***Pavement Surface Properties Consortium –*A Research Program at the Virginia Smart Road**

**Phase II**

# Background

Functional pavement considerations are fundamental to the performance and management of pavements. In addition to structural and durability requirements, an optimum pavement wearing surface should provide a combination of a good riding quality, adequate friction and macrotexture, and a low noise level. All these properties are highly influenced by the various components of the pavement surface texture. Figure 1 summarizes the relationship between the most relevant pavement texture characteristics and their effect on pavement-vehicle interaction.

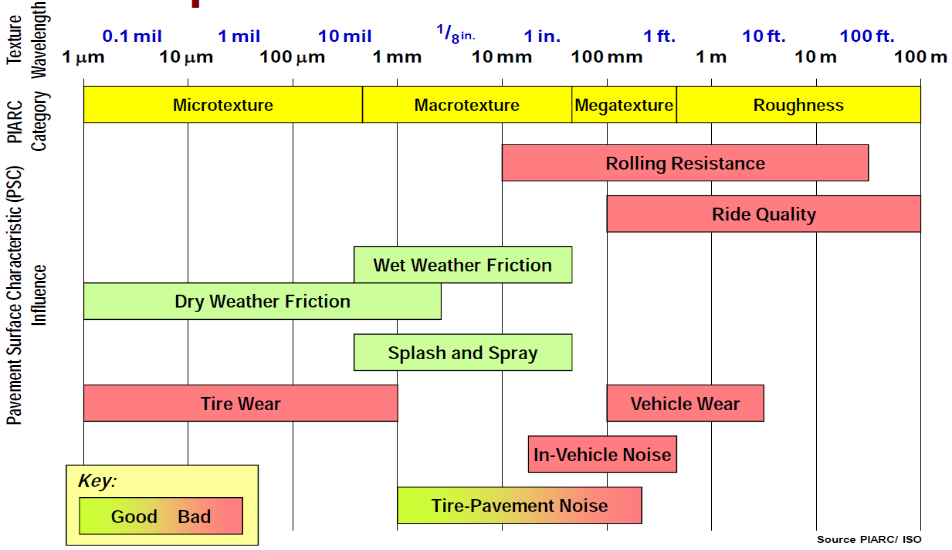


Figure . Texture wavelength influence on pavement-vehicle interaction.

# Objective

The main objective of this pooled-fund program has been to conduct applied research focused on enhancing the level of service provided by the roadway transportation system by optimizing pavement surface characteristics.

Phase I of the study has included regular verification and validation of the participant’s equipment, opportunities for technology transfer, and the accumulation of a significant body of knowledge on the measurement of pavement surface properties. Practical and tangible results have been documented and disseminated though a large number of publications (listed in Appendix I). Examples of technologies that were evaluated as part of the program include high-friction surface (HFS) treatments and Continuous Friction Measuring Equipment (CFME). HFS treatments have been adopted as a low-cost countermeasure as part of FHWA’s Every-day-Counts program. CFME’s are currently being used to support the development of a new generation of friction management programs.

Phase 2 of the program is expected to continue to support the members’ effort to produce high-quality surface property measurements, evaluate new and emerging technologies, as well as dissemination and technology transfer activities. This second phase will focus on addressing some of the emerging challenges in the evaluation of pavement surface properties and the changes needed to best support the next generation of pavement asset management systems, including support for MAP21-related initiatives. It will also seek participation of industry through the pooled-fund or an industrial affiliate program.

# Research Plan

The five-year program will be developed in cooperation with the consortium participants and will include at least the following components:

## Equipment Rodeos at the Virginia Smart Road.

The annual equipment rodeos will continue to be a core component of the program. In addition to providing a valuable opportunity for the verification and calibration of the equipment, these events also provide consortium members with a forum for discussion of common challenges, and a unique opportunity to seek solutions for these challenges, learn from each other, and be exposed to emerging practices and technologies.

### Equipment Comparisons

Pooled-fund partners will be invited to participate in one equipment comparison/verification round-up per year at the Smart Road (expenses paid). The Smart Road facility includes a variety of “real world” flexible and rigid surfaces (Figure 2) and offers very convenient and controlled conditions.

|  |  |  |
| --- | --- | --- |
| ***C2***  ***SM 9.5 D SuperPave*** | ***K2***  ***OGFC*** | ***L2***  ***SMA 9.5 D*** |
|  |  |  |
| ***CRC1***  ***Tined CRCP*** | ***JPCP3***  ***JRCP*** | ***JPCP1***  ***Ground JRCP*** |

Figure . Sample of Pavement Surfaces Available at the Virginia Smart Road.

These comparisons will permit assessment of the reproducibility and repeatability of smoothness, friction, macrotexture, and tire-pavement noise measurement techniques and equipment (See Figure 3). Other possible objectives of the equipment round-up may include group demonstration and assessment of emerging technologies and international harmonization studies.

|  |  |
| --- | --- |
|  | |
|  |  |
| \\tomahawk\users\fac_staff\edeleonizeppi\Private\Desktop\Rodeo\Rodeo 2010\Photos\Pic 327.jpg | Rodeo - 029 |
| Rodeo - 087 | holiday parade 013 |

Figure . Profile, Friction, Macrotexture and Noise Comparisons at the Virginia Smart Road

### Equipment Calibration, Verification, and Certification

Phase 2 is expected to also include calibration services for the locked–wheel trailers. The last three equipment rodeos have included force and water flow verification and calibration and before and after testing for those members interested in the service. This second phase may offer an opportunity to develop a standard procedure for calibration that may partially eliminate need for some more invasive (and expensive) procedures at the fabricator’s shop or traditional national centers.

Furthermore, depending on the final recommendations of TPF 5(063) “Improving the Quality of Pavement Profile Measurement,” the consortium may be able to provide more formal profiler certifications in addition to the verifications conducted as part of the annual equipment rodeos. Current verification procedures already included comparisons with reference profile measurements that may provide the foundation for these certifications.

## Technology Transfer

Another key aspect of the program has been the dissemination of the consortium experiences and findings through technology transfer activities. Past success and reputation should strengthen the effectiveness of future activities of this nature.

### Technical Publications and Presentations

The consortium has produced a large number of technical reports, papers and presentation (see Appendix I for a detailed list), which has supported the development of a significant body of knowledge in pavement surface characteristics and vehicle-road interaction. In addition to directly support the consortium objectives, the data collected through consortium activities has been used by researchers in the U.S. and overseas to advance pavement evaluation and enhance knowledge and understanding of the impact of the road surface on the users.

### Short courses and webinars

Over the years, the consortium has conducted various outreach activities in partnership with its members. These have included webinars and short courses on pavement surface characteristics. In particular, the consortium researchers have developed, with partial support from the Mid-Atlantic university transportation Center (MAUTC), a short course composed of a series of modules that covers introduction to vehicle-road interaction (e.g., ride quality, friction, tire-pavement noise, etc.), data quality management, and “optimized” pavement surfaces. The complete course or any of the modules are available to be offered though a distance learning webinar or in person at any of the participants locations and will be made available to academic institutions to be incorporated into regular academic classes. The second phase of the program may include a series of webinar or short course as requested by the consortium members.

### Technological Support Services

Consortium resources will be available to support partners with the evaluation of emerging related technologies and their application. These evaluations may be complemented with demonstrations of the technologies (e.g, OBSI, CFME, etc.) through pilot programs, equipment loans and/or purchase, and development of specifications for the acquisition of equipment or services, and/or support for the establishment of measurement programs. One possible example is supporting the quality assurance and acceptance of HFS treatments. HFS treatments are emerging as an effective safety measure, but agencies are having problems evaluating their frictional properties after constructed due to the difficult geometry in which they are placed. The consortium could investigate the best system(s) for testing HFS installations and, if warranted, establish a program-based service for its members.

## Research on Emerging Topics

Finally, the consortium provides a unique opportunity to conduct specific studies of common interest that require measurement of pavement surface properties undera controlled traffic and/or environmental conditions on different types of road surfaces. These will be proposed and selected by the consortium participants. Examples of potential topics that were proposed at the last technical Advisory Committee meeting include the following:

* ***Evaluation of emerging 3D systems and their impact of current practices for characterizing pavement surfaces***. Some of the consortium members have already acquired, and others are considering upgrading their pavement evaluation systems to include, technologies that producing 3D mapping of the pavement surface. A potential research project could focus on assessing the benefits and potential challenges that come with the adoption of these technologies. The project could also investigate the most appropriate methods for verifying repeatability and accuracy of available systems and methods.
* ***Novel ways of characterizing macrotexture***. The consortium has already conducted research that suggested that current methods for characterizing pavement macrotexture can be improved, proposed a novel approach that has been partially tested, and suggested further improvements. A potential follow up project could focus on testing the approach more thoroughly and assessing the feasibility of the proposed possible improvements.
* ***Impact of MAP-21 requirements on current practices.*** The implementation of MAP-21 is bringing new focus on measuring the performance of the road networks uniformly across the country. A potential research project could focus on the impact of MAP-21 requirements on the way we measure, process and report pavement surface properties. This may require contrasting practices across the country, assessing the appropriateness of current standards and evaluating the need of new or improved standards.
* ***Identification and correction of localized roughness***. For example, the consortium could prepare a synthesis that addresses common causes for localized roughness, methods to identify, and ways for correcting it. Depending on the interested of the members and the market for the product may be pursued through a different avenue, such as NCHRP.

# Benefits

Phase I of the program has proven that the establishment of a collaborative research program can provide an accessible and efficient way for highway agencies and other organizations to conduct research on pavement surface properties. The collaboration has helped the participating agencies verify the operation and accuracy of the equipment used for their pavement evaluations. Some specific benefits of participating in the consortium include:

* Very favorable return on investment - each member enjoys pool of resources - core facility already established - operation costs shared by many.
* All consortium participants will have priority and free access to the facility during the pre-accorded dates.
* Consortium participants will select key areas of program emphasis, as well as specific research projects.
* Workforce development - scientists/engineers trained on pavement surface properties through master’s and doctoral thesis funded through the consortium.
* Yearly attendance to the RPUG meeting, including simplification of the travel procedure for state travelers.

# Appendix I - Outcomes of Phase I

## Reports:

1. Flintsch, G.W., and McGhee, K.K, de León Izeppi, E.D., and Nejafi, S., *The Little Book of Tire Pavement Friction, Version 1.0*, September 2012.
2. de León Izeppi, E.D., Flintsch, G.W., and McGhee, K.K, *Field Performance of High-Friction Surface*, Virginia Transportation Research Council,, VTRC 10-CR6, , Jun 2010, Charlottesville, VA, 28 pp.

## Peer-reviewed journal and conference papers produced based on the consortium studies:

1. Najafi, S., Flintsch, G.W., and Medina, A., “Linking roadway crashes and tire–pavement friction: a case study,” *International Journal of Pavement Engineering*, 2015,DOI: 10.1080/10298436.2015.1039005, **In Press**.
2. Katicha, S.W., Mogrovejo, D.E., Flintsch, G.W., and de Leon Izeppi, E.D. “Adaptive spike removal method for high speed pavement macrotexture measurements by controlling the false discovery rate,” *Journal of the Transportation Research Board*, 2015, paper No. 15-4500, **In Press**.
3. Mogrovejo, D.E., Flintsch, G.W., de León Izeppi, E.D., and McGhee, K.K. “Tire-Pavement Noise Evaluation and Equipment Comparison Using On Board Sound Intensity Methodology over Several Pavement Surfaces in Virginia,” 2014, *Journal of the Transportation Research Board*, vol. 2403, pp. 17-27.
4. Evangelisti, A., Katicha, S., de Leon, E., Flintsch, G.W., D’Apuzzo, M., Nicolosi, V., “Measurement Error Models (MEM) regression method to Harmonize Friction Values from Different Skid Testing Devices,” *Transport Research Arena*, Apr 14-17, 2014, Paris, France.
5. D’Apuzzo, M., Evangelisti, A., de León Izeppi, E.D., Flintsch, G.W., Estimation of Pavement Macrotexture from Hot-Mix Asphalt Properties,” *17th International Road Federation World Meeting & Exhibition*, Nov 10-14, 2013, Riyadh, Kingdom of Saudi Arabia.
6. Najafi, S., Flintsch, G.W., de León, E., McGhee, K.K, “Assessment of Operational Characteristics of Continuous Friction Measuring Equipment (CFME),” *International Journal of Pavement Engineering*, 2013, Vol. 14(8), pp 706-714, Taylor & Francis, DOI: 10.1080/10298436.2012.667097.
7. de León Izeppi, E., Flintsch, G.W., and McGhee, K.K. “Effect of Water, Speed, and Grade on Continuous Friction Measurement Equipment (CFMEs),” ASTM STP 1555 *Pavement Performance: Current Trends, Advances, and Challenges*, 2013 (Choubane, B., Editor).
8. Mogrovejo, D.E., Flintsch, G.W., de León Izeppi, E.D., and McGhee, K.K. “Effect of Air Temperature and Vehicle Speed on Tire/Pavement Noise Measured with On-Board Sound Intensity Methodology,” paper 13-3765, *92nd Annual Meeting of the Transportation Research Board*, Jan 13-17, 2013, Washington, DC.
9. Zhao, G., Flintsch, G.W., “Comparative Analysis on Promising Algorithms for Pavement Homogeneous Segmentation,” paper 13-4650, *92nd Annual Meeting of the Transportation Research Board*, Jan 13-17, 2013, Washington, D.C.
10. De León, E., Flintsch, G.W., McGhee, K.K., “Limits of Agreement Method for Comparing Pavement Friction Measurements,” *Journal* *of the Transportation Research Board*, 2012, vol. 2306, pp. 188-195.
11. Fuentes, L.G., de León, E., Flintsch, G.W., Martinez, G., “Determination of Pavement Macrotexture Limit For Use in The International Friction Index (IFI) Mode,” *Journal* *of the Transportation Research Board*, 2012, vol. 2306, pp. 138-143.
12. de León Izeppi, E.D., Flintsch, G.W., Archilla, A.R., Sequeira, W., “[Data Processing and Analysis Software for Continuous Friction Measurement Equipment](http://trb.metapress.com/content/g5j72832840l8nw4/),” *Journal of the Transportation Research Board*, 2011, TRR 2227, pp. 163-170.
13. El Gendy, A., Shalaby, A, Saleh, M, Flintsch, G.W., “Stereo-vision applications to reconstruct the 3D texture of pavement surface,” *International Journal of Pavement Engineering*, 2011, Vol. 12(3), pp. 263-273.
14. Flintsch, G.W., de León Izeppi, E., Saleh, H, “Infrared Stereo Vision for Pavement Texture Analysis,” *First T&DI Congress – Integrated Transportation and Development for a Better Tomorrow* (presentation only), Mar 13-16, 2011, Chicago, IL.
15. Najafi, S., Flintsch, G.W., de León, E.D., McGhee, K.K., “Implementation of Cross-Correlation to Compare Continuous Friction Measuring Equipment,” paper [11-2](http://pressamp.trb.org/conferenceinteractiveprogram/PresentationDetails.aspx?ID=34536)083, *90th Annual Meeting of the Transportation Research Board*, Jan 23-27, 2011, Washington, DC.
16. Saleh, M., Flintsch, G.W., de León, E.D., McGhee, K.K., Abbott, A.L., “Pavement Texture Analysis Using Infrared Stereo Vision,” paper 11-[27](http://pressamp.trb.org/conferenceinteractiveprogram/PresentationDetails.aspx?ID=34536)39, *90th Annual Meeting of the Transportation Research Board*, Jan 23-27, 2011, Washington, DC.
17. Flintsch, G.W., de León Izeppi, E.D., McGhee, K.K., Najafi\*, S., “Speed Adjustment Factors for Locked-Wheel Skid Trailer Measurements,” *Journal of the Transportation Research Board*, 2010, TRR 2155, pp. 117-123.
18. Flintsch, G.W., de León Izeppi, E.D., McGhee, K.K., Shetty, S.S., “Profiler Certification Process at the Virginia Smart Road, paper [10-2513](http://pressamp.trb.org/conferenceinteractiveprogram/PresentationDetails.aspx?ID=34536), *89th Annual Meeting of the Transportation Research Board*, Jan 10-14 2010, Washington, DC.
19. Flintsch, G.W., de León Izeppi, E.D., McGhee, K.K., Roa, J.A., “Review of High-Friction Surface Technologies: Constructability and Field Performance,” paper [10-2072](http://pressamp.trb.org/conferenceinteractiveprogram/PresentationDetails.aspx?ID=34536), *89th Annual Meeting of the Transportation Research Board*, Jan 10-14 2010, Washington, DC.
20. Flintsch, G.W., de León, E.D., McGhee, K.K., Roa, J.A., “ “Field Performance Evaluation of High-Friction Surfaces,” International Seminar, *Maintenance Techniques to Improve Pavement Performance*, World Road Association (PIARC), Aug 24-26, 2009, Cancun, Mexico.
21. de León, E.D., Flintsch, G.W., Saleh, M.I., McGhee, K.K., “Stereo Vision Application for Macrotexture Measurement,” scheduled for presentation at the *Sixth International Conference on Maintenance and Rehabilitation of Pavements and Technological Control (MAIREPAV6)*, Jul 8-10 2009, Torino, Italy.
22. de León Izeppi, E., Flintsch, G.W., Saleh, M., and McGhee, K.K., “Area-Based Macrotexture Measurements: A Stereo Vision Approach.” Paper 09-3067, *88th Meeting of the Transportation Research Board*, Jan 2009, Washington, DC (CD-ROM).
23. Flintsch, G.W., de León, E., Izeppi, Roa, J., McGhee, K.K., and Swanlund, M., “Evaluation of the International Friction Index Coefficients for Various Devices,” *6th Symposium on Pavement Surface Characteristics*, *SURF 2008,* October 20-22, Portoroz, Slovenia (CD-ROM)..
24. Flintsch, G.W., de León, E., Izeppi, Saleh, M., McGhee, K.K., and Swanlund, M., “Area-Based Macrotexture Measurements using Stereo Vision,” *6th Symposium on Pavement Surface Characteristics*, *SURF 2008,* October 20-22, Portoroz, Slovenia (CD-ROM).
25. Trifirò, F., Flintsch, G.W., Guerrera, G., de León E. and McGhee, K.K., “Comparison of Friction Measuring Devices and Preliminary Evaluation of the International Friction Index Coefficients,” paper [08-1816](http://www.trb.org/am/ip/paper_detail.asp?paperid=21393), 87th *Annual Meeting of the Transportation Research Board*, Jan. 13, 2008 , Washington, DC (CD-ROM).

## Publications from other projects that used data from the consortium (not a comprehensive list):

1. Katicha, S.W., El Khoury, J., and Flintsch, G.W. “Assessing the effectiveness of probe vehicle acceleration measurements in estimating road roughness,” *International Journal of Pavement Engineering*, 2015,DOI: 10.1080/10298436.2015.1014815, **In Press**.
2. Bryce, J., Katicha, S., Flintsch, G.W., Sivaneswaran, N., Santos, J. “Probabilistic Lifecycle Assessment as a Network-Level Evaluation Tool for the Use and Maintenance Phases of Pavements.” *Journal of the Transportation Research Board*, 2015, vol. 2455 (1), pp. 44-53.
3. Fuentes, L.G., Flintsch, G.W., de León Izeppi, E.D., “Evaluation of the Use of the International Friction Index on Skid Data obtained using Friction Models, *Journal of Testing and Evaluation*, Nov. 2014, Vol. 42(6), DOI: 110.1520/JTE2013006.
4. Bryce, J., Joao Santos, Gerardo Flintsch, Samer Katicha, Kevin McGhee, and Adelino Ferreira, 2014. “Analysis of Rolling Resistance Models to Analyze Vehicle Fuel Consumption as a Function of Pavement Properties.” *12th International Conference on Asphalt Pavements,* Kim, R. (ed.), June 2014, pp. 263-273. Taylor and Francis Group: London
5. Viner, H., Hargreaves, D., Dunford, A., Nesnas, K., Parry T., and Flintsch, G.W., “Development of a Prediction Model for Splash and Spray,” proceedings of the *7th Symposium on Pavement Surface Characteristics* (SURF 2012), Sep. 18-21, 2012, Norfolk, VA
6. Tang, L., Flintsch, G.W., and Viner, H., “Exposure Model For Predicting Splash and Spray,” *Proceedings of the 7th Symposium on Pavement Surface Characteristics* (SURF 2012), Sep. 18-21, 2012, Norfolk, VA*.*
7. Flintsch G.W., Williams, B., Gibbons, R., Viner, H., “Assessment of the Impact of Splash and Spray on Road Users - Controlled Experiment Results,” *Journal* *of the Transportation Research Board*, 2012, vol. 2306, pp. 151-160.
8. Flintsch, G.W., Valeri, S., Katicha, S.W., de Leon, E.D., Medina-Flintsch, A., “Pilot Demonstration of the Use Probe Vehicle Dynamic Signatures to Measure Road Smoothness,” *Journal of the Transportation Research Board*, 2012, vol. 2304, pp. 158-165.

## Other presentations based on the results of the consortium:

1. de León Izeppi E., Toom, P., “Achieving High Correlations of Inertial Profilers with Reference Profilers at the Smart Road,: Pavement Evaluation 2014, Blacksburg, VA, Sept 15-18, 2014.
2. Flintsch, G.W., “Some Lessons Learned from Surface Properties Research at the Virginia Smart Road,” 2013 H.W. Kummer Lecture, *ASTM Committee E17 on Vehicle - Pavement Systems*, Jacksonville, FL, Dec 10, 2013.
3. Flintsch, G.W. “Using Profile Data for Supporting Asset Management Decisions,” invited presentation, *1st European Road Profiler User Group Meeting*, Copenhagen, Denmark, Sep 10-12, 2013.
4. S. Katicha, G.W. Flintsch, “Use of Probe Vehicles to Measure Road Ride Quality,” *Road Profiler User Group Meeting*, San Antonio, TX, Sep. 16 to 19, 2013.
5. E. de León Izeppi, G.W. Flintsch, “[Profiler Certification Process at the Virginia Smart Road](http://www.rpug.org/download/2013/6-3-Edgar%20de%20Le%C3%B3n%20Izeppi.pdf),” *Road Profiler User Group Meeting*, San Antonio, TX, Sep. 16 to 19, 2013.
6. de León, E.D., Flintsch, G.W., “Continuous Friction Measuring, Equipment (CFME) Loan Program: GripTester and DYNATEST HFT,” *Pavement Evaluation 2010*, Roanoke, VA, Oct 24-26, 2010.
7. Najafi, S., Flintsch, G.W., de León, E.D., “Performance Characteristics of Continuous Friction Measurement Equipment (CFME),” *Pavement Evaluation 2010*, Roanoke, VA, Oct 24-26, 2010.
8. de León, E.D., Flintsch, G.W., “Continuous Friction Measuring, Equipment (CFME) Loan Program: GripTester and DYNATEST HFT,” *Pavement Evaluation 2010*, Roanoke, VA, Oct 24-26, 2010.
9. Najafi, S., Flintsch, G.W., de León, E.D., McGhee, K.K., “Speed Adjustment Factors for the Locked-wheel Skid Trailer,” *The* *21st Annual Road Profiler Users' Group Meeting*, Dec. 9-11, 2009, Atlanta, GA.
10. Shetty, S.S., Flintsch, G.W., de León Izeppi, E.D., McGhee, K.K., “Preliminary Results from the Profiler Certification Exercise at the Virginia Smart Road,” *The* *21st Annual Road Profiler Users' Group Meeting*, Dec. 9-11, 2009, Atlanta, GA.