USE OF EMERGING TECHNOLOGIES IN SUPPORT OF PAVEMENT PRESERVATION DECISION MAKING

by

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ABSTRACT

Pavement preservation represents a proactive approach to maintaining and extending the lives of existing highways. Not surprisingly, pavement performance is at the heart of the preservation decision-making process. Traditionally, non-structural factors, such as distress and ride quality, have been used as the primary indicators for pavement preservation strategy selection and timing. However, these factors do not address structural condition, which is of great significance since the concept of preservation is predicated upon applying treatments to structurally sound pavements. Accordingly, the Federal Highway Administration (FHWA) undertook a study to identify emerging technologies to better characterize pavement conditions, predict future deterioration and demonstrate their applicability in the selection and timing of preservation strategies. As part of this study, a literature review and expert interviews were conducted to build a foundation for identifying and evaluating technologies. The evaluation process resulted in four technologies being recommended based on their potential application for pavement evaluation and forecasting. Case study reviews of these technologies were prepared, which highlighted the benefits provided by implementation of the technologies by agencies as well as some of the challenges faced during implementation. This paper focuses on the use of the recommended technologies within the pavement preservation operations of highway agencies. To accomplish this, relevant information extracted from the case study reviews as well as implementation considerations developed during the study are presented in the paper.

INTRODUCTION

In 2013, the Federal Highway Administration (FHWA) funded a project titled "Technologies to Determine Indicators for Pavement Preservation Strategies" to identify emerging technologies to better characterize pavement conditions, predict future deterioration and demonstrate their applicability in the selection and timing of pavement preservation strategies (Rada, et.al. 2013). Traditionally, non-structural factors, such as pavement distress and ride quality, have been used as the primary indicators for pavement preservation strategy selection and timing. However, these indicators do not tell the complete story, especially as far as structural condition is concerned, which is of great significance since pavement preservation is predicated upon applying treatments to sound pavements.

As part of the project, a literature review and expert interviews were undertaken to identify potential technologies. An evaluation of potential technologies was then undertaken and four technologies were recommended based on their potential to support pavement preservation strategy selection and timing. The evaluation criteria used included value (ability/effectiveness to support preservation process), availability (presence in the country), maturity (readiness of technology), cost, ease of implementation, and others (e.g., speed and safety). Based on the evaluation, the following technologies were recommended:

- Dynatest Highway Friction Tester (HFT) for friction and texture evaluation.
- High frequency surface wave technology for structural condition assessments.
- ARA Rolling Wheel Deflectometer (RWD) for structural condition assessments.
- RoLine technology for ride measurements.

Case studies reviews and implementation guidelines were then developed for the four technologies.

This paper discusses the use of the recommended technologies within the pavement preservation decision-making process for the first three technologies – the fourth one is not included due to paper length restrictions. Information extracted from the case study reviews as

well as implementation considerations are presented to demonstrate how agencies can use the technologies within their pavement preservation operations.

CASE STUDY REVIEWS

Highway Friction Tester (HFT)

The Highway Safety Improvement Program (HSIP) was continued as a core Federal-aid program under the Moving Ahead for Progress in the 21st Century Act (MAP-21) legislation that went into effect in 2012. The objective of HSIP is to achieve a significant reduction in traffic fatalities and serious injuries on all public roads. An important consideration in achieving this objective is pavement friction and, with this consideration in mind, FHWA has issued a pavement friction management technical advisory. This advisory indicates that the locked-wheel method can be used with either the ribbed or smooth tire, but the former is more commonly used by highway agencies. The ribbed tire is considered less sensitive to pavement macrotexture and water film depth than the smooth tire. The locked-wheel method and the fixed slip method (which HFT uses) are recommended as appropriate methods for evaluating pavement friction on highways. The latter method has the ability to operate continuously, which results in a better theoretical relationship to braking with anti-lock braking system (ABS).

Dynatest developed the continuous fixed slip HFT shown in Figure 1. The device is intended to assist agencies with (1) better modeling of how frictional characteristics of pavements change over time, (2) proactively identifying early-stage safety problems, and (3) forensic testing through evaluation of pavement friction at crash sites.

FIGURE 1. Highway Friction Tester (Fugro, 2012)

The HFT is a self-contained continuous friction measurement device that can be mounted in various types of trucks, which allow a variety of water tanks. With a 1,893 liter (500 gallon) water tank, for example, continuous peak friction testing can be performed for up to 43.4 kilometers (27 miles). The device uses a two axis force transducer mounted on a retractable fifth wheel assembly, which provides dynamic vertical and horizontal tractive force measurement. The fifth wheel assembly is driven at 14% slip ratio. The device meets ASTM E2340 requirements for continuous fixed slip friction measurement device, and it provides friction

coefficients at 0.3-m (1-ft) intervals. These measurements can be done at traffic speeds between 15 and 130 kph (10 and 80 mph). It can also perform dry or self-wetted measurements.

Through a demonstration project sponsored by the FHWA, the Texas Transportation Institute (TTI) and Texas DOT conducted an evaluation of fixed slip and locked-wheel skid measurement systems aimed at identifying improvements to existing Texas DOT measurement capabilities (Fernando et al., 2013). Towards this end, TTI established test sections on which side-by-side tests were conducted. The sections covered a range of surfaces, including seal coats or surface treatments, hot-mix asphalt (HMA) surface, permeable friction course, concrete pavement with conventional transverse tines, and concrete bridge deck with longitudinal tines. These sections included six skid calibration sections located at the Texas A&M Riverside Campus and 11 test sections on in-service pavements located in Brazos and Grimes Counties.

Friction measurements were collected using two locked-wheel skid trailers and a HFT. Friction measurements on the 17 sections were conducted over a three-day period. All runs were made at 80 kph (50 mph). On each section, a HFT run was first performed to collect dry texture laser measurements in the wheel path. Afterwards, six repeat runs were made on each Riverside friction section, and three on each highway section. Each device was run within minutes of the other two, so the effect of changes in ambient conditions was considered to be negligible.

From the review of the resulting data, it was determined that the friction numbers from the HFT were higher than the skid numbers (SNs) from the locked-wheel skid trailers except for one section, which had a friction value below 10. Given the difference in the way friction is measured between the HFT and locked-wheel trailer, the correlation between the two devices was examined. Figure 2 shows an acceptable correlation between devices, as demonstrated by the coefficient of determination (R^2) and standard error of the estimate (SEE). Since the intercept of the regression line in this line was determined not to be statistically significant, the regression lines were re-evaluated with the intercept set to zero. Based on this re-evaluation, it was concluded that the regression lines for the locked-wheel trailers are quite comparable and, if the data are pooled, the resulting slope is about 0.67, indicating the locked-wheel skid number is about two-thirds of the HFT friction number.

TTI researchers also examined data from tests conducted at Pennsylvania State University at 65 kph (40 mph) and a reasonable linear relationship was again obtained based on results from tests conducted with the Pennsylvania skid trailer and the HFT friction numbers. The 0.623 slope of the regression line was similar to that determined in the TxDOT study.

In summary, the locked-wheel and fixed slip methods are considered appropriate by FHWA for evaluation of pavement friction. The advantage of the fixed slip method is the ability to operate continuously, which provides a better simulation to modern ABS. Moreover, skid numbers from locked-wheel trailers and HFT friction numbers appear to have a reasonable correlation on sections covering a wide range of friction values.

While the cost of the HFT is higher, it provides more detailed and reasonable friction results due to its ability to perform continuous testing and to simulate ABS. The biggest challenge in implementing HFT is to educate agencies on the benefits of the technology. However, given the benefits associated with the HFT, this challenge should be easy to overcome. Another challenge to implementation of the HFT is the water tank size limitation for network-level friction investigations. For agencies responsible for large networks, it could be difficult to conduct network-level friction testing. However, in addition to increasing tank size, pavement texture and surface condition measurements could be used to tailor friction testing. For example,

for potential high risk areas, 100% friction measurement using the HFT could be done, while for general network purposes, the friction testing sample frequency could be reduced.
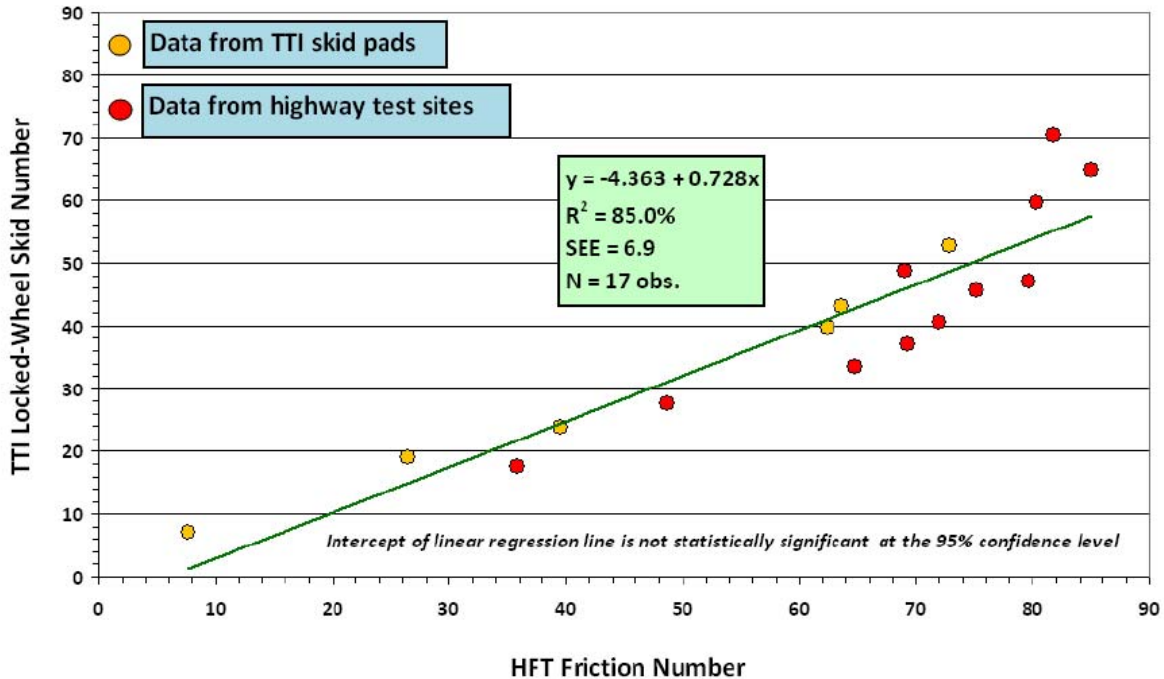
FIGURE 2. Comparison of TTI Locked-Wheel SNs and HFT friction numbers (Fernando et al., 2013)

High Frequency Surface Wave Technology
Measurement of pavement structural condition over time in terms of damage associated with load-related cracking in HMA can be monitored using nondestructive testing (NDT) devices. Falling Weight Deflectometers (FWD) can be used for this purpose, but measurements from these devices are more sensitive to structural changes in the foundation layer as a result of the low frequency impulses used by the loading mechanism and are not as sensitive to changes in the near surface layer properties. Since ultra-sonic (US) technology uses higher frequency impulses than FWDs, they can be more sensitive to the properties of the near-surface layer.
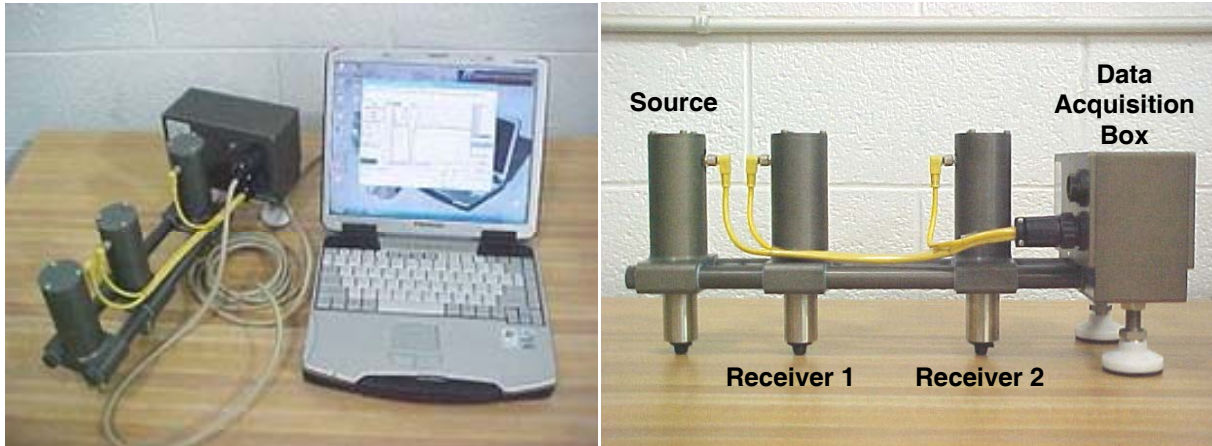
The Portable Seismic Pavement Analyzer (PSPA) was selected because it evaluates the damage associated with load-related cracking in the HMA layer, which can be monitored in order to assess the condition of the pavement prior to initiation of cracks or cracks becoming visible. The PSPA components are shown in Figure 3 – it consists of two ultrasonic transducer receivers and an impact source. The device is controlled by a laptop computer. Using the data collected, the modulus of the surface layer can be calculated as follows:

$$E_{field} = 2\rho[(1.13 - 0.16\upsilon)V_R]^2(1 + \upsilon)$$

Where: V_R = velocity of surface waves, ρ = mass density and υ = Poisson's ratio. The modulus is adjusted to a reference temperature of 77 °F based on the following equation:

$$E_{77} = \frac{E_t}{1.35 - 0.0078(t - 32)}$$

Where: E_{77} = moduli at 77 ºF, kip per square inch (ksi) and E_t = moduli at temperature t (in ºF), ksi.

**FIGURE 3. Components of Portable Seismic Pavement Analyzer (Jurado et al., 2012)**

A study of the ability of the PSPA to monitor pavement condition at the Texas Mobile Load Simulator (TxMLS) found that using seismic NDT technology to monitor degradation of pavements was feasible. Other findings included: (1) information from seismic testing makes it possible to relate degradation and remaining life of flexible pavements to measured pavement response and (2) modulus of HMA layer in seismic testing is more sensitive to cracking than rutting (Yuan et al., 1999). The Texas DOT also undertook a study to evaluate tools that can measure thickness and modulus of in-situ pavement layers. The study compared two laboratory tests and two field tests and addressed the repeatability and reproducibility of the methods, means of relating the measured parameters to the design moduli, and relating the parameters to performance of the pavement. Field testing carried out using the PSPA showed a COV of about 10% with moduli ranging from 3500 to 4709 MPa (515 to 683 ksi) (Nazarian et al., 2002). The study concluded that seismic data can be used to carry out QC of the HMA layer.

The PSPA technology has also been used by FHWA at their Pavement Testing Facility (PTF) using two accelerated loading facility (ALF) machines. The ALF facility consists of 12 full scale pavement test sections. The total thickness of the test sections above the AASHTO A-4 subgrade is 660 mm (26 in.) with HMA thickness of 100 mm (4 in.) and 150 mm (6 in.) for lanes 1 through 7 and 8 through 12, respectively. Between the HMA layers and the existing crushed aggregate base (CAB) is a new 100-mm (4-in.) thick CAB layer. Prior to loading, each pavement lane surface was heated with the radiant heaters to help induce aging for eight weeks. A super-single tire was then used to apply loading resulting in an applied wheel load of 7,257 kg (16 kip) while maintaining a pavement surface temperature of 19ºC (66 ºF).

In this paper, the focus of the FHWA study is on the comparison between lane 2 and lane 6 (Jurado et al., 2012). Each of the test sites were divided into seven subsections where PSPA measurements were periodically taken in the longitudinal direction at three transverse locations. As loading increased and cracks began to develop, loading was temporarily stopped to collect PSPA measurements.

Figure 4 shows how the mean modulus for test section 2 decreases over time as the number of passes increase and microcracking develops. The error bars represent ± 1 standard deviation, while the vertical lines represent the amount of fatigue cracking observed at the time of the measurements. The coefficient of variation ranged from 14% to 34% with an average of 24%. As shown in Figure 4, there is a negligible modulus reduction up to about 8,000 passes and no visible surface cracking, but a strong reduction in modulus is seen between 13,000, where 9% surface area was cracked, and 17,000 passes. In total, the modulus of test section 2 decreased 40% prior to top-down cracks becoming visible. The study concluded that the PSPA was capable of measuring significant damage before cracking begins to appear.
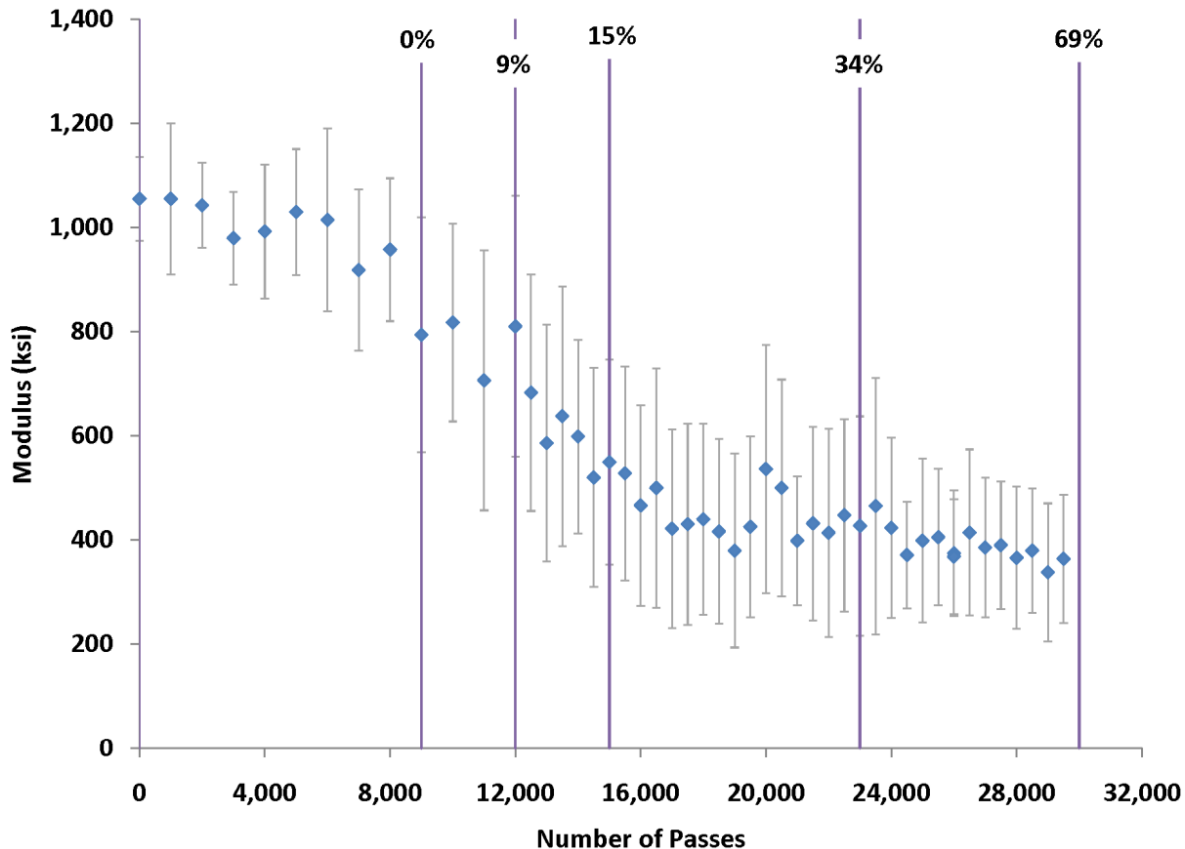
FIGURE 4. Reduction in PSPA modulus with accumulated loading and percent cracking (Jurado et al., 2012)

As a result of the FHWA PTF study conclusion, the PSPA is considered a viable device to monitor damage associated with load-related cracking in HMA in order to assess condition of the pavement prior to initiation of cracks or cracks becoming visible. A benefit of the PSPA is that data collection is relatively quick and results in a direct measure of the surface layer modulus without having to use backcalculation. This allows for the monitoring of dispersion curves (modulus profiles) with time to assess condition of the pavement prior to initiation of cracks or cracks becoming visible.

There are, however, challenges to face when implementing the PSPA for use in network-level pavement management activities. One challenge is educating agency personnel on the

benefits of the PSPA. Another challenge is the slow operational speed, which can cause safety issues as traffic control is required.

ARA RWD
Historically, pavement structural condition has been determined using measured deflections and FWDs represent the state of the practice, but they have shortcomings. FWD testing is a stop-and-go operation that requires lane closures, which can cause traffic disruptions, and production rates are lower than those associated with a continuous testing operation. To overcome these issues, moving pavement deflection testing devices such as the ARA RWD have been developed.

ARA developed the RWD (shown in Figure 5) in cooperation with the FHWA. The device is primarily intended for network-level evaluation of flexible pavements. The theory of operation is based on the spatially coincident methodology for measuring pavement deflections. The RWD uses four triangulation lasers to collect continuous deflections at normal highway speeds; three measure the unloaded pavement surface profile, while the fourth one located between the dual tires behind the rear axle of the RWD truck measures the deflected surface produced by a 40 KN (9 kip) load through two wheels spaced 330 mm (13 in) apart. Deflections are calculated by subtracting the profile of the deflected shape from that of the un-deflected shape profile measured at the same location.

FIGURE 5. ARA Rolling Wheel Deflectometer (provided by Doug Steele of ARA)

The four distance-measuring lasers are attached to an aluminum beam of 25.5 ft (7.8 m) length retrofitted into a custom-built trailer of 53 ft (16 m) length. The entire laser and beam system is enclosed in a climate-controlled chamber to maintain the measurement system at a constant temperature during field testing. The four lasers are positioned 43 in. (1.1 m) above the

roadway surface in the right vehicle wheel path. The rear most laser, which is the only one located in the deflection basin, is located above the rubber tires, approximately 7 in (178 mm) to the rear of the RWD axle centerline.

In 2007, the Louisiana Department of Transportation and Development (LaDOTD) decided that their PMS would be improved if the structural condition of in-service pavements was considered in selecting suitable treatment methods, which would help avoid applying preventive treatments on structurally deficient pavements. Due to cost, production and safety considerations, the use of FWDs was limited and the value of the collected data could not be justified, but this changed with the introduction of the RWD.

To assess the potential use of the RWD, LaDOTD undertook a field evaluation to (1) quantify repeatability and effects of testing speeds on RWD measurements, (2) study relationship between RWD and FWD measurements and pavement conditions, and (3) develop a simple model to estimate pavement SN from RWD deflection measurements (Elseifi et al., 2012). A comprehensive field testing program was undertaken. As part of this effort, the HMA network (about 2,000 km [1,250 miles]) in Louisiana's District 05 was tested using the RWD. A total of 58 sections were also tested with the FWD. Next, 16 sections within Louisiana's District 05, each 1.5 miles long, were selected for a more detailed evaluation of the RWD; these sections covered a wide range of pavement structures and conditions.

To assess repeatability and the effects of vehicle speed on the measured deflection, triplicate RWD runs were performed on the 16 research test sections at speeds of 20, 30, 40, 50 and 60 mph (30, 50, 65, 80 and 100 kph). In addition, FWD testing was conducted at the same time on the outer wheel path at 0.1-mile (160 m) intervals. To assist with analysis, pavement layer thicknesses were determined using a combination of ground penetrating radar (GPR), cores and review of construction documents. Pavement roughness, temperature and distress surveys were also performed in support of the analyses.

Based on the field test results, it was determined that more scatter existed for sections in poor condition, while those in good condition were more uniform. The repeatability of the RWD measurements evaluated using the COV which had a range of 7 to 20 percent, with an average of 15 percent, which was considered good. The results also indicated that the RWD measurements successfully reflected pavement conditions and structural integrity by providing a larger average deflection and scattering for sites in poor condition.

The influence of test speed on the deflections was found to be minimal, which was confirmed by a statistical analysis of variance (ANOVA) that revealed the data groups were not statistically different. In looking at the variation of the average deflections, the scattering and uniformity of the RWD and FWD data appear to closely follow the condition of the pavement. It was determined that the two devices report similar trends, but the mean center deflections were statistically different for 15 of the 16 test sections, with larger deflections reported by the RWD, which was anticipated given its loading configurations. Although the mean deflections were statistically different, a strong correlation between the two devices was found when using an exponential model.

A model was then (1) developed and calibrated to predict pavement structural number (SN) from RWD measurements based on data collected at 16 research sections, (2) validated using the data collected at 58 validation sections, and (3) demonstrated on the District 05 network. The relationship between the SN determined based on the FWD and RWD measurements at the 58 validations sites is illustrated in Figure 6. As shown, there is an acceptable relationship between the two, which supports the use of the proposed model. The

model was then applied to the 220 sections that comprise Louisiana's District 05 network and the resulting data were used to develop the recommended pavement structural condition threshold values.

As a result of the field evaluation study, it was also recommended that RWD testing be implemented as a screening tool to identify structurally deficient sections. Before its formal implementation, the LaDOTD intended to pursue additional field evaluations. These would involve other districts, and ultimately the entire state network. However, the economic crisis that began in 2008 precluded these evaluations. Nonetheless, LaDOTD is still interested in pursuing them once funds are available as well as implementing the RWD. Moreover, the LaDOTD has continued to explore issues related to the implementation of the RWD within the State. Much work remains to be done, but LaDOTD have shown the value of the RWD to pavement preservation.
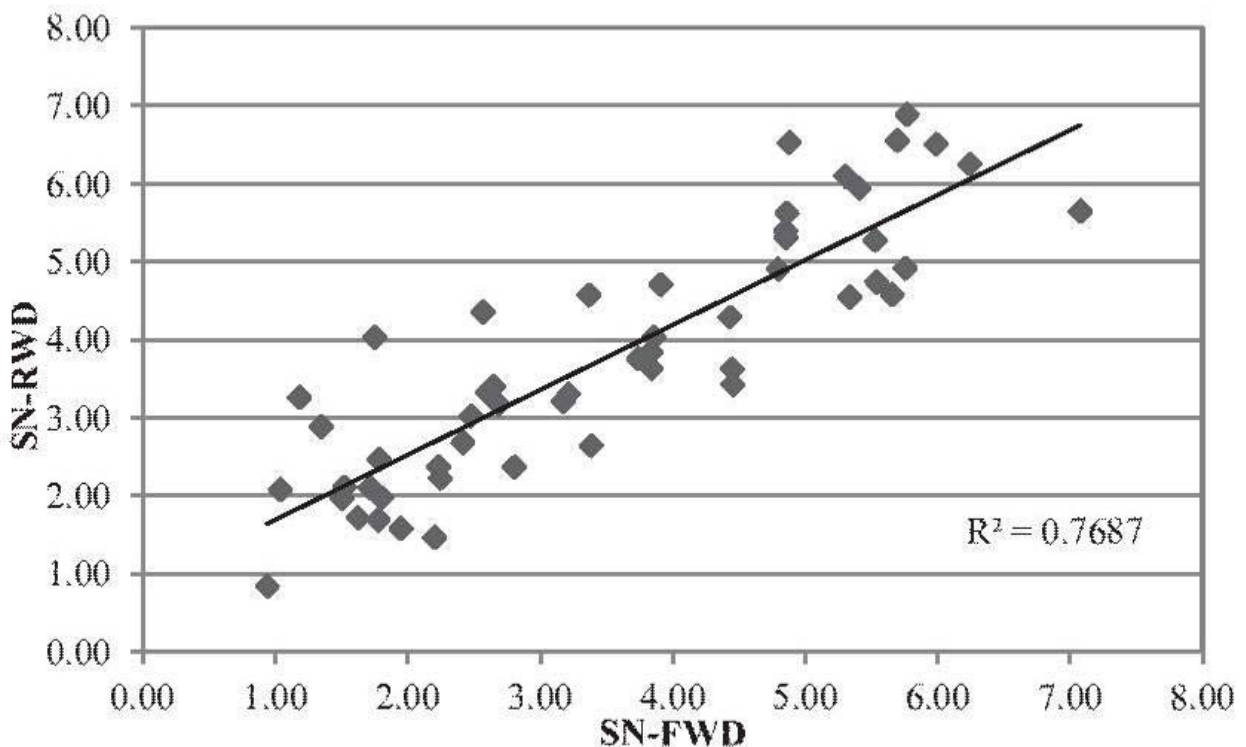
FIGURE 6. SN relationship based on FWD and RWD deflections (Elseifi et al., 2012)

In summary, a number of benefits will be realized through implementation of the RWD, but perhaps the most important one is avoiding application of preventive treatments on structurally deficient pavements, which is critical since application of preservation treatments is based on the premise that pavement is structurally sound. Perhaps the greatest challenge in implementing the RWD is buy in of the technology by the highway agency, but this was not an issue for the LaDOTD. The next biggest challenge is funding for evaluation and implementation of the RWD technology. The third and last challenge relates to the availability of the RWD; only one unit is available in the country, which means it could take weeks or months to do the testing.

IMPLEMENTATION CONSIDERATIONS
The case study reviews presented in the previous section of the paper provided insight into the technologies identified and highlighted the many benefits these technologies can provide to agencies that implement them into their PMS, pavement preservation strategy selection, and decision-making process. However, as these technologies are emerging, there are challenges agencies may face during implementation. The major implementation challenges are acceptance of technology within agency, readiness of technology, general technology implementation issues, technology implementation funding requirements and actual technology implementation process. Despite these challenges, agencies can successfully implement the technologies with proper planning. An agency interested in implementing one of the technologies can follow the five implementation steps summarized below:

1. Agency acceptance of technology -- Gaining acceptance within an agency is dependent on several factors including education on the technology, demonstrating the benefits to the agency, demonstrating cost benefits and having one or more champions within the agency.

2. General technology implementation approach -- Once an agency has gained acceptance of the technology, the next implementation step is determining the general implementation approach and the main consideration for doing this is deciding whether to purchase the equipment or to contract the services from the equipment vendor; frequency and difficulty of testing should be considered. For the RoLine, HFT, and PSPA technologies, agencies have the ability to purchase the equipment or contract the services associated with the equipment. For the RWD, the only option for the foreseeable future is to contract the services.

3. *Detailed technology implementation plan* -- A detailed technology implementation plan should be developed and contain a clear scope of work. It is recommended that the plan consist of preliminary trials and a full implementation. The intent of the trials is to demonstrate the use of the technology and, through this demonstration, to confirm the benefits to be realized. The full implementation will involve agency personnel but can also include input from local university(ies), vendors, and possibly consultants. This part of the plan addresses all of the elements to get the technology operational within the agency, including integration within pavement preservation/PMS activities, personnel training, database/data storage issues, and data analyses and interpretation issues.

4. Obtaining funding for implementation of technology – If an agency has gotten to this point, it is because there is wide acceptance of the technology within the agency and a willingness to invest in it. Per the previous step, there are two types of funding that should be considered: (1) funding for preliminary trials and (2) funding for full implementation.

5. Actual implementation of technology – Step 3 produced a detailed implementation plan. This step moves the plan forward to actual implementation and it includes addressing data collection, analysis and storage, use of data within pavement preservation/PMS decision-making process and the feedback, assessment and update process.

Depending on the challenges faced by each agency, one or more of the above steps may not apply. Also, the above steps are clearly generic in nature. Specific implementation issues relating to the technologies were included with the respective case study reviews.

SUMMARY AND CONCLUSIONS
This paper presented some of the findings and conclusions from a FHWA funded study aimed at identifying emerging technologies to better characterize pavement conditions, predict future deterioration and demonstrate their applicability in the selection and timing of pavement preservation strategies.

At the start of the study, a literature review and expert interviews were conducted to identify potential technologies. In all, 15 candidate technologies were identified and they were evaluated using criteria that included value, availability, maturity, cost, ease of implementation, and others pavement preservation-related factors. From the evaluation, four technologies were recommended for further consideration – HFT, PSPA, RWD and RoLine.

Due to space limitations, summary case studies reviews were presented for the first three technologies (HFT, PSPA and RWD). RoLine was found to be the highest rated technology, but it is also the best known of the four and hence the focus on the other three. Two of the three technologies were also selected because they address the structural condition of pavements, which is of great significance since pavement preservation is predicated upon applying treatments to sound pavements.

In addition to case study reviews, implementation considerations were also addressed to demonstrate how agencies can use the technologies within their pavement preservation operations. Perhaps the biggest implementation challenge is educating highway agency personnel, but this should be easy given the benefits the three technologies in question offer. Other implementation challenges are technology specific and, if desired, they can be overcome – HFT water tank size and associated network coverage limitation, slow speed of operation and need for traffic control for PSPA, and only one RWD device available in the country

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