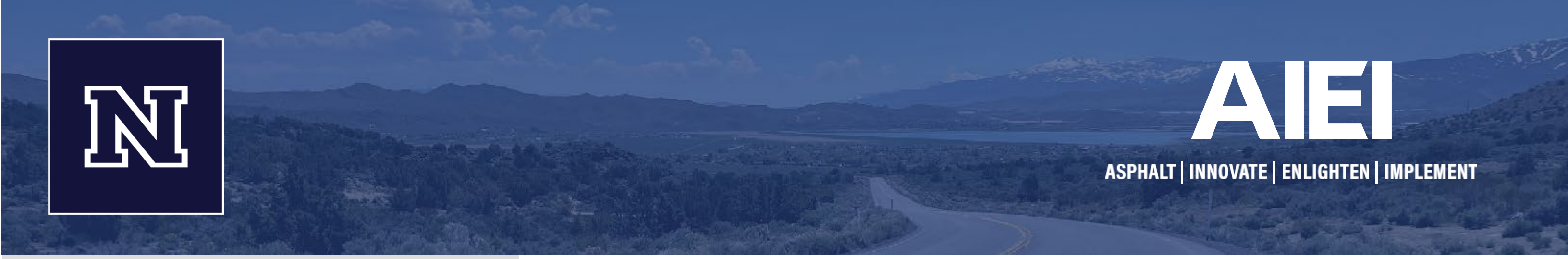


TECH BRIEF

UNR–TB–25–1105

AUTHORS

Nam H. Tran (ORCID: 0000-0001-8183-4741), Biswajit Bairgi (ORCID 0009-0000-6593-0549), and Donald Watson (ORCID: 0000-0002-0785-782X), National Center for Asphalt Technology, Auburn University

Danny Gierhart, Greg Harder, Mark Blow, Dave Johnson, Jhony Habbouche, Jason Wielinski, and Grover Allen, Asphalt Institute

Timothy B. Aschenbrener (ORCID: 0000-0001-7253-5504), Office of Infrastructure, Federal Highway Administration

DISCLAIMER

This document is disseminated under the sponsorship of the U.S. Department of Transportation (USDOT) in the interest of information exchange under the cooperative agreement No. 693JJ32350026. The U.S. Government assumes no liability for the use of the information contained in this document.

The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers’ names appear in this technical brief only because they are considered essential to the objective of the document. They are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

All AASHTO and ASTM standards mentioned in this document are non-governmental, voluntary standards and are not required under Federal law.

NOVEMBER 2025

A Review of Specifications and Measurement Methods for Asphalt Pavement Density

Achieving proper in-place density is essential for long-term performance and durability of asphalt pavements. This document summarizes current practices and emerging technologies for measuring in-place density. It begins with a review of the State Department of Transportation (DOT) specifications for density acceptance, including baseline references, measurement methods, quality metrics, and incentive structures. Although core testing remains the primary method for acceptance due to its accuracy, its drawbacks—being destructive, time-consuming, and limited coverage—have prompted increased interest in non-destructive testing (NDT) alternatives. The review covers several NDT methods, including nuclear and non-nuclear density gauges, dielectric profiling systems (DPSs), and intelligent compaction (IC) technologies. Each method is examined based on its operating principles, applications, limitations, and key factors affecting its results. A comparative analysis shows trade-offs in accuracy, data coverage, and operational complexity. The document also discusses future trends, such as the integration of multi-NDT platforms that enable real-time and continuous density monitoring. Overall, this review highlights the increasing trend toward the use of intelligent, data-driven tools for compaction assessment. However, to facilitate the adoption of advanced NDT systems, it is essential to develop and implement a quality assurance program (QAP) that effectively utilizes the collected data to improve pavement performance.

Introduction

Proper in-place density measurement is crucial during quality control (QC) and acceptance of pavement construction to ensure the desired performance and longevity of asphalt pavements. Inaccurate measurements can result in insufficient density, leading to early pavement distress, compromising the pavement's functional and structural integrity, and reducing its service life. Furthermore, inaccurate measurements can lead to incorrect and/or inappropriate pay adjustments.

Testing field cores has long been the standard method for assessing pavement density and acceptance. As a result, core density is typically the quality standard to which other density procedures are correlated. Cores are also useful for a variety of reasons:

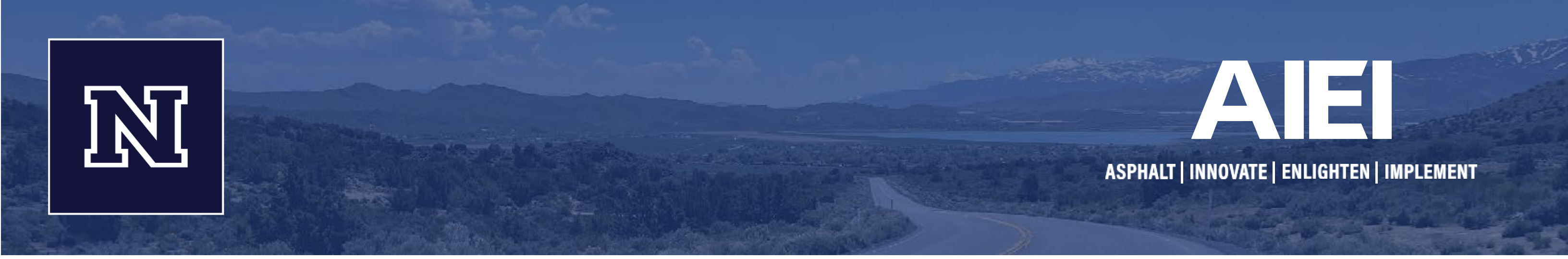
- Provides an opportunity to measure layer thickness since thickness, or spread rate, is a pay factor property for some agencies
- Allows retesting of the same specimen in case calculations need to be verified
- Provides a visual confirmation that random sampling procedures were used
- Enables technicians to observe potential deficiencies such as segregation and stripping in the underlying layers

While generally accurate, the coring technique has notable drawbacks: it is destructive, covers only limited areas, and the results are not immediately available.(1)

To overcome these challenges, NDT methods have been explored in search of viable alternatives to the traditional core testing method. Techniques, such as nuclear and non-nuclear density gauges, DPS, and IC, offer quicker assessments and enable greater coverage without causing damage to the pavement. However, the application of these technologies may be limited within quality assurance programs due to concerns about accuracy and a limited understanding of their operational principles. It is essential that the equipment used in these methods be properly calibrated and a correlation to core results be established. Calibration refers to a procedure established by the manufacturer of the device to ensure the equipment is operating and functioning correctly. Correlation is the process of establishing a relationship between the device results and those of a measured property, such as core density results. For example, the test results of nuclear and non-nuclear gauges may be affected by the type and thickness of underlying layers, which could change the correlation even within the same project. This document aims to enhance the understanding of in-place density assessment for asphalt pavements by reviewing the specifications set by State DOTs and the measurement methods currently in use and under evaluation. The review of DOT specifications addresses several key aspects, including the baseline for calculating relative density, the methods used to measure in-place density, quality measures for density, lower specification limits, and maximum incentives related to in-place density. Additionally, the review of measurement methods covers both conventional and NDT techniques. This includes core sampling and testing, nuclear density gauges (NDG), non-nuclear density gauges (NNDG), DPS, and IC. The document examines the working principles, applications, limitations, and factors that affect the accuracy of each measurement method. Furthermore, the document discusses future trends and innovations in the application of NDT methods.

Density Specifications

The in-place density of asphalt pavement is critical for ensuring structural integrity and long-term performance. Achieving higher density through adequate compaction enhances aggregate interlock, improves resistance to rutting and cracking, and extends fatigue life.(2) Additionally, increased density reduces permeability, preventing the infiltration of moisture and air. Air infiltration accelerates asphalt binder oxidation, while moisture infiltration compromises structural integrity and can lead to binder stripping. Oxidation and stripping can result in premature cracking and raveling of the pavement mixture. Studies have shown that reducing in-place air voids by just 1 percent can improve



fatigue performance by 8.2 to 43.8 percent and increase rutting resistance by 7.3 to 66.3 percent, potentially extending pavement life by approximately 10 percent.(3)

Due to the importance of in-place density, State DOTs have established specifications to ensure that asphalt pavements are compacted to the required density levels for optimal performance. Thus, the density specifications from all 50 states and the District of Columbia were reviewed in 2025 and documented in this tech brief. The review focused on five key aspects: (a) the baseline for calculating relative density, (b) methods for measuring in-place density, (c) quality measures used for density acceptance, (d) lower specification limits for density, and (e) maximum incentives for in-place density.

Baseline for Calculating Relative Density

The review found that 50 of 51 DOTs utilize the theoretical maximum specific gravity (G_{mm}) of plant mix during production or the lab mix from the mix design as the baseline for calculating relative density (Table 1). The relative density is expressed as the percentage of the bulk specific gravity of the compacted specimen (G_{mb}) to G_{mm}. The location from which samples are taken to determine G_{mm} values varies widely. Some states utilize the G_{mm} value obtained from lab mix during mix design, while others determine G_{mm} of plant mix collected from the haul truck at the plant, from the roadway behind the paver, or from a windrow in front of the paver. Additionally, field sampling and reheating protocols can differ. The value used for calculations can range from a single sublot value to a lot average. One agency uses G_{mb} of plant-mixed, laboratory-compacted specimens as a baseline value in place of G_{mm}.

Table 1. Baseline for Density Acceptance

Aspect	Description
Standard practice for relative density calculation	50 of 51 DOTs use G_{mm} as the baseline.
Location from which samples are taken to determine G_{mm}	Lab mix during mix design; or plant mix sampled from haul truck, roadway behind paver, or windrow in front of paver.
Difference in G_{mm} utilization for computations	Ranges from single sublot to lot average values.
Sampling and aging protocols	Vary across DOTs in terms of procedure and implementation.
Alternative approaches to baseline density calculation	One agency uses G_{mb} of plant-mixed, laboratory-compacted specimens as the baseline value in lieu of G_{mm}.

Methods Used to Measure In-Place Density for Acceptance

Figure 1 indicates that 36 DOTs use density measurements from field cores to compare with baseline measurements for acceptance. Seven DOTs use nuclear or non-nuclear density gauges, and another eight DOTs allow the use of either method.

Quality Measures Used to Accept In-Place Density

To measure the quality of in-place density, state DOTs selected quality measures (i.e., statistical measures) that can quantify the average and/or the variability of in-place density. Typical quality measures used to assess in-place density include percent within limits (PWL), percent defective (PD), lot average (including moving averages), and average absolute deviation (AAD). PWL and PD are complementary measures (i.e., PWL = 100% - PD). Figure 2 and Table 2 summarize each method and its usage among DOTs.

Specification Limits for Density

DOTs are cautioned to use their own data set when considering quality measures and specifications for acceptance. Simply copying another state's specifications may not be successful because data sets from different states can result in different specification limits, especially if the quality measures differ. For example, among DOTs that use the PWL quality measure, one specifies a minimum acceptance level of 90.0, while others have a minimum acceptance level as high as 93.0. Figure 3 and Figure 4 present the distribution of lower specification limits for DOTs that adopt the PWL and lot average quality measures, respectively. Both figures indicate that a lower specification limit for density of 92.0 is the most widely adopted by DOTs. The most widely adopted lower specification limit for the DOTs that use the lot average quality measure is also 92.0. However, a lower acceptance limit of 92.0 is more stringent when using PWL than the lot average. It is important to note that several DOTs also have upper limits for density to ensure the pavement has a sufficient volume of air voids to allow for thermal expansion and contraction due to seasonal temperature changes. A maximum density of 97 to 98 percent of G_{mm} is commonly used.

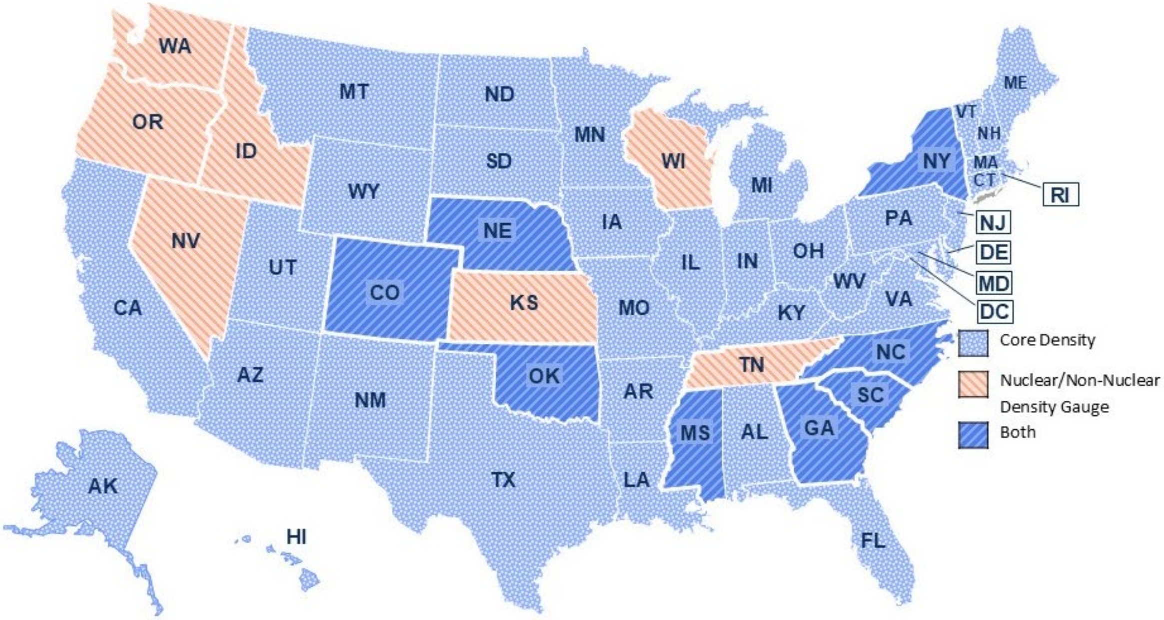


Figure 1. Methods Used to Measure In-Place Density for Acceptance.

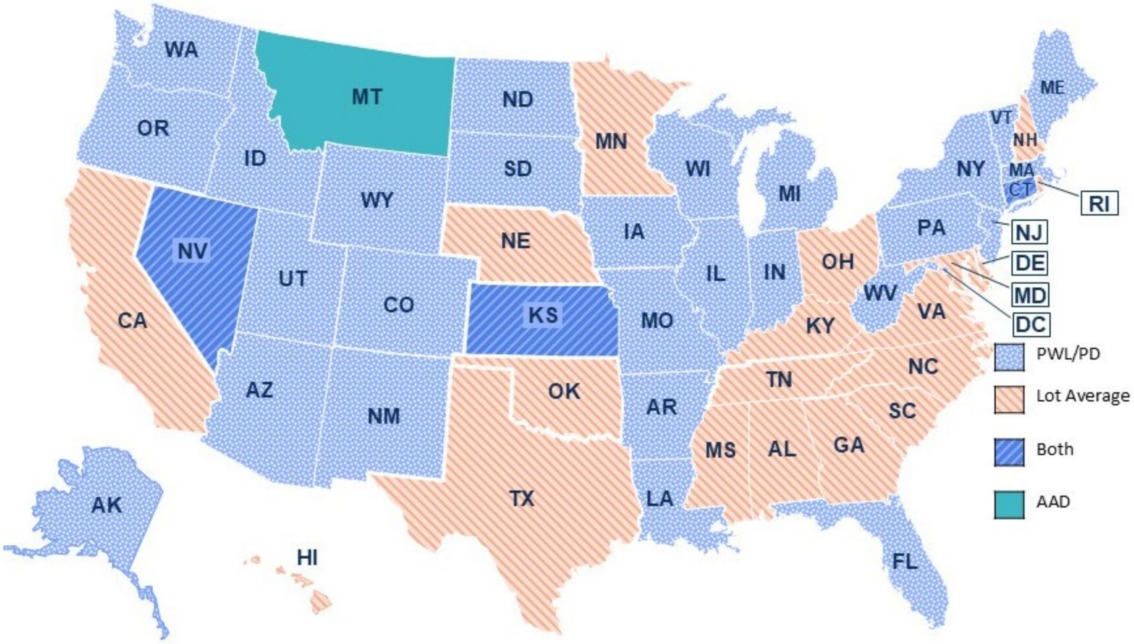


Figure 2. Quality Measures Used to Quantify the Level of Quality of In-Place Density.

Table 2. Summary of In-Place Density Quality Measures Used by DOTs

Quality Measure	Description	No. of DOTs	Notes
PWL or PD	The percentage of the lot or pavement section that falls within (for PWL) or outside (for PD) the specification limits. PWL = 100 – PD.	27	PWL uses standard deviation to address testing variability.
Lot Average	Calculates the mean density for a given lot or pavement section.	20	Lot average does not account for testing variability.
Both PWL and Lot Average	PWL may be used on some projects depending on class and size while lot average may be used on other projects.	3	3 DOTs (Connecticut, Kansas, and Nevada) typically use PWL but allow the use of lot average for low tonnage projects (such as <2500 tons).
AAD	Measures the mean of absolute deviations of individual density values from the mean (of a lot or pavement sections) or a target value (i.e., control strip density).	1	Least commonly used method. Reflects variability in the form of deviation from a target value but does not fully capture variability within a sample set.

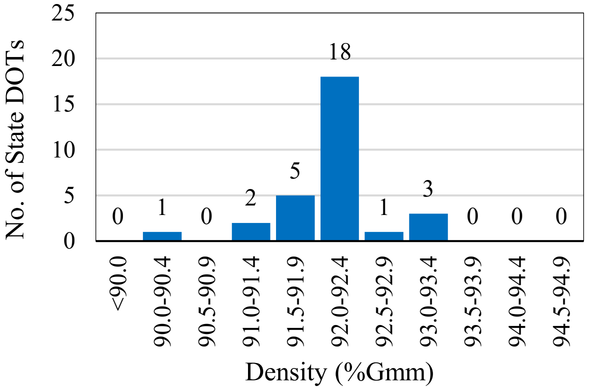


Figure 3. Lower Specification Limit in PWL Specifications.

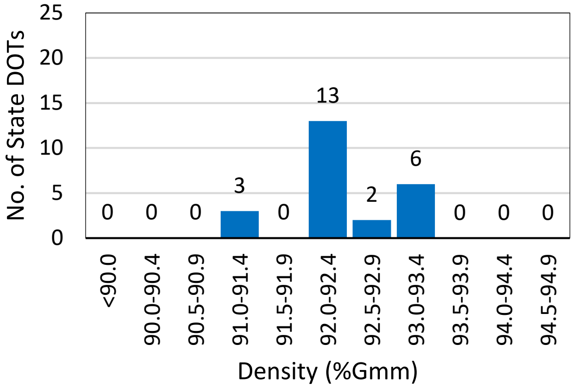


Figure 4. Lower Specification Limit in Lot Average and AAD Specifications.

**Numbers added up to 54 because three states use two quality measures.*

Maximum Incentives for In-place Density

Several DOTs provide pay adjustment schedules to encourage contractors to achieve higher densities. The review found that 39 DOTs offer density incentives, while 12 DOTs do not. Figure 5 shows the maximum incentives for density offered by different DOTs for their high-traffic roadways, with incentives being as high as 10 percent of the unit bid price for the asphalt mixture. Nine of the 12 states that do not provide density incentives adopt the lot average as a quality measure.

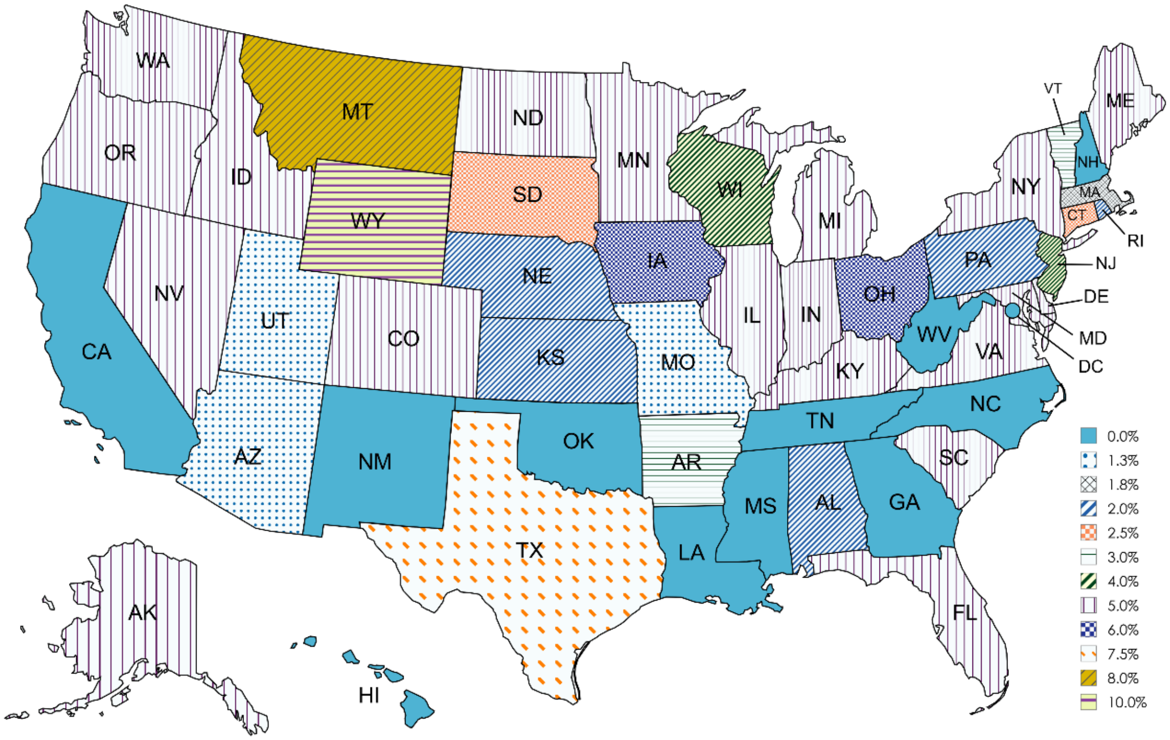


Figure 5. Maximum Incentives (%) for In-Place Density.

Density Measurement Methods

Proper and reliable measurement of in-place density is essential for ensuring the long-term performance of asphalt pavements. This section reviews both conventional core testing and NDT methods. The review focuses on the principles, applications, and limitations of each technique, as well as the recommended practices for obtaining reliable measurements.

Table 3 provides a comparative summary of the methods for measuring in-place density. Core testing is considered the standard method because it allows for direct measurement of density. However, it is a destructive method, and its coverage is limited. NDGs are accurate, quick, and efficient, but require strict regulatory requirements and project-specific correlation. NNDGs are also quick and have no regulatory burdens, but their accuracy and precision are still not comparable to those of core testing and NDG methods.(5) DPS and IC rollers represent significant advancements in NDT technologies. Unlike NDG and NNDG, these tools allow continuous real-time data collection over the entire mat area. Higher equipment costs can be a barrier, particularly for IC. Additionally, extensive training for the operator and data analysis expertise is critical for the successful operation of DPS and IC methods.

Core Testing

Testing field cores, as outlined in AASHTO T 166, is the most widely used method for measuring in-place density. The core testing method directly measures in-place density after compaction is completed and has been used to correlate other non-destructive test measurements with density. This process involves extracting cores from the pavement, sawing if necessary to an appropriate depth, drying the cores, and testing them in a laboratory to determine their bulk specific gravity (G_{mb}). The G_{mb} is then compared to the theoretical maximum specific gravity (G_{mm}) to determine relative density. The percent air voids in a specimen equals 100 minus the percent relative density. Both 6-inch and 4-inch diameter cores have been utilized.

Cores have other practical advantages, such as providing an opportunity to measure layer thickness. This is important since some agencies have pay factors based on conformity to specified layer thickness or spread rate. Cores also allow retesting of the same specimen if calculations need to be verified and provide a visual confirmation that random sampling procedures were used. The review of specifications, as presented in Figure 1, shows that 37 out of 51 DOTs use cores for acceptance and eight others use a combination of either cores or NDG. However, this method is destructive and requires repairs to the cored location afterward. Additionally, cores may be damaged if taken before the compacted asphalt mixture has sufficiently cooled, or when trying to pry cores loose from the underlying layers.(1)

Table 3. Summary of Density Measurement Methods

Method	Core Testing	Nuclear Density Gauge (NDG)	Non-Nuclear Density Gauge (NNDG)	Dielectric Profiling System (DPS)	Intelligent Compaction (IC)
Description	Provides density via G_{mb} method.	Provides a relative density through a correlation using reflected gamma radiation to core density.	Provides an estimate of density by using electromagnetic wave and reflection methods correlated to core density.	Provides an estimate of density by using electromagnetic wave and reflection methods correlated to core density.	Provides a relative density through a correlation using intelligent compaction measurement values (ICMVs) to core density.
Applicability	Primary acceptance method for most DOTs.	Primarily used in QC to optimize roller patterns and monitor pavement density. Results are used for acceptance by some DOTs.	Primarily used in QC to optimize roller patterns and monitor pavement density.	Primarily used in QC to optimize roller patterns and monitor pavement density.	Primarily used in QC to optimize roller patterns and monitor pavement density.
Coverage Area	Limited spot areas typically selected on a random basis.	Limited spot areas typically selected on a random basis.	Limited spot areas typically selected on a random basis.	Varies from a continuous line to full-lane width.	Displays immediate results for the roller width and a visual display of the full lane width.
Uniqueness	Typically used as the standard for correlation of other methods. May be used in forensic investigations to evaluate binder and gradation compliance of paving mixtures to the JMF.	Typically requires radiation safety training of the operator and periodic monitoring of radiation detection badges worn by personnel.	Provides a dielectric-based density estimation.	Provides a dielectric-based density estimation. May be used by mounting on a mobile cart, or vehicle.	Provides instant results for roller operators to determine if additional rolling of an area is needed. Identifies areas that may have been missed with the roller during transitions when changing directions.
Challenges	A destructive method that requires repair to the cored surface. Potential for damage when removing cores from the hole.	Requires licensing by the U.S. Nuclear Regulatory Commission (NRC). Requires frequent correlation to cores, and daily standardization and periodic calibration by the manufacturer using standard blocks.	Requires correlation to cores. Sensitive to mix type and composition, gauge orientation, layer thickness.	Requires correlation to cores or gyratory compacted samples. Multiple calibration procedures for the equipment. Requires specialized knowledge. Limited equipment available for full lane width density monitoring. Sensitive to layer thickness, mix type and composition.	Requires correlation to cores. Sensitive to mix temperature, layer thickness, and stiffness of mixture. Higher equipment cost. Requires specialized knowledge and training for the operator.

Nuclear Density Gauges

Nuclear density gauges (NDGs) are widely used for measuring in-place density. To conduct the measurement, the gauge is placed on the pavement surface, as shown in Figure 6. Readings are taken at random locations to ensure a representative sampling of the pavement materials. As illustrated in Figure 7, the gauge contains a small radioactive source, typically Cesium-137, which emits gamma rays into the pavement material. These rays can either be scattered or absorbed by the pavement material. A detector within the gauge measures the amount of returning gamma radiation, which is then processed to calculate the relative density of pavement materials. The higher the radiation detected, the lower the density of the pavement material.

Figure 6. Nuclear Density Gauge (Photo Credit: Biswajit K. Bairgi).

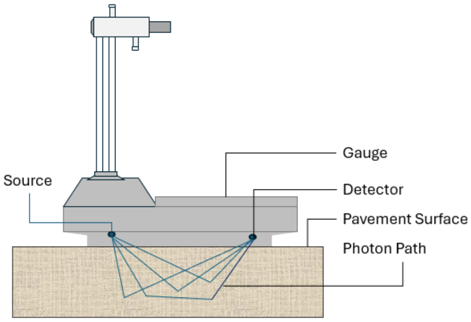


Figure 7. Nuclear Density Gauge Working Principle (Reproduced from reference 2).

NDG methods provide immediate density readings that are correlated to core testing results. Their operation is straightforward and efficient, allowing multiple readings to be taken at random locations to ensure representative data. This allows for timely adjustments to the rolling pattern, improving compaction uniformity. Hence, NDGs have become essential tools for both contractors (QC) and agencies and are considered non-destructive alternatives to core testing methods. Some DOTs incorporate NDG data into acceptance decisions.

AASHTO T 355 outlines the requirements for calibration, measurement, reporting, and correlation with cores of NDG testing. Since NDGs use radioactive materials, licensing and regulation by the Nuclear Regulatory Commission is required. The NDG must be calibrated by the manufacturer when new and every six to twelve months afterward, depending on the particular licensing requirements. A daily standard count must be taken on a density block specific to each gauge. The daily standard count is compared to previous standard counts and must be within a specified tolerance to ensure the gauge functions correctly.

Operators must complete radiation safety training and must adhere to specified safety protocols. NDGs typically operate in backscatter mode, which lowers the radioactive source rod to a position near the pavement surface and makes NDG measurements sensitive to moisture content, surface texture, mixture composition, and pavement thickness. Variability also exists for different gauges, measurement modes, recording time intervals, and project locations. Thus, project-specific and gauge-specific correction factors should be developed through proper correlation to cores to improve reliability. Recently, low-activity nuclear density gauges (LNDGs) have been evaluated as a potential alternative. These devices yield results comparable to NDGs but are not subject to regulatory restrictions, making them an attractive option for field use.(4)

Non-Nuclear Density Gauges

Non-nuclear density gauges (NNDGs) work by emitting low-energy electromagnetic waves from a transmitter into the asphalt pavement, as shown in Figure 8. As the electromagnetic waves interact with asphalt pavement constituent materials, a portion of the waves is reflected and detected by a receiver in the gauge. The reflection data is then processed to measure impedance, calculate the dielectric constant, and estimate pavement density using calibrated algorithms. The process is sensitive to the composition of asphalt pavement, particularly air void content, making correlation to core density critical for accuracy. Two types of NNDGs are currently available, including the Pavement Quality Indicator (PQI) and the PaveTracker, as shown in Figure 9 and Figure 10, respectively.

NNDG testing follows AASHTO T 343, which outlines specifications for equipment, operational procedures, and correlation to core density. NNDGs provide quick and straightforward measurements of pavement density without the radiation safety concerns and regulatory requirements of NDG. However, NNDG readings tend to underestimate core density.(5) This discrepancy is particularly pronounced in mixtures with different gradation types, where NNDGs exhibit reduced sensitivity to density variation.(5) As a result, NNDGs are generally not used for density acceptance. Instead, they are most effective for identifying rolling patterns and QC.(6)

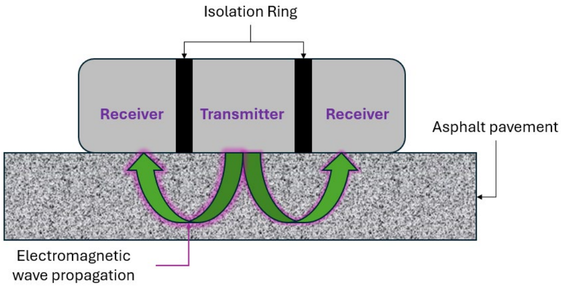


Figure 8. Working Mechanism (Reproduced from reference 1).

Figure 9. PQI (Photo Credit: Jason Nelson)

Figure 10. PaveTracker (Photo Credit: Jason Nelson).

It is essential to perform routine correlation using materials with known densities to ensure reliable results. Project- and mixture-specific correlations are highly recommended. Additionally, gauge orientation must be taken into consideration. Density readings can be higher when the gauge is placed parallel to the paving direction compared to when the gauge is positioned transversely.(6)

Dielectric Profiling System

The dielectric profiling system (DPS) is a non-destructive technology that uses ground penetrating radar (GPR) for continuous measurements of pavement density. The system operates by emitting electromagnetic waves into the pavement using GPR sensors. When these waves encounter changes in material or the surrounding environment, part of the signal is reflected to the receiving antenna

(Figure 11). For example, the received signal may encompass scattering from aggregates underneath the layer surface and from surface reflection. (7) The reflected signals are analyzed to calculate the dielectric constant, similar to that used in the NNDT gauges. The dielectric constant is then correlated to the density of the asphalt mixture.(8) The dielectric constant is inversely proportional to the air void content in the asphalt surface layer, indicating that a higher dielectric value corresponds to a lower air void or higher density, and vice versa. This correlation can be established by testing laboratory specimens or field cores for a particular mixture or project.(9)

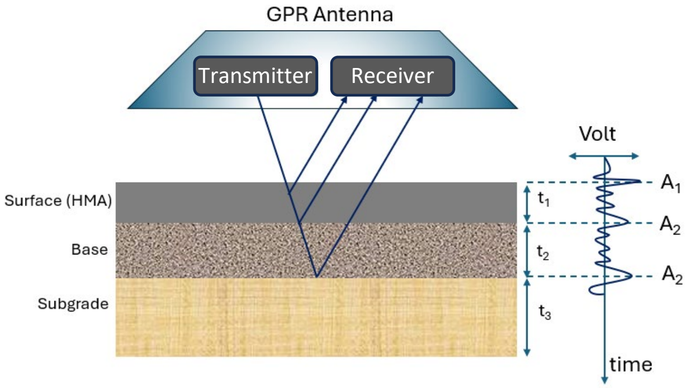


Figure 11. Ground Penetrating Radar Working Principle (Reproduced from reference 7).

DPS testing adheres to the specifications outlined in AASHTO T 414 and PP 98, which include requirements for equipment and software, equipment calibration, and procedures for density measurement. Both test procedures use a correlation from dielectric to air voids. PP 98 also describes extensive procedures for equipment calibration using multiple methods. For example, the system requires air calibration to remove associated noise from the antenna from that of the recorded signal, metal plate calibration to measure antenna amplitude, evaluation of metal antenna variation to determine variability from the metal plate calibration, and calibration of the distance measuring instrument (DMI). The DPS collects continuous dielectric measurements as it moves over the pavement surface. This is typically done using a wheel-cart-mounted system with three GPR sensors (Figure 12). Each pass over the surface generates continuous dielectric profiles with a high sampling rate, roughly ten readings for every foot traveled. This method provides a much higher sampling density than traditional techniques, yielding up to 100,000 measurements per mile.(9)

Figure 12. Dielectric Profiling System (Photo Credit: Fabricio Leiva).

DPS can be utilized for both QC and, with the appropriate QAP, acceptance during construction. It gives contractors rapid feedback to adjust rolling patterns and verify uniform density. The continuous data it collects allows detailed evaluation of compaction uniformity and highlights localized deficiencies, such as cold spots and longitudinal joints. For DOTs, DPS enables nearly full-coverage density assessment, reducing reliance on random cores for acceptance and payment. Agencies can develop a project-specific density–dielectric correlation (using cores or plant-mixed pucks) and validate it periodically. When paired with tools like Veta, DPS data can be mapped to quickly spot problem areas, improve documentation, and support dispute resolution.(10)

Despite its benefits, DPS has limitations.(9) It provides indirect measurements, and its accuracy depends on proper equipment and correlation to the air voids of the asphalt mixture. The dielectric–void relationship is sensitive to mixture components (e.g., aggregate type and binder content) and environmental factors (e.g., moisture). Accurate readings depend on the isolated surface reflection at the top layer; if a thin layer is tested, reflections from underlying layers can interfere. Vibrations, especially when using vehicle- or roller-mounted systems at high speeds, can introduce signal noise, although walking-speed surveys and moving average filters help reduce this effect.(1)

Analyzing and interpreting DPS data requires specialized knowledge, as GPR signals and density correlation models can be complex and project-dependent.(1) Software tools are available to aid the correlation process, but customization may be required depending on the project and mixture types. With these considerations in mind, DPS can significantly enhance pavement density assessment and reduce reliance on traditional coring methods.

Intelligent Compaction

Intelligent Compaction (IC) technologies enhance asphalt pavement compaction by equipping rollers with measurement systems that provide real-time feedback and record the entire compaction process. The ability of IC to track each roller pass (start and end points) and map the entire mat area offers consistent and uniform coverage. It is especially helpful for nighttime paving to ensure no gaps in coverage. While IC primarily measures stiffness-related parameters, various methods have been developed to determine in-place density using these data.(11) IC rollers, as shown in Figure 13 and Figure 14, utilize accelerometers to capture drum vibrations reflecting material stiffness, global navigation satellite systems (GNSS) to track roller movement and pass counts, infrared sensors to monitor surface temperature, and onboard systems to visualize compaction progress through Intelligent Compaction Measurement Values (ICMVs).(12) Some systems have been developed, however, that are marketed as IC technology when they are based only on a pass-count relationship and do not have drum resistance or stiffness monitoring components.

The use of IC to assess asphalt pavement density is based on the principle that higher density generally results in greater stiffness, which can be measured through the roller's vibration response.(12) IC systems capture and quantify this response using various ICMVs. Common values like Compaction Meter Value (CMV) and Resonant Meter Value (RMV) reflect stiffness but can be influenced by the underlying support, mix temperature, and roller settings which results in a weak correlation with core densities.(14) For example, CMV may show little correlation with asphalt properties on untreated bases but becomes sensitive to asphalt modulus on cement-stabilized layers.(11) Another approach, Volvo's "Density Direct," uses an artificial neural network to estimate real-time density. This system analyzes vibration frequency components and their power intensities, which are then matched to known density profiles considering mix type, temperature, and roller characteristics.

Figure 13. Intelligent Compaction Roller
(Photo Credit: Jason Nelson).

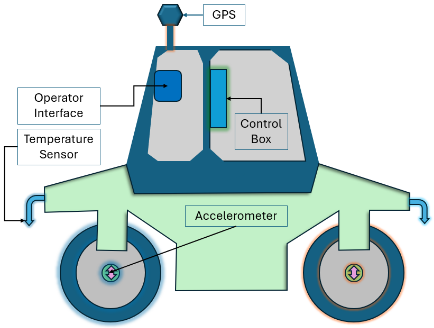


Figure 14. Illustration of an IC Roller (Reproduced from reference 13).

IC data have several applications in density assessment. Real-time stiffness data help operators adjust compaction efforts promptly, improving uniformity and reducing over- or under-compaction. IC provides full coverage of the pavement area, unlike spot tests, and helps develop temperature-based compaction curves that align with dynamic modulus behavior.(11,12)

Although IC is not used for acceptance testing, it may be used to support enhanced QC. AASHTO R 111 provides guidelines for IC system verification, measurements, and roller pass count coverage analysis, and several DOTs have developed state-specific guidelines for using IC. Managing and integrating large volumes of IC data with existing systems remains a significant challenge that requires substantial resources.(15) Effective use of IC rollers also demands proper training for personnel.,

In summary, IC offers valuable QC tools for monitoring compaction quality and determining density trends in asphalt pavements, but it currently cannot replace traditional density testing for final acceptance. Continued advancements in sensors, modeling, and asphalt-specific specifications are essential for realizing its full potential in density determination.

Future Trends and Innovations

Future innovations in asphalt pavement density measurement will likely emphasize integrating multiple NDT methods and the development of advanced intelligent compaction systems. A shift toward compactor-mounted sensors is also anticipated, replacing traditional setups with systems that enable non-contact, continuous monitoring and allow for immediate adjustments during the compaction process.

The trend is moving toward continuous data collection methods, such as those enabled by DPS, which offers full lane width assessments compared to conventional spot testing. To further improve accuracy, ongoing research is refining density prediction models by incorporating variables like mix composition, moisture content, and temperature.

Summary and Recommendations

Reliable measurement of in-place density is critical to ensuring the performance, durability, and service life of asphalt pavements. This document reviewed current specifications across State DOTs and discussed both traditional and emerging methods for assessing density in the field.

The review results indicate that most DOTs use G_{mm} as the basis for calculating relative density and rely primarily on field core testing for acceptance. While core testing provides direct and reliable measurements, it is destructive and limited in coverage. To address these limitations, NDT methods—such as nuclear and non-nuclear density gauges, DPS, and IC—have gained traction for QC and, in some cases, as supplementary acceptance tools.

NDGs are widely used for accuracy and speed, but require strict regulatory oversight due to their use of radioactive materials. NNDGs offer a safer and simpler alternative, though their accuracy and sensitivity to mixture variability are not comparable to NDG and core testing methods. NDGs and NNDGs provide limited coverage similar to cores. DPS and IC represent the next generation of NDT technologies. IC offers continuous, real-time assessment of the compaction operation, and DPS provides rapid information related to density and compaction uniformity. However, project-specific correlation, operator training, data management, and analysis tools are crucial to ensure reliable results.

To advance the practice of in-place density measurement, the following recommendations are offered:

- Maintain core testing as the reference standard for acceptance and use it to correlate NDT methods to ensure consistency and reliability.
- Expand the use of continuous measurement technologies for construction QC. Their ability to provide near-full coverage and real-time feedback can enhance compaction practices and identify areas of concern, particularly along longitudinal joints.
- Invest in training and analytical capacity to support accurate equipment calibration, interpretation, and data integration from advanced NDT systems.
- Standardize calibration and correlation protocols across projects and agencies to improve the comparability and credibility of results from NDT methods.
- Foster the development and evaluation of integrated systems that combine technologies such as advanced NDT, infrared thermography, and unmanned platforms to create a comprehensive data-driven approach to compaction monitoring.
- Support the inclusion of advanced NDT tools in pilot specifications and performance-based acceptance frameworks to encourage broader implementation and continuous improvement.

In conclusion, the future of asphalt pavement density measurement lies in a strategic blend of proven methods and innovative technologies. By adopting intelligent non-destructive systems supported by robust equipment calibration, correlation, analytics, and QAP, agencies and contractors can improve QC and acceptance, optimize compaction practices, and extend the life of pavement infrastructure.

References

1. Wang, S., Sui, X., Leng, Z., Jiang, J., & Lu, G. (2022). Asphalt Pavement Density Measurement Using Non-Destructive Testing Methods: Current Practices, Challenges, and Future Vision. Construction and building materials, 344, 128154.
2. Roberts, F. L., Kandhal, P. S., Brown, E. R., Lee, D. Y., & Kennedy, T. W. (1996). Hot Mix Asphalt Materials, Mixture Design, and Construction (2nd ed.). National Asphalt Pavement Association Research and Education Foundation.
3. Tran, N., Turner, P., & Shambley, J. (2016). Enhanced Compaction to Improve Durability and Extend Pavement Service Life: A Literature Review. NCAT Report 16-02. Auburn University, Auburn, Alabama: National Center for Asphalt Technology.
4. Dep, L., Mwimba, S., Sawyer, J., Best, J., & Croom, C. (2023). A New Method for Measuring In-Place Density of Asphalt Pavements Using a Low-Activity Nuclear Density Gauge. In Airfield and Highway Pavements 2023, 267–279.
5. Williams, S. G. (2008). Non-Nuclear Methods for HMA Density Measurements. Final Report No. MBTC 2075. Mack-Blackwell Rural Transportation Center.
6. Apeagyei, A. K., & Diefenderfer, B. K. (2011). An Evaluation of the Potential Use of Non-Nuclear Density Gauges for Asphalt Concrete Acceptance. Report No. FHWA/VCTIR 11-R15. Virginia Center for Transportation Innovation and Research.
7. Azari, Hoda, and Liu, Heng (2024). Validating a Density-Profiling System for Asphalt Compaction Assessment. Report No. FHWA-HRT-24-143. Federal Highway Administration., U.S. DOT, Washington D.C.
8. Al-Qadi, I. L., Leng, Z., Lahouar, S., & Baek, J. (2010). In-Place Hot-Mix Asphalt Density Estimation Using Ground-Penetrating Radar. Transportation Research Record: Journal of the Transportation Research Board, 2152(1), 19–27.
9. Hoegh, K., Steiner, T., Zegeye Teshale, E., & Dai, S. (2020). Minnesota Department of Transportation Case Studies for Coreless Asphalt Pavement Compaction Assessment. Transportation Research Record: Journal of the Transportation Research Board, 2674(2), 291–301.
10. Von Quintus, H., Nabizadeh, H., Hand, A. J., & Hajj, E. (2023). A Practice for Including Intelligent Construction Equipment in Quality Assurance Programs. Report No. FHWA-HIF-23-007. Federal Highway Administration., U.S. DOT, Washington D.C.
11. Hu, W., Jia, X., Zhu, X., Gong, H., Xue, G., & Huang, B. (2019). Investigating Key Factors of Intelligent Compaction for Asphalt Paving: A Comparative Case Study. Construction and Building Materials, 229, 116876.
12. Chang, G. K., Xu, Q., Rutledge, J. L., & Garber, S. I. (2014). A Study on Intelligent Compacting and In-Place Asphalt Density. Report No. FHWA-HIF-14-017. Federal Highway Administration., U.S. DOT, Washington D.C.
13. Sivagnanasuntharam, S., Sounthararajah, A., & Kodikara, J. (2023). In-Situ Spot Test Measurements and ICMV for Asphalt Pavement: Lack of Correlations and The Effect of Underlying Support. International Journal of Pavement Engineering, 24(1), 2198770.
14. Xu, Q., & Chang, G. K. (2016). Adaptive Quality Control and Acceptance of Pavement Material Density for Intelligent Road Construction. Automation in Construction, 62, 78–88.

15. Federal Highway Administration. (2024). Utilizing Intelligent Compaction to Ensure Quality and Uniformity of Pavement Materials (FHWA-HIF-24-097). U.S. Department of Transportation.
16. Leng, Z., Al-Qadi, I. L., Shangguan, P., & Son, S. (2012). Field Application of Ground-Penetrating Radar for Measurement of Asphalt Mixture Density: Case Study of Illinois Route 72 Overlay. Transportation Research Record: Journal of the Transportation Research Board, 2304(1), 133–141.
17. Mooney, M. A., Rinehart, R. V., White, D. J., Vennapusa, P. K. R., & Facas, N. J. (2010). Intelligent Soil Compaction Systems. Transportation Research Record: Journal of the Transportation Research Board, 2101(1), 1–9
18. Gallivan, V. L., & Horan, R. D. (2009). Intelligent Compaction: Overview and Advances. Transportation Research Record: Journal of the Transportation Research Board, No. 2104, 1–7.

AIEI

ASPHALT | INNOVATE | ENLIGHTEN | IMPLEMENT

Connect with us on our LinkedIn page to keep current with all team member events and program progress!

UNR–TB–25-1105

For other cooperative agreements materials, information, or technical assistance, please visit:
https://www.fhwa.dot.gov/pavement/asphalt/coopmaterials/
https://www.unr.edu/wrsc/tools/asphalt

This material is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange under agreement number 693JJ32350026 Development and Deployment of Innovative Asphalt Pavement Technologies. The U.S. Government assumes no liability for the use of the information in the non-FHWA-branded documents.