SHRP2 Solution:

Technologies to Enhance Quality Control on Asphalt Pavements

Pave-IR Scan^{TM} Primer

Introduction

In-place density is a critical factor in determining pavement durability in hot mix asphalt (HMA) mixtures. Localized non-uniform zones of mix, often defined as segregation, are low-density areas in the HMA mat. Although very localized, segregation is a major construction-related problem with an adverse impact on pavement service life. For example, Figure 1 includes a photograph of two cores that exhibit longitudinal aggregate segregation at the surface of a mat.


Figure 1

The core to the right in Figure 1 clearly shows a concentration of coarse aggregate at the surface. This concentration of coarse aggregate caused a "weak" spot where a longitudinal crack started at the surface and is propagating downward through the HMA . The core to the left is similar, but the crack has propagated through all of the HMA layers and the coarse aggregate have become dislodged by traffic and exhibits severe raveling along the longitudinal crack. This condition can occur in a few years after construction and require premature maintenance or rehabilitation. The infrared scanner technology is being used to ensure these conditions are identified on a real time basis during the paving operation.

The purpose of this document is to overview the technology in terms of the equipment, how the equipment is used, and an interpretation of the data to reduce the risk of missing HMA defects that will have a detrimental impact on the long term performance of the mixture.

Mat Defects: Segregation and Low Density and Their Impact on Performance

The most common form of HMA segregation is truck-end segregation which occurs where the HMA at the ends of the truckload is colder and sometimes coarser in gradation. These locations show up on the mat as regularly spaced defects and can vary from small areas on either side of the paver to larger areas that extend across the width of the HMA mat being placed. Over time, these locations fail prematurely or require maintenance because of the entry of water, air and the application of traffic loads. The segregated locations deteriorate rapidly because of their lower density, higher permeability, and higher susceptibility to raveling and fatigue cracking. Early distress not only results in poorer ride quality for the traveling public but also require agencies to use resources earlier than planned to maintain the pavement to an acceptable level of ride quality.

Historically, HMA segregation was thought of as a mechanical phenomenon consisting of localized concentrations of coarse gradation. Although this type of segregation exists, the discovery of how thermal signatures from the HMA relate to segregation altered the definition of segregation to include both physical and thermal definitions. Building on the concept of temperature differentials from aggregate segregation, several agencies completed research projects demonstrating that infrared (IR) thermography can be used for detecting segregated areas. Using IR thermography, segregated locations show up as cold spots or areas, and the severity of segregation is quantified by the magnitude of the temperature differential in localized areas. Essentially, the cold spot results in low-density areas of the compacted HMA mat. These cold spots can also exhibit a coarser gradation and lower asphalt cement content increasing the susceptibility for raveling and cracking.

Realizing the importance of mitigating segregation in HMA construction, many agencies implemented segregation check procedures that are mostly based on visual inspection and discrete testing. Although visual inspection is a part of the solution to identify and eliminate segregation, the human eye cannot always see anything unusual in the HMA mat. Contributing to the problem of detecting segregation is the increased use of night paving, which makes it difficult to visually see mat defects, and if you cannot see the defect, it is less likely to be eliminated.

Although many departments of transportation (DOTs) include segregation check procedures within their quality assurance (QA) program, the procedures and test methods only test a very small portion of the mat and are likely to miss many small localized areas, even if those areas occur in a pattern or at cyclical intervals along the mat. In short, spot inspection methods risk overlooking problem areas and are labor intensive.

Achieving proper density, free of segregation, is a key component to long life HMA mixtures. Most DOTs sample the HMA mat by coring, which represents a small fraction of the area placed. The core density or percent compaction is used to determine if the HMA mat meets the acceptance criteria. Localized segregation, however, may not decrease the density below the unacceptable value for the entire core as shown in Figure 1. Areas with defects, or segregation, are usually identified through visual assessment, but the subjective approach leaves room for error and disputes. Thus, it is in the best interest of the DOT and contractor to eliminate segregation and low density areas.

Infrared Thermography – Identifying Mat Defects

The ideal toolset for identifying areas with HMA segregation should include a continuous monitoring system that detects segregation quantitatively and in real time for QA. Agencies seeking to push the state of the art have turned to the use of infrared (IR) technology to obtain quantitative, full-coverage monitoring and evaluation of HMA mats prior to compaction.

IR thermography is a technology that can be used to provide feedback in real time to paving crews through visual and quantitative outputs. Recent studies have shown that IR imaging can be used to assess in-place density or defects during construction by monitoring the mat's surface temperature while providing nearly 100 percent continuous coverage of the new HMA mat. Mat defects are visually located on a real time temperature graph, and summarized in color coded tables to assist the paving crews. Additional software can be used by office personnel to track paving progress and obtain a more granular view of possible locations of mat defects.

Infrared Thermography Technology – Defined

Infrared thermography is a diagnostic, nondestructive evaluation, method that relates changes in surface temperature of a material to surface or subsurface internal defects. Thermography simply means the mapping of isotherms, i.e. contours of the equal temperature over the surface of a material or component, and is a method of evaluating materials by measurement of their surface temperature. Basically, heat-sensing materials are used to detect irregularities in temperature contours and such thermal irregularities can be related to defects and/or flaws.

Infrared thermography involves the use of non-contact surface temperature measurement to diagnose subsurface conditions. The basis of the measurement is that the surface temperature at a defect will differ from the "normal" or background surface temperature. Surface temperature is detected using an infrared sensor that provides the required infrared radiation.

Infrared cameras and sensors have been used for civil structures because they provide a two-dimensional image of large surfaces and they operate like a conventional video camera. The main difference is that the intensity levels of the infrared image are related to the infrared radiation (i.e., surface temperature) rather than the intensity of light. An infrared sensor produces an output voltage proportional to the received infrared radiation at a point.

IR thermography has been used for the detection of segregation in newly placed HMA as well as stripping and debonding between HMA layers due to discontinuity in the temperature caused by the difference in voids between two areas. Analyses of test results have shown that changes in IR data are related to changes in HMA properties, such as air voids, gradation, and/or permeability.

The potential of IR to serve as a QA tool for evaluating HMA mixtures during the placement operation has been studied in detail. The results from these studies have concluded the use of IR technology can be used for newly placed HMA lifts located near the surface, but the technology is less reliable for thicker HMA layers to detect anomalies located below the surface.

Pave-IR Scan™ Equipment

Figure 2

The equipment and materials that are used to continuously monitor the surface temperatures is simple to use and install. The product or system being used on multiple demonstration projects is called Pave-IR Scan™, developed by MOBA Mobile Automation. The pieces of equipment within this system include: an IR mast base, mast extension, and mast arm; the IR scanner itself; the monitor; a distance measuring instrument (DMI); a combined wireless communication and GPS unit; wiring; and various connection bolts and materials. All of the pieces of equipment, except for the mast base, extension and arm, fit into an easily transported case as shown in Figure 2. The case can be handled by one person.

The Pave-IR Scan™ sells for $30,000 to $35,000. The IR scanner is robust and needs the same care and treatment as a video camera. No regular maintenance is required. After an initial training session (less than 4 hours), the IR scanner is easy to use on a day to day basis.

Installation of the Pave-IR Scan™ Equipment

The four major components of the Pave-IR Scan™ are the IR mast and base plate, the IR scanner, the DMI, and the monitor. The Pave-IR Scan™ mast is easily attached to the paver using four to eight bolts and a flat steel plate or mast base. In some cases, installation of the scanner mast base plate required holes to be drilled for the mounting bolts. Rarely will the installation process require any welding of the IR mast base plate to the paver for short duration use. For long duration use, welding the mast or base plate directly to the paver provides the most robust solution.

The plate or base of the mast is attached just inside or outside the hand rail for the ladder to the paver driving positions. The location

Figure 3

Figure 4

does not interfere or restrict movement of paving personnel working on or around the screed. The installation procedure takes less than 2 hours to complete for most pavers. Figure 3 shows the IR scanner mast base plate mounted with four bolts. In some cases, the IR mast is attached to the hand rail using a “U-bolt” for stability. Figure 4 shows the Pave-IR Scan™ unit installed which is not restricting any of the paving personnel from doing their job.

Figure 5

The GPS unit and IR scanner are placed on the mast arm. The scanner includes an IR sensor mounted to a step motor which sweeps the paving surface to measure the surface temperature. Figure 5 shows the GPS unit and IR scanner in place. The Pave-IR Scan™ unit is powered by the onboard generator or is connected directly to machine power, which is typical of a more permanent installation.

The other important component is the DMI that is used to measure the distance the paver is moving so the surface temperature readings can be tied to a length or station. Figure 6 shows the DMI on the wheel hub of the paver.

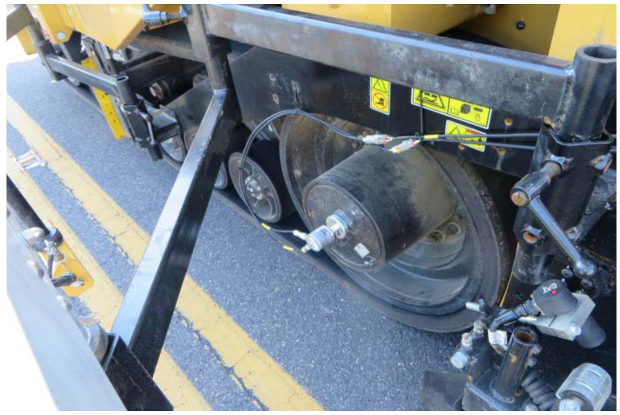


Figure 6

The monitor is attached to the mast so the paving personnel can easily see the screen and make adjustments in reviewing the temperature data on the screen. Figure 7 shows the IR monitor and its general location attached to the mast.

Figure 7

Data Collection: Measuring Surface Temperature

The IR scanner (see Figure 5) measures the surface temperature of the material within the line scan on a continuous basis as the paver is moving forward. The sensor rotates or cycles from side to side at a specified width as the paver moves down the paving lane. It is recommended that the line scan takes readings at a sufficient distance behind the screed (typically 6 feet) to reduce the interference of paver personnel being in the line scan as they walk on and off on the screed, but not so far behind the screed that the sensor range is exceeded.

The IR sensor operates by detecting the amount of electromagnetic energy emitted from the target. As the temperature of the target increases, the amount of emitted energy increases. In the simplest form of use, IR cameras and sensors take snapshots of the surface and, through post-processing, provide temperature distribution statistics of individual images. Temperature contour plots from the IR sensor data are created by merging multiple images.

The IR line scanner images the entire scan width and provides adequate data-collection and data processing features for uniformity measurements. The scan width is normally set up to make sure the edges of the HMA mat are within the scan. A two-dimensional contour plot is provided on the monitor as the output in both real time and post-processing without the need to merge any IR images together. Figure 8 is an example of the two dimensional contours presented in a color diagram for the temperatures collected by the scanner. As shown, all temperature data are presented on the image including surface temperatures just outside the edge of mat along one side of paving.

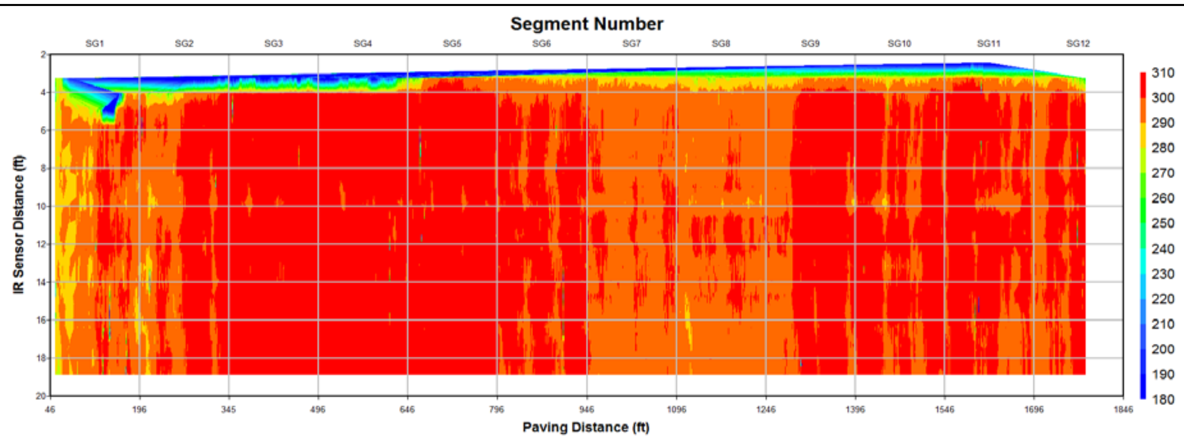


Figure 8

The Pave-IR data for all paving operations are provided in a proprietary ".paveproj" file format, which includes the raw temperature data collected from the Pave-IR system. The ".paveproj" file is imported into the MOBA Pave Project Manager software so a .txt file can be exported and saved. The Pave Manager software is proprietary program and comes with the purchase of the IR scanner device.

The distribution of the raw temperature data can be displayed or illustrated in terms of a histogram of the data. Figure 9 shows a typical histogram of the raw, unfiltered temperature data. Figure 9 also shows the basic statistics obtained from the temperature data, namely: the average, standard deviation, maximum, minimum, 98.5 and 1.0 percentile, and the

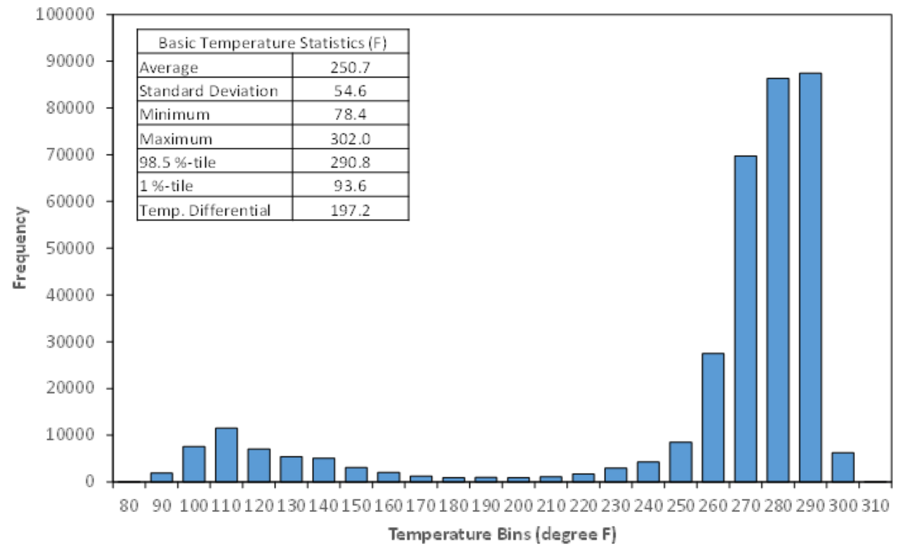


Figure 9

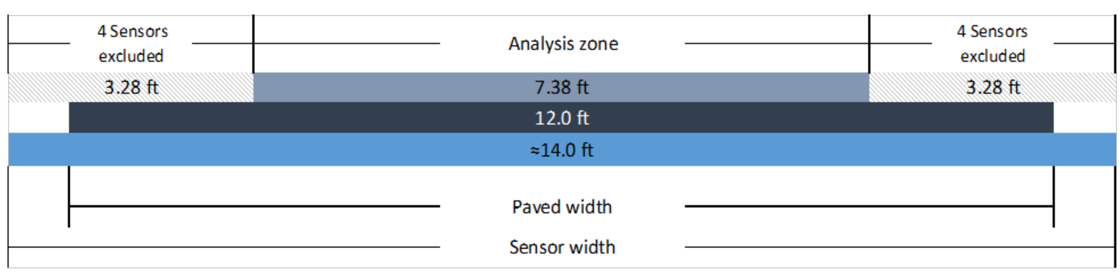
temperature differential. As shown in Figure 9, the data has a large range of temperatures (90°F - 300°F). It is clear that some of the low temperatures are not representative of the mat temperature.

Although it is difficult to explain the reason behind such temperature measurements in the data, the low temperatures can be caused by: (1) the temperatures measured towards the paving edge (see Figure 8); (2) temperature recorded during extended paver stops; and/or (3) human interference (i.e., the system measuring the temperature of a person in between the IR scanner and the mat). The data pre-screening criteria are discussed in the next section to ensure non-mat temperatures get removed from the analysis to evaluate mat temperature uniformity.

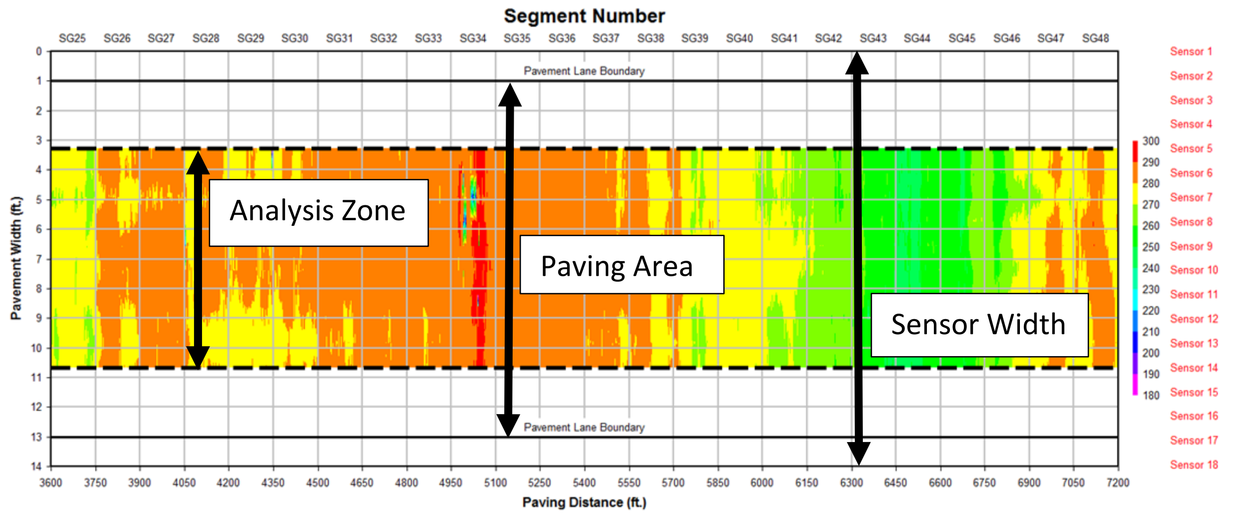
Prescreening Criteria of Pave-IR Scan^{TM} Data

In order to eliminate invalid mat temperature readings recorded within the line scan during paving, all thermal profiles are pre-screened by the software using the following criteria (the first two criteria were adopted from Tex-244-F):

1. Eliminate temperature measurements within two feet of the edge of the uncompacted mat: To meet this criterion, the raw data temperature contour plots are visually inspected to determine the edge of the paving lane. The edge of the paving lane can vary for the different paving days or collection times, especially with variable lane widths. Selected point locations can be excluded based on the mat edge. Eight point locations, four on either side of the scanned width, are excluded from each edge to account for the paved surface and the uncompacted mat criteria. In some cases, only one point on each side of the HMA mat is eliminated. The points to be eliminated are defined by the individual analyzing the temperature data. Figure 10 shows a schematic of the analysis zones and the contour plot configuration relative to the mat edges (paved width) and width of the line scan (sensor width).
2. Eliminate locations of paver stops greater than 10 seconds: The raw thermal profiles from the sampling locations are examined and locations are identified where the paver was stopped for more than 10 seconds. Per Tex-244-F, the thermal profile within 2 ft. behind and 8 ft. in front of each of these areas (in the direction of paving) are eliminated from the analysis. The user can complete an analysis of the data that includes temperatures in the locations of paver stops greater than 10 seconds. However, including temperatures within the paver stops requires an analysis of the data from the .txt files external to the software.
3. Eliminate temperature readings below the minimum temperature (typically 170°F) or above the maximum temperature (typically 400°F): This criterion is to remove any temperature readings influenced by other potential interferences such as human interference, roller interference, and any random error associated with data collection. The minimum and maximum temperatures are entered by the user prior to paving in setting up the project file for a day's paving.



(a)



(b)

Figure 10

The software automatically completes the pre-screening of the temperature data. The user, however, can override the criteria because the raw temperature data remain in the files that are stored. Thus, changes can be made to the interpretation of the data post-construction. Figure 11 shows an example of the histogram of mat temperatures after pre-screening the data where all low, non-mat temperatures have been excluded or removed.

Temperature Differential Criteria

The criteria for thermal segregation or temperature differential used by most agencies were adopted from the specification developed by the Texas Department of Transportation (TxDOT) (i.e., Tex-244-F), which defines the temperature differential, T_{diff}, as the following:

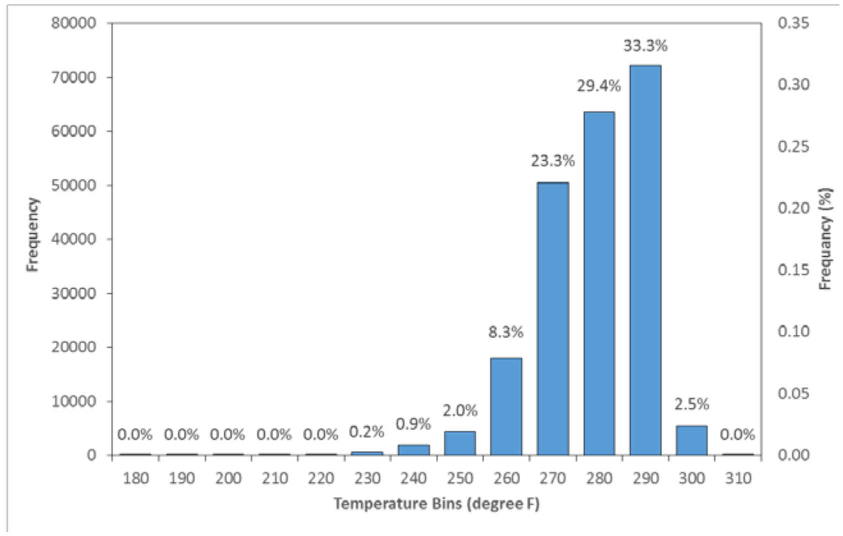


Figure 11

$$T_{diff} = T_{98.5} - T_{1.0} \quad (1)$$

Where $T_{98.5}$ and $T_{1.0}$ are the 98.5 and 1.0 percentiles obtained from the distribution of the temperature data, respectively.

A graphical schematic of the temperature differential is provided in Figure 12. Tex-244-F requires that temperature differential, T_{diff}, be calculated in 150 ft. segments. According to the proposed specification for Pave-IR from the American Association of State Highway and Transportation Officials (AASHTO), the presence and severity of temperature differential (referred to as thermal segregation in the AASHTO specification) is defined as the following:

- T_{diff}, ≤ 25 degree Fahrenheit (°F): No to minor temperature differential (or segregation)
- 25 °F < T_{diff}, ≤ 50 °F: Moderate temperature differential (or segregation)
- 50 °F < T_{diff},: Severe temperature differential (or segregation)

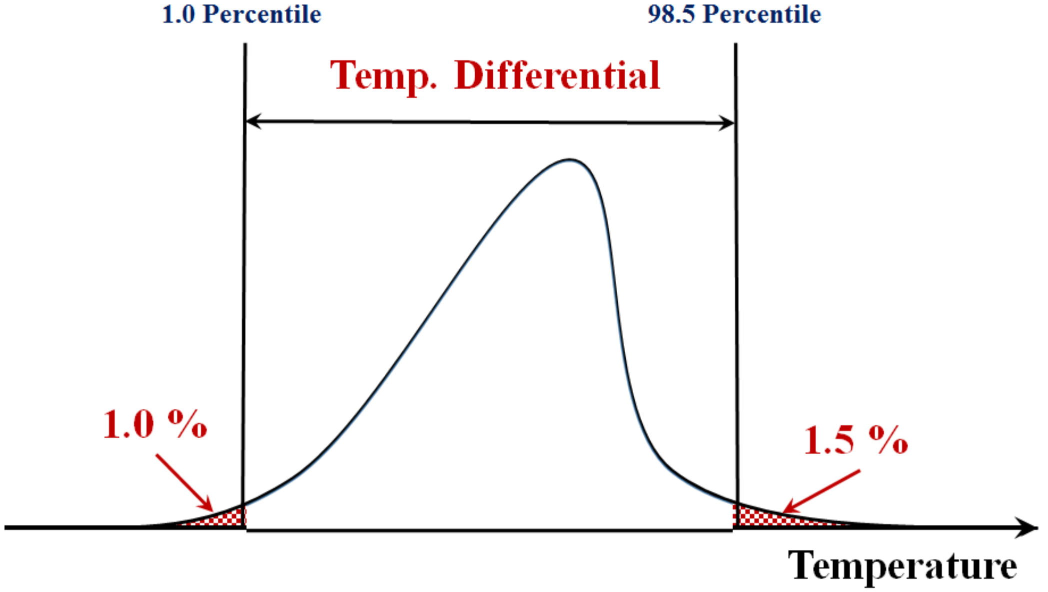


Figure 12

Application of Pave-IR Scan™ Data

The Pave-IR Scan™ system was used on ten field demonstration projects included in the SHRP II program. The agencies that participated in the field demonstrations included: Alabama DOT, Alaska DOT, Eastern Federal Lands of FHWA, Illinois DOT, Maine DOT, Missouri DOT, New Jersey DOT, North Carolina DOT, Virginia DOT, and West Virginia DOT. Some of the comments from contractor and agency personnel relative to using the Pave-IR Scan™ are listed below:

- Improves communication between plant and paver personnel to reduce the temperature differential to the lowest value possible. The paving contractor was able to cut the temperature differential in half on a couple of the field demonstration projects simply by adding additional delivery trucks and/or using a material transfer vehicle.
- The visual image or display of the temperature differential on the monitor is undisputable in terms of variation in densities or percent compaction. Paver personnel, as well as contractor management personnel start to take notice on what field-plant activities increase and decrease the temperature differential.
- It is a good forensic tool to investigate reasons or troubleshoot for low and/or non-uniform mat density.

- Monitoring the temperature differentials on a lot by lot basis for quality control purposes, determines when the paving contractor needs to take some type of action to reduce the temperature differentials.
- Use of the IR scanner definitely reduces the risk of being penalized for low percent compaction by the agency. If the temperature differential in above 15^{o}F, the risk of being penalized by the agency increases.
- It removes the guess work and subjective opinions from identifying mixture segregation.
- Nearly 100 percent of the mat surface is inspected, so the concern of basing a decision to penalize a contractor is not based on just a few random samples.
- The Pave-IR Scan^{TM} system can be used to resolve disputes between the contractor and agency related to the mat uniformity in terms of density and segregation. More importantly it can serve as a benefit to both the agency and contractor in terms of defining potential causes of low density and high variability in the density measurements.
- Provides a reduction in future (short and long-term) maintenance costs. Projects or areas with severe temperature differentials will exhibit premature cracking and raveling.