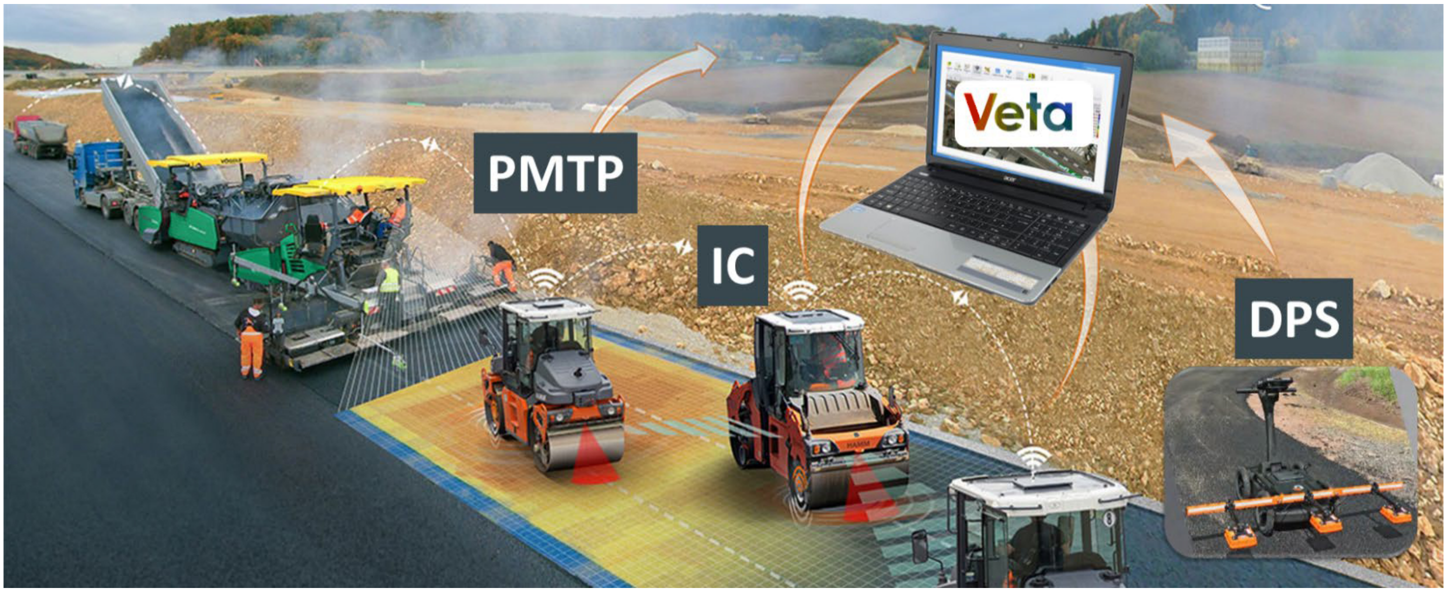
NDT AND ICT FOR ASPHALT PAVEMENT CONSTRUCTION TECH BRIEF



Source: Adapted from Wirtgen America, GSSI

Introduction of NDT ICT for Asphalt Construction

The International Society for Intelligent Construction (ISIC) describes intelligent construction technologies (ICTs) as combining modern science and innovative construction technologies. ICT applications extend throughout the infrastructure life cycle, encompassing survey, design, construction, operation, and maintenance. ICTs aim to improve pavement construction quality, reduce costs, and enhance safety.

Non-destructive testing (NDT) ICTs in asphalt construction offer significant benefits, such as providing real-time feedback on the construction operation and comprehensive full-coverage measurement of the as-built pavement properties. These technologies can improve quality assurance (QA) processes by measuring pavement quality characteristics such as density and smoothness. ICTs also reduce risks and uncertainties and facilitate the collection of digital as-built data for the creation of digital twins or other digital representations of pavements. Other emerging non-destructive evaluation (NDE) technologies for pavements include highspeed 3D ground penetration RADAR (GPR) and traffic-speed deflectometer (TSD) for measuring project-level pavement layer thicknesses and structural performance. Together, the above NDT ICTs and NDEs can provide a complete assessment of pavement quality and uniformity.

This Tech Brief focuses on Paver Mounted Thermal Profile (PMTP) systems, Intelligent Compaction (IC), Dielectric Profiling Systems (DPS), and Veta software. The intent of this tech brief is to summarize these technologies, their capabilities, shortfalls, and appropriate usage at the present time to support QA while also meeting the Title 23 Code of Federal Regulations Part 637 Subpart B (CFR) compliance requirements.

Contents

The tech brief is structured as follows:

Paver Mounted Thermal Profile Systems

Technical Summary

Figure 1. PMTP system measuring thermal profiles behind the paver.
(Source: Wirtgen America)

PMTP systems combine the measurement of continuous asphalt surface temperature profiles with their geospatial locations to determine thermal segregation. The temperature sensors used by PMTP systems can be either infrared scanning sensors or a thermal camera mounted on a paver. The temperature profiles are divided into grids of 1 foot x 1 foot size or smaller (Figure 1). Asphalt thermal segregation correlates to areas of low density, which can lead to premature failure. PMTP systems continually monitor the asphalt surface temperatures immediately behind the trailing edge of the screed plate during asphalt paving to assess temperature segregation. This allows contractors to improve paving practices and reduce segregation, thus improving the pavement quality (Tanquist et al., 2022). Some PMTP systems have near real-time remote monitoring capabilities, allowing review of PMTP data from mobile devices or remote computers.

AASHTO R 110-22 "Standard Practice for Continuous Thermal Profile of Asphalt Mixture Construction" includes two methods for thermal segregation classification: Differential Range Statistics (DRS) and Thermal Segregation Index (TSI). Both methods analyze temperature data in sublots that span 150 feet of paving. DRS is the difference between the 98.5 percentile and 1 percentile of the temperature data within a sublot. TSI is a composite index of the variability of surface temperature measurements (standard deviation) and the transverse geospatial variability of surface temperature (transverse semi-variogram index, TSVI) within a sublot. The TSVI evaluates the geospatial uniformity in the transverse direction of the mat to identify longitudinal bands of thermal segregation. Therefore, TSI indicates thermal variation and longitudinal thermal streaking (Tanquist et al., 2022). Veta software can perform DRS and TSI thermal segregation analyses. Several Departments of Transportation (DOTs) have studied the correlation between thermal segregation and density to develop the methods and thresholds in AASHTO R 110-22.

Benefits

Thermal segregation may occur at all stages of paving, including asphalt production, truck loading and unloading, and during paving. Inadequate paver setup and operational issues, such as mix build-up, worn components, incorrect settings, running the hopper low or empty (Figure 2), and others, often lead to longitudinal segregation in the form of low-temperature streaks in asphalt mats. Issues at the asphalt plant, such as saturated aggregate stockpiles, storage duration, overheated mixing drums, and others, can cause fluctuations in mat temperatures. PMTP systems' real-time temperature profile display allows the paving crew to identify these issues and take immediate corrective actions.

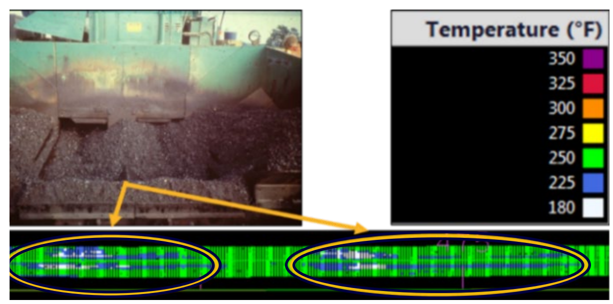


Figure 2. Effects of running the paver hopper low on the thermal profile.
(Source: MnDOT)

PMTP systems also measure paver speeds, paver stop locations, and stop durations. Changes to paver speed and paver stops can cause paver screed fluctuation and can lead to areas of localized roughness. Paver stops lead to asphalt cooling in the paver or transport equipment. Furthermore, rollers may not get close enough to the paver to compact the area directly behind the paver. The cooled asphalt can cause temperature segregation and low densities. Using PMTP data enables paving crews to identify and avoid such problems, thereby increasing the chance of receiving full payment by optimizing asphalt delivery and enhancing communication between the field and plant crews.

Several DOTs have reduced severe thermal segregation since implementing PMTP systems. For example, Missouri DOT (MoDOT) reported a 10 percent decrease in severe segregation since implementing PMTP in 2017 (Chang et al., 2023).

Challenges and Limitations

Commonly reported challenges are low PMTP data quality and data loss due to the Global Navigation Satellite System (GNSS). Paving in areas with dense tree canopies would not receive sufficient satellite signals for triangulation, resulting in low GNSS precisions or data loss. Paving in poor cellular coverage areas may impact both GNSS precision (if corrections are transmitted via cellular) and data transmission. PMTP operation issues may also cause data loss or contaminated data, such as loose or faulty cable connection, incorrect installation, inaccurate calibration, and obstructions like umbrellas, personnel, or smoothness skis between the PMTP thermal sensors and the mat.

Intelligent Compaction

Technical Summary

Intelligent Compaction (IC) is the compaction of road materials, such as soils, aggregate bases, or asphalt pavement materials, using modern vibratory rollers equipped with GNSS receivers, accelerometers, temperature sensors, and an onboard computer reporting system (Figure 3). IC rollers facilitate real-time compaction monitoring and timely adjustments to the compaction process by integrating measurement, documentation, and control systems. The onboard display helps operators track roller pass counts, asphalt surface temperatures, and levels of compaction (i.e., intelligent compaction measurement value - ICMV), increasing consistency and uniformity of compaction efforts. Data can be used to calculate coverage maps to ensure the proper number of passes were made across the mat and assess the level of compaction (Transtec Group, 2024).

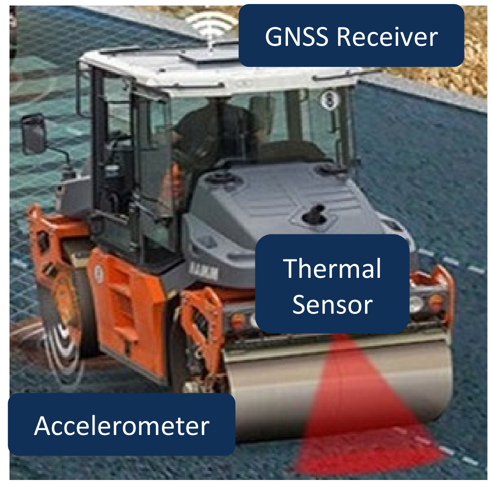


Figure 3. IC roller for asphalt compaction.
(Source: Adapted from HAMM)

AASHTO R 111-22, "Standard Practice for Intelligent Compaction for Embankment and Asphalt Pavement Applications," provides guidelines for IC system verification, measurements, and roller pass count coverage analysis. IC test data in a trial section can be used to determine the target passes required to reach the required density. IC roller coverage can be calculated as the percentage of compacted areas with a cumulative pass count greater than or equal to the target passes for the given data lot.

Benefits

IC removes the guesswork from the paving process by providing roller operators with real-time precise coverage tracking, which is particularly beneficial for night paving. Monitoring compaction roller passes and mat surface temperatures helps operators achieve uniform compaction efforts, promoting consistent densities, which increases pavement service life, reduces maintenance costs and associated traffic impacts, and increases the likelihood of a higher pay factor for the work.

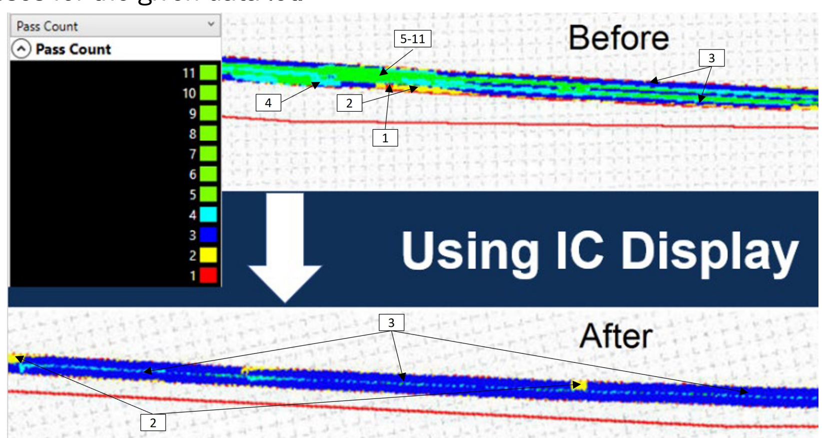


Figure 4. Example of improved roller pass consistency when using IC.
[Source: TPF-5(128) Study - Indiana Site]

IC can enhance construction consistency and efficiency. During the Transportation Pooled Fund TPF-5(128) study, a "blind test" was conducted to cover the IC display while operators were instructed to compact as usual. After the operator was trained to use the IC display to guide roller operation, the before and after roller passes showed drastic improvements in consistent roller passes (Figure 4).

Combining IC with spot tests can mitigate the risks of relying solely on limited spot testing. This combination allows for comprehensive monitoring of the rolling passes across the entire mat. By consistently tracking pass counts and temperatures, uniform density is more probable.

Challenges and Limitations

Low-quality satellite signals and/or correctional signals can cause poor IC data and even data loss, like the challenges mentioned for PMTP systems. Accurate IC data requires real-time kinematic (RTK) GNSS, which needs both good-quality satellite and correctional signals. The correction signal can be from an on-ground base station or Virtual Reference Station (VRS). The former involves a daily setup, while the latter is vulnerable to low cellular coverage areas. Other challenges include incorrect sensor installation, faulty cables and connections, or other equipment-related failures. Temperature sensors should be cleaned and calibrated routinely to avoid inaccurate readings due to dirt, fog, or electrical issues. Commercially available accelerometer-based stiffness measurements, which cannot differentiate pavement layers and have depth limitations, are typically not used for paving. They are used instead to determine relative measurements for pre-mapping subgrade or subbase materials before paving. This helps identify and repair weaker base areas and verify if the IC equipment was operated in a vibratory or static mode to validate the established target roller pattern.

Dielectric Profiling Systems

Technical Summary

DPS systems use dipole-type GPR antennas to measure the dielectric of the asphalt mixture. The technology uses a surface reflection method to measure the dielectric constants of the asphalt mixture. DPS sends a radar signal to the asphalt pavement surface; part of the signal reflects, and then the radar records the reflected signal. The dielectric constant of the pavement is calculated based on the recorded signal amplitude and measured response amplitude from a metal plate. The resulting dielectric can predict density and air void content (Hoegh et al., 2019, 2020) (Figure 5).

Figure 5. DPS equipment using pushcart.
(Source: Gilliland, 2022)

AASHTO PP 98-19 "Standard Practice for Asphalt Surface Dielectric Profiling" specifies the DPS equipment and software requirements. The DPS training tools are available on Minnesota DOT's (MnDOT's) DPS website, which is accessible at https://www.dot.state.mn.us/materials/dps/index.html.

Benefits

DPS offers a non-destructive means to evaluate asphalt density, enhancing quality assurance in pavement construction. DPS measures the asphalt mat's dielectric constant and can be used to estimate density when correlated with field asphalt cores or laboratory gyratory-compacted samples, resulting in a substantial data set compared to traditional coring methods. It can estimate the equivalent of 100,000 cores per mile of pavement surface (Hoegh et al., 2020).

Asphalt density is closely correlated to pavement longevity. An extra one percent density may result in 10 percent extra service life (FHWA, 2023). Evaluating full coverage density offers significant advantages over localized spot testing. Most DOTs check one location per sublot. For example, one core is sampled every 500 tons. The limited sampling of spot testing results in higher risks for the producer and agency, increasing the chances of missing localized problem areas that govern the life of the pavement. Full coverage density evaluation can detect variations and inconsistencies that spot tests might miss. Since the testing can occur immediately after the finish roller, the near real-time data can be used to improve paving practices and compaction efforts, which increases pavement service life, reduces maintenance costs and associated traffic impacts, and increases the likelihood of a higher pay factor for the work (Wilson et al., 2019).

DPS offers about three times better repeatability and twice the reproducibility for both the gyratory-compacted sample and roller-compacted field pavement density measurements compared to the current ASTM standard practice methods for determining pavement density (DPS Digest, 2023).

Challenges and Limitations

Variations in the aggregate source can significantly impact the density-dielectric relationship in asphalt mixtures. Mixtures with high-dielectric aggregates, such as limestone, may require more frequent validation using core or gyratory samples (Teshale et al., 2019). In thinner asphalt lifts (under 2 inches), there is a potential for underlying pavement layers to affect the measured dielectric and calculated air voids or density (Leiva et al., 2022b). Moisture on the pavement surface can increase the measured dielectric. Therefore, it is recommended that testing be conducted on dry pavement (FHWA, 2022).

Figure 6. Truck-mounted DPS equipment.
(Source: ESS, 2023)

Pushcart-mounted DPS (Figure 5) raises safety concerns that can be addressed using vehicle-mounted DPS (Figure 6) or other automation methods, such as robotic operations. However, vehicle-mounted equipment operated at higher speeds than a pushcart-mounted system may reduce data quality and the number of samples.

Researchers and industry experts are developing roller mounted DPS to display dielectric values or estimated density in real-time during compaction. Challenges include managing the effects of compaction water and roller vibrations. However, promising solutions are emerging for offering real-time DPS for QC and production control.

Veta Software and Case Studies

Introduction to Veta Software

Veta is a geospatial software tool designed to manage ICT data efficiently. Initially developed in 2012 with funding from FHWA, Veta primarily focused on displaying, editing, layering, and analyzing IC data. Over the years, it has expanded to include PMTP and DPS. Veta is compatible with data from various IC, PMTP, and DPS vendors, allowing users to import and analyze multiple data types within a single project. This integration facilitates a comprehensive investigation of construction processes, offering a one-stop solution for efficient troubleshooting and decision-making. Powerful analysis features include filtering and analyzing the data per user-defined sublots for efficient quality assessments (Figure 7). The software's development and enhancements are supported and funded by TPF-5(466) National Road Research Alliance (NRRA). Veta is free for users and can be downloaded from www.intelligentconstruction.com (Transtec Group, 2024).

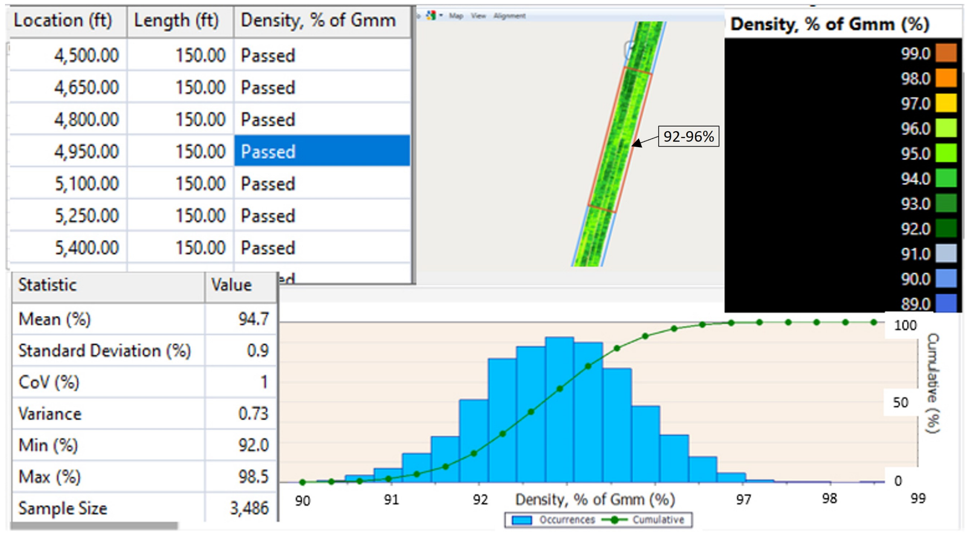


Figure 7. Statistical analysis of data by sublot using Veta.
(Source: MnDOT, 2024)

Leveraging ICT Data for QA

Importing ICT data into Veta allows users to view different data types simultaneously. Figure 8 shows the influence of roller passes on asphalt DPS density data in Veta. The IC pass count data (lower map) shows that only one pass was made on the edges of the paved lane, while eight passes or more are in the transitional areas between roller patterns. The other areas show a pass count of about three, with the overlapping of the roller drum increasing some areas to four passes. The corresponding density in Figure 8 (top map) mirrors the pass count data. On the edges where only one pass was made, the estimated density approximately ranges from 85 percent to 92 percent, with much of the edges below 90 percent. The overlapped areas of rolling patterns show densities as high as 98 percent, and the areas with three to four passes show densities averaging around 95 percent. This figure illustrates the direct impact of pass count on density, highlighting the potential for significant density variations depending on spot test locations. Compaction temperatures also play a critical role, and although they are not highlighted in this case study, they should be considered when viewing compaction efforts. ICTs can enhance construction processes and improve quality control with real-time onboard data displays that allow contractors to adjust paving operations in a timely manner to optimize construction practices and pavement quality.

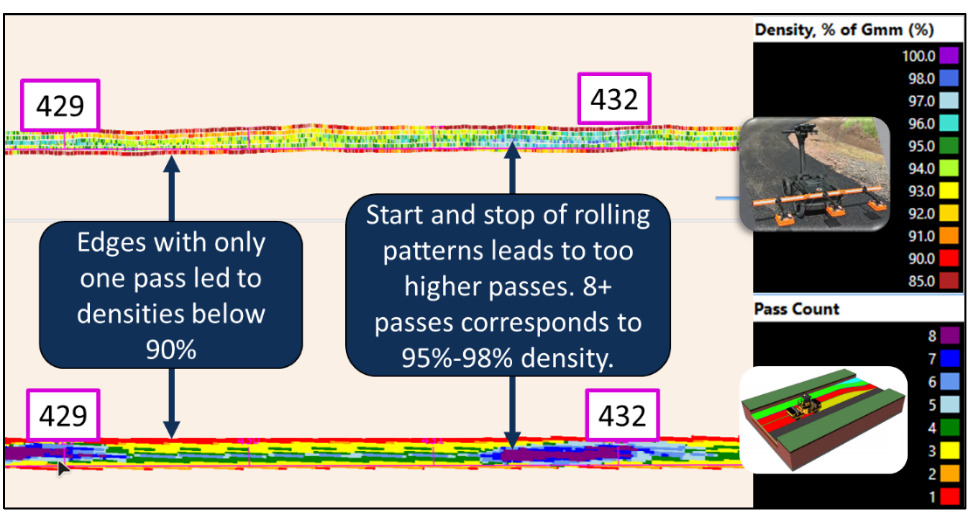


Figure 8. Comparing IC pass count data with DPS estimated density.
(Source: ISIC, 2022)

Additionally, the data collected from ICTs serve as permanent records, proving invaluable for future reviews and forensic analyses. Consequently, ICT data can be an essential component of comprehensive digital as-builts, aiding in immediate operational adjustments and long-term planning for rehabilitation and reconstruction projects. The subsequent examples demonstrate a few commonly viewed data trends from projects that use Veta to leverage ICT data.

Figure 9 shows the influence of paver stops and thermal segregation on DPS density. A paver stop is shown on the left map. The asphalt mat temperature behind the paver stop cools to 140°F to 160°F before the paver starts up again. The corresponding DPS estimated density at this location shows results as low as 89 percent. PMTP data also correlates closely to smoothness. Figure 10 shows the influence of paver stops on pavement smoothness. The top map shows paver stops and durations in Veta. The lower map shows areas of localized roughness from ProVAL (a program for pavement profile viewing and analysis). At each paver stop, localized roughness occurs.

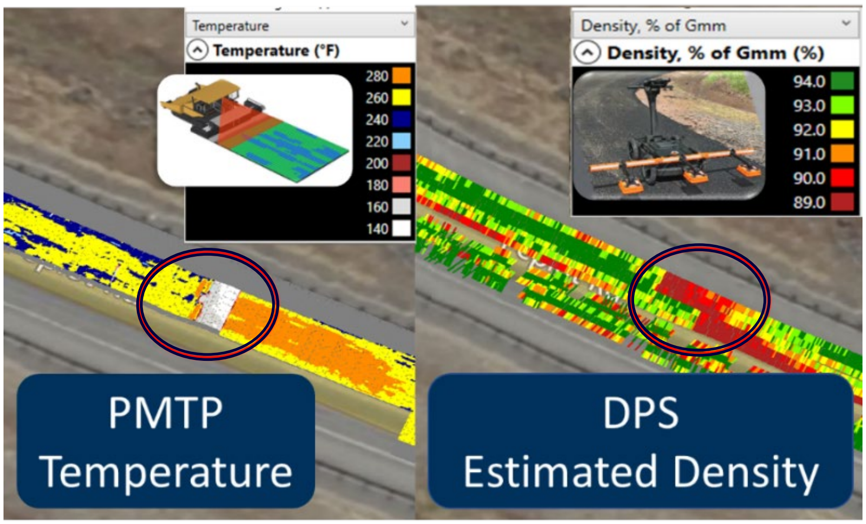


Figure 9. Comparing a paver stop with DPS estimated density.
(Source: ISIC, 2022)

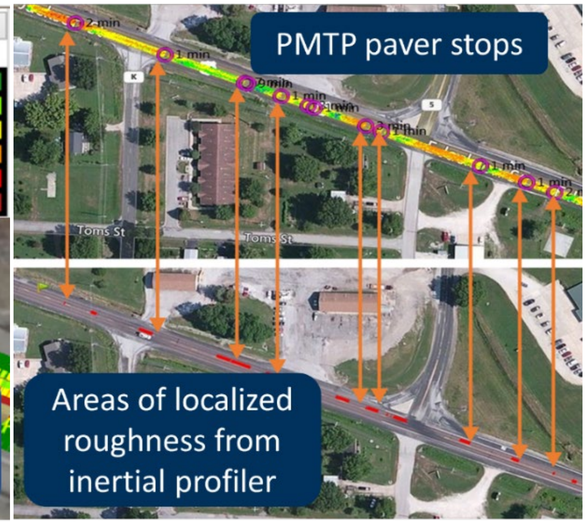


Figure 10. Comparing PMTP paver stops with areas of localized roughness.
(Source: The Transtec Group, 2017)

Veta has several advanced analysis tools to aid users with troubleshooting. For example, the "search tool" can produce heat loss curves at selected locations by combining the PMTP and IC data (Figure 11). At time 0, the PMTP temperature is shown at the selected location. All subsequent temperatures are from the combined IC rollers, plotted with the elapsed time between passes. The heat loss curves can be compared with estimated "allowable" compaction times from other tools, such as MnDOT's PaveCool.

Combining IC, PMTP, and DPS data can leverage the values of all ICTs to guide contractors and agencies in enhancing paving consistency and addressing areas of low quality through improved paving operations.

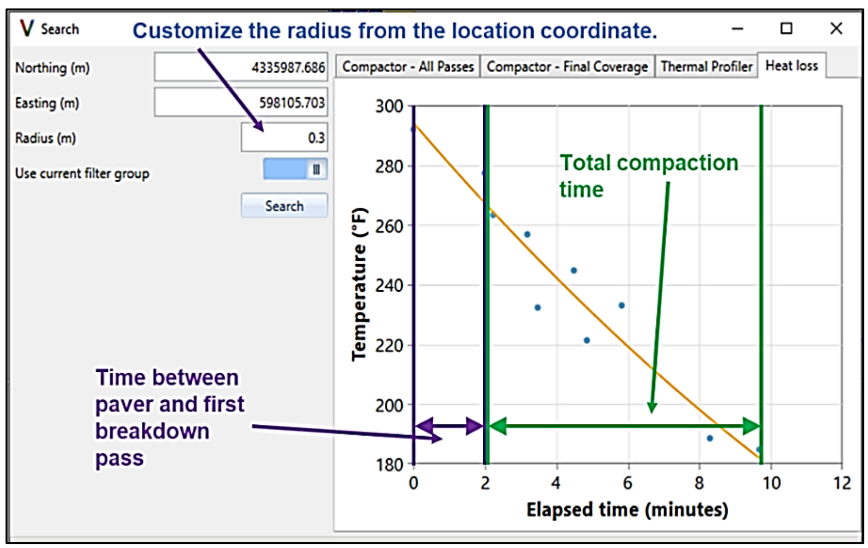


Figure 11. The search tool heat loss curves in Veta.
(Source: The Transtec Group, 2022)

Agency Use of Veta

Veta is specified in AASHTO R 110-22 and R 111-22 as the standard software for ICT data analysis. Several DOTs use Veta to filter, analyze, and report ICT results. MnDOT is one such leading state that fully implemented IC and PMTP in 2018 on contracts where the net paving length is greater than or equal to two miles (MnDOT, 2022). MnDOT hosts resources and training materials, including video tutorials, on their Advanced Materials and Technology Resources website (MnDOT, 2024). Minnesota contractors are required to create Veta projects using IC and PMTP data to be submitted to MnDOT along with project summary sheets that track IC pass count coverage and thermal segregation classifications by ICT data lots that are defined by the construction date, material type, lift, centerline offsets of paved lanes, and directions of travel, specified in AASHTO PP 114-22.

Quality Assurance Using NDT ICTs

The CFR includes the following key elements for a QA program (Figure 12): QC, agency acceptance, qualification of personnel and laboratories, independent assurance, and dispute resolution (FHWA, 1995). A few considerations for using NDT ICTs in DOT QA programs are included here. Note that the below considerations are not all-encompassing.

Figure 12. QA core elements.
(Source: FHWA, 2023)

Using NDT ICTs as QC Tools

Defined in CFR, QC encompasses contractor or vendor operational techniques and activities to fulfill contract requirements. This includes all activities specified by the agency or owner in the QA program, enabling the contractor to monitor, assess, and adjust its production or placement processes. QC includes implementing corrective actions or adjustments to maintain continuous control over production or placement processes. All ICTs can be used as contractor QC tools and may be required by a DOT as part of a quality control program.

Using IC and PMTP as Acceptance Tools

The CFR permits the use of results from contractor testing for agency acceptance, provided that the DOTs QA program meets specific requirements. One of those requirements is that the DOT must use an appropriate process to verify the contractor's results. The data collection methods used in ICT differ from the conventional sampling of material (e.g., coring) because the IC and PMTP instrumentation is part of the contractor's equipment. Therefore, the agency's conventional validation and verification methods, which perform the same sampling and testing methods as QC for data comparison, cannot be applied to this ICT data. Thus, new data verification procedures must be developed to meet the CFR requirements for ICT data if an agency chooses to use IC or PMTP data as part of acceptance. DOTs that do not have similar QA programs for ICT data can use ICT systems as QC tools (Von Quintus et al., 2023).

Some DOTs, like MnDOT and MoDOT, are developing procedures to verify contractor PMTP and IC data so that these technologies can be used for acceptance. For example, MoDOT staff use 19,200-pixel NIST-certified infrared cameras to capture pavement images twice per paving shift. These dense data sets are then compared with contractor PMTP data, which is cropped to match the footprint of the images. MoDOT also verifies contractor IC pass count coverage using agency-owned, magnetic-mounted, solar-powered, centimeter-accuracy GNSS tracking devices. The data from these devices is output using the same dimensions and offsets as the contractor data, with similar data sample sizes, allowing the pass count information to be directly compared and verified. MoDOT's IC pass-count verification devices use post-processed RTK corrections, minimizing data loss challenges with cellular or GPS coverage (Chang et al., 2022).

Using DPS as an Acceptance Tool

DPS equipment usage differs from IC and PMTP systems since the equipment may be owned and operated by either the contractor or the DOT. Specific requirements in the CFR are predicated upon who owns and operates the equipment. The DOT should test the lab-compacted specimens or cores used for density correlation. If any contractor results are used for correlation, periodic and regular verification checks must be performed. The laboratory, personnel, and equipment should be qualified and/or certified. The QA program should also include dispute resolution, such as using referee testing as the basis for resolution (Von Quintus et al., 2023).

Conclusions

ICTs, such as IC, PMTP systems, and DPS, can significantly improve asphalt pavement construction quality, efficiency, and safety with real-time or near real-time feedback and full-coverage measurement capabilities, contributing to better and more complete QA. Despite some challenges, the positive impact of ICTs is substantial, establishing new industry standards and guiding future technological advancements. Veta is a technical solution for managing various ICT data required in relative ICT AASHTO standards. It simplifies ICT data management and reports by using one standardized software platform. Veta facilitates the correlation of ICT data for troubleshooting and data analysis. Additionally, Veta supports future project digital delivery by providing digital as-built data.

Compliance with the CFR requirements is required for DOTs implementing NDT ICTs in QA programs. As decision-making tools, IC, PMTP systems, or DPS must comply with these regulations. Whether the equipment and data are contractor or agency-owned influences how these technologies are utilized in compliance with CFR standards. MnDOT and MoDOT are working on PMTP and IC data QA for future acceptance applications.

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