Dielectric Profiling System

Implementation Plan (Roadmap)

Final Report

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Definitions

AASHTO	American Association of State Highway and Transportation Officials
AAD	average absolute deviation
CFR	Code of Federal Regulations
DOT	department of transportation
DMI	distance measuring instrument
DPS	dielectric profiling system
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
GPR	ground penetrating radar
GPS	global positioning system
HDPE	high density polyethylene
IA	independent assurance
MATC	FHWA Mobile Asphalt Technology Center
NDE	non-destructive evaluation
PC	percent conforming
PWL	percent within limits
QC	quality control
QA	quality assurance
RDM	rolling density meter
SGC	Superpave gyratory compactor
SHRP2	Second Strategic Highway Research Program
TMD	theoretical maximum density

Executive Summary

The Dielectric Profiling System (DPS) is a generic term for a ground penetrating radar (GPR) system used to measure the dielectric profile of asphalt pavement that can be correlated to in-place pavement density. DPS systems are cart mounted or can be mounted on other delivery systems such as an ATV or other vehicle. GPR for pavement uniformity was developed during the second Strategic Highway Research Program (SHRP2) as part of Technologies to Enhance Quality Control on Asphalt Pavements (R06C). Geophysical Survey Systems, Inc. (GSSI) developed the rolling density meter (RDM), a DPS unit which provides GPR measurements at walking speed. The unit reports the surface dielectric constant or, if calibrated to cores or laboratory samples, in-place density in real time. Other vendors have also developed similar units. Minnesota DOT currently leads National Pooled Fund Study TPF-5(443), Continuous Asphalt Mixture Compaction Assessment Using Density Profiling System (DPS) to further develop DPS systems, develop AASHTO standards, provide training and technical assistance, and develop specifications.

The benefit of using a DPS system is increased pavement life through accurate measurement of in-place density over a significant portion of the pavement. Current practices test only an exceedingly small portion of the pavement, 0.003% in one estimate. There are a number of common occurrences in paving that can lead to limited areas of low density. Examples include end-of-load segregation, thermal segregation, errors in joint construction, various screed mis-adjustments, and breaks in the roller pattern. These defects fail first, requiring accelerated schedules for maintenance or rehabilitation, typically for the whole pavement, when the majority of the pavement may be in acceptable condition. Ohio DOT estimates that increasing pavement service life by one year by reducing or eliminating these limited areas of low density would save their statewide resurfacing program $65 million annually. This illustrates the concept that savings in repair costs during a pavement's life and overall longer life due to the use of DPS technology will reduce the overall life-cycle cost of the pavement.

The use of DPS technology can help Contractors improve their processes, particularly if combined with other technologies such as intelligent compaction and infrared thermal imaging to provide a pavement with more uniform density. Thus, DPS is also a tool for Contractor process improvement.

If DPS data collection is paired with an intelligent construction data management tool such as Veta and then paired with the Agency's pavement management system, a feedback loop is provided between construction defects, in terms of in-place density, and future pavement failures.

A Roadmap Development Workshop was held on April 20-21, 2021, to obtain stakeholder input for developing an implementation plan for Agency use of DPS as an acceptance tool for asphalt pavements during construction. Participants representing the Federal Highway Administration, State Highway Agencies, paving industry (not DPS vendors), consultants, and academia attended the workshop. They were apprised of FHWA's requirements for quality assurance, progress to date on the pooled fund study, and three lead States' examples of efforts towards advancement and acceptance of DPS. The participants considered potential barriers and opportunities facing implementation and identified a set of strategies, goals, and tactics to include in the implementation plan. They discussed various methodologies for using DPS for quality assurance. The group also provided input for a marketing plan to be used by FHWA.

The overall goal of the Roadmap was developed as a mission statement: *Use of DPS Technology for Contractor quality control and Agency acceptance to measure asphalt density in order to improve asphalt pavement performance by enhancing pavement uniformity and minimizing pavement defects*.

A number of strategies and tactics were developed to meet this goal.

General

- Identify champions or trusted voices, both Agency and industry, regional, and on a State basis. Utilize industry leaders to support the benefits.
- Identify shortcomings with current systems that only measure in-place density for a small fraction of the area paved and that are likely to miss defects.
- Develop pictorial examples that demonstrate coverage between current systems and DPS and display variations in density. Show what is being missed with the current measurement system using gauges or cores and how that influences overall pavement life.
- Develop flyers or handouts that cover case studies, testimonials, and demonstration efforts.

Agency

- Quantify life-cycle costs and benefits to communicate to Agency leadership. Improved in-place density equals longer pavement life.
- Improve software and connectivity for data analysis and data management so as not to overwhelm project staff.

Contractor

- Choose Contractors carefully for initial projects:
  - Ask for volunteers.
  - Contractor selection can aid or hinder implementation.
  - Culture of Contractor toward QC, quality minded or low-cost. Choose Contractors with well-established QC programs.
- Provide Contractors with exposure to technology through loan or demonstration projects.
- Incentivize Contractors to use the technology. Consider incentive for uniformity as an initial step.
- Agencies need to make long-term commitments to Contractors who invest in the technology. Need to maintain fairness in bidding. Cost of testing equipment should not be used to preclude smaller Contractors.

Workshop participants agreed that significant progress has been made on developing the DPS technology and refining its ability to generate meaningful data that can (a) give the Contractor the opportunity to improve their process in a timely fashion and (b) be used for acceptance of pavements by Agencies.

Potential challenges remain, however.

- Agencies and Contractors can be resistant to change.
- Contractors may fear additional penalties with increased coverage.

- Trying to achieve nearly full coverage with just a pushcart requires walking several times the distance paved and is somewhat time consuming. Agencies and Contractors may not have enough existing personnel and resources to collect and manage the data.
- While there are multiple vendors of DPS technology, there is currently a gap because one vendor has advanced the furthest.
- Complexity of the technology requires good training programs for all involved parties.

Agency representatives expressed that in States that have participated in the pooled-fund study, pilot programs may be feasible in 2023 or 2024. In such States, DPS data collected at longitudinal joints could be used as the basis for incentive pay. The consensus was that using DPS data for acceptance of the entire pavement mat would be premature just now.

Specifically, it was suggested that possibly as soon as 2023, some States could write contracts with incentive pay for densification on longitudinal joints as measured by DPS. As the technology is further refined and developed over time, and as Agencies and Contractors become more comfortable with it, expanding use of DPS to measure the full width of the mat is expected.

Next Steps for Marketing and Education Efforts

The workshop participants discussed the steps for building acceptance of DPS as a standard tool in the industry. The elements addressed included audiences, timelines, marketing channels and avenues, resources to be developed, trusted voices, and key messages.

Briefly stated, marketing DPS to the industry will begin with building the business case for the technology; addressing its costs and risks; and formulating a compelling rationale for adopting the new technology. Economics, environmental sustainability, and safety were the chief benefits identified. The business case will provide the foundation for all future steps in the process.

Marketing/education efforts will be needed for all levels of the industry, including Agency officials (DOT Secretaries, FHWA field offices, et al.) and Contractor personnel (company owners, paving site workers, lab technicians, et al.). There is an immediate need for one-page summaries of projects where the technology has been used that document the resulting process improvement and improvement in overall quality.

Overview

This report describes the outcomes of an Implementation Plan (Roadmap) development workshop held to discuss the use of the dielectric profiling system (DPS) to measure the in-place density of asphalt pavements. The goal was to obtain stakeholder input for Agency use of DPS as an acceptance tool for asphalt pavements during construction. Discussion included various tactics that can be used for implementation. The objectives of the workshop included:

- Present an overview of technology to educate stakeholders not yet familiar with DPS.
- Work with stakeholders to identify gaps hindering implementation, including system improvements, and research needed to fill those gaps.
- Discuss various methodologies for using DPS for quality control and Agency acceptance.
- Discuss means and tactics for implementing DPS for acceptance of in-place asphalt pavement density.
- Provide input for a marketing plan to be used by FHWA.

The desired outcomes from the workshop were to gather stakeholder feedback and establish an acceptable path moving forward to implement DPS for acceptance of in-place density of asphalt pavements. Also, to obtain feedback on what should be focused on in the future to meet this goal. The feedback obtained in the workshop was used to develop this report.

Stakeholders included Agency, industry, academic and consultant representatives. The majority of State Agency representatives were selected from participants in the ongoing National Pooled Fund Study TPF-5(443), Continuous Asphalt Mixture Compaction Assessment Using Density Profiling System (DPS) managed by Minnesota Department of Transportation (MN DOT). Several representatives of the Federal Highway Administration also participated. Industry representatives included asphalt Contractors, asphalt Contractor association representatives, and a construction equipment representative. The University of Nevada, Reno and the National Center for Asphalt Technology at Auburn University represented academic institutions. A list of the attendees is provided in Appendix A.

Background

Importance of In-Place Density

The air void content of both in-place and laboratory-compacted asphalt pavements may be the single factor that most affects the performance of a properly designed mixture *(1-2)*. A mediocre mix, well-constructed with good in-place air voids, will often perform better than a good mix that has been poorly constructed *(1)*. In-place air voids between 3 and 8% for surface mixes passing through or above the Superpave defined restricted zone will generally provide good performance *(2)*. To limit permeability concerns, in-place air voids less than 5 to 7% may be required for larger nominal maximum aggregate size mixtures, stone matrix asphalt, or coarse-graded Superpave mixtures *(3)*. In-place air voids that are too high may result in permeability to water and excessive binder oxidization, resulting in moisture damage, cracking, or raveling *(2, 4, 5)*. Very low in-place air voids may result in permanent deformation or loss of skid resistance.

Numerous studies link in-place density to pavement performance. Linden et al. (*4*) produced one of the first studies documenting the effects of compaction on asphalt pavement performance. Combining data from a literature review, a survey of State Agencies, and data from Washington State DOT's pavement management system concluded that every 1% increase in pavement air voids over 7% reduces pavement life by about 10%. Wang et al. (*6*) analyzed data from 55 pavement sections to relate average in-place air void content to pavement service life as part of an effort to develop pay factors for asphalt pavements. Based on the slopes of the regression lines, additional 1% voids reduced the life of the surface lift by 1.1 years and the intermediate layer by 0.8 years. The authors concluded (*6*), "Approximately one percent increase in the air voids content results in one year reduction of pavement life." The average in-place air voids ranged from approximately 3 to 9%.

Seeds et al. (*7*) summarized several research studies relating the effect of in-place air voids on fatigue performance. Tran et al. (*8*) added an additional study to that original analysis. The laboratory studies were based on flexural beam fatigue. The data are summarized in Table 1.

Table 1 Effect of Air Voids on Fatigue Performance (*7-8*)

Study	Lab/Field Experiment	Mix Type	Air Void Range Evaluated	Decrease in Fatigue Life for 1% Increase in Air Voids
Epps and Monismith (*9*)	Lab	British Standard	4-14%	20.6%
		CA Hveem fine graded	5-8%	43.8%
		CA Hveem coarse graded	2.5-7%	33.8%
Harvey and Tsai (*10*)	Lab	CA Hveem dense graded	1-3%, 4-6%, 7-9%	15.1%
Epps et al. (*11*)	Lab	Superpave fine graded	4, 8, 12%	13.5%
		Superpave fine Graded plus 2% baghouse	4, 8, 12%	13.3%
		Superpave coarse graded	4, 8, 12%	9.0%
	Field	Superpave fine/fine-plus graded	4, 8, 12%	21.3%
		Superpave coarse graded	4, 8, 12%	8.2%
Fisher et al. (*12*)	Lab	Superpave dense graded	4-11.5%	9.2%

Epps et al. (*11*) analyzed field data from the WesTrack experiment relating rutting to in-place air voids. Two sets of analyses were performed, one using direct regression between measured properties, air temperature, and performance; and the other using properties generated from mechanistic-empirical analyses. In the first case, a 1% increase in air voids resulted in an 11.5, 9.6, and 66.3% increase in rutting, for the fine-graded, coarse-graded and replacement coarse-graded mixes, respectively. In the second analysis, a 1% increase in air voids resulted in a 7.3% increase in rutting for the original fine- and coarse-graded mixtures and a 10.9% increase in rutting for the replacement coarse-graded mixture.

State of Practice for Testing In-Place Density

Coring has historically been considered the most accurate means of determining in-place pavement density. However, many owners are reluctant to have many cores taken from new pavement surfaces. While there are means to execute good-quality patches of destructive core holes, frequently the patch quality is low.

Non-destructive nuclear density gauges were introduced in the 1960's to measure pavement density (*13*). Most nuclear gauges are used in backscatter mode. A radioactive source emits gamma photons. Photons are either absorbed or scattered back to gamma photon detectors mounted some nominal distance from the source in the base of the gauge. As density increases, fewer photons are scattered back to the detectors. By having multiple detectors at difference distances from the source, depth of measurement can be somewhat controlled in certain devices. Typical testing times for nuclear gauges range from 15 seconds to 2 minutes, with longer times improving accuracy. Agency testing frequency varies, but approximately ten tests every 5,000 lane feet are common. The radioactive source in nuclear gauges requires special licensing for Agencies or Contractors to possess, and special training and exposure monitoring for operators.

Non-nuclear gauges were first introduced in the late 1990's (*14*). TransTech's Pavement Quality Indicator (PQI) uses an electrical sensing field to measure the dielectric constant of the asphalt pavement. The device sits directly on the pavement surface. The density of the asphalt is proportional to the dielectric constant. Troxler's PaveTracker uses a similar principle. These devices do not require either a license for radioactive materials or employee monitoring. The devices read essentially instantly, allowing more tests to be taken. Agency-required testing frequencies are similar to nuclear gauges, although some Agencies require multiple tests to be averaged for one location.

One major disadvantage of the three previously described methods – coring, nuclear density gauge, and non-nuclear or electrical impedance gauges – is the limited sampling frequency. Using cores, Rick Bradbury, from Maine DOT, estimated they evaluate only 0.003% of the pavement's surface. Because in-place density is critical for pavement performance, Agencies have sought non-destructive means to evaluate the entirety of a pavement surface. NCHRP Project 10-65 considered ground penetrating radar (GPR) and intelligent compaction as methods to provide greater coverage of in-place density. Development continued under the SHRP2 program, *Using Infrared and High-Speed Ground Penetrating Radar for Uniformity Measurements on New Asphalt Concrete Layers* (*15*). Based on work completed as part of the SHRP2 R06C study, Geophysical Survey Systems, Inc. (GSSI) developed the rolling density meter (RDM) (generically known as DPS), which provides GPR measurements at walking speed (*16*).

DPS Overview and Description

GPR uses radar pulses consisting of electromagnetic radiation to image the subsurface. Pulse frequencies are typically in the microwave band. While the first patent for use of electromagnetic pulses for subsurface investigations was filed in 1926, it wasn't until the 1970's that the technology became commercially available. At this point, it was typically used to locate subsurface objects. One of the earliest uses of GPR technology was to determine layer thicknesses of asphalt pavements. The interface between differing materials, such as asphalt and aggregate base, causes a portion of the transmitted waves to be reflected. Two-way travel times of the reflected waves can be calibrated to layer thickness, for example, by taking cores. These calibrated travel times can then be used to predict the thickness of the asphalt and aggregate base layers along the length of the pavement.

The dielectric constant of an asphalt pavement can be measured with GPR technology. The dielectric constant is correlated with in-place density of the asphalt pavement. The dielectric constant of the surface layer can be calculated using the surface reflection amplitude according to Equation 1 (*15-16*):

$$e_r = \left[\frac{1 + A_0/A_i}{1 - A_0/A_i}\right]^2$$

where,
e_r = dielectric constant of the surface layer,
A_0 = amplitude of the surface reflection at the air/asphalt interface, and
A_i = initial antenna amplitude. May be measured with a metal plate calibration, representing 100% reflection.

In the late 1990's, the Finnish National Road Administration was the first agency to develop procedures for using GPR for quality control/quality assurance (QC/QA) of asphalt pavements using the surface reflection technique (*15*). Finland's QC/QA GPR procedures are documented in (*15*). 1-GHz, air-coupled, horn antennae have been primarily used in Europe. However, 1-GHz antennae are not currently FCC compliant. Thus, 2.2-GHz systems were initially used in the United States. Efforts conducted as part of SHRP 2 research to further this technology concentrated on high-speed measurements in Texas and Florida (*15, 17*).

Cart-mounted GPR systems for asphalt density testing were developed around the time of SHRP 2 by a few producers. GSSI's PaveScan RDM consists of a rolling cart with up to three 2.0-GHz antennas processed using a concentrator box. An on-board computer reports the surface dielectric constant in real time. Earth Science Systems produces the Asphalt Pavement Scanner, a single 2.0-GHz antenna cart and tablet computer package. Sensors & Software produces the Pavement Density Profiler, a single antenna cart and touchscreen computer package. The first two systems are compliant with AASHTO PP 98-20, Asphalt Surface Dielectric Profiling System using Ground Penetrating Radar. The third system may be compliant, but has not yet been validated. AASHTO PP 98-20 requires single or multi-channel air-coupled GPR systems with operational frequencies between 1 and 3 GHz. All antennas in a given system must have the same frequency.

The dielectric constant can be calibrated to in-place density using cores or Superpave Gyratory Compactor (SGC) pucks. When using cores, static readings are taken over the core location with the DPS prior to coring. Core locations should be selected to provide the widest range of in-place density readings possible. Whereas calibrations using cores are based on surface reflection measurements (the same as the normal pavement measurements), measurements on SGC pucks are based on direct-transmission, time-of-flight measurements.

Three antenna (channel) systems are ideally spaced 1.5-feet apart, requiring two to three passes to achieve full coverage of a typical lane. GSSI's system allows data to be collected at four user-selectable rates: core scan (40 readings/foot), walk (10 readings/foot), fast walk (5 readings/foot), vehicle (2 readings/foot). The software provided with GSSI's RDM will recommend coring locations to ensure the proper range of dielectric constants are sampled. Software was developed to produce graphical maps of dielectric constant or voids once calibrated to cores. Frequency distributions of measured density (based on dielectric constant) can also be produced, which could be used to determine pay factors.

Currently, Minnesota DOT is leading the National Pooled Fund Study TPF-5(443), Continuous Asphalt Mixture Compaction Assessment Using Density Profiling System (DPS). The goal of this pooled fund study is to:

A) further advance and improve the system based on experience and needs from participants so that the system can effectively and efficiently support their quality assurance programs,
B) develop AASHTO standards for equipment and operator certifications, and data collection protocols and analysis methods,
C) support communication between participants,
D) provide training and technical assistance that includes providing support for specification development and strategies for Agency full implementation, and
E) conduct technology promotion and marketing for the system.

Benefits of DPS

The benefit of using a DPS system is increasing pavement life through accurate measurement of in-place density over a significant portion of the pavement. Current practices used for quality assurance test only an exceedingly small portion of the pavement, 0.003% in one estimate. There are a number of common occurrences in paving that can lead to limited areas of low density. Examples include end-of-load segregation, thermal segregation, errors in joint construction, various screed mis-adjustments, and breaks in the roller pattern. These areas of low density fail first, requiring maintenance or rehabilitation, typically for the whole pavement, when the majority of the pavement may be in acceptable condition. Ohio DOT estimates that increasing pavement service life by one year by reducing or eliminating these limited areas of low density would save $65 million per year. Thus, savings in repair costs during a pavement's life and overall longer life due to the use of DPS technology will reduce the overall life-cycle cost of the pavement.

DPS technology can identify these limited areas, particularly if combined with other technologies such as intelligent compaction and infrared thermal imaging, allowing Contractors to alter procedures to prevent or eliminate them, providing a pavement with more uniform density. Thus, DPS is also a tool for Contractor process improvement and quality control.

If DPS data collection is paired with an intelligent construction data management tool such as Veta (*18*) and then paired with the Agency's pavement management system, a feedback loop is provided between construction defects, in terms of in-place density, and future pavement performance.

Finally, nuclear gauges require the Agency to have a license for radioactive materials and provide training and exposure monitoring for workers. Many Agencies and Contractors would like to discontinue the use of nuclear gauges for this reason.

Workshop Overview

FHWA Requirements for Quality Assurance

Since the goal of the workshop was to develop an implementation plan to use DPS for Agency acceptance, it is important to understand all FHWA's requirements for a quality assurance program to enable the stakeholders to speak the same language during the workshop. FHWA provided a presentation entitled "FHWA Quality Assurance Requirements for Dielectric Profile System (DPS)" (*19*). Title 23 of the Code of Federal Regulations (CFR) 637.203 defines quality assurance (QA) as "All those planned and systematic actions necessary to provide confidence that a product or service will satisfy given requirements for quality." The core elements of a QA Program are technician certification/qualification, lab accreditation/qualification, independent assurance, Agency acceptance, Contractor quality control (QC), and dispute resolution.

Certified technicians are required for all Contractor QC and Agency sampling and testing used in the acceptance decision. Certification may use State, regional partnership, or national programs. Programs should include formal, hands-on training and/or on-the-job training; written and hands-on examinations; periodic re-qualification (typically 3-5 years); and a process for revoking certifications for performing incorrect procedures, falsifying statements, or falsifying data.

Laboratories are required to be accredited or qualified depending on their role in the QA program. The Agency's central lab, private dispute resolution labs, and private independent assurance labs must be accredited. Labs conducting Agency verification testing and Contractor QC testing must be qualified or accredited. The AASHTO resource Accreditation Program or equivalent programs approved by FHWA must accredit laboratories; individual Agencies can qualify labs within their jurisdiction.

Independent assurance (IA) is an evaluation of acceptance sampling and testing including the effects of technician procedures and testing equipment. Independent assurance can be done using either a project approach or a system approach. In 2018, 28 Agencies used a system approach, 14 a project approach, and 10 a hybrid approach (includes Puerto Rico and District of Columbia) (*19*). The project approach evaluates Agency acceptance and Contractor QC personnel on an individual construction project. In this approach, typical IA sampling, testing, and observation frequency is a minimum of 10% of acceptance testing. A systems approach evaluates acceptance and QC across all active construction projects one to two times per year for all active testing personnel. IA personnel and equipment should not be used for project acceptance testing.

Procedures for dispute resolution are required when Contractor data is used in the acceptance decision. Dispute resolution includes a documented process to address discrepancies in Contractor QC and Agency verification testing and typically includes referee testing by a different accredited lab than that which ran the original tests.

Contractor QC includes materials sampling and testing used to control the process. If Contractor QC data is used in the acceptance decision, then the Contractor must use certified technicians and qualified or accredited laboratories, and the Agency must provide independent verification sampling and testing. The primary objectives of acceptance are measuring the quality of all materials produced and placed by the Contractor and determining the corresponding payment the Contractor should receive. In 2018, 34 State Agencies used Contractor data for acceptance (*19*). If the Agency uses Contractor test data for acceptance, it is good practice to validate the Contractor's data using a statistical comparison, typically the F-tests to compare population variance and t-tests to compare population means once enough test results have been completed and reported.

Percent within limits (PWL) is the primary methodology used by Agencies to determine pay adjustments for quality. Percent conforming (PC) and average absolute deviation (AAD) are also used. In 2018, 32 State Agencies used PWL for acceptance and to determine pay adjustments for asphalt pavement density (*19*). PWL uses the mean and standard deviation of the test data to estimate the percentage of material between the lower and upper specification limits, assuming a normal distribution. For PWL, increasing the number of cores or gauge readings for in-place density improves the estimate of the standard deviation, which reduces the variability of the estimated PWL. In this regard, the increased number of measurements with DPS would be beneficial when using PWL or percent conforming. Percent Conforming (PC) is an off-shoot of PWL that measures the percentage of test results between the lower and upper specification limits rather than performing statistical calculations to estimate the PWL. AAD is another method used by a few Agencies that measures the absolute value of the deviation between the mean of the test data and the specified target. A successful program for Agency acceptance using DPS will need to address all FHWA's requirements for QA.

At the conclusion of the FHWA presentation, a group discussion was held on QA. The workshop participants discussed the following topics that will need to be addressed by States as they implement DPS for acceptance:

- Certification of DPS equipment. This topic will be addressed by the ongoing pooled fund study.
- Certification of operators. This topic will be addressed by the ongoing pooled fund study.
- Use of cores to verify and validate Contractor QC DPS results versus using another DPS unit operated by the Agency or an independent firm that they hire.
- How to deal with localized areas of low density within a percent conformance type of specification. Alaska DOT developed some preliminary guidance to address this for longitudinal joints.

The establishment and meeting of a follow-on small Technical Working Group of key agencies is suggested to discuss in detail viable approaches for using DPS for acceptance while meeting FHWA requirements.

Development of AASHTO Standard for DPS

A provisional practice published for DPS equipment, AASHTO PP 98-20, Asphalt Surface Dielectric Profiling System using Ground Penetrating Radar, specifies the equipment and software requirements and calibration and verification for DPS systems. The calibration section includes equipment calibration of the antenna(s), distance measuring system, and GPS system (if used).

MN DOT provided a presentation entitled "AASHTO Specification Development: Equipment and operator certifications and standard test method including correlation with gyratory specimens and strategies for equipment calibration, standardization and checks" (*20*). While AASHTO PP 98-20 is adequate to make sure that equipment is working properly, a test method or methods is/are needed to cover correlation of a mix's dielectric constant to in-place density of that same mix, field DPS data collection, and field DPS data quality checks. Further, standards are needed for equipment and operator certification.

One method of correlating the dielectric constant to cores is to take static measurements with the DPS system at the core location prior to coring, cut the core, and then measure the density of the core. To get the best correlation, testing the widest range possible of in-place density is important. As part of the ongoing pooled fund study, MNDOT worked with a vendor to develop a system to measure the dielectric constant of SGC pucks. The system uses a stand to hold an antenna, a data acquisition box, a Delrin® block, and a metal plate to measure the dielectric constant based on the pulse velocity time-of-flight method (*21*). Delrin® is a form of polyoxymethylene, a thermoplastic with excellent dimensional stability. The Delrin® block is used as a spacer between the antenna and SGC puck. Since the dielectric constant is measured by time-of-flight, the thickness of the SGC pucks is critical. MNDOT currently recommends using the final height measured by the SGC. SGC samples should be prepared at design (typically 4%), medium, and high air voids. Production laboratory-compacted samples can also be tested to monitor the calibration.

Field data collection protocols are still being developed and to some extent depend on Agency preference. Typical sensor spacing with a three-antenna device is 1.5 feet. To collect joint density, an antenna should be 6 inches away from the unconfined joint. This is to prevent the antenna's Fresnel zone reading off the new mat. Three passes provide a high degree of coverage, as shown in Figure 1. This represents the maximum data that can typically be collected with a walking unit. A swerve survey is another alternative. In this method, the operator swerves from one side of the mat to the other while walking longitudinally. This allows data to be collected across the width of the mat.

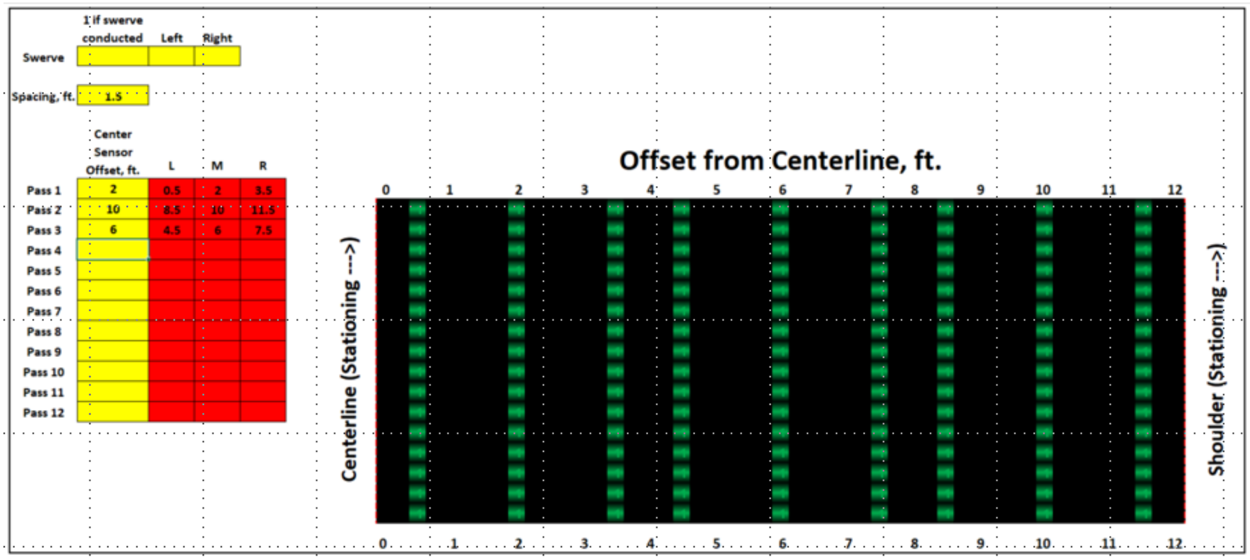

Figure 1. Example straight line data collection with three passes covering both joints (*20*).

Some Agencies using DPS have had issues with out-of-specification sensors (antennas). Component temperatures and differing sensor heights have also been found to affect sensor readings. AASHTO PP 98-20 specifies a maximum inter-antenna dielectric variation of 0.08. Several procedures have been investigated to check this in the field to ensure multi-antenna systems are providing the same results. One method is to use a high-density polyethylene (HDPE) plate. A plate that is large enough to avoid edge effects from the antenna Fresnel zone and thick enough to avoid influence from the underlying material is quite heavy, making it difficult to move around for field use. In-place density tends to be more consistent in the longitudinal direction over short distances. A transverse line can be tested across the mat to compare the sensor readings, so that the different antennas are taking readings at locations spaced longitudinally from one another. A swerve test, done in two directions (Figure 2), can be conducted to compare the sensors to the population median. The outer sensors cover the same area; the center sensor has 70% similar coverage.

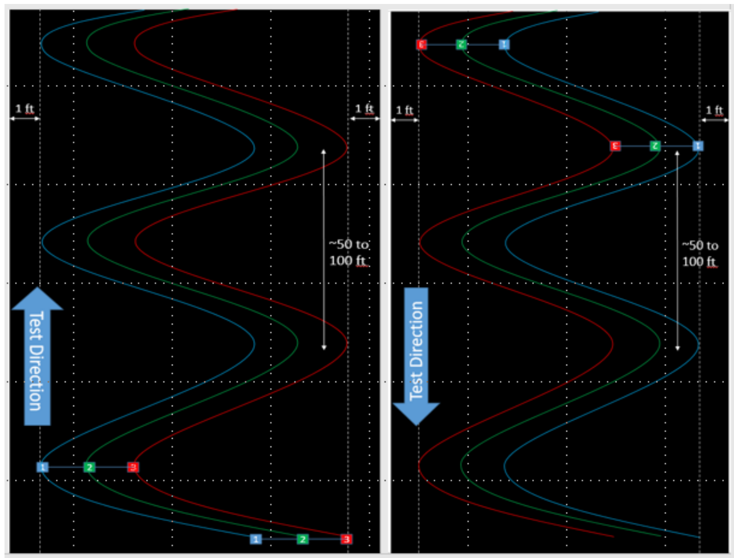

Figure 2. Swerve test example to field check sensors (*20*).

For equipment and operator certification, a process similar to AASHTO R 56-14, Standard Practice for Certification of Inertial Profiling Systems, is envisioned by the DPS pooled-fun study participants. The National Center for Asphalt Technology (NCAT) currently operates one of the inertial profiling system certification centers. NCAT is evaluating certifying DPS units on the same facility using a total of five pavement sections, four dense-graded asphalt test sections with four different in-place density levels ranging from 88% to 94% of theoretical maximum density and an open-graded friction course section. Existing in-place density will be documented with nuclear gauge readings at one-foot intervals along three lines, one for each antenna and 32 cores. It is expected that similar centers will be developed regionally around the country.

At the end of the presentation, there was a group discussion on needs for the AASHTO Standard(s). The majority of that discussion appears again in the breakout sessions.

Gaps To Be Filled for Implementation

As part of the workshop, a series of breakout sessions and group discussions were held to elicit feedback from the participants. The following are a series of questions and synopsis of the answers provided during the workshop:

1) What are the gaps which need to be filled prior to implementing DPS for acceptance of in-place density? This should be as encompassing as possible. Examples include calibration, effects of mix changes, effect of moisture (which would influence how closely the DPS measurements could be taken after the finish roller), acceptable testing patterns, bias and repeatability between equipment, acceptance parameters for DPS, and Agency/Contractor risk compared to conventional density testing.

- The gap that was most frequently identified was how to deal with correlations between dielectric and in-place density, potentially between DPS units from different manufacturers. This is important considering a project potentially could utilize three different DPS units representing Contractor QC, Agency verification or acceptance, and independent assurance. The antenna frequency affects the measured dielectric constant. AASHTO PP 98-20 allows a range of 1-3 GHz. The antenna frequency and height affect the Fresnel zone or area over which the dielectric constant is measured. Can the same correlation between dielectric constant and in-place density be used for two different units from the same manufacturer? Do the same SGC pucks need to be used to calibrate all of the DPS units used on a project?

- Related to the previous is the precision and bias between DPS units of the same brands and different brands. This is to be addressed as part of Pooled Fund Study TPF-5(443)
- Also related to calibrating and ensuring the unit(s) are functioning properly is the need for a "gold standard" calibration block that could be used to compare and check units. Ideally, the block would have a dielectric constant of similar magnitude to asphalt and would have reported values for different center frequency antennas that do not change with time. HDPE is not affected by frequency, while asphalt is, so this is important for different brands of antennas. Plastic materials, in general, would not be affected by aging. This block could also serve as a diagnostic test. Potential materials will be investigated as part of Pooled Fund Study TPF-5(443).
- Training was seen as a significant need by a number of participants. Training is specifically addressed later in the report.
- With any new technology, champions or trusted voices are needed on the state and national levels to push the technology forward.
- As noted under FHWA's requirements for quality assurance, State Agencies use different forms of specifications for acceptance. Guide specifications for acceptance using DPS for in-place density are needed to assist Agencies in developing their own specifications.

2) What research needs to be completed prior to implementation, if any? What research is essential before implementing for acceptance?

- The most frequently identified response was the cause of bias between core-based and SGC puck-based calibrations between the dielectric constant and in-place density seen in some cases. Agencies would like to minimize coring.
- Residual moisture in the mix or differing asphalt absorption with time were identified as possible causes for the bias sometimes seen between calibrations based on cores or SGC pucks. Moisture can have a significant effect on the measured dielectric constant. There are two potential sources of moisture: moisture left in the aggregate when it is coated with asphalt and moisture introduced onto the surface of the mix from rollers during compaction or rain. Various methods were discussed to possibly address this.
    - Alaska, as well as several other Agencies, split samples to measure both mix moisture and asphalt content. This is typically used to correct asphalt contents measured using the ignition method, where mix moisture would be measured as additional asphalt binder.
    - Ohio specifies a two-hour oven cure period before gyrating SGC samples on field-produced mix. This helps drive off residual moisture and facilitates absorption. Some other Agencies follow similar procedures with different curing times.
    - The dielectric constant of SGC pucks needs to be measured prior to testing with AASHTO T166 to ensure the puck is dry. Since cores are based on surface reflection measurements, the dielectric must be measured before the core is cut.
    - Use of CoreLok® and CoreDry® were discussed. CoreLok can produce more consistent measurements of sample density compared to AASHTO T166, particularly at higher air

void levels. The CoreLok also protects the sample from moisture. CoreDry would only be expected to remove moisture in interconnected voids, not residual moisture in coated aggregates.

  - Methods of measuring moisture in the field are being investigated. Are dielectric readings potentially affected by moisture in underlying layers? Alaska notes placing a piece of plastic on the mat can be used to identify the presence of moisture. Moisture, if present, will collect on the underside of the plastic.

- At what point do changes in gradation, asphalt content, RAP content, or aggregate type affect calibration? Daily checks of production samples should detect mix changes affecting the calibration, but allowable tolerances are needed.
- What layer thickness can DPS accurately be used on? Surface reflections may not read the lower portion of thicker lifts. Readings on thin lifts could be affected by the underlying lift. Are readings affected by coarser mixes or mixes with higher surface texture such as stone-matrix asphalt and open-graded friction course?

3) What DPS system improvements, including software, are needed for Agencies and Contractors to routinely use for QA? What is the need and current status of support and maintenance resources?

- Simplify the software as much as possible. In particular, data analysis procedures need to be streamlined.
- Add real-time analysis tools, such as determining current PWL. Add the ability to detect/analyze localized defects.
- Need troubleshooting tools to identify when a sensor is not reading properly. GSSI has added pop-up windows if system is measuring out of range or if quality check data are out of range.
- Pushcart versus a vehicle-mounted unit was discussed. Consensus was that having options was good. A vehicle-mounted system that incorporated multiple technologies could be valuable to Agencies in the future. Flexibility of different equipment, including size, was discussed in other sessions. A cart is larger than current gauges. ATV-mounted or Gator-mounted systems are larger yet. Vehicle-mounted systems could be used by Agencies needing to test multiple projects.
- Any enhancements to make the system more repeatable, such as identifying moisture or ensuring consistent sensor height, would be valuable system improvements if the system were to be used for QA.
- While not specifically addressed in responses during this session, the need for real-time vendor support during construction was noted. If being used for acceptance, significant down time is not acceptable. Current equipment costs initially make “standby” or “backup” units prohibitively expensive.

4) How can we best use DPS systems as-is?

- It would be beneficial if States participating in Pooled Fund Study TPF-5(443) held “rodeos” to demonstrate the technology to surrounding States. FHWA’s Mobile Asphalt Technology Center currently has three units to lend to State Agencies with two more units expected to be acquired soon.
- Can use the system to assess pavements for uniformity or for monitoring longitudinal joints.
- DPS is being used for forensic evaluations.

- Results can be combined with other technologies, such as infrared thermal imaging and intelligent compaction, for Contractor process improvement.
- May be best suited initially on interstate projects with Agency personnel and then expanded to other applications as more experience is gained.

5) What are logistical constraints of rental versus purchase options for equipment?

- The equipment is still evolving. Initially, vendors have upgraded initial equipment as improvements were made. Will this continue as equipment becomes more common? Rental options during this evolution may be advantageous.
- Rental units could be a good option for smaller State Agencies and Contractors.
- Would training and maintenance be included with rental agreements? What is the warranty on purchase?
- If the DPS is rented, who is liable if the equipment breaks down or is not working properly? Under Minnesota's pay for data program, the Contractor would be losing money if the equipment was not working. Vendors need to support breakdowns and rapidly get equipment working properly again.
- Rental options could provide Contractors with exposure/experience to DPS to see first-hand the benefits of the system and help to justify the expenditure.
- Contractors need good-faith commitment from an Agency that equipment will continue to be used in the future to justify expenditure.

Achieving Success

Agency Approaches to Deployment

Minnesota DOT

Minnesota (MN) DOT has been working to develop a robust process toward using DPS for acceptance of in-place density. Much of this effort involved developing the procedures to be included in future AASHTO standards, including sensor checks and calibration of the dielectric constant to in-place density. After collecting data with the walk-behind cart and exploring methods to maximize coverage, MN DOT considered alternates, such as a Gator with a sliding arm and a robot (Figure 3).

Figure 3. Walking Cart, Gator Mounted, and Prototype Robotic DPS Units (*22*).

Contractors have used MN DOT's DPS equipment for real-time identification of areas with high and low density. DPS equipment has been used to evaluate the benefits of process changes, such as including an additional roller in the compaction train, adding a warm-mix additive to the mixture, and differing rolling techniques for echelon paving. MN DOT has combined DPS with infrared thermal imaging and intelligent compaction to provide an overall evaluation of construction practices. DPS data will be integrated into a future release of Veta software, which already incorporates infrared thermal imaging and intelligent compaction, to automate geospatial analysis of DPS data. MN DOT has also used DPS as a forensic tool to document in-place density after a known paving issue. MN DOT is currently paying Contractors to collect DPS data and is continuing to do so in 2021.

Ohio DOT

Ohio DOT sees reduced pavement life due to built-in defects from the time of construction. Examples of built-in defects include potholes (mostly due to delamination), raveling, joint deterioration, longitudinal cracking, and bumps. Ohio DOT currently takes 10 cores per production day, typically representing 1,500 to 2,000 tons of asphalt mix placed. Defects are consistently missed at this sampling rate. Ohio DOT's DPS unit collects 54,000 measurements over the same 2,000 tons. Ohio DOT sees good correlations between DPS and cores. The correlations are slightly better than with nuclear gauges and significantly better than non-nuclear gauges.

Ohio DOT developed four main goals to evaluate DPS technology in 2020 using two GSSI RDM units:

- Evaluate QA process,
- Evaluate swerve data collection,
- Evaluate SGC puck calibrations, and
- Develop joint density collection procedures.

The swerve procedure allows the mat to be scanned in a single pass using a gentle wander from edge to edge. The swerve eliminates bias and allows sensor comparisons. Distance measurements, from the DPS' on-board distance measuring instrument (DMI), can no longer be referenced to project stationing with this technique. Fewer data points are collected as compared to multiple linear passes. Specifying the gentle wander is difficult.

Strong correlations were developed between time-of-flight dielectric constants and density of SGC pucks. Ohio DOT validation core locations were tested with DPS surface reflection measurements prior to coring. The correlation between field dielectric measurements and field core densities was weaker, but still good. An offset of approximately 2% density was observed between the two correlations (Figure 4).

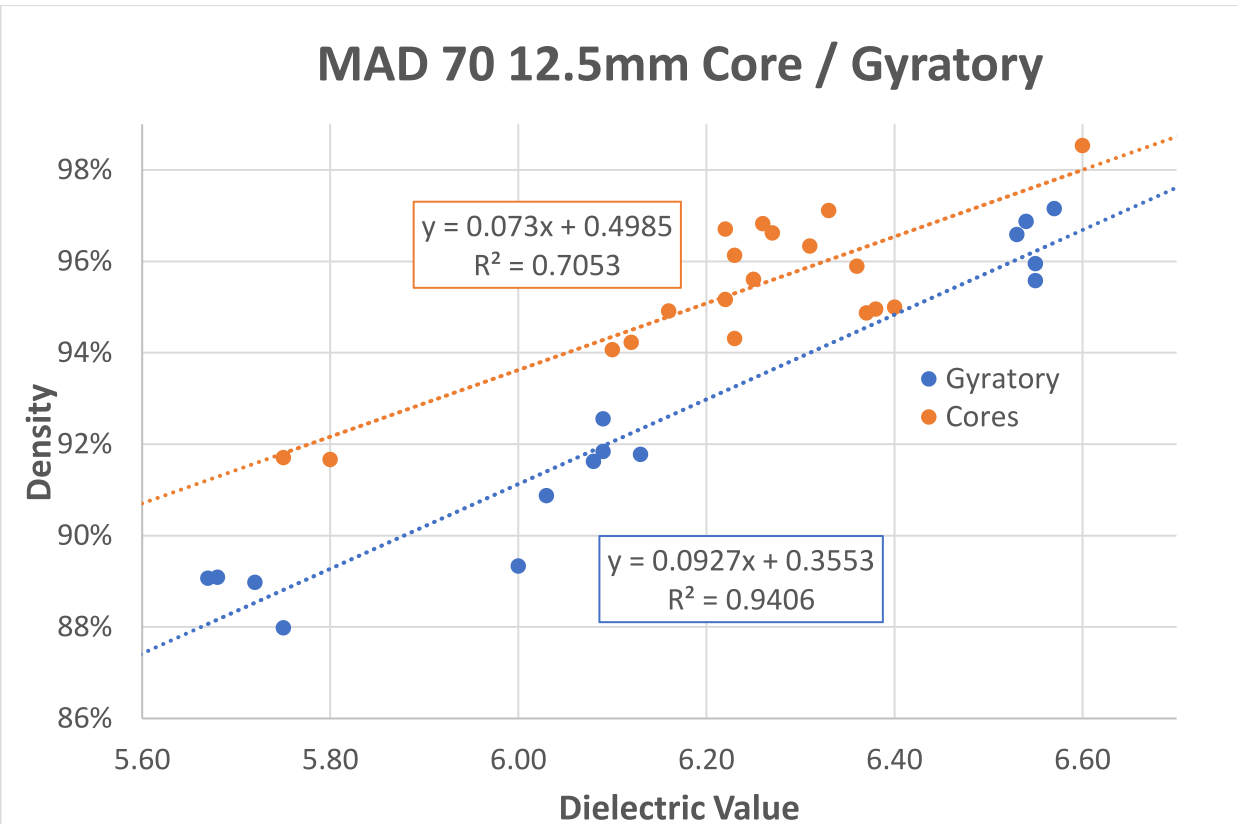

Figure 4. SGC Puck and Core Correlations with Dielectric Constant (*23*).

When running QC/QA simulations with two units, there was an issue with one unit's antenna calibration. This resulted in differences in the measured dielectric constants between the two units with mean differences of in-place density of 0.4 to 2.0% over six lots.

Ohio DOT plans to continue evaluating the items planned for 2020 in 2021. Additional evaluations of QA procedures and tolerances between machines will be evaluated. Ohio DOT plans to develop specifications for pilot/shadow projects.

Alaska DOT

Alaska DOT's primary reason for using DPS is that it reveals the entire compaction picture. In the 10-15 minutes it typically takes to set up and drill one core, a DPS operator can collect readings for over 12,000 locations, 50% of the total area, at one result every square foot of surface, of a 2,000-foot-long lane segment. Random spot tests often miss defects. Full coverage testing rarely misses a defect or at a minimum misses significantly fewer issues. Contractors may fear that defect identification will lead to additional penalties; Alaska instead proposes incentives for process improvement.

Statistical estimates, such as PWL, using the mean and standard deviation are needed with density spot checks using cores or nuclear gauges. In Alaska, 10 cores are typically taken per 5,000-ton lot at a rate of one per 500-ton sublot. With DPS full-coverage testing, the entire population of density values is known, rendering statistical population estimates unnecessary. Statistical estimates of PWL, used by many Agencies, can be replaced with the actual PC measured by DPS. Full-coverage density mapping greatly improves the accuracy of quality pay factors, estimates of service life, and life-cycle costs while promoting higher density and better uniformity. Uniform, highly compacted pavements provide longer pavement life and lower maintenance costs. Higher density improves fatigue life and is a cost-effective way to increase pavement life. Alaska proposes a density bonus of 5% (incentive/disincentive) that rewards both higher density and higher conformance to a minimum density level. This approach is estimated to increase pavement fatigue life by 30-90% when the target density and conformance levels are obtained.

Alaska's experience demonstrates that longitudinal joint density equal to mat density values can be achieved using tools such as the notched wedge joint and infrared joint heaters. Alaska has proposed a method for DPS joint density evaluation in 100-foot segments. If a segment does not meet minimum compaction requirements, it must be sealed at the time of construction.

Alaska DOT's proposed incentive for compaction increases linearly from $0 per 100 feet at 91.0% of theoretical maximum density (TMD) to $200 per 100-feet at 96.0% TMD. This level of incentive then remains constant until 98.0% of TMD. Additionally, Alaska includes a PC bonus factor that increases linearly from 0 at 90% to 1 at 100%. With this bonus factor, a minimum of 90% of joint density readings need to be above a minimum density of 91% to receive any compaction incentive. For less than 90% PC, the joint must be sealed. The joint bonus paid by Alaska DOT is the product of the incentive based on the average density times the PC bonus factor. For example, if the average joint density for a 100-foot segment was 96% of TMD and 98% of the readings were above the minimum density of 91% of TMD, the compaction incentive would be $200 x the PC bonus factor of 0.8 = $160 (*24*).

For mat density, Alaska replaced PWL with PC. Under current specifications, less than 50% PC triggers removal and replacement. Alaska is evaluating a mat density PC to trigger a sand seal or fog seal at the time of construction. They are also evaluating how to use the defect detection feature built into GSSI's PaveScan RDM software. Recent pilot projects identify 8 ft^2 with less than 92% density as a mat defect. Identified defects can be exported and listed in station order for each paving shift. Incentives based on average density and PC, like those described above for joint density, are proposed for mat compaction.

Agency approaches to deployment were discussed in a breakout session. The following summarizes that discussion:

- Florida indicated that in-place density is currently their lowest pay factor and that more pavement was removed and replaced due to low in-place density than for any other cause. Idaho seconded this notion. Implementing a system that just added more penalties is unlikely to be successful.
- There was widespread support for implementing DPS with incentives for better density and uniformity. Incentives can be justified when considering pavement performance versus in-place density, repair, and overall life-cycle costs. Incentives help Contractors invest in equipment and work to improve their processes. Need to balance incentives between in-place density and smoothness. It was noted that neglecting in-place density to achieve better smoothness was detrimental to long-term performance.
- Contractors are receptive to finding issues and improving processes, but some issues are outside what the Contractor is responsible for, such as yielding base or otherwise deteriorated/non-uniform underlying pavement structure that hinders compaction. How can these areas be detected and accounted for?
- DPS could be implemented through shadow projects where technology is used to monitor constructed densities but pay is based on the current system. This could allow Agency and Contractor to understand what is going on, such as localized defects missed by the current system, and see benefits of the technology. MN DOT is currently paying Contractors to collect a certain minimum percentage of the data, much like a shadow project.
- It is important to engage industry early and get State Contractor associations on board.
- DPS technology has been used for forensic evaluations. Dielectric can still be calibrated to cores.

Benefits to Contractors of DPS Implementation

Potential benefits to Contractors were discussed in a breakout session. The best use of non-destructive evaluation tools like DPS is as a tool to improve the construction process. A consultant who participated in the workshop has used DPS technology combined with infrared thermal imaging and intelligent compaction to help Contractors improve uniformity and quality. Using this approach has helped Contractors obtain incentives for both in-place density and smoothness. Real-time data is also a big benefit, particularly when combined with other technologies that allow the Contractor to identify the cause of non-uniform areas, such as cold mix or rollers missing areas due to refilling water tanks, etc.

Strategies for Deployment, Tools and Tactics

Buy-in from Agencies and Contractors: Executive, Manager, Staff and Field Personnel

A brainstorming breakout session addressed what buy-in was necessary to move DPS technology forward with both Agencies and Contractors. The following highlights the discussion:

- Buy-in from upper management is important. Need leaders that want better quality and are willing to pay for it (incentives).

- Senior management at Washington State DOT takes their lead from the State's pavement office and will support their recommendations. The State pavement office needs to develop a long-range plan for implementation.
- Many States have strong Contractor associations with potential influence over Agency upper management. Need to establish working teams with industry from the beginning to discuss technologies collaboratively and share experiences. Keep as simple as possible. Stage implementation goals.
- It is good to involve as many people as possible. Early stakeholder involvement in the development process makes buy-in more likely. A key is involving the right people, those who can affect implementation.
- For Veta Software, Minnesota started with a general roadmap, so everyone knows what is coming. Gradually added to the Contractor's responsibility as information and training progressed. Change of staffing is an issue for the Agency. Turnover results in loss of experience and requires additional training.
- Industry groups, such as the National Asphalt Pavement Association and the Asphalt Institute, were involved in the workshop. If buy-in is achieved with these groups, whom Contractors respect, then buy-in from Contractors will be easier.

Tools and Tactics to Support Implementation

Following the discussion on buy-in, the discussion continued to outline tools and tactics to support implementation. The following summarizes the discussion:

General

- Identify champions or trusted voices, both Agency and industry, regional and on a State basis. Utilize industry leaders to support the benefits.
- Identify shortcomings with current systems that only measure in-place density for a small fraction of the area paved and that are likely to miss defects.
- Develop pictorial examples that demonstrate coverage between current systems and DPS and display variation in density. Show what is being missed with the current measurement system using gauges or cores and how that influences pavement life.
- Develop flyers or handouts that cover case studies, testimonials, and demonstration efforts.

Agency

- Quantify life-cycle cost-benefit to convey to Agency leadership. Improved in-place density equals longer pavement life.
- Provide software and connectivity for data analysis and data management so as not to overwhelm project staff.

Contractor

- Choose Contractors carefully for initial projects:
  - Contractor selection can aid or hinder implementation.
  - Choose Contractors with well-established QC programs.
  - Ask for volunteers in a group setting.
- Provide Contractors with exposure to technology through loan or demonstration projects.

- Incentivize Contractors to use the technology. Consider incentive for uniformity as an initial step.
- Agencies need to make long-term commitment to Contractors who invest in the technology.
- Need to maintain fairness in bidding. The cost of testing equipment should not be used to preclude smaller Contractors.

What Obstacles Could Hinder Agencies and Contractors from Supporting this Technology?

While DPS technology offers significant benefits in the measurement of in-place density and uniformity, which could lead to significant improvements in pavement life, there are still potential obstacles. The workshop participants were asked to identify these in a breakout session. A summary is provided below:

- Resistance to change. Acceptance of the status quo. Fear of additional penalties.
- Adequate personnel on both the Agency and Contractor side. Hawaii indicated inspectors were concerned that the additional effort would increase their workload. The same could be true for the Contractor. Several suggested that trying to achieve nearly full coverage with a pushcart is a full-time job. However, Alaska's experience with Agency personnel suggests full coverage is achievable with a pushcart while still allowing time for additional duties.
- Education improves buy-in.
- While there are multiple vendors of DPS technology, there is currently a gap where a single vendor has advanced their system the furthest.
- Complexity of the technology requires good training programs.

Marketing: Taking DPS Forward

There are few government programs that are more present in the lives of Americans than streets and highways. As the late Byron N. Lord, a former official at FHWA, used to say, our highway system is part of "the majesty of the United States." More prosaically, Americans use their roads and highways to get to everything: school, work, play, worship, entertainment, fellowship with family and friends. While the public may not know much about highway engineering, the quality, safety, and capacity of highways is apparent to all.

Funding comes from the public and is distributed to Agencies through legislative bodies. Federal and State Agencies administer those funds in ways that provide maximum benefit to the taxpayer at the lowest cost. Contractors – and, ultimately, paving crews – are charged with constructing and maintaining the facilities.

All these people form a web in which every person is accountable for their decisions and actions. The web of accountability is a very good reason that people in the highway industry take a "show-me" attitude when presented with innovations. They know that they will be judged by the users based on the product – the highway – and that the product will be in place for a long time.

In the highway industry, therefore, marketing is a matter of persuasion through education based on facts. Introducing a new product, practice, or technology requires building a compelling case and presenting that case to multiple audiences at multiple levels. In the process of presenting a new technology, questions may come from anyone – a legislator, a highway department secretary or commissioner, an engineer, or a paving Contractor; and when those questions come, there need to be good answers.

Building the case for the DPS technology has begun well, with research projects at MnROAD and field testing in several States.

Participants in the virtual workshop held on April 20-21, 2021, suggested that at this time, the next appropriate steps toward implementation would be pilot programs in States that are part of the pooled-fund study.

Specifically, it was suggested that in 2022, some States could write contracts with incentive pay for densification on longitudinal joints as measured by DPS. As the technology is further refined and developed over time, and as Agencies and Contractors become more comfortable with it, expanding use of DPS to measure the full width of the mat is expected.

The recommended marketing plan for DPS includes an analysis of the following:

I. Audiences

II. Timeline

III. Marketing channels

IV. Marketing resources to be developed

V. Avenues for delivering messages

VI. Trusted voices

VII. Key messages – the business case for DPS

VIII. Action plan and next steps

Audiences

Decision Makers

- Public sector:
  - Federal Highway Administration
    - U.S. DOT Secretary
    - FHWA Administrator
    - FHWA Executive Director
    - FHWA Office of Research, Development, and Technology
    - FHWA Office of Infrastructure
    - FHWA Division Offices
  - State Departments of Transportation / AASHTO
    - DOT Secretary/Commission in each State, plus their leadership team
    - Chief Engineer in each State
    - Chief Engineers at toll highway authorities, counties, cities, and metropolitan planning organizations (MPOs)
    - Chief of Research/Technology in each State (Title may vary), plus their teams
  - AASHTO Committee on Construction
  - AASHTO Committee on Maintenance
  - AASHTO Committee on Materials and Pavements

- Private sector:
    - Pavement Contractors

  Top management

  Materials and construction staff
    - Consulting engineers

ASPHALT PROFESSIONAL SOCIETIES

- Association of Asphalt Paving Technologists
- International Society for Asphalt Pavements

ASPHALT INDUSTRY TRADE ASSOCIATIONS

- Asphalt Institute (AI)
- Asphalt Pavement Alliance (APA)
- National Asphalt Pavement Association (NAPA)
- State Asphalt Pavement Associations

ACADEMIA

- MnROAD, Minnesota DOT's research arm
- National Center for Asphalt Technology (NCAT)
- National Road Research Alliance (NRRA)
- Texas Transportation Institute (TTI)
- Transportation Research Board (TRB)
- Economists

These audiences can also be thought of as communities, such as:

- POLICY MAKING AND FUNDING COMMUNITY
    - Legislators
    - Top U.S. and State DOT officials
    - Top AASHTO officials
- RESEARCH COMMUNITY
    - Academia
    - AASHTO Special Committee on Research and Innovation and its Research Advisory Committee
    - Economists
    - Research engineers at FHWA
    - Research engineers at State DOTs
- CONSTRUCTION COMMUNITY
    - AASHTO Committee on Construction and its subcommittees
    - Contractors
    - Regional Asphalt User/Producer Groups [Northeast (NEAUPG), North Central (NCUAPG), Pacific Coast (PCCAS), Rocky Mountain (RMAU/PG), and Southeast (SEAUPG)]
    - State DOT construction officials

Timeline

Workshop participants agreed that significant progress has been made on developing the DPS technology and refining its ability to generate meaningful data that can (a) give the Contractor the opportunity to make adjustments in a timely fashion and (b) be used for acceptance of pavements by Agencies.

Challenges remain, however.

- The data stream provided by DPS is extremely rich; so much so that the user (the pavement Contractor) may find it challenging to interpret.
- Paving projects may be in locations without internet connectivity, which would mean field crews may not be able to upload the data until they return to the facility at the end of the day. This is one example of a barrier to real-time adjustments that may be indicated by the data.

Agency representatives expressed that in States that have participated in the pooled-funds study, pilot programs in 2023-2024 may be feasible. In such States, DPS data collected at longitudinal joints could be used for incentive pay. The consensus was that using DPS data for acceptance of the entire pavement mat would be premature just now.

Based on the successful outcomes of such pilot programs, multiple States might move ahead with implementing DPS for incentive pay for the full mat. As the technology matures and research demonstrates the validity of the use of DPS data for density, the stage could be set for using DPS data for acceptance of the pavement.

For all these reasons, a measured pace in marketing, education, and training efforts is advisable.

Marketing Channels

A robust marketing program will utilize all available channels. These include web sites, print and digital publications, in-person and virtual gatherings, trade shows, videos, and webinars. Printed materials to be used at in-person meetings may include infographics, one-pagers, flyers, posters, banners, press releases, leave-behinds, and brochures.

Meetings and Presentations

- A number of persuasive reports were presented during the April 20-21 workshop and the pre-workshop webinars. These could be adapted by their authors for specific events. The next step would be reaching out to the conference sponsors to get spots on their programs. MN DOT staff have already been invited to speak at some user-producer meetings in 2021.
- Face-to-face gatherings. Once in-person meetings become the norm again, presentations at conferences will be an effective way to get the word out. An added benefit of face-to-face meetings is peer-to-peer networking among attendees.
- For State highway engineers, a highly trusted source of information is presentations at AASHTO committee and subcommittee meetings by their peers from other States. For Contractors, presentations at regional and national pavement conferences serve a similar purpose.

Here is a list of upcoming national meetings, training programs, and trade shows, in chronological order:

- AASHTO Special Committee on Innovation and Research (Virtual Meeting July 13-15, 2021)

- AASHTO Committee on Materials and Pavements Virtual Annual Meeting, July 26-August 4, 2021
- AASHTO Committee on Construction Virtual Annual Meeting, August 9-13, 2021
- NAPA Midyear Meeting, July 18-21, 2021, Nashville
- TRB Annual Meeting, January 9–13, 2022, Washington, DC
- NAPA Annual Meeting, January 23-26, 2022, Scottsdale, AZ
- World of Asphalt March 29-31, 2022, Nashville (Includes People, Plants, and Paving training program)
- NAPA Midyear Meeting, July 10-13, 2022, Santa Barbara, CA
- TRB Annual Meeting, January 8-12, 2023, Washington, DC
- CONEXPO CON/AGG March 14-18, 2023, Las Vegas (Includes People, Plants, and Paving training program)

There are 39 State Asphalt Pavement Associations. All hold meetings where new technologies can be presented. Many also provide training to Contractors and, in some States, to Agency personnel. A listing of the State Asphalt Pavement Associations and their contact information is at https://www.asphaltpavement.org/about/napa-partners/state-asphalt-pavement-associations

Marketing Resources to be Developed

Participants discussed the needs for marketing tools and resources.

- FHWA Tech Briefs
- Magazine articles – Highway trade publications such as *Roads & Bridges*, *Asphalt Pro*, *Asphalt Pavement* (NAPA), and *Asphalt* magazine (AI) reach a broad cross-section of the target audiences identified by the workshop participants. A regular flow of magazine articles, each tailored to the readership of the given magazine, could introduce the technology to readers and keep it in front of decision makers.
- NCHRP Research Reports
- One-pagers/leave-behinds – For top-level policy makers, a one-pager showing the economic, safety, construction, and environmental sustainability benefits of the technology. Could include cost-benefit analysis. For State DOT secretaries and top leadership, would optimally be tailored for that State. The same one-pagers and leave-behinds would also be appropriate to share with legislators.
- Trade show exhibit and handouts – For both Agencies and Contractors, exhibiting at highway-related trade shows can be effective. Examples include TRB, World of Asphalt, and CONEXPO. Some State and regional asphalt associations also host trade shows. Developing promotional displays and printed handouts should be considered.
- Tri-fold brochure with general messages about benefits.

- Web site – A robust web site dedicated to DPS would be an asset. The site should be created by a stakeholder other than a manufacturer. Content could include sections devoted to research reports, case studies, training videos, success stories, and links to articles in the highway trade press.
- Webinars and online meetings. While we are still in the pandemic and most meetings are being held virtually, web-based events are a way to overcome limits on in-person gatherings. It is expected that even after the pandemic, webinars, Zoom meetings, Microsoft Team meetings, and other remote learning technologies will still be widely used because of their convenience and cost-effectiveness. As a note, the Asphalt Pavement Alliance sponsors webinars that attract hundreds of consulting engineers.

Trusted Voices

The messenger can be as important as the message.

In every part of the asphalt industry, people trust research institutions, such as MnROAD and NCAT, because over the decades they have provided reliable, implementable, real-world solutions.

In Agencies, people trust their peers and proven leaders. Putting this into action means, for example, making the case for DPS at AASHTO committee and subcommittee meetings. The Chief Engineers in every State are respected as informed, impartial voices. FHWA personnel who have worked on the DPS project will also have great credibility with Agencies.

For the Contractor audience, a mix of research and Agency voices carry great authority. In addition, peers who have had experience with the technology can be effective spokespeople.

The Regional Asphalt User/Producer Groups [Northeast (NEAUPG), North Central (NCAUPG), Pacific Coast (PCCAS), Rocky Mountain (RMAU/PG), and Southeast (SEAUPG)] share new technologies from State to State within their regions. They are specifically structured to include industry, State Agencies, and Federal Agencies.

Key Messages – The Business Case for DPS

For a new technology to succeed, those backing it need to build a business case – a solid justification for investing in it. The business case evaluates the benefits of the technology, its costs and risks; the costs and risks of other options; and a compelling rationale for adopting the new technology. It also provides a future vision.

By looking at the business case for DPS, we can arrive at key messages that will persuade target audiences to explore investing in it.

For Funding Agencies: Economics, Safety, and Sustainability

Economics

It has long been known that uniformity and better densification of the mat lead to longer pavement life.

Longer pavement life saves money for the owner Agency.

A credible economic argument can be developed. For example, “The cost of using DPS on this paving project is X. Using DPS, we can predict an improvement in density of XX. It is known that this level of improvement extends pavement life by XXX years, potentially saving XXXX billion over the life of the roadway."

Longer pavement life reduces delays for users of the pavement.

Sustainability

The longer the life of the pavement, the more will be saved in time, money, and materials. This is an economic benefit. This also reduces construction-related delays for the traveling public.

Saving time and materials on pavement rehabilitation also reduces carbon consumption and carbon emissions. This is an environmental benefit.

By reducing delays for the traveling public, we can reduce excess emissions from vehicles that are idling as they wait to pass active construction sites. Less time spent in traffic is a social benefit; reduced emissions an environmental benefit.

Potentially, there could be safety aspects of using DPS, especially for Agencies who currently conduct coring after the original lane closures for paving by reducing worker exposure. For the traveling public, pavements in good condition are safer to use than pavements in poor condition. These would also be social benefits.

The longer the life of the pavement, the better – for the Agency, for the taxpayer, for the highway user, and for the environment.

For Contractors: Improvements in Construction Practices and Crew Safety

DPS measures and promotes uniform density of the constructed asphalt pavement.

By providing data in almost-real time, DPS makes it possible for the crew to make improvements and take corrective action while still on that paving job.

DPS can be used to measure density at the longitudinal joint, one of the places most at risk for early failure due to inadequate compaction.

DPS can provide almost 100% coverage of the asphalt mat, in contrast to the existing practice of using randomly selected cores or gauge readings.

Using DPS, Agencies can offer density incentives that are fairer to Contractors than the existing practice of taking random cores which may or may not be representative of the pavement overall.

DPS data can help roller operators optimize their rolling patterns.

Vision for the Future of DPS

Meaningful, accurate, almost-real-time density measurements will result in longer-lasting pavements. We can look to a future in which the needed data will be collected in a timely fashion and incorporated into paving projects. This will confer benefits on taxpayers, highway users, Agencies, and construction crews.

Action Plan and Next Steps

With DPS technology having made strides in development but product rollout still in the pilot phase, now is the time to start building the marketing platform.

Near Term – First Steps (2021-2022)

The core audiences for DPS in 2021-2022 will include:

- DOT Secretaries/Commissioners and top leaders within those Agencies
- Chief Engineers, Construction Engineers, Materials Engineers, and other senior management level personnel in all States
- FHWA Division leaders in all States
- Contractors in States where pilot projects are contemplated
- Workers in Contractors' laboratories and paving crews

With these audiences in mind, the following activities are recommended:

Web Site

Create a robust web site dedicated only to DPS to gather all the information currently available. It should have the potential to be built out over the next 5 to 10 years as new information and materials develop, and as the technology moves from pilot programs to wide implementation.

Outreach to Key Individuals

Reach out to Chief Engineers in every State.

Reach out to FHWA Divisions in every State.

Presentations at Conferences

DPS Development Team members have many opportunities to get on the programs at industry conferences and make presentations tailored for the audience at each one. For 2021 and the first half of 2022, we suggest making presentations at the following events:

- AASHTO Committee on Construction Virtual Annual Meeting, August 9-13, 2021
- AASHTO Special Committee on Innovation and Research (Virtual Meeting July 13-15, 2021)
- TRB Annual Meeting, January 9–13, 2022, Washington, DC – The deadline for submitting a paper for TRB 2022 is August 1, 2021.
- NAPA Annual Meeting, January 23-26, 2022, Scottsdale, AZ – Presentation would be tailored to a Contractor audience.
- World of Asphalt, March 29-31, 2022, Nashville, which includes the People, Plants, and Paving training program; the presentation would be for training the paving crew. (Exhibiting at the 2022 trade show would be premature.)
- Regional User/Producer Group Meetings – Kyle Hoegh will be speaking on DPS at the Southeastern Asphalt User/Producer Group Meeting, November 16-18, 2021, Knoxville, TN.

Printed/Digital Materials

Create a one-pager for DOT Secretaries/Commissioners and top leadership focusing on economic, environmental, and safety messages.

Create infographics showing the economic, environmental, and safety benefits. For example, economic analysis – “investing X will save YY a year.”

Print Publications

DPS is an attractive subject for the editors and readers of the transportation trade journals (*Roads & Bridges*, *Asphalt Pro*, AI’s *Asphalt* magazine, and NAPA’s *Asphalt Pavement* magazine). Their editors are always looking for high-quality content of interest to their readers, who are both Contractors and Agency people. Lead times can be long, from three to six months or longer. Job stories from the summers of 2020 or 2021 would likely be welcomed by editors of the magazines. *Roads & Bridges* and *Asphalt Pro* are mainly Contractor-focused. *Asphalt Pavement* (NAPA’s magazine) and *Asphalt* (AI’s magazine) reach Contractors as well as engineers and Agency personnel at all levels of government; of the magazines, *Asphalt Pavement* and *Asphalt* use the most technically sophisticated articles.

There are also opportunities to publish reports about DPS in the transportation technical publications (*Transportation Research Record* [TRB’s official journal], the FHWA *Tech Briefs*, and NCHRP *Research Reports*).

Videos

As appropriate, create videos for targeted audiences. These would include video explainers for policy makers, video promotional tools for building support for the technology, and training videos for paving crews and asphalt lab workers. MN DOT is currently shooting field training videos for the GSSI RDM 2.0 as part of the pooled fund study.

Create a YouTube channel that uniquely focuses on pavement DPS (i.e., not DPS for analyzing other products in industries such as electronics, chemicals, food, and medicine).

Cross-post the videos on both the DPS web site and the DPS YouTube channel.

Trade Shows 2022

Consider exhibiting at the TRB Annual Meeting, January 9-13, 2022. FHWA and AASHTO have already reserved space in prominent positions on the show floor. Is there an opportunity to piggyback on their space, perhaps using DPS banners and handouts? If not, consider reserving a dedicated space and creating a stand-alone booth. In either case, if the group wishes to have a presence there, materials (booth or banners, printed materials, etc.) will need to be created.

The big trade show for asphalt construction is World of Asphalt, March 29-31, 2022. Exhibiting on the trade show floor may not be appropriate until the technology is in wider use; however, the show also includes the People, Plants, and Paving training program, where paving crews go for training.

Mid Term (2023-2026)

By 2023, it is anticipated that DPS will have progressed beyond pilot programs in a few States to wider implementation. As use of the technology expands, the marketing team will need widen its focus to include more Contractors as well as consulting engineers.

To meet the demand for education and training for all audiences, the activities outlined for 2021-2022 should be continued.

Suggested new activities include:

Create webinars for audiences including Contractors and consulting engineers. (Note that the Asphalt Pavement Alliance's webinars reach hundreds of consulting engineers.)

Create new educational and training materials for paving crews and asphalt lab workers.

Consider exhibiting at CONEXPO in March 2023 and March 2026.

Long Term (2027 and beyond)

Continue activities outlined above and build on them.

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Appendix A: Workshop Participants

Name	**Affiliation**	**Role**
Steve Cooper	FHWA	Lead
Tom Yu	FHWA	Attendee
Dennis Dvorak	FHWA	Attendee
Kevin Kliethermes	FHWA	Attendee
Hoda Azari	FHWA	Attendee
Monica Jurado	FHWA	Attendee
Leslie McCarthy	FHWA	Attendee
Jeff Withee	FHWA	Attendee
Rich Giessel	AK DOT	Agency
Wayne Rilko	FL DOT	Agency
Guangming Wang	FL DOT	Agency
Kyle Buyuan	HI DOT	Agency
Mark Wheeler	ID DOT	Agency
Craig Wielenga	ID DOT	Agency
Ed McCarty	MD DOT	Agency
Larry Riggleman	MD DOT	Agency
Dale Peabody	ME DOT	Agency
Kyle Hoegh	MN DOT	Agency
Curt Turgeon	MN DOT	Agency
Jeff Brunner	MN DOT	Agency
Rebecca Embacher	MN DOT	Agency
Dai Shongtao	MN DOT	Agency
Glenn Engstrom	MN DOT	Agency
Ryan Martin	MO DOT	Agency

Name	Affiliation	Role
Amy Beise	ND DOT	Agency
Mike Reynolds	NE DOT	Agency
Tom Kane	NY DOT	Agency
Craig Landefeld	OH DOT	Agency
Kim Schofield	WS DOT	Agency
Jeff Uhlmeyer	WS DOT	Agency
Adam Hand	University of Nevada, Reno	Academic
Ervin Dukatz	Flyereld Consulting, LLC	Consultant
Bryce Wuori	Wuori Consulting, LLC	Consultant
Mark Blow	Asphalt Institute	Industry Association
Brett Stanton	Asphalt Pavement Association of Michigan	Industry Association
John Crane	Flexible Pavements of Ohio	Industry Association
Brandon Brever	MN Asphalt Pavement Association	Industry Association
Brett Williams	NAPA	Industry Association
Greg Tomon	Lindy Paving	Industry Contractor
Matthew Oman	Mathy Construction	Industry Contractor
Brian Nagel	Caterpillar	Industry Equipment Mfg.
Prashant Ram	APTech	MATC Contract Support
Fabricio Leiva	NCAT	Research
Margaret Cervarich	QES	FHWA Contract Support
Dennis Morian	QES	FHWA Contract Support
Nathan Morian	QES	FHWA Contract Support
Robin Patroni	QES	FHWA Contract Support
Brian Prowell	QES	FHWA Contract Support

Appendix B: Pre-Workshop and Workshop Agendas

Develop a National Implementation Plan (Roadmap) for use of Dielectric Profiling Systems (DPS) for Acceptance of In-place Asphalt Pavement Density

Pre-Workshop Webinar 1: March 31, 2021
Dielectric Profiling System 101

All times Eastern

11:00 am	Welcome	Stephen Cooper
11:05 am	Importance of In-place Density of Asphalt Pavements	E. Ray Brown
11:15 am	Overview of Dielectric Profiling Systems	Shongtao Dai - MN
11:45 am	Advantages of DPS – State Perspective	Kyle Hoegh - MN Rich Giessel – AK Craig Landefeld - OH
12:30 pm	Questions	

Pre-Workshop Webinar 2: April 14, 2021
DPS Roadmap Goals

All times Eastern

11:00 am	Welcome	Brian Prowell/Stephen Cooper/Tom Yu
11:20 am	Objectives for the Workshop a. Workshop Goal, Objectives, and Desired Outcome b. Participant Role c. Housekeeping	Brian Prowell
11:40 am	Current State of FHWA/MNDOT Pooled Fund Study a. Research needs b. Equipment Improvements c. Development of Standard Test Method	Shongtao Dai
12:10 pm	Overview of Meeting Agenda and Breakout Sessions	Brian Prowell
12:25 pm	Links to Supporting Information	
12:30 pm	Adjourn	

Pre-Workshop Webinar 1 and Presentations are available at:
https://www.advancedmaterialsservices.com/dps-101.html

Dielectric Profiling System (DPS) Implementation Plan (Roadmap) Development Workshop

Dates: April 20 and 21, 2021

Location: MS Teams (hosted virtually by FHWA)

Workshop Support Staff
Logistics (FHWA):
Facilitator: Brian Prowell AMS/QES

Workshop Goal: Obtain stakeholder input in developing an Implementation Plan (Roadmap) for agency use of dielectric profiling systems (DPS) as an acceptance tool for asphalt pavements during construction. Discuss various tactics that can be used for implementation.

Workshop Objectives:

- Present an overview of technology to educate stakeholders not yet familiar with DPS.
- Work with stakeholders to identify gaps hindering implementation, including system improvements, and research needed to fill those gaps.
- Discuss various methodologies for using DPS for quality control and agency acceptance.
- Discuss means and tactics for implementing DPS for acceptance of in-place asphalt pavement density.
- Gather stakeholder input for QES team to develop outlines of acceptance programs.
- Provide input for a marketing plan to be used by FHWA.

Desired Outcome: Gather stakeholder feedback and establish an acceptable path moving forward to implement DPS for acceptance of in-place density of asphalt pavements. Also, obtain feedback on what should be focused on in the future to meet this goal. The feedback obtained in the workshop will be used by QES to prepare a Roadmap for DPS implementation.

Day 1: April 20, 2021 — Identifying Gaps Needed for Implementation

All times Eastern

10:30 am **Welcome and Introductions** Brian Prowell

a. Welcome from FHWA — Stephen Cooper
b. Welcome from MNDOT — Jeff Brunner
c. Introductions by All – Name, Organization, Position

11:00 am **Examples of DPS Efforts Towards Advancement & Acceptance**

a. Minnesota DOT — Kyle Hoegh
b. Ohio DOT — Craig Landefeld
c. Alaska DOT — Rich Giessel

12:10 pm **Breakout Session #1** – Ice breaker. Define the Mission and Goals for Success. What are the benefits of DPS versus current practice? What challenges can DPS solve? What will motivate Agencies and industry to implement? – *Three groups Agency/Industry*

1:00 pm **Lunch** break

2:00 pm **Breakout Session #1 Report Outs** – QES

2:30 pm	FHWA Requirements for QA	Dennis Dvorak
3:00 pm	**Group Discussion on QA**	*Agency/Industry*
3:55 pm	**Development of AASHTO Standard** Equipment and operator certifications and standard test method including correlation with compacted samples and strategies for equipment calibration, standardization and checks.	Kyle Hoegh
4:25 pm	**Recap of Day 1**	Brian Prowell
4:30 pm	**Adjourn Day 1**	

Day 2: April 21, 2021 Using DPS for Acceptance

All times Eastern

10:30 am	**Review Day 2 Agenda**	Brian Prowell
10:35 am	**Group Discussion on AASHTO Standard**	*Agency/Industry*
11:15 am	**MNDOT Example Training Video**	
11:30 pm	**Group Discussion on Equipment Support and Training Needs**	
12:00 pm	**Breakout Session #2** – Gaps needed for implementation, research needed to fill gaps and system improvements needed for implementation – *Three groups Agency/Industry*	
1:00 pm	**Lunch**	
2:00 pm	**Breakout Session #2 Report Outs**	QES
2:25 pm	**Breakout Session #3 –** Implementation. Define Opportunities, Strategies for Deployment, Tools & Tactics. Identify Roles and Responsibilities. – *Three groups Agency/Industry*	
3:20 pm	**Breakout Session #3 Report Outs** – QES	
3:45 pm	**Marketing Plan – Brainstorming** Reflect on discussion points made throughout the workshop while considering key aspect of implementation planning to help summarize the groups thoughts for implementation moving forward, including: Communication Strategies & Tactics Key Messages Outreach Plan	Margaret Cervarich / All
4:30 pm	**Workshop Wrap-Up & Next Steps** a. Summary and concluding comments. b. Workshop follow-up actions.	Brian Prowell/Stephen Cooper
4:45 pm	**Adjourn Workshop**	