Standing Committee on Pavement Surface Properties and Vehicle Interaction (AFD90)
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Pavement Surface Properties and Vehicle Interaction: Past, Present and Future

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HISTORY OF THE COMMITTEE

Road Surface Properties Related to Vehicle Performance (D-B4) existed from 2/1/1954 to 1/31/1970. Surface Properties -Vehicle Interaction (A2B04) existed from 2/1/1970 to 1/31/1982 when it was changed to A2B07. The standing committee on Pavement Surface properties and Vehicle Interaction (AFD90) was formed in 2/1/1982 as A2B07. The list below provides the names of the chairs of the committee:

Mikhail , Magdy	4/15/2018-4/15/2021
Chang, George	4/15/2012-4/14/2018
McGhee, Kevin	4/15/2006-4/14/2012
Wambold, James	2/1/2000- 4/14/2006
Yager, Thomas	2/1/1994 – 1/31/2000
Henry, John	2/1/1988 – 1/31/1994
Parish, A.	2/1/1982- 1/31/1988
Ivey, Don	2/1/1976- 1/31/1982
Meyer, W.	2/1/1970- 1/31/1976
Mahone, David	1/1/1964-1/31/1970

INTRODUCTION AND BACKGROUND

The scope of the Transportation Research Board (TRB) AFD90 committee "Pavement Surface Properties and Vehicle Interaction" is concerned with the interactions between the vehicle and traveled pavement surfaces as they affect safety, comfort, convenience, sustainability and economics. Areas of interest include evaluation, modeling and quantification of the factors that influence the interactions of the vehicle and the pavement surface. The committee has several focus areas:

1. Profile Measurement and Use
2. Texture Measurement and Use

3. Tire-Pavement Friction
4. Tire-Pavement Noise
5. Pavement Surface-Related Safety and Environmental Related Issues

This paper will provide a brief description of the above focus areas, how each subject changed over time by presenting the past and present state of practices and future trends and emerging issues.

PROFILE MEASUREMENT AND USE

Past and Present State of Practices

The past state of practice of this focus area included measurement of pavement surface profiles and management of existing pavements with a combination of straight-edge based devices and response-type road roughness measurement systems. HRB Bulletin 264, circa 1960 (1), includes an excellent review of measurement devices by Francis Hveem.

Each device produced a measure of roughness, but the scale was not reproducible among devices. The literature within HRB and TRB includes heavy content related to measurement quality, correlation between devices, and attempts at standardization by various owner agencies. Fundamental developments helped define the current state of the art:

1. *Introduction of the inertial profiler:*

This was introduced by Spangler and Kelly in the early 1960s. The first publication was in HRB Bulletin 328 (2), which described technology, used to measure road profile by the automotive industry. (This was published under the committee on road surface properties related to vehicle performance.) Inertial profilers offered the possibility of measuring the undistorted profile over a wide range of wavelengths that applicable to ride quality, and a reproducible measurement system. See Figure 1.

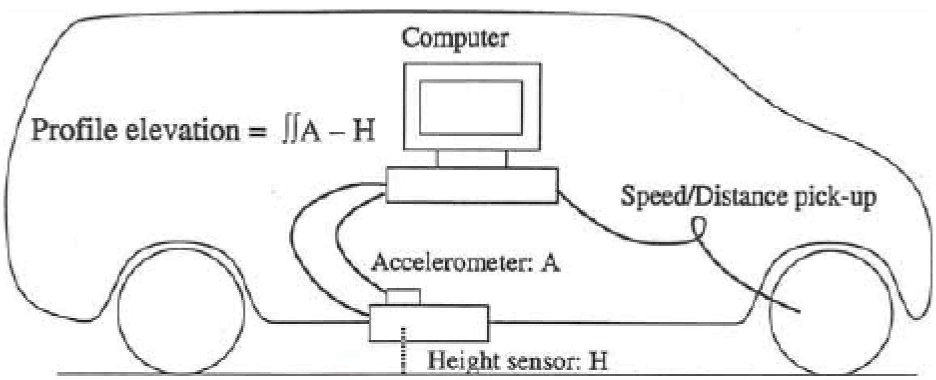

Figure 1. Inertial Profiler

2. *Introduction of the International Roughness Index (IRI):*

The Intentional Roughness Index was defined as a time-stable, reproducible roughness scale, and was derived from profile. It was intended as a correlation standard for response-type systems. Once inertial profilers proliferated (due to an eventual reduction in cost), the IRI became the standard scale for roughness in pavement management. Eventually, inertial profilers and the IRI replaced straight-edge devices as the preferred scale for construction QA/QC. (The development of the IRI was initiated by TRB through NCHRP research (3).

The current state of practice and best practices: include profiler certification methods, use of IRI for pavement management and construction quality control/assurance, advanced analysis tools (Power Spectral Density (PSD), etc.), better quality sensors (wide-footprint height sensors), and specialized applications (smoothness for bridges, curling for concrete pavements, etc.). Four relevant AASHTO standards (4) contain a lot of the practical value in the state of the art.

M 328-14 (2018) Inertial Profiler

R 54-14 (2018) Accepting Pavement Ride Quality When Measured Using Inertial Profiling Systems

R 56-14 (2018) Certification of Inertial Profiling Systems

R 57-14 (2018) Operating Inertial Profiling Systems

The current issues for profile measurement include:

(1) Urban applications (Relevance of IRI at low speed, measurement challenges at low speed, impact of stop and go on data collection , the need for a non-inertial measurement device).
(2) Fusion with other data (GPS-based fusion with distress images/measurements, and GPS-based integration with a broader asset management strategy).
(3) Better, more automated leveraging of profile data (identification of hot spots, automated feature recognition).
(4) Applying certification/verification to network survey profilers for HPMS reporting and pavement management.

Future Challenges
The committee will need to address challenges and opportunities by improvements in Laser sensors for profile measurements, improvement in video and image collection and recognition, and geospatially location associated with road surface measurement. The committee will aim for the following:

- Assist to the community with implementation of the new Federal rules
- Incorporate crowd-sourced roughness information in a rational manner.
- Implement best practices for urban applications (3-5 years). Develop and standardize of 3-D surface measurement (certification, interpretation algorithms).
- Quantify the cost of roughness (excess fuel consumption, vehicle wear/operational cost, discomfort, reduced pavement life, etc.) using objective data.
- Leverage connected and automated vehicle infrastructure. Implementation of connected and automated vehicles will include real-time monitoring of vehicles responses and the driving environment. Real-time information from sensor readings and video images can augment traditional road surveys to monitor the status of the road surface.
- Support connected and automated vehicles. Connected and automated vehicles will cause a change in travel speeds, travel patterns, vehicle design, passenger orientation, and

passenger behavior (i.e., reading or working while traveling). Changes will be needed to road surface design and ride comfort criteria to account for this.

TEXTURE MEASUREMENT AND USE

The macrotexture of the pavement is related to several tire-pavement interactions such as friction, rolling resistance, tire-pavement noise, and splash and spray.

Past and Present State of Practices

The most common method to measure the macrotexture of a pavement surface used to be the Sand Patch Test, which is described in ASTM Standard E965 (5). In the sand-patch test, a known volume of glass spheres that meet a specified standard is spread on a pavement surface to form a circle, thus filling the surface voids with sand. A parameter called the Mean Texture Depth (MTD) is computed from the measurements obtained from this test as shown in Figure 2. Determination of the macrotexture of the pavement using this method requires lane closures, exposes the operator to a risk of an accident, and provides data on a limited portion of the pavement surface. The results obtained from the sand patch test can be operator dependent.

Figure 2. Sand Patch Test

With the advent of laser sensors, the macrotexture of a pavement surface can be determined today using data collected by laser sensors at highway speeds. The ASTM Standard E1845 describes the procedure for computing a parameter called the Mean Profile Depth (MPD) from the data collected by laser sensors. Determination of MPD using this procedure requires texture data to be collected at sample intervals not exceeding 1 mm, with a vertical resolution of at least 0.5 mm. Single spot laser sensors are being widely used to collect macrotexture data for computation of MPD. These sensors collect data along a longitudinal path, and the MPD along the longitudinal path is computed from the collected data. Recently, data collected by line lasers that are used to compute profile data have been used to compute MPD. These line lasers collect data along a line that is at least 100 mm in a direction transverse to the travel direction. The data collected by these sensors are then used to compute a Mean Segment Depth (MSD) value using the procedure described with ASTM E1845, and these MSD values are then averaged to compute the MPD.

On some pavement surfaces, the MPD can depend on the direction of the data collection (i.e., along the travel direction or perpendicular to travel direction). Examples of such surfaces include Portland Cement Concrete (PCC) surfaces that have a longitudinal texture such as longitudinal tinning, diamond grinding, and longitudinal grooving. The data collected by single-spot laser sensors on such surfaces can result in obtaining MPD values that are erroneous. This is because the laser sensor can collect data in the trough of a groove and then on the surface of the pavement. Collecting data on these surfaces using a line laser that collects data transverse to the travel direction can result in a representative MPD value.

An issue that can be encountered in the data collected by laser sensors is the presence of spikes in the data. A suitable spike elimination routine must be incorporated in the software to eliminate the spikes before computing the MPD Stationary devices that use laser sensors are also available to collect data to compute MPD. These include the Circular Texture (CT) Meter, ELAtextur, and Ames Engineering Scanner.

Walk along devices are also currently available to collect macrotexture data on pavements. These equipment include a line laser that is mounted transverse to the travel direction, and the line laser are capable of obtaining transverse profiles at longitudinal sampling intervals of 1 mm. MSD values are computed for each transverse profile and then averaged to obtain the MPD value. The TM2 developed by WDM is an example of such equipment. RoboTex is a device that was developed by Transtec Group that operates on a similar principle, except that the device moves along the pavement surface through remote control. However, this device is not commercially available.

Future Challenges

3D systems that collect data along the entire transverse profile of the lane are now available. If such systems can collect data that satisfy the requirements listed in ASTM 1845 (i.e., a longitudinal data interval of at least 1 mm, a transverse data interval of at least 1 mm, a resolution of at least 0.5 mm), a MSD can be computed along a 100 mm length along any longitudinal path of the pavement, and then averaged to compute the MPD. Data from systems will also provide the ability to compute the MPD transverse to the travel direction.

The data collected from such 3D systems can be used to simulate a sand patch test, which will provide the ability to simulate a sand patch test at any location on the pavement surface. Currently in the United States, the MPD is the most widely used parameter for characterizing the macrotexture of a pavement. Other parameters that take into account tire envelopment on the pavement surface could be developed in the future to better characterize the macrotexture. Such parameters can address the water evacuation potential of the pavement surface.

TIRE PAVEMENT FRICTION

Past and Present State of Practices

Friction or grip between the rubber tires of motor vehicles and the various highway surfaces has been a major focus for the committee over the years. One hundred years ago, motor vehicles did not travel so fast. As motor vehicle speeds have increased so has friction demand, also with speed increases so has the need for greater macrotexture. According to the AASHTO Guide for Pavement Friction; “pavement friction is the force that resists the relative motion between a vehicle tire and a pavement surface” 6). Tire pavement friction is the result of the interaction between the tire and the pavement, not a property of the tire or the road surface individually (6). The first widely used testing device was a trailer developed by GM and manufactured by K. J. Law. Its design became the basis for the ASTM – E274 standard.

The current state of practice continues the application of the locked wheel friction testing systems as well as a variety of continuous friction measuring equipment (CFME) devices are used to quantify friction on the highway. Figure 3 shows a locked wheel skid device. These systems are typically used at highway speeds often without the need for traffic control. There are a wide variety of stationary devices that measure friction or quantify highway surface texture in some way. These devices require some sort of traffic control if they are to be used in the field. They are also often used in the laboratory environment (7).

Figure 3. Locked Wheel Skid Truck

The PIARC experiment developed the International Friction Index (IFI) to compare and harmonize between various methods used around the world to measure friction and texture (reference). The IFI is composed of two parameters: a speed constant (Sp) and a friction number at 60 km/hr (F60). The speed constant (Sp) is ideally predicted by a macrotexture measurement (8).

Future Challenges

Friction demand is not well understood nor easily quantified. There is a need to identify all the micro-texture and macro-texture parameters which contribute to friction and grip. Once that is complete, we need to develop safe and efficient means to measure and quantify the various attributes in a non-contact fashion. Then we will be able to accurately predict friction and grip by simulation much like what have been done with inertial profile technology and road roughness.

Long Term Goals

Building on the recently completed work on the practices for calibration, quality assurance and harmonization of friction measurement devices, AFD90 will work on disseminating the knowledge to implement the latest practices and techniques to ensure high-quality, harmonized friction measurement equipment and practices. The focus areas will be:

- Encouraging the continuation of the yearly harmonization work and future research of the International Friction Workshop in the US and fostering the adoption of the results in the newly created yearly European Friction Workshop.
- Assisting in the development of corresponding quality standards for both measurement equipment and measurement processes including the calibration and harmonization of devices.
- Helping in the establishment and promoting the development of unified equipment performance and conformity certification standards and operator training certification.

Recent advancement in research prompts AFD90 to concentrate and put emphasis on the use of micro- and macro-texture values and characteristics for describing frictional characteristics in both academic research and practice.

TIRE PAVEMENT NOISE

Past and Present State of Practices

The demand for quieter pavements surface was non-existent in the United States, therefore little expertise, much less experience can be found here. Therefore, most of the early developments occurred in Europe.

Today, this climate has changed, traffic noise pollution has become a growing problem, particularly in urban areas where the population density near major thoroughfares is much higher and there is a greater volume of commuter and commercial traffic. To mitigate the noise – at least for those living and working near these roads – engineers are currently resorting to noise barriers at a cost of two million dollars or more per mile. But while effective in many instances, noise barriers aren't always the best solution for noise pollution. A renewed demand for quieter pavements now exists, and the solutions to fill this demand are more readily available and proven (9).

The most common way of measuring noise is "at the side of the road". Technically, these are termed wayside measurements, and can be done either at a fixed distance from the road (commonly 7.5 or 15 m), or else at the location of receivers such as a residential backyard or playground. Ideally, wayside measurements include the measurement of sound levels using microphones, as well as traffic speeds and classifications (9).

There are currently two methods for measuring tire-pavement noise: Close proximity (CPX) and on-board sound intensity (OBSI). Figure 4 shows the OBSI system. AASHTO standards for measuring tire pavement noise exist.

Figure 4. On Board Sound Intensity (OBSI)

Future Challenges

Alternative solutions to noise barriers need to be studied and considered

The committee should be looking to foster a cooperative effort with the tire industry towards the development of optimum surface properties of both components to reduce noise while maintaining maximum grip and life.

Enhance the knowledge about quiet pavements, their longevity as well as safety-related and other environmental effects, and share this with relevant federal and state authorities and pavement contractors.

SAFETY AND ENVIRONMENTAL RELATED ISSUES

Past and Present Practices

In the past, safety has not been the first concern of the committee. There has been very little work towards incorporating safety in any vehicle-surface relationships developed by research, and there is very little evidence that safety has been guiding pavement management decisions. However, the major areas of work of the committee relate to parameters that affect road safety more than any areas of any other committee. These activities are friction, texture, and roughness.

Today, this focus area continues to be a forum through which transportation engineer's work with experts on vehicle and tire dynamics to understand the interaction of vehicles and travelled surfaces, "on safety and environmental related issues". Short term goals should include a better understanding of the factors predicting vehicle behavior and factors which indicate the outset of a crash. To better achieve this goal, it is asked that emphasis be placed on encouraging the full range of disciplines involved in crash reduction to become involved with the work of the Committee. This will provide synergies for innovative solutions through a more holistic assessment of crash prediction for which the travelled surface makes a significant contribution.

Future Challenges

Emerging issues relate to the use of continuous measurement of skid resistance. In support of these technologies, it will be important to develop a better understanding the link between breaking/accelerating tire contact stress as well as tire contact stress resulting from centrifugal forces on the deterioration of skid resistance on the travelled surface. This work will provide better predictive tools to define materials able to withstand the stresses imposed at the surface. The aims of the other groups are similar to those of this group, but this group should continue to focus on crash reduction targets resulting from more targeted solutions using predictive tools of skid resistance demand along a highway. International experience indicates that even using crude tools related to physical condition, such as sharp bends and intersections, can result in 20-30% reductions in accidents with benefit cost ratios in excess of 20.

Training and staff development is seen as a high focus activity as the changing focus from spot measures to continuous measurement which requires new skills and knowledge. This should be achieved through Workshops, Conferences and Seminars. Research on various topics, such as macrotexture, microtexture, splash and spray, and others, will be encouraged to understand how it can be measured and its impact on crash rates. In wet-freeze regions use of de-icing and anti-icing chemicals pose a potential risk to the roadside environment. Another example of research that is required is the role of macrotexture on the quantity of chemical required to achieve adequate safe conditions.

To further our aim, support will be given to conferences that address all aspects of crash reduction such as the Safer Roads Conference to be held in Richmond Virginia, 12 – 14 May 2020

SUMMARY

The different focus areas for pavement surface properties and vehicle interaction will continue to evolve and improve from the current state of practice. The use of 3-D data collection will play a major role; continuous data collection will be more widely applied in the future replacing spot measurements. The large amount of data being collected will require automated analysis which will tax the practitioners to align the computer results with past methods. The new US federal rules require performance risk-based decisions and will help moving the transportation system towards performance based results. Improvements in measurements and characterization of surface characteristics will impact safety and comfort for the travelling public.

REFERENCES

1. Hveem, F. N., “Devices for Recording and Evaluating Pavement Roughness” HRB 264
2. Quinn, B.E. and Thompson, D.R., "Effect of Pavement Condition on Dynamic Vehicle Reactions," HRB Bulletin 328, 1962.
3. “Calibration of Response-Type Road Roughness Measuring Systems” NCHRP 228, 1980.
4. Standard Specification For Transportation Materials and Methods of Sampling and Testing, August 2018.
5. Annual Book of ASTM Standards, Section 4, Volume 4.03, 2017
6. Guide for Pavement Friction, AASHTO 2008
7. The little Book of Pavement Friction – Virginia Tech
8. Wambold, J., Antle, C., Henry, J., and Rado, Z. (1995). "PIARC (Permanent International Association of Road Congress) Report." International PIARC Experiment to 22 Version 1.0 September 2012 Compare and Harmonize Texture and Skid Resistance Measurement, C-1 PIARC
9. Robert Otto Rasmussen, Robert J. Bernhard, Ulf Sandberg, Eric P., Mun, “The Little Book of Quieter Pavements,” FHWA-IF-08-004,