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16. Abstract

Past research projects illustrated temperature differentials greater than 25 °F on hot-mix asphalt (HMA) construction projects indicate potential segregation problems in the mat. Through the years infrared cameras have been used to collect thermal data on newly placed HMA projects. Texas Transportation Institute (TTI) researchers refined infrared methods for detecting segregation on paving projects by developing an infrared temperature bar and accompanying data collection and processing software package. As a combined system, called Pave-IR, TTI's system allows for much simpler data collection and analysis procedures as compared to using infrared cameras. This report documents pilot efforts to implement Pave-IR into Texas Department of Transportation operations, including the current equipment development and example data from Pave-IR.

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PILOT IMPLEMENTATION OF PAVE-IR FOR DETECTING SEGREGATION IN HOT-MIX ASPHALT CONSTRUCTION

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EXECUTIVE SUMMARY

This report documents the current Pave-IR system developed by the Texas Transportation Institute (TTI) for pilot implementation into operations of the Texas Department of Transportation (TxDOT). TTI currently has three operable units of Pave-IR, which consists of a transverse bar with 10 infrared sensors immediately behind the paver, and the Pave-IR software package, which collects and displays the thermal profile in real time as the paving train progresses. In addition to real-time data display, Pave-IR can display in real time whether the paving temperatures fall within user-defined limits, and during paving Pave-IR can provide a histogram of temperatures every 100 ft. (30.5 m). Post-processing functions in Pave-IR currently consist of data playback and review, spot temperature display, and creation of a histogram of the placement temperatures for the entire data file.

Together Pave-IR hardware and software provide a system that is rugged, easy to service and maintain, simple to set up and operate, and useful for providing a large amount of near full-coverage data for evaluating hot-mix asphalt (HMA) paving projects during placement. In many instances Pave-IR surveys have revealed significant thermal variations in HMA paving projects which likely would not have been detected without Pave-IR. Pave-IR surveys can not only be used to evaluate a project for thermal segregation, but should also be performed after implementation of corrective action on the project to ensure the effectiveness of changes made to the placement process.

CHAPTER 1

THE CURRENT PAVE-IR SYSTEM

BACKGROUND

In 1996 Read revolutionized how industry viewed segregation when he used an infrared camera to determine that temperature differentials in HMA appeared related to segregation (*1*). With Read's discovery, the concept of segregation types including *thermal* segregation in addition to gradation segregation began. After Read's initial work, other agencies began experimenting with thermal imaging for evaluating paving projects, and efforts to further clarify exactly what the observed temperature differentials meant were initiated. Numerous independent projects determined that temperature differentials in excess of 25 °F were cause for concern and should be investigated for segregation (*2*-*4*).

In evaluating thermal imaging as a tool for examining hot-mix asphalt construction, the previously described projects relied on infrared cameras for field data collection. However, cost considerations, a narrow field of view, the need to merge multiple images, and complexities with accurately referencing the thermal image with a location on the pavement all contributed to drawbacks for implementing infrared cameras (*4*). Because of these drawbacks, implementation recommendations from previously completed TxDOT project 0-4126 included using spot infrared sensors on a transverse bar. This temperature bar would collect thermal scans across the transverse profile at predetermined distance intervals. Figure 1.1 illustrates the concept of the proposed temperature bar. Texas Transportation Institute researchers have now brought this concept to near maturity in a system called Pave-IR, capable of collecting, processing, and displaying the thermal scans of a paving project in real time.

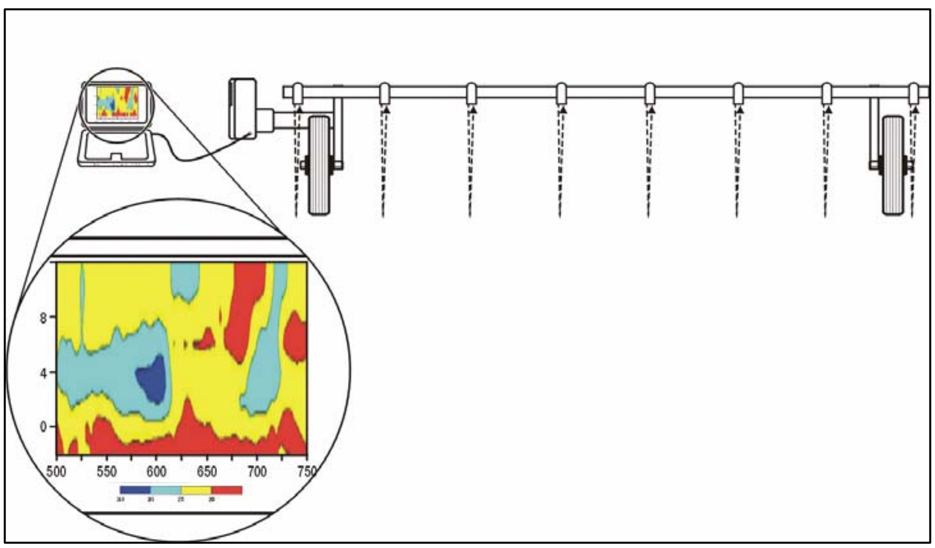


Figure 1.1. Concept Infrared Temperature Bar (*4*).

OVERVIEW OF THE CURRENT PAVE-IR SYSTEM

To overcome the problems noted with the infrared cameras, a team at the Texas Transportation Institute set out to bring the infrared temperature bar concept to fruition. Primary design features, problems encountered, and development of the first two generation devices are described elsewhere (5). Table 1.1 summarizes key hardware specifications of Pave-IR.

Table 1.1. Key Pave-IR Hardware Specifications.

Number of infrared sensors	10
Typical sensor spacing	13 inches
Mat analysis width	10 to 12 feet
Typical sensor working height	3 feet
Sensor spectral response range	8 to 14 µm
Sensor distance:spot ratio	10:1
Sensor temperature measurement range	-40 to 1112 °F
Sensor ambient operating temperature range	32 to 185 °F

The current Pave-IR system, thought optimal for implementation, uses two temperature bars attached directly to the paver. Each bar contains five infrared sensors. When compared to previous operator-propelled prototypes, this two-bar setup allows for easier transport, improved setup time, and improved safety of operators by eliminating the need for personnel to push the bar. This setup also ensures constant distance of the temperature bars behind the screed. In addition to the new two-piece temperature bar, the current Pave-IR system uses a master control cable that links the temperature bars to a master control box. This new cable significantly reduces the quantity of exposed wiring, and the control box contains all the necessary signal conditioners and the data transfer junction for connection to the computer.

Figure 1.2 shows the current Pave-IR system in use on a paving project. The two cables coming from the temperature bars at the middle of the paver merge into one cable before connecting to the master control box.

Figure 1.2. TTI's Current Pave-IR System Collecting Project Data.

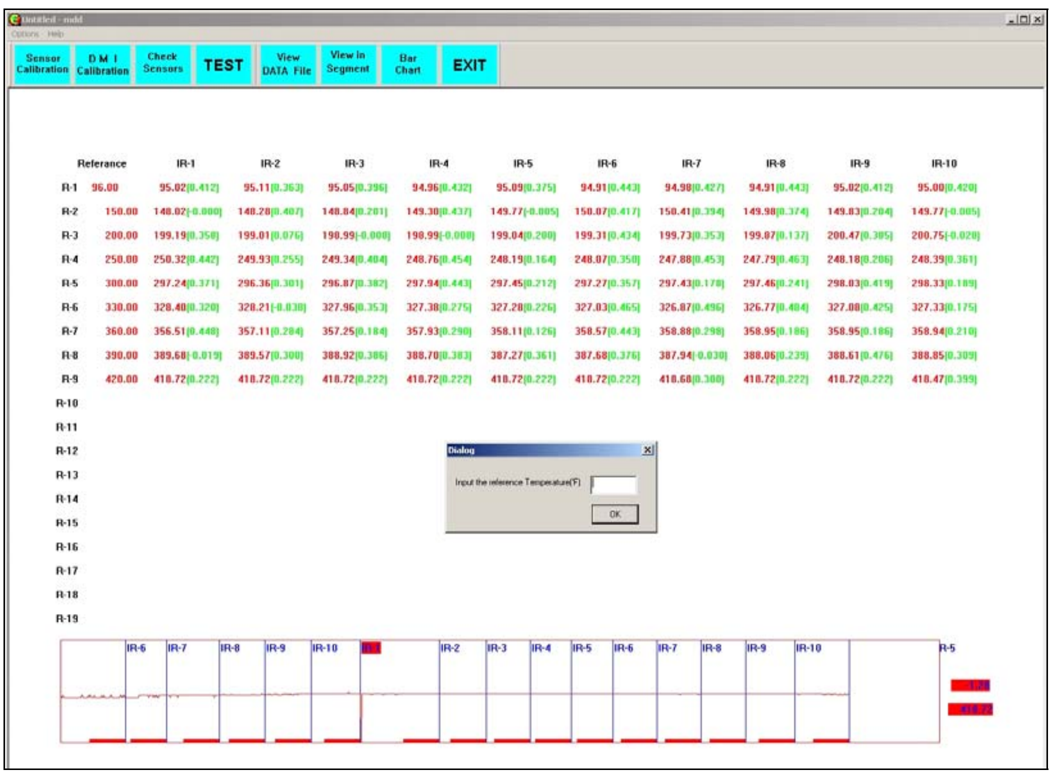
CLOSER DETAILS OF PAVE-IR SYSTEM COMPONENTS

While the basic idea of Pave-IR simply centers on infrared sensors above a pavement mat, the finer details make the system near ready for full implementation. TTI has developed a method for system calibration, hardware which is rugged in the field, simple to set up, and easy to maintain. An accompanying software package created by TTI is simple to operate and handles all functions of Pave-IR ranging from calibration to real-time data display to post-processing analysis.

System Calibration

To ensure accuracy of the infrared sensors, Pave-IR software includes a module for calibration of the infrared sensors. The calibration is performed in the lab with a blackbody source with an accuracy of ±0.9 °F ±0.25 percent of reading and a stability of ±0.2 °F. Figure 1.3 illustrates the basic calibration setup.

(a) Infrared Sensor in Blackbody for Calibration.



(b) Pave-IR Calibration in Progress.

Figure 1.3. Infrared Sensor Installed in Blackbody for Calibration (a) and Pave-IR Calibration in Progress (b).

System Hardware

The Master Control Box

Figure 1.4 shows the master control box previously described. This box weighs approximately 18 lb and measures approximately 15 x 11 x 10 in. The control box helps ensure easy setup and transportability of many required Pave-IR components while also providing the components protection from damage. This box also contains an inverter to provide 120 VAC power to eliminate dependency on laptop batteries for running the computer. The paver battery provides power to the master control box to run the system. If in need of servicing, the box can be disassembled by simple removal of sheet metal screws.

Figure 1.4. Master Control Box for Pave-IR.

The Temperature Bars

The current Pave-IR temperature bars contain the infrared sensors already mounted and pre-wired for easy connection to the master control box. Each bar opens along a hinged joint for access to the sensors and internal wiring. When closed and secured shut, the bars provide protection to the sensors and wiring. Slots in the bars allow adjustment of sensor spacing to measure paving widths ranging from 10 to 12 ft. Figure 1.5 shows the sensor side and the internal side of a temperature bar.

Figure 1.5. Sensor Side and Internal Sides of Temperature Bar.

Software

Pave-IR software completes the Pave-IR system. This software allows for calibration of the sensors, calibration of the DMI, collection of transverse scans at user-defined distances (typically set at every 2 inches), real-time data display, real-time analysis of whether temperatures in a scan fall within user-defined limits, real-time display of a histogram of measured temperatures at user-defined intervals (typically set at every 100 ft), post-processing data playback, and post-processing display of a histogram of measured temperatures for the entire project. Chapter 2 illustrates some of the features of Pave-IR software by summarizing results from a field project on US 82 in the Paris District.

CHAPTER 2

EXAMPLE FIELD USE OF PAVE-IR

BACKGROUND OF FIELD SURVEYS

In Texas Pave-IR has been used to investigate the thermal profiles of numerous pavement projects. When performing these surveys, basic project data is recorded prior to performing any measurements. Items recorded include:

- Contractor
- Mix type
- Placement operation factors, including:
  - Haul distance
  - Truck type (insulated or not, tarped or not, end dump, belly dump, or flow-boy)
  - Windrow elevator or material transfer device (MTD) model
  - Paver model
  - Target placement temperature
- Ambient air temperature
- Average wind speed
- Sky conditions
- Starting limit location of testing

During data collection, both contractor and DOT personnel periodically check the status of the survey since Pave-IR provides visual data in real time. At the end of data collection, the data is analyzed and a technical memo is prepared summarizing the observations, results, and recommendations from the thermal survey. An example case study from the pilot implementation of Pave-IR is summarized below. In this example from the Paris District Pave-IR was used to detect significant temperature variations and subsequently validate improvements in the placement process by implementation of changes in the contractor's operations.

RESULTS FROM TYPE D HMA IN PARIS DISTRICT

On this Type D mix placed on US 82 in January 2005, a thermal survey revealed significant temperature differentials along the longitudinal profile. The HMA utilized PG 64-22 asphalt cement with a job mix formula (JMF) asphalt content of 6.4 percent and a target field compaction of 91 to 95 percent density. This project utilized end-dump trucks into a MTD. Approximately 1700 feet of data were collected in the westbound outside lane starting at Station 1745+34. Based on observations at the project site and discussions with project personnel, numerous recommendations were made regarding the project involving everything from plant operations through rolling patterns. Based upon the survey, the DOT met with the contractor and worked to improve the quality and uniformity of the project through better control at the plant, utilization of a different model MTD, and altered rolling patterns. With modified operational procedures, the project resumed in April 2005. Collected data show the operational changes significantly improved mat placement uniformity. Figures 2.1 and 2.2 contrast the resultant thermal profiles from the initial to the modified operation. Figures 2.3 and 2.4 illustrate how the changes in operations significantly tightened the measured placement temperature distribution. With the initial operation, approximately 95 percent of measured temperatures fell within a 90 °F window. With the new operation based upon the recommendations from the thermal survey, approximately 95 percent of measured temperatures fell within a 40 °F window. Based upon recommendations from the initial project survey with Pave-IR, the modified operation reduced the range of mat placement temperatures by over 50 percent. Without Pave-IR, the extent of variability in the initial paving operation likely would not have been discovered.

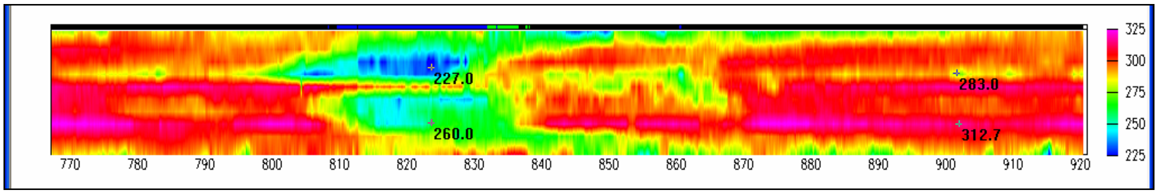


Figure 2.1. Example Thermal Profile form Initial Paving Operation on US 82.

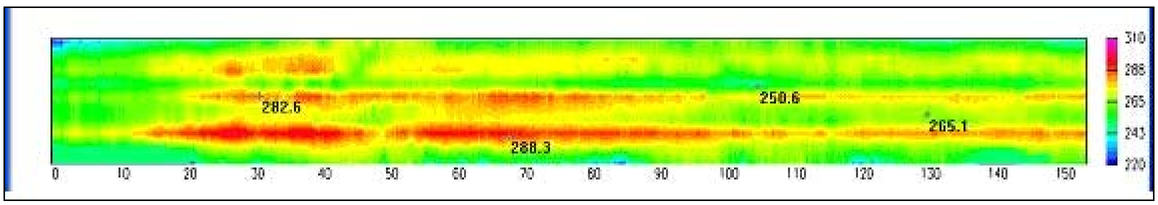


Figure 2.2. Example Thermal Profile from Modified Paving Operation on US 82.

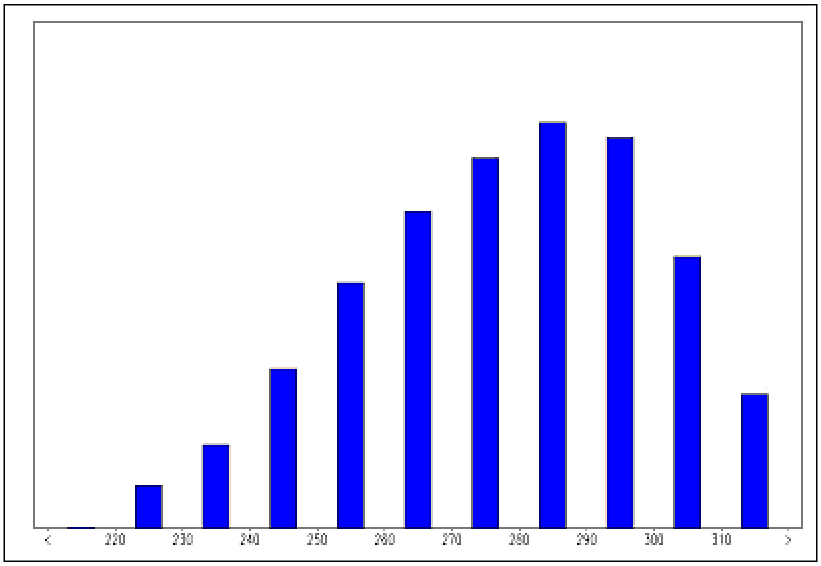


Figure 2.3. Histogram of Measured Mat Placement Temperatures from Initial Paving Operation on US 82.

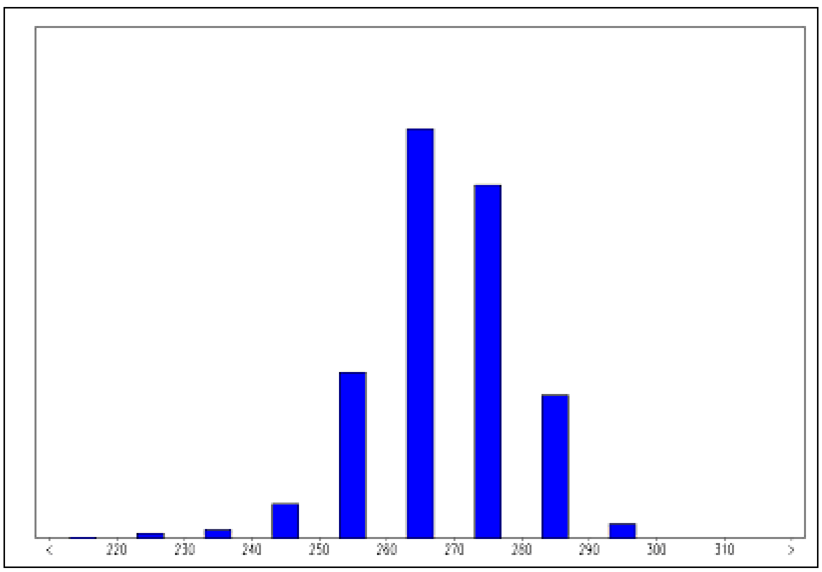


Figure 2.4. Histogram of Measured Mat Placement Temperatures from Modified Paving Operation on US 82.

CHAPTER 3

RECOMMENDATIONS

TxDOT should continue use of Pave-IR for evaluating HMA construction projects for thermal uniformity. Numerous previous projects illustrated the significance of temperature differentials on HMA quality. Pave-IR can rapidly and easily measure substantial amounts of thermal profile data on paving projects for quality assessment. The hardware of the system is rugged, simple to set up, and easy to maintain. Software of Pave-IR allows for system calibration, control of numerous real-time processing functions, real-time data display, and post processing playback and analysis. The newest system, which mounts to the paver, is thought optimal for field use. This system has setup time and safety advantages over operator-propelled systems. All systems should be calibrated at least once a year. TTI has a blackbody source for use in servicing the calibration needs of Pave-IR.

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