site analyzed for changes in texture between 2007 and 2010 looked promising. As shown in Figure 4.9, this part of I-64 appears to show decreasing texture between 2007 and 2009, with 2010 texture values comparable to those of 2009. This happens to be

a concrete section, so it was possible that, if the roadway were new in 2006 or 2007, the rough tines could be worn away by traffic, resulting in lower friction numbers. This section, however, is reportedly not new pavement, so the change in texture is harder to explain.

Comparison of the friction numbers for this section of I-64 to the texture, however, showed that the friction values in 2007 and 2008 were actually lower than in 2009 and 2010, contrary to what the texture values might suggest. The friction values are shown in Table 4.1.

The other roadway sections examined did not show a trend of decreasing friction over time. The other comparisons are shown in Appendix A.

In one last attempt to identify a reliable relationship between texture and friction, the research team attempted to identify roadway sections that had

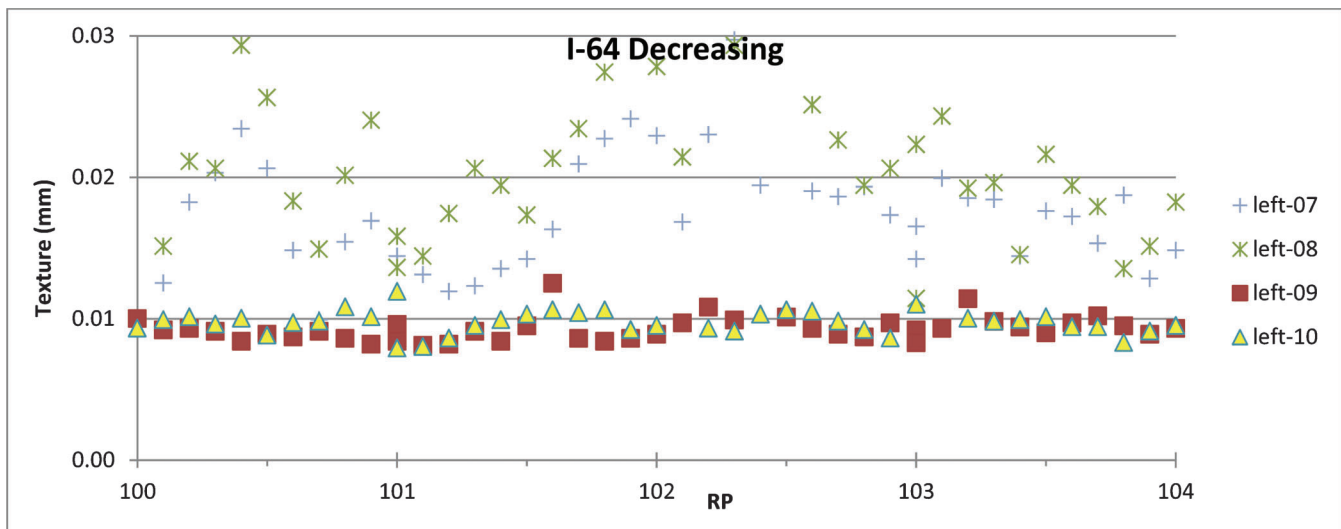


Figure 4.9 Change in texture over time, I-64.

TABLE 4.1
Friction Numbers over Time, I-64

Approximate RP	FN40 in 2007	FN40 in 2008	FN40 in 2009	FN40 in 2010
100–101	27.5	26.9	37.3	44.4
101–102	31.1	33.0	31.1	46.8
102–103	29.2	32.2	39.7	42.4
103–104	29.7	30.9	38.8	37.9

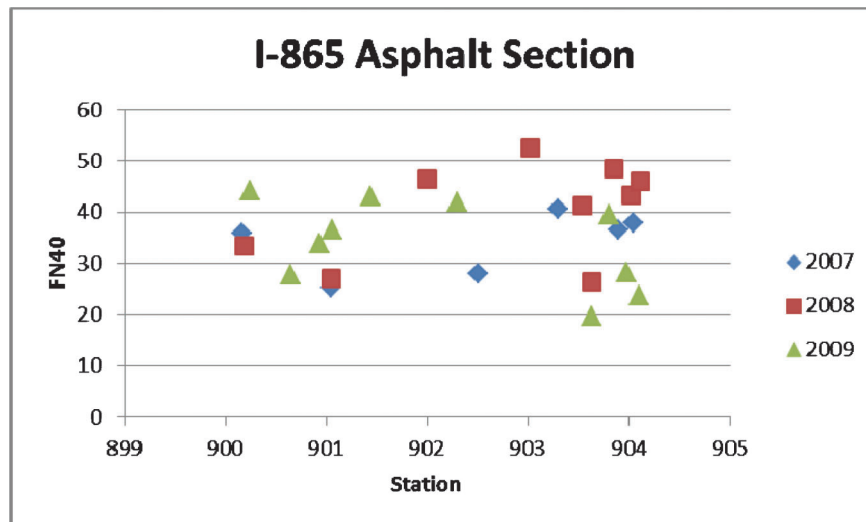


Figure 4.10 Change in friction over time, I-865.

experienced a loss in friction, then the corresponding textures were explored. Dr. Shuo Li, of INDOT Research, identified a few sections to investigate. An example from I-865 is shown in Figure 4.10 and Table 4.2. The data in Table 4.2 indicates that the texture in the left wheel path has been quite stable over the years from 2007 through 2010 although the friction values seem to show a drop from 2008 to 2009, as shown in Figure 4.10.

4.3 Possible Explanation for Lack of Correlation

The analyses presented above indicate that, at the present time and with the data currently available, it is not appear feasible to use texture from the Pathway van as a surrogate to model changes in friction in years when the friction testing is not conducted. The fact that

the literature shows a strong relationship between texture and friction, however, makes one wonder why the current data does not demonstrate that relationship. The literature cited in the introductory part of this report did reflect the need to consider both micro- and macrotexture when looking at pavement friction; neither measure, by itself, is sufficient to explain surface friction. A graph from a 2002 study by G. W. Flintsch et al., who investigated the effects of micro- and macrotexture on friction at various speeds, reinforces this finding and may help to explain the negative results of this project. Their findings, illustrated in Figure 4.11, show that changing the aggregate macrotexture has a much greater effect on friction than changing the microtexture (26). That is, increasing the macrotexture for a given microtexture results only in a small change—a flattening of the curve relating coefficient of friction to speed. Changing the microtexture for a given macrotexture, however, results in moving the entire curve up or down. Changing the microtexture, then, has a much greater impact on friction than the macrotexture, but both types of texture do have an effect. Unfortunately, the texture data available to INDOT is macrotexture data, so the effects of the microtexture are not captured.

With currently available laser technology, it is not possible to measure microtexture at highway speeds, so

TABLE 4.2
Range of Left Wheel Path Textures over Time, I-865

	Minimum	Maximum	Average
2007	0.0061	0.5196	0.01939
2008	0.0058	0.4400	0.01996
2009	0.0059	0.4443	0.01983
2010	0.0064	0.04351	0.02022

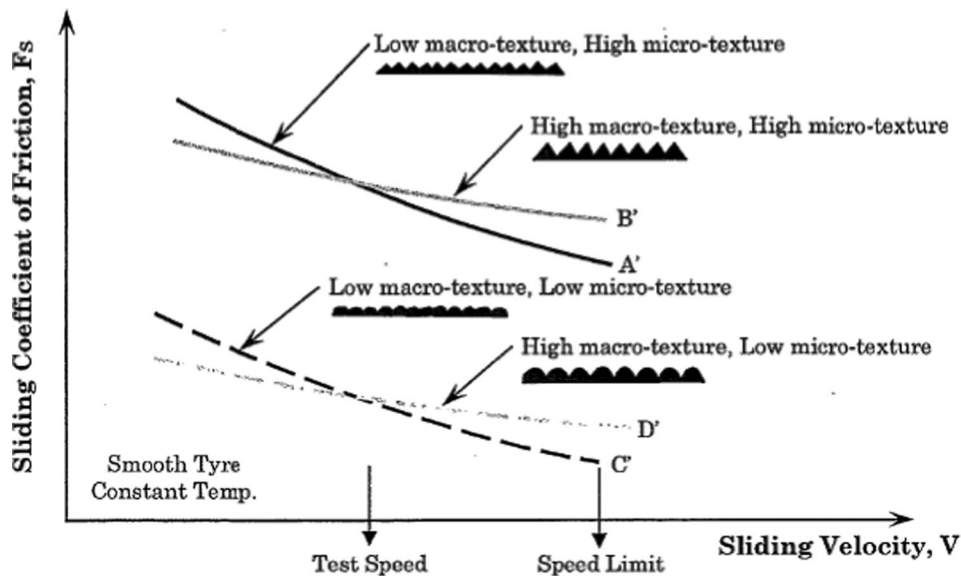


Figure 4.11 Effects of micro- and macrotexture on surface friction at various speeds (26).

the data analysis is missing a critical component. Li, Nouredin and Zhu (2) investigated the possibility of measuring micro- and macrotexture using lasers to enhance the safety of the friction monitoring program. The towed friction trailers typically operate at speeds of 30, 40 and 50 mph. Traffic, however, is frequently traveling at much higher speeds, especially on interstates where the legal limit of as much as 70 mph is frequently exceeded. The authors examined the possible use of non-contact laser technology in place of the towed friction trailer. They confirmed the findings of many other researchers that pavement friction depends on both the micro- and the macrotexture. They also concluded that no commercially available laser system is currently available that is capable of capturing microtexture. Future research and developments in the areas of laser or image processing may make use of laser based texture measurements feasible in lieu of measuring friction with the towed friction trailer (2).

5. CONCLUSIONS

At the present time and with the data that is readily available, it is not feasible to incorporate friction in the pavement management system through use of the texture data collected during routine condition monitoring with the Pathway van. The available data was analyzed in a variety of ways, and no reliable, or even remotely definitive, relationships could be found to identify pavements that might demonstrate inadequate friction because of low texture. It is theorized that this lack of a correlation, or minimum texture value to provide adequate friction, is at least in part because the current texture measurements are of the macrotexture only and the significant effects of microtexture are not being captured. Future advances in laser technology,

however, may make measuring micro-texture feasible. This concept could be revisited in the future.

6. RECOMMENDATIONS FOR IMPLEMENTATION

At the present, it is not feasible to incorporate management of pavement friction in the Pavement Management System through the use of the pavement texture data collected during routine pavement condition monitoring. INDOT should remain open to consideration of future technological advances that may make it feasible to quantify the effects of pavement microtexture at highway speeds. The Office of Research and Development is ideally suited to continue to search for feasible technologies.

For spot testing for forensic analysis or for testing in places where the towed friction trailer cannot operate safely, it would be possible to measure friction and texture using the DFT and CTM as outlined in other research, as these values have been correlated with the towed friction trailer data. The CTM is particularly well suited to forensic analyses since its data can be analyzed to separate the effects of micro- and macrotexture, which helps to identify the causes of low friction. The North Central Superpave Center has this equipment and expertise in its sue and would be available to assist with spot investigations.

REFERENCES

1. Federal Highway Administration. *Pavement Friction Management*. Technical Advisory T 5040.38. June 17, 2010, <http://www.fhwa.dot.gov/pavement/t504038.cfm>. Accessed 9/27/2012.
2. Li, S., S. Nouredin, and K. Zhu. *Safety Enhancement of the INDOT Network Pavement Friction Testing Program*:

- Macrotecture and Microtexture Testing Using Laser Sensors*. Publication FHWA/IN/JTRP-2010/25. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2010. doi: [10.5703/1288284314248](https://doi.org/10.5703/1288284314248).
3. Kennedy, C. K., A. E. Young, and I. C. Butler. Measurement of Skidding Resistance and Surface Texture and the Use of Results in the United Kingdom. In *Surface Characteristics of Roadways: International Research and Technologies*. ASTM STP 1031. W. E. Meyer and J. Reichert, Eds. American Society for Testing and Materials, Philadelphia, 1990, pp. 87–102.
 4. Dewey, G. R., A. C. Robords, B. T. Armour, and S. R. Looman. Aggregate Wear and Pavement Friction. In *Transportation Research Board Annual Meeting Preprint CD-ROM*. Transportation Research Board, Washington, D.C., 2001.
 5. Henry, J. J. *Evaluation of Pavement Friction Characteristics*. Synthesis of Highway Practice No. 291. Transportation Research Board, Washington, D.C., 2000.
 6. Prasanna, R., B. Nageswaran, and P. W. Jayawickrama. Use of Relational Database Management Systems Principles in Reliable Prediction of Pavement Skid Resistance. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1655, Transportation Research Board of the National Academies, Washington, D.C., 1999, pp. 192–199.
 7. McDaniel, R. S., and B. J. Coree. *Identification of Laboratory Techniques to Optimize Superpave HMA Surface Friction Characteristics*. Interim Report. Joint Transportation Research Project No. C-36-56K, Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, October 2003.
 8. Yager, T. J., and F. Bühlmann. Macrotecture and Drainage Measurements on a Variety of Concrete and Asphalt Surfaces. In *Pavement Surface Characteristics and Materials*, ASTM STP 763. C. M. Hayden, Ed., American Society for Testing and Materials, Philadelphia, 1982, pp. 16–30.
 9. Abe, H., J. J. Henry, A. Tamai, and J. Wambold. Measurement of Pavement Macrotecture Using the CTMeter. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1764, Transportation Research Board of the National Academies, Washington, D.C., 2000, pp. 201–209.
 10. McGhee, K. K., and G. W. Flintsch. *High-Speed Texture Measurement of Pavements*. Final Report, Report No. VTRC 03-R9, Virginia Transportation Research Council, Charlottesville, Virginia, 2003.
 11. Kulakowski, B. T., and D. W. Harwood. Effect of Water-Film Thickness on Tire-Pavement Friction. In *Surface Characteristics of Roadways: International Research and Technologies*. ASTM STP 1031. W. E. Meyer and J. Reichert, Eds., American Society for Testing and Materials, Philadelphia, 1990, pp. 50–60.
 12. Kandhal, P. S., and F. Parker Jr. *Aggregate Tests Related to Asphalt Concrete Performance in Pavements*. NCHRP Report 405. National Academy Press, Washington, D.C., 1998.
 13. Jayawickrama, P. W., R. Prasanna, and S. P. Senadheera. Survey of State Practices to Control Skid Resistance on Hot-Mix Asphalt Concrete Pavements. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1536, Transportation Research Board of the National Academies, Washington, D.C., 1996, pp. 52–58.
 14. Doty, R. N. Study of the Sand Patch and Outflow Meter Methods of Pavement Surface Texture Measurements. In *Surface Texture versus Skidding: Measurements, Frictional Aspects, and Safety Features of Tire-Pavement Interaction*, ASTM STP 583. American Society for Testing and Materials, Philadelphia, 1975.
 15. Diring, K. T., and R. T. Barros. Predicting the Skid Resistance of Bituminous Pavements Through Accelerated Laboratory Testing of Aggregates. In *Surface Characteristics of Roadways: International Research and Technologies*. ASTM STP 1031. W. E. Meyer and J. Reichert, Eds., American Society for Testing and Materials, Philadelphia, 1990, pp. 61–76.
 16. Bruner, D. W., J. C. Choi, and T. R. West. *Development of a Procedure to Identify Aggregates for Bituminous Surfaces in Indiana*. Publication FHWA/IN/JHRP-95/11. Joint Highway Research Project, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 1996. doi: [10.5703/1288284313187](https://doi.org/10.5703/1288284313187).
 17. Augustin, H. Skid Resistance and Road-Surface Texture. In *Surface Characteristics of Roadways: International Research and Technologies*. ASTM STP 1031. W. E. Meyer and J. Reichert, Eds., American Society for Testing and Materials, Philadelphia, 1990, pp. 5–13.
 18. Gunaratne, M., N. Bandara, J. Medzorian, M. Chawla, and P. Ulrich. Correlation of Tire Wear and Friction to Texture of Concrete Pavements. *Journal of Materials in Civil Engineering*, Vol. 12, No. 1, American Society of Civil Engineers, Washington, D.C., 2000, pp. 46–54.
 19. Huihua, X., and J. J. Henry. The Use of Fuzzy-Sets Mathematics for Analysis of Pavement Skid Resistance. In *Surface Characteristics of Roadways: International Research and Technologies*. ASTM STP 1031. W. E. Meyer and J. Reichert, Eds., American Society for Testing and Materials, Philadelphia, 1990, pp. 39–49.
 20. Henry J. J. Use of Blank and Ribbed Test Tires for Evaluating Wet Pavement Friction. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 788, Transportation Research Board of the National Academies, Washington, D.C., 1981, pp. 1–6.
 21. Henry J. J., and K. Saito. Skid-Resistance Measurements with Blank and Ribbed Tires and Their Relationship to Pavement Textures. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 946, Transportation Research Board of the National Academies, Washington, D.C., 1983, pp. 38–43.
 22. Kowalski K. J, R. S. McDaniel, J. Olek, A. Shah A, and S. Li. Development of the International Friction Index Flag Value. In *AATT 2008 Conference Proceedings*, Athens, Greece, May 2008.
 23. Kowalski, K. J., R. S. McDaniel, and J. Olek. *Identification of Laboratory Technique to Optimize Superpave HMA Surface Friction Characteristics*. Publication FHWA/IN/JTRP-2010/06. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2010. doi: [10.5703/1288284314265](https://doi.org/10.5703/1288284314265).
 24. Roe P. G., D. C. Webster, and G. West. *The Relation between the Surface Texture of Roads and Accidents*. Transport and Road Research Laboratory, Research Report 296, Crowthorne, Berkshire, U.K., 1991.
 25. Pulugurtha, S. S., K. Patel, and P. R. Kusam. Macrotecture Thresholds from a Safety Perspective for Pavement Management. Presented at the Transportation Research Board Annual Meeting, Washington, D.C., January 22–25, 2012.

26. Flintsch G. W., I. L. Al-Qadi, R. Davis, and K. K. McGhee. Effect of HMA Properties on Pavement Surface Characteristics. In *Proceedings of the Pavement Evaluation*

2002 Conference, Roanoke, Virginia, 2002, cited in *Guide for Pavement Friction*, NCHRP Web-Only Document 108.

APPENDIX A
EXPLORATION OF CHANGE OF TEXTURE OVER TIME

Decreasing indicates traveling in direction of decreasing reference posts (i.e., westbound or southbound) and increasing indicates traveling in the direction of increasing reference posts (eastbound or northbound). Data shown is for left wheel path, but no differences were observed between wheel paths. (Note: scales differ.)

