Investigation of Construction-Related Asphalt Concrete Pavement Temperature Differentials

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Table of Contents

Chapter 1 - Executive Summary ................................................................. 1
Chapter 2 - Determining and Conducting Density Profiles.......................... 3
  General ........................................................................................................ 3
  Determining the Location of the Density Profiles ...................................... 4
  Density Profile Procedure ........................................................................ 6
Chapter 3 - Field Observations ................................................................. 9
  General Observations ............................................................................... 9
  Uniform temperatures ............................................................................. 10
    Uniform Temperatures in the Paving Process ...................................... 11
    Uniform Temperatures at a Start/Stop Point ..................................... 13
  Non Uniform Temperatures .................................................................... 14
    Aggregate Segregation Observations ................................................. 14
    Longitudinal Temperature Streaking Captured During Paving .......... 16
    Cool Spots Captured During Paving .................................................... 18
    Start/Stop Point with Typical Temperature Differential .................... 18
    Start/Stop Point with Minimal Temperature Differential ................... 19
    Start/Stop Point Lasting over 30 Minutes .......................................... 20
    Consumption of Cold/Old and Hot/New Mix from a Windrow .......... 21
    The Effects of Clamshelling the Paver Wings ................................... 23
    Paving Over a Waste Pile of Asphalt Mix ......................................... 26
  Night Paving Observation ...................................................................... 27
Chapter 4 – Results ............................................................................... 29
Chapter 5 – Conclusions ......................................................................... 35
Chapter 6 – Recommendations ................................................................ 41
References ............................................................................................... 43
Appendix A – Infrared Density Profile Graphs
Appendix B – Summary of Field Data
Appendix C – Infrared Density Reports
List of Tables

Table 1: Summary of Reports ................................................................. 9
Table 2: Density Profiles ................................................................. 29
Table 3: Effect Pickup machines have on density Profile .................. 32
Table of Figures

Figure 1: Density Profile Layout .......................................................... 6
Figure 2 and 2A: Uniform Temperatures During the Paving ...................... 10
Figure 3 and 3A: Uniform Temperatures During the Paving ....................... 12
Figure 4 and 4A: Uniform Temperature at a Stop/Start Point ...................... 13
Figure 5 and 5A: Aggregate Segregation .............................................. 14
Figure 6 and 6A: Longitudinal Temperature Streaking .............................. 16
Figure 7: Cool Spots ............................................................................ 17
Figure 8 and 8A: Typical Stop/Start Point ............................................. 18
Figure 9 and 9A: Minimal Temperature Differences at Stop/Start Point ........ 19
Figure 10 and 10A: Stop/Start Point Lasting over 30 Minutes .................... 20
Figure 11 and 11A: Old/Cold Windrow Pile (before Paving) ....................... 21
Figure 12 and 12A: Old/Cold Windrow Pile (after Paving) ......................... 22
Figure 13 and 13A: Emptying Paver wings during paving ......................... 23
Figure 14 and 14A: Clamshelling Effects on the Mat ............................... 25
Figure 15: Waste/Cold HMA Piles ..................................................... 26
Figure 16: Effect the Waste/Cold HMA Piles have on the Mat ..................... 26
Figure 17: Temperature Differences vs. Density Differences ....................... 30
Figure 18: Mix Type in Relation to Temp/ Density .................................... 31
Figure 19: Pickup machine vs No Pickup machine in relation to Temp/Density 32
Figure 20: Haul Time vs Temperature Change ....................................... 33
Figure 21: Lift Thickness vs Density Differences .................................... 34
Chapter 1

Executive Summary

In 1999 the Minnesota Department of Transportation (Mn/DOT) joined the California, Texas, and Washington State Departments of Transportation in forming a research partnership. The partnership was named the State Pavement Technology Consortium (SPTC). The consortium was formed to share information on pavement practices including design, rehabilitation, decision-making, and research. Specific to research the consortium is concerned with how pavement orientated studies are identified, conducted, funded, and implemented.

The main objective of this paper was to gather infrared temperature and density data on a number of Minnesota Hot Mix Asphalt (HMA) paving projects in the 2000 construction season to investigate the effects, if any, temperature segregation has on the paving process and the resulting pavement compaction. The second objective was to collect specific information related to the construction such as the type of mix, the equipment used in the construction process, and environmental conditions and the effects they may have on the paving process and the resulting pavement compaction.

One of the main problems facing the asphalt paving industry is hot mix asphalt segregation. Segregation is generally put into two categories, one is aggregate segregation and the other is temperature segregation. In aggregate segregation there is a concentration of either coarse or fine material in some areas of the paved mat. These areas are often characterized by different surface textures from the surrounding material and can usually be seen by the naked eye. Temperature segregation is the isolated pockets of different temperatures created in the paving process. These areas may or may not produce irregularities in the mat that can be seen. Stroup-Gardiner and Brown
(1) have come up with a more thorough definition of segregation: “Segregation is the lack of homogeneity in the hot mix asphalt constituents of the in-place mat of such a magnitude that there is a reasonable expectation of accelerated pavement distress(es).” Previous research from the Washington Department of Transportation (WSDOT), NCAT and others has suggested that there is a correlation between material segregation and temperature differentials created in the paving process. Temperature differentials greater than 25°F can cause areas of cooler material not to be compacted to the same densities as the surrounding warmer material. These areas can exhibit poor structural and textural characteristics, poor performance and durability, and can have shorter life expectancy and higher maintenance costs.

The identification of these temperature differentials is captured with the use of a thermal imaging infrared camera. All objects no matter their temperature emit radiation. Measuring this radiation emitted allows you to determine the temperature of any and all points in the viewing spectrum of the camera. The temperature segregation will show up as different colors representing areas of different temperature. After a maximum predetermined temperature differential has been exceeded additional testing and inspection can be performed to determine the level of distress that may or may not be present.
Chapter 2

Determining and Conducting Density Profiles

General

This test method provides a procedure for determining the in-place density of compacted asphalt concrete pavements using an infrared camera to select the location of the density profile. Density measurements are made using a nuclear density gauge. A density measurement shall be the average of two density readings taken at the same location at 90° from each other. The readings shall agree within 1.0 lbs/ft³ of the average to be valid. This method was modified for the Minnesota Department of Transportation from work developed by both the Washington and Texas Department of Transportation.

The criteria for choosing the location of a density profile is based on the variation in temperatures at an area in the newly paved asphalt mat prior to its compaction. The criteria is:

- $\Delta T \geq 25^\circ F$-Perform Density Profile
- $\Delta T \leq 25^\circ F$-Perform Normal quality control testing

A two-person team is required to complete the testing. One person operates the infrared and digital cameras, and identifies the areas that require a density profile. The other person acts as a vehicle spotter, records data on data sheets, marks the areas identified for density profiles, and operates the nuclear density gauge.

The following equipment is used during the field-testing:

- Infrared digital camera
• Nuclear density gauge
• Digital camera
• Site Data Form (siteform.doc)
• Nuclear Density Gauge Form (densityprofile.xls)
• 100 ft measuring tape
• One yard stick
• Marking paint
• Keel/road crayon

Determining the Location of the Density Profiles

The general procedures for identifying the location of the density profiles is outlined below:

1. Take one set of infrared and digital visual images of each of the following for each site:
   • Mix being dumped by plant into a truck
   • Existing surface in front of paver
   • Truck bed or windrow pile
   • Paver hopper
   • Screed extender

2. Take one set of infrared and digital visual images of the mat to indicate mat rolling temperatures as follows:
• Image immediately prior to breakdown rolling
• Image immediately prior to intermediate rolling
• Image immediately prior to finish rolling

3. Take infrared and digital visual images of the mat, and search for locations to perform density profiles
• Stand within 30 feet behind the screed of the paver.
• Look towards the paver and view the entire lane.
• Adjust the camera to include the high and low temperatures.
• Scan the fresh pavement for any cool spots on the mat. Infrared images should be taken as noted below in areas that have not been compacted, and have not been on the pavement for more than 1 minute.
  ♦ If a temperature differential of 25°F or more exists, Mark the spot with the yardstick. Take an Infrared and digital image of the same location using the yardstick as a reference. Determine the transverse offset from the edge of the pavement to this spot. This will become the zero foot point of the density profile, which will be performed after the mat has been completely compacted.
  ♦ If the temperature difference is less than 25°F, perform normal quality assurance testing.
• Infrared images and density profiles should also be performed in areas of noticeable visual segregation and anytime there is a stop/start of the paving operation. The procedure is the same as the above.
Density Profile Procedure

After the identified and marked points for the density profiles have been compacted completely then begin the density profile testing. A density profile is described as a 50-foot line placed longitudinally on the mat with density readings taken approximately every five feet. Density readings will not be located within the outer 24 inches of the mat. See Figure 1.

1. Return to a marked zero point and layout the rest of the profile on the mat:

- Measure the transverse offset from the edge of the pavement. The entire profile will maintain this offset. However, visually observe the mat and include segregated areas adjacent to the profile by adding additional test points and note their offset and location in the profile.

- Mark the first test points 10 feet from the zero point in the opposite direction that the paver is paving.

- Mark the rest of the test points every five feet moving the direction the paver is paving for a total of 10 points minimum. Therefore, the profile extends from −10 feet to 35 feet at a minimum. See Figure 1.

**Figure 1- Density Profile Layout**

---

- Low Temperature Area
- Paver Direction

---
2. Place the nuclear density gauge on a test point and make sure the gauge lies flat on the mat and does not wobble.

- Take two one-minute readings at 90° apart with the nuclear density gauge, in the same location, and record the readings.

- Before moving the gauge average the two readings. Compare each individual reading to the average. If either of these readings vary by more than 1.0 lb/ft³ from the average, take additional readings until two readings have been obtained that are within 1.0 lb/ft³ of the average and discard all other readings.

- Move the gauge approximately five feet in the direction of paving and take the next reading. If a segregated area is visible in between the 5-foot distance, take an additional set of readings at that location.

- Repeat this procedure until a minimum of ten sets of two readings has been completed.

- An additional density profile should be performed in a uniform area within 5 feet of the original profile.

- A minimum of three density profiles should be performed per day.
Chapter – 3

Field Observations

General Observations

Mn/DOT, office Materials and Road Research office created 22 Infrared Image Analysis/Nuclear Density Gauge Reports from September to November of 2000. The 22 reports were created from 16 paving projects spanning 6 of the 8 Mn/DOT districts. Multiple reports were done if a paving change took place or if data was collected during a different day. See the Appendix for a table showing a summary of the reports and for detailed infrared reports with field observations. Each report analyzes a new asphalt mat over a 3 to 6 hour period on one day, with one type of asphalt mix, and on one short section of one road. Table 1 summarizes the 22 reports of the 16 individual paving projects.

Table 1 – Summary of reports

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Infrared Reports</td>
<td>22</td>
</tr>
<tr>
<td>Number of Individual Projects</td>
<td>16</td>
</tr>
<tr>
<td>Projects using Pickup Machine</td>
<td>11</td>
</tr>
<tr>
<td>Projects not using pickup Machine</td>
<td>5</td>
</tr>
<tr>
<td>Average Haul Time (one way)</td>
<td>27.4 min</td>
</tr>
<tr>
<td>Average Ambient Air Temp</td>
<td>56.5°F</td>
</tr>
</tbody>
</table>

The weather during the data collection was generally calm with temperatures ranging from 80°F in September to 20°F in November. Project SP 6810-06 had the most extreme weather conditions that we visited with ambient air temperatures of 40°F and 20-mph winds. The coldest temperatures encountered were in early November on
Project SP 2408-18 with ambient air temperatures of 20°F. Otherwise, the average weather was 56.5°F with less than 5-mph winds.

The following observations are based on 22 infrared reports and 16 site visits. It is important to realize that these observations are based on a limited set of data and does not represent each job in its entirety. Transverse temperature profiles are shown on the individual pictures even though the density profiles were collected longitudinally.

**Uniform Temperatures**

Figure 2 and 2A below shows a typical mat paved using a windrow elevator with uniform temperatures. The transverse temperature differentials on lines LI01 and LI02 are both about 11°F.

**Figure 2: Uniform Temperatures during Paving IR Image**

(IR image A0913-12, SP 5203-84)
Figure 3 and 3A is an example of uniform temperature of a mat paved using an end
dump operation. Line LI01 has a transverse temperature differential of 18°F. Line LI02
has a temperature differential of 33°F. This difference in differentials is due to the yellow
spots that occur only in the outer two feet of the mat. These cooler spots were typical on
this job. Usually the temperature differential will occur across the entire width of the mat
versus just at the outer edges.
Figure 3: Uniform Temperature during Paving IR Image

(IR image A0831-04, SP 2762-12)

Figure 3A: Uniform Temperature during Paving Digital Image
Figure 4 and 4A is a typical image of a stop/start point that was only a few minutes long on a mat that was paved using a windrow elevator. The transverse temperature differential in line LI01 and L102 is about 10°F and 12°F respectively. The difference in longitudinal temperatures between the old and new mats is about 19°F. This was about a 5-minute long stop for the paving operation.

**Figure 4: Uniform Temperatures at a Start/Stop point IR Image**

(A0908-09, SP 1905-24)

![IR Image](image)

**Figure 4A: Uniform Temperatures at a Start/Stop point Digital Image**

![Digital Image](image)
Non-uniform Temperatures

Aggregate segregation was not a significant problem on any of the 22 sites visited. However, there were instances where a part of a mat would have a coarse and more open surface texture.

Figure 5 and 5A shown below, are examples of a coarse spot in the mat. The yardstick in both the IR image and the digital image mark the exact same spot. In the IR image the yardstick can be seen just above line LI01 with the right tip at the cool spot. In the digital image the yardstick can be seen with the right tip at a coarse spot that has a more open surface texture. There is about a 50°F temperature differential between the segregated area and the rest of the mat.

Figure 5: Aggregate Segregation IR Image

(IR image A0912-10, SP 3208-17)
Figure 6 and 6A show an example of longitudinal temperature differentials creating in the paving process. Note the air temperature was in the 70°F and the paver rarely stopped. This longitudinal temperature streaking was consistently occurring in every part of the mat with temperature differentials from 30 to 50°F. This type of temperature differential is usually caused by poor paver adjustment.
Figure 6: Longitudinal Temperature Streaking IR Image

(IR image A0912-08, SP 3208-17)

![IR Image A0912-08, SP 3208-17](image)

Figure 6A: Longitudinal Temperature Streaking Digital Image

![Digital Image](image)
Figure 7 shows cool spots occurring during the paving process. The temperature differentials caused by these cool spots are around 50°F. This pattern is consistent, but the severity of the temperature differential varies with every truckload. At times the temperature differential will only be 20 to 30°F. These cool spots are usually associated with much cooler material being passed through the paver or cooler material being dropped in front of the paver and not being mixed in with the new material.

**Figure 7: Cool Spots IR Image**

(IR image A1002-07, SP 2786-119)

Figure 8 and 8A show a typical stop/start point. Line LI02 and LI01 have temperature differentials of only 10°F and 25°F respectively. The difference in temperature between the old and new mat is about 40°F. In this instance the paver sat still for about 5 minutes waiting for a new truck of mix.
Figure 8: Typical Stop/Start point IR Image

(IR image A0920-06, SP 6810-06)

Figure 8A: Typical Start/Stop Points Digital Image
Figure 9 and 9A is an example of a stop/start point that has minimal temperature differences between the old and new mats. Spots SP04 and SP05 are on opposite sides of the screed mark and have about the same temperature of about 290°F. The screed mark is at spot SP01. The paver only stopped long enough to switch trucks. Line LI01, which goes through the cool spot, has a temperature differential of 31°F. The ambient air temperature was around 80°F. The trucks did not use tarps, and the haul time was about 40 minutes.

Figure 9: Minimal Temperature Differential at Stop/Start Point IR Image

(IR image A0831-03, SP 2762-12)
Figure 9A: Minimal Temperature Differential at Stop/Start point Digital Image

Figure 10 and 10A show a 30 minute stop/start point paved using a windrow elevator. The paving was done in 56°F weather with calm winds. The temperature differential between the old and new mat is 77°F.

Figure 10: Start/stop point lasting over 30 Minutes IR Image

(IR image A0926-16, SP 3604-64)
Figure 10A: Start/stop lasting over 30 Minutes Digital Image

Figure 11 and 11A show a windrow of mix while the paver is stopped and is waiting for a new load of mix. Spots SP01 and SP02 show temperatures of 131 and 172°F respectively. The following Figures 12 and 12A are the result of this windrow coming out the paver.

Figure 11: Old/Cold Windrow Pile (before paver) IR Image

(IR image A0926-06, SP 3604-64)
Figure 11A: Old/Cold Windrow Pile (before paver) Digital Image

Figure 12 and 12A show a cool pattern that was caused by the paver consuming the end of the old and cold windrow pile from figures 11 and 11A. The paver paves a cool pattern with a minimum temperature of 198°F and a transverse temperature differential of 40°F.

Figure 12: Old/Cold Windrow Pile (after paver) IR Image

(Image A0926-01, SP 3604-64)
Figure 12A: Old/Cold Windrow Pile (after paver) IR Image

Figure 13 and 13A is an example of a stop/start point during which the paver operator completely emptied the paver hopper by elevating the hopper wings just before stopping. The paver stopped at SP01. The cool patterns occur just before, during, and after the stop/start point. The transverse temperature differentials in lines LI01 and LI02 are 77°C and 57°C respectively.

Figure 13: Emptying Paver Wings during Paving IR Image

(IR image A0915-09, SP 62-633-02)
Figure 13A: Emptying Paver Wings during Paving Digital Image

Figure 14 and 14A show a typical fan pattern caused by elevating the wings of the paver hopper in order to consume the cool stagnant asphalt mix that collects in the wings otherwise known as clamshelling. The lowest temperature in the cool spots is around 180°F. The temperature differential transversely across the mat is about 56°F. Once the stagnant mix is consumed the paver again becomes consistent with an 18°F transverse temperature differential.
Figure 14: Clamshelling Effects on the Mat IR Image

(IR image A1013-07, Olmsted project C104-00-06)

Figure 14A: Clamshelling Effects on the Mat IR Image
Figure 15 shows a waste pile of asphalt before paving is done on it. In this case a skid steer made a straight edge on the merge lane that was just paved on the right side of the image. The excess asphalt was neatly put into a windrow along with additional material added for the paver to complete this lane. The resulting mat is shown in figure 16.

**Figure 15: Waste/Cold HMA Piles Digital Image**

(Picture 53, SP 2762-12)

Figure 16 shows the new mat that was created when the paver paved over the waste pile of asphalt from figure 15. The cool streak marks the exact location where the material was placed. The minimum temperature is 155°F. Line LI01 has a 112°F transverse temperature differential.
Figure 16: Effect the Waste/Cold HMA Piles have on the Mat IR Image

(IR image A0830-17, SP 2762-12)

Night Paving

Only one state project was investigated in order to observe the effects of night paving. Data was collected on two consecutive nights and two Infrared Image Analysis/Nuclear Density Gauge Reports were made. The state project was SP 2786-119 filmed on 10/01/2000 and 10/02/2000.

This was an end dump operation. The ambient air temperature was in the low 60°F with no wind on both nights. In general there were no unusual temperature anomalies other than the typical cyclic temperature patterns seen on this kind of operation. The plant was less than 5 miles away, and the one way travel time for the trucks was less than 10 minutes. The trucks did not use tarps, but the mix delivered was hot and still uniform in temperature. The paver hopper and screed showed uniform temperatures. The transverse temperature profiles across the entire width of the mat were very uniform. Even at every stop/start point the temperature differential across the stop/start point
were 25 or 30°F. This was due in part to the trucks always being able to keep the paver moving and the close proximity of the plant for keeping the mix hot.
Chapter – 4

Results

The following is a discussion of the results found from the 16 individual projects visited and 22 Infrared reports that were generated. From the 22 reports, 64 density profiles were analyzed. It is important to point when viewing the results that two criterion were set forth by the State Pavement Technology Consortium to help evaluate the results of an individual density profile. The first is that the high minus the low-density readings could be no more than 6.0 lbs/ft³. The second is that the average minus the low-density readings can be no more than 3.0lbs/ft³. For the purposes of discussion and to eliminate any redundancy only the results from the high minus the low will be shown in the up coming graphs. The results from the average minus the low are very similar to those discussed and can be found in the appendix to this report. In analyzing this data it was important to compare a multitude of variables in order to help determine if any patterns were developing or if one variable has more impact then any other. Below is a list of comparisons and their individual results.

Percent of Density Profiles Passing or Failing the 25°F Temperature Criteria

<table>
<thead>
<tr>
<th>Table 2 – Density Profiles</th>
<th>( \Delta T &gt; 25^\circ F )</th>
<th>( \Delta T &lt; 25^\circ F )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Profiles</td>
<td>35</td>
<td>29</td>
</tr>
<tr>
<td>Failed both density criteria</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Passed both density criteria</td>
<td>17</td>
<td>27</td>
</tr>
<tr>
<td>Failed only high – low</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Failed only mean – low</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Percent passing</td>
<td>48.6%</td>
<td>93.1%</td>
</tr>
<tr>
<td>Percent failing</td>
<td>51.4%</td>
<td>6.9%</td>
</tr>
</tbody>
</table>
From table 2 above it can be seen that the density profiles that have temperature differences of 25°F or greater resulted in a 50% split of those passing and failing the density requirements. Of those having a temperature differential of less than 25°F, 93% passed the density requirements.

The results from the Washington State Department of transportation study found a stronger correlation between temperature differences greater then 25°F and density performance. They performed a total of 69 density profiles. Of the 69, 89% of those that temperature differentials of greater than 25°F failed the density criterion and 80% of those that had temperature differentials of less then 25°F passed the density criteria.

**Figure 17: Temperature Differences vs. Density Differences**

The results of the Figure 17 above generally show that as temperature differences rise the density differences increase along with them. There are several other points on this graph that do not follow this trend. These out lining points suggest that just because
temperature differences are high does not necessarily mean that density differences have to be high or that if temperature differences are low that you will not have large density differences. After reviewing these points individually we found no outstanding or unusual circumstances that would explain their deviation from the trend. These points show us that construction practices play a major role in the paving process and that even with high temperature differentials good paving practices can eliminate these high density differences and poor practices can result in high density differences at low temperature differentials.

Figure 18: Mix Type in relation to Temperature/Density

![Figure 18](image)

Figure 18 again looks at temperature differences vs. density differences but in relation to mix type. No significant conclusion can be drawn from this graph to suggest that mix type has an impact on density. It should be noted that not all mix types were represented equally or in large enough samples for comparisons.
Figure 19: Pickup Machine vs. No Pickup Machine in relation to Temperature/Density

Table 3 - Effect Pickup Machines have on Density Profiles

<table>
<thead>
<tr>
<th>Pickup Machine Vs. No Pickup Machine</th>
<th>$\Delta T &gt; 25^\circ F$</th>
<th>$\Delta T &lt; 25^\circ F$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pickup</td>
<td>No Pickup</td>
</tr>
<tr>
<td>Number of Profiles</td>
<td>24</td>
<td>11</td>
</tr>
<tr>
<td>Failed both density criteria</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>Passed both density criteria</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Failed only high – low</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Failed only mean – low</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Percent passing</td>
<td>54.2%</td>
<td>36.4%</td>
</tr>
<tr>
<td>Percent failing</td>
<td>45.8%</td>
<td>63.6%</td>
</tr>
</tbody>
</table>

Figure 19 and table 3 above also look at temperature differences vs. density differences but consider the effects using a pickup machine has on these properties. Although field observations suggest that using a pickup machine will result in a more uniform mat with
fewer occurrences of temperature differentials the results above show that there is a limited difference between the two processes. It is should be noted that this data considers only the density profiles performed and does not consider the number of occurrences of temperatures differences between the two processes. The table shows that if temperature differentials are held below 25°F there was greater than 90% passing the density criteria for either case. If temperature differences were greater than 25°F there was a 54% to 36% advantage to those passing the density requirement using a pickup machine.

Figure 20: Haul Time vs. Temperature Change

The results of figure 20 above do not show any significant impact haul time has on the temperature differentials experienced. There are short haul times with large temperature differentials and long haul times with small temperature differentials.
Figure 21 was developed to determine if there is a correlation between the lift thickness of the mat and the density differences encountered. The results of the graph seem to suggest that the thinner the lift the more potential there is to experience higher temperature differentials. Caution should be used in making a conclusion to this effect because there was a much larger sample of projects having 1.5” lifts. To make a fair comparison more jobs with thicker lifts should be studied.
Chapter – 5

Conclusions

The infrared camera worked very well as a tool to identify temperature variations in the mat. When compared to other thermometers and heat sensing guns the IR camera reads the same temperatures but also displays more useful information than heat sensing guns allowing the operator to see the temperatures on the entire mat instead of just one point. This allows the operator to easily understand the characteristics and locations of the temperature patterns.

Aggregate segregation was not a significant problem on any of the jobs that we visited but all of the jobs did exhibit areas of temperature segregation. On almost every density profile there was a reduction in density associated with the cool spots. In general it was observed that the densities dropped about 3 lbs/ft$^3$ at a cool spot compared to the surrounding mat. This observation suggests that the cool spots have a direct impact on the densities.

Typically it was observed that windrow operations were generally more uniform in temperature with fewer visual anomalies than the end dump operations. The windrow elevator can keep the paver moving at a constant rate eliminating the need to stop the paver to receive a new charge of mix to the paver hopper. This is dependent on the asphalt plant and asphalt trucks being able to deliver enough mix to keep the windrow in front of the paver. In an end dump operations a truck must dump its load into the hopper and is constantly starting and stopping each time the load of mix is consumed to switch trucks. This constant cycle often leads to more occurrences of cool spots. Although field observations have suggested that jobs using pick up machines may produce a more uniform mat because they are able to keep moving the results of the data show...
that if cool spots are observed there is virtually no difference between using a pickup machine or not using one.

After comparing some of the individual variables including mix type, haul time, and the type of paving operation none of these individually seem to make a significant impact on the paving process. While our data did not show that they individually had a significant impact they all play an important role in the paving process and have the potential to make a significant impact. After stating this there seems to be one variable that is hard to quantify that plays a significant role in controlling the development of temperature segregation which is using good construction practices. As can be seen from the data, even at high temperature differentials you can achieve low-density differentials with good paving practices and at low temperature differentials you can develop high-density differentials with poor paving practices.

Looking at both the results from Minnesota and Washington that if the temperature differentials can be held below 25°F there is a high probability that these areas will have little or no reduction in density from the surrounding area.

Based on the 16 sites visited it was observed that there are specific events that caused temperature segregation or mats with non-uniform temperatures. On sites where these specific events were minimized, or eliminated, the mat consistently had uniform temperatures with minimal cool spots. The following discusses each of these specific events.

- **Lack of remixing the asphalt mix between the asphalt delivery truck and the paver hopper.**

  It was observed that the cold crust that formed on the asphalt pile in the delivery truck does not uniformly mix with the rest of the hot interior mix when
it is transferred directly to the paver hopper. As a result cool spots appear in the mat.

- **Lack of using tarps on asphalt delivery trucks**

  It was observed that only one site used tarps to cover the asphalt pile in the delivery trucks. The crust of the asphalt pile in the truck bed will cool to various degrees depending on the weather conditions and the amount of time the asphalt pile sits. At times the difference in temperature between the crust and the interior mix was as great as 90°F. These observations suggest that minimizing the degree to which the asphalt crust cools will minimize the severity and occurrence of cool spots in the mat.

- **Allowing the paver to stop**

  It was observed that at every point that a paver stopped there was a varying degree of cool patterns in the mat. On a few end dump operations where the trucks were able to have the paver stop only long enough to switch trucks it was observed that these cool patterns were minimized greatly. The longer the paver has to sit the more time the old mat, which can not yet be rolled due to its proximity to the paver, will cool. Temperature differentials between the new and old mats at the stop/start points were observed as high as 70 to 90°F. The temperature of the old mat has been observed around 175°F. These observations suggest that limiting the amount of times and the length of time the paver has to stop will limit these temperature differentials at the stop/start points.
• Poorly adjusted paver settings

It was observed that some sites had mats with a lot of temperature streaks and other sites did not have temperature streaks. Yet the methods and equipment used would be exactly the same between the two sites. These observations suggest that the way the paver operator has the paver adjusted and the way that the paver is operated matters in the placement of a mat to obtain uniform temperatures. It has also been observed that when the paver operator realized that the mat was not uniform and that after making some adjustments to the paver the mat became much more uniform. These observations suggest that a correctly adjusted paver is necessary to limit the temperature variations that occur in a mat.

• Completely emptying the paver hopper and/or elevating the wings of the paver hopper in order to consume the stagnant mix that collects in the wings

It was observed that it is very common for asphalt mix to collect in the wings of the paver hopper, and that paver operators will elevate the wings of the hopper in order to dump this mix onto the longitudinal conveyor to the screed. When this occurs a cool spot will form on the mat in a butterfly or fanned pattern. This event is very predictable. If you dump the cool mix in the wings into the central conveyor a cool spot will form immediately thereafter. These observations suggest that the stagnant mix in the hopper wings should never be dumped into the asphalt mat. It should be left alone during the job and then wasted away from the pavement structure at different times during the day. Ideally paver hoppers should be designed to eliminate the collection of this stagnant mix.
• **Dumping cold asphalt into the paver hopper**

It was observed that the crust at the end of an old windrow pile was 100°F cooler than the new windrow that was just being placed. This occurred, because the paver had to stop in order to wait for more trucks to deliver asphalt mix. The paver left about 20 feet of the end of a windrow in front of it. When the paver resumed paving this cold mix came out as a cool pattern in the mat. The mix had cooled so much that the remixing action of the windrow elevator could not even the temperatures out. Also the temperatures were so much cooler in the entire pile that that section of mat was much cooler than the section of mat paved with new hot mix.

In other cases cold asphalt would be dumped into the paver hopper either by shovel or by a Bobcat skidsteer. This asphalt had been collected off of the ground and had cooled considerably while it sat. Once this mix was paved the mat contained cool spots with large temperature differentials.

These observations suggest that at no time should an old and cold pile of asphalt mix be dumped into the paver hopper. It will result in cool spots every time.

• **Paving over cold asphalt piles left on the road, which do not pass through the paver hopper, but get spread out by the paver screed only**

It was observed that waste asphalt piles would be left in front of the paver with the intent to have the paver screed level and blend this pile into the mix fed by the paver hopper conveyor. This waste asphalt never enters the paver hopper. The waste asphalt will be considerably cooler than the mix delivered
by the trucks. As a result a cool spot will form in the mat in the exact location that the waste asphalt was placed.

These observations suggest that asphalt should never be left on the ground in the path of the paver. If it occurs it should be shoveled off to the side of the paving area.
Chapter – 6

Recommendations

During the first phase of this study which was completed during the 2000 construction season it was determined that temperature segregation is occurring on Minnesota paving jobs and can easily be identified with the use of an infrared camera. Furthermore the cooler areas seem to have a direct impact on the density readings in the effected area.

In the second phase of the study which will take place in the 2001 construction season it will be important to concentrate on gathering a more representative sample of each of the areas of concern such as mix type, environmental conditions, air temperature, and others. Collection of this data will help determine if any one or all of these factors are a key contributor to large temperature differentials.

Specific to the density profiles we need to make sure that we not only take density readings in areas of temperature or aggregate segregation but we also need to take additional companion profiles in adjacent areas of uniform temperature and texture. The ideal situation would consist of taking a minimum of 6 density profiles per job, three in effected areas and three in areas of uniform temperature. This may not be feasible on every job do to time constraints but every effort should be made to complete as many accompanying profiles as possible.

It would also be beneficial to track these locations over the long run to help determine if these areas of temperature segregation and reduced density result in areas of premature distress.
Third phase of this study will be to implement the information gained in these studies into a quality control measure that can be used by both contractors and Mn/DOT to produce better long lasting asphalt pavement. The timeline for implementation of this third phase has not been set.
References

Appendix A

Infrared Density Profile Graphs
Appendix B

Summary of Field Data
### Summary of Visits

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Appendix C

Infrared Density Reports

A complete copy of all the individual infrared density reports can be viewed on the

Minnesota Road Research web site at:

www.mrr.dot.state.mn.us