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Robert C. Rea

Hamzeh Haghshenas

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Nebraska Department of Transportation

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Robert C. Rea, P.E.
Assistant Materials and Research Engineer
Nebraska Department of Transportation
Email: robert.rea@nebraska.gov

Hamzeh F. Haghshenas, Ph.D.
Materials and Research Engineer
Nebraska Department of Transportation
Email: hamzeh.haghshenas@nebraska.gov

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Late season paving is common and often performed in colder temperatures, which is the most challenging environment for attaining optimal in-place density/compaction The in-place density of asphalt pavement greatly affects the lifespan of the pavement. It is also a key factor in preventing major pavement distresses, such as rutting, cracking, stripping (due to water damage) and aging. This research project aims to evaluate and compare the effectiveness of different compaction, delivery, and mix design characteristics to ensure the optimization of in-place asphalt pavement density. To this end, various laydown methods (i.e., Standard Pick-up Machine (SPM) and Material Transfer Vehicle (MTV)) and compaction equipment (i.e., double drum steel rollers, pneumatic rollers, and combination rollers with both steel and pneumatic tires), using both static and vibratory modes were employed. In addition, the effect of different aggregate blend combinations (i.e., using less coarse ledge rock) and asphalt binders (i.e., PG 58V-34, PG 40-40, and PG 52-40) on in-place density were studied. Four test sections were constructed over four separate days of paving, during cold weather conditions. The in-place density was measured using four methods: 1) Conventional/traditional cut roadway cores, 2) Combination of Infrared Continuous Thermal Scanning (ICTS) with conventional/traditional cut roadway cores, 3) Pavement Quality Indicator (PQI), and 4) Rolling Density Meter (RDM) utilizing Ground Penetrating Radar (GPR). The obtained results were compared and contrasted to the current testing, acceptance and construction methods system at Nebraska Department of Transportation (NDOT) and recommendations for future construction specifications and best practices were presented.

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Abstract:

Late season paving is common and often performed in colder temperatures, which is the most challenging environment for attaining optimal in-place density/compaction. The in-place density of asphalt pavement greatly affects the lifespan of the pavement. It is also a key factor in preventing major pavement distresses, such as rutting, cracking, stripping (due to water damage) and aging. This research project aims to evaluate and compare the effectiveness of different compaction, delivery, and mix design characteristics to ensure the optimization of in-place asphalt pavement density. To this end, various laydown methods (i.e., Standard Pick-up Machine (SPM) and Material Transfer Vehicle (MTV)) and compaction equipment (i.e., double drum steel rollers, pneumatic rollers, and combination rollers (CR) with both steel and pneumatic tires), using both static and vibratory modes were employed. In addition, the effect of different aggregate blend combinations (i.e., using less coarse ledge rock) and asphalt binders (i.e., PG 58V-34, PG 40-40, and PG 52-40) on in-place density were studied. Four test sections were constructed over four separate days of paving, during cold weather conditions. The in-place density was measured using four methods: 1) Conventional/traditional cut roadway cores, 2) Combination of Infrared Continuous Thermal Scanning (ICTS) with conventional/traditional cut roadway cores, 3) Pavement Quality Indicator (PQI), and 4) Rolling Density Meter (RDM) utilizing Ground Penetrating Radar (GPR). The obtained results were compared and contrasted to the current testing, acceptance and construction methods system at Nebraska Department of Transportation (NDOT) and recommendations for future construction specifications and best practices were presented.

Chapter 1. Introduction

Asphaltic concrete (AC) is used in approximately 85% of paved roads and highways in Nebraska. AC has a vital role in the United States transportation infrastructure from both a safety and economic perspective. As a result, increasing the durability of asphalt pavements to prevent major damage and deterioration as well as minimizing the large cost of pavement rehabilitation and maintenance has been the focus of Departments' of Transportation (DOTs) for many years. Proper compaction and optimizing in-place pavement density are imperative to achieve high-quality, longer-lasting pavement structures.

Most DOTs specify asphalt pavement to be constructed at a minimum in-place density at 91 to 92.5% of its theoretical maximum density. However, it has been shown that with proper techniques, attaining densities of up to 95% are possible in most cases. Research studies have found that for every 1% increase in density, the roadway service life will increase an estimated 5%, up to as much as 15% [4]. This potential for improving and increasing pavement performance has become a primary focus of DOTs and the Federal Highway Administration (FHWA).

Many studies including the ones aforementioned have evaluated the effects of factors such as; in-place compaction equipment, laydown methods, material delivery, testing methods, and mixture design, on density of asphaltic pavement. However, through advances in testing and measurement technology, there is an opportunity for major advancements for real-time measurement methods to measure in-place density in a more rigorous manner, improve upon functional-structural performance expectations, and improve pavement construction quality in cold weather conditions.

1.1 Objectives

This research project objective was to evaluate and compare the effectiveness of different compaction, delivery, and mix design characteristics to ensure the optimization of in-place asphalt pavement density. To this end, various laydown methods (i.e., Standard Pick-up Machine (SPM) and Material Transfer Vehicle (MTV)) and compaction equipment (i.e., double drum steel rollers, pneumatic rollers, and combination rollers with both steel and pneumatic tires), using both static and vibratory modes were employed. In addition, the effect of different aggregate and binder variations, i.e., using less coarse ledge rock, and different binders PG 58V-34, PG 40-40, and PG 52-40 were studied. Four techniques including: 1) Conventional/traditional cut roadway cores, 2) Combination of Infrared Continuous Thermal Scanning (ICTS) with conventional/traditional cut roadway cores, 3) Pavement Quality Indicator (PQI), and 4) Rolling Density Meter (RDM) utilizing Ground Penetrating Radar (GPR) were used to measure the in-place density. It is worthy to note that 'optimization' in this study means finding a method that provides the most uniform and maximum in-place density/compaction of the asphaltic pavement.

1.2 Organization of Report

This report includes four chapters. After this introduction, Chapter 2 presents the mixture, equipment and testing facilities used in this study. Chapter 3 discusses the in-place density measured using different techniques for the sections constructed through different compaction, delivery, and mix design strategies. Finally, Chapter 4 summarizes the main findings and conclusions of this study.

Chapter 2. Mixtures, Equipment, Coring, and Test Sections

2.1 Mixture Design

The NDOT Type SLX mixture used in this study is a fine graded mix with a nominal maximum aggregate size (NMAS) of 0.375 inch (9.5 mm), 50 gyration @ N_{des}. This mixture contained 35% reclaimed asphalt pavement (RAP) material, a PG 58V-34 binder and an optimum binder content of 5.4% by weight of total mixture. This mix was produced in a continuous parallel flow drum plant. This type of SLX mixture is widely used in Nebraska for lift thicknesses of 1 to 3″. For this project, the lift thickness was 1.5″, and in a few areas it was thinned down to 1.25″ due to geometric elevation issues. One of the mix modifications in this study replaced the PG 58V-34 with softer binders (i.e., PG 40-40 and PG 52-40). With this change, the RAP content increased to 50% to accommodate the softer binders in an effort to prevent excessive softening of the mix. The other mix modification was an aggregate change that lowered the coarse crushed rock content by 10% and increased the natural sand content by 10%, essentially producing a finer graded mix. Table 1 summarizes the mixtures used in this study. The mix designs are described in Appendix A.

Table 1. Asphalt mixtures used in this study.

Mixture ID	Type	Mixture Composition
SLX_S	Standard SLX	PG 58V-34, 35% RAP
SLX_M_40-40_R50%	Modified SLX	PG 40-40, 50% RAP
SLX_S_58V-34_0.5	Standard SLX	PG 58V-34 with 0.5% higher binder content
SLX_M_52-40_R50%	Modified SLX	PG 52-40, 50% RAP
SLX_M_58V-34_LCR10%	Modified SLX	PG 58V-34 with 10% less crushed rock (LCR) (10% more washed sand), 35% RAP

2.2 **Equipment**

2.2.1 Construction Equipment

To construct the sections, two different delivery machines and three different roller compactors are utilized as shown in Table 2. The paver used on this project was a 2018 Caterpillar 1055F with SE60V screed.

Table 2. Equipment used in this study.

Equipment	**Brand**	**Image of Equipment**
Standard Pick Up Machine (SPM)	1996 Barber Greene BG650	

Material Transfer Vehicle (MTV)	2018 Weiler 2850B	
7 Tire Pneumatic Roller (Static and Vibratory)	Sakai GW751	
Combination Steel / Pneumatic Roller (Static and Vibratory)	2007 Ingersoll Rand SD77	
Double Drum Steel Rollers	2018 Caterpillar, CAT CB15	

2.2.2 Measuring Equipment

A variety of devices were used to measure the density and temperature of the asphalt layer. These devices included Infrared Continuous Thermal Scanner (ICTS), Pavement Quality Indicator (PQI), and Rolling Density Meter (RDM) – Ground Penetrating Radar (GPR). The ICTS was used to monitor real-time thermal profile of the road during the construction paving. The PQI and RDM-GPR were employed to measure the in-place density of the layers. The recorded densities were then compared to traditional coring and density measurement methods. Each device is briefly described in the following sections:

2.2.2.1 Infrared Continuous Thermal Scanner (ICTS)

In asphalt paving, optimal and uniform temperature of the asphalt materials is a crucial factor which can significantly affect pavement performance. As a result, a thermal visualization of the construction process provides important insights into the temperature consistency of the material and can open up new optimization potentials.

ICTS used in this study can produce a real-time thermal profile of the road during the construction paving. The manufacturer states that the IR temperature scanner (MTPS-100) covers a wide thermal profile of the built-in layer over a total width of up to 42′ (13 m). Although, this device does not directly deal with in-place density, thermal segregation can consequently result in insufficient in-place density. This can be detected in real time during the paving operation, by fully automatic visualization of the temperature. This quick detection of possible thermal segregation may provide an opportunity to take action and find a resolution for the segregated locations while paving. The infrared continuous thermal scanner used in this study is shown in Figure 1.

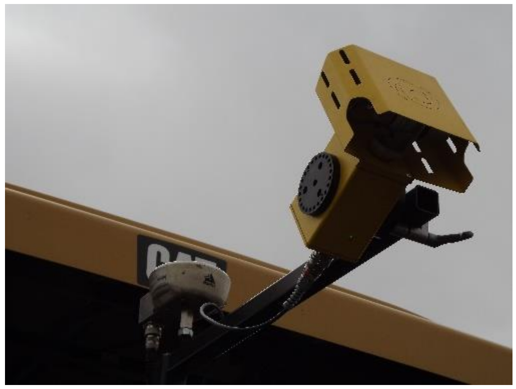


Figure 1. Infrared continuous thermal scanner (ICTS).

2.2.2.2 Pavement Quality Indicator (PQI)

The PQI 380 is a non-nuclear asphalt density gauge that utilizes an advanced GPS system which enables position and independent time logging. The PQI 380 conforms to ASTM standard D7113 and AASHTO T 343-12. Figure 2 shows the PQI device used in this study.

Figure 2. Pavement quality indicator (PQI).

2.2.2.3 Rolling Density Meter (RDM) – Ground Penetrating Radar (GPR)

Geophysical Survey Systems, Inc. developed the rolling density meter (RDM) for asphalt paving construction quality assurance/quality control. The RDM is operated on a manually propelled cart to collect the measurements from the field. It measures and records the dielectric constant of asphalt, through ground penetrating radar (GPR) sensors. The GPR sensors make continuous readings and then a concentrator box processes the collected data. Global positioning system (GPS) data can be recorded in conjunction with GPR data. A view of the RDM-GPR is shown in Figure 3.

Figure 3. Rolling density meter (RDM) – Ground penetrating radar (GPR).

2.3 **Coring**

The coring process was conducted the following construction day after each test section was constructed, the construction lanes remained closed until the cores were acquired. The coring locations were selected biasedly (highest and lowest temperature regions of asphalt pavement detected by ICTS) to see the effect of mixture temperature during the construction process and density readings were then taken by the PQI and RDM-GPR. Six-inch cores were taken from the selected areas as shown in Figure 4(a) and then were diamond saw cut at the lift line as shown in Figure 4(b) for laboratory density testing. Over 43 cores, a minimum of 3 per section, were taken.

(a) (b)

Figure 4. Field samples: (a) Coring 6″ diameter, (b) Cut cores for lab density testing.

2.4 Test Sections

There was a total of 13 sections constructed on Hwy 281 North of Hastings, Nebraska. The four-day project took place in October 2018. Two different delivery methods (Standard Pick-up Machine (SPM) and Material Transfer Vehicle (MTV)) were investigated in this study, along with several compaction methods as outlined in Table 3. It should be noted that the compaction procedure "Method 1" is the most common method currently used in the Nebraska. The modifications to the paving mix design studied are outlined in Table 1. The information regarding the type of mixture, delivery methods and compaction process employed in each section is summarized in Table 4. The length of test section varied from a minimum of 500 to 4500′.

Table 3. Different compaction methods utilized in this study (rolling patterns were sequential).

Method	Compaction Procedure
1	First pass: Breakdown double steel drum static, then vibratory after- Intermediate double steel drum, Finish: Double steel drum roller
2	First pass: Breakdown double steel drum static, then vibratory after- Intermediate **7 tire pneumatic static**, Finish: Double steel drum roller
3	First pass: Breakdown double steel drum static, then vibratory after- Intermediate **7 tire pneumatic vibratory**, Finish: Double steel drum roller
4	First pass: Breakdown double steel drum static, then break vibratory after- **Intermediate 7 tire pneumatic vibratory**, **combination roller vibratory**, Finish: Double steel drum roller
5	First pass: Breakdown steel drum static, then vibratory after- Intermediate, **combination roller vibratory**, Finish: Double steel drum roller

Table 4. Construction information and measuring devices used for each section.

Day	Date	Section	Delivery Method	Mixture (see Table 1)	Compaction Procedure (see Table 3)	Measuring Techniques
Day 1 Main Focus: *Effect of Different Delivery Methods*						
1	Oct 10	1	PSM	SLX_S	Method 1	ICTS, PQI, RDM-GPR, Coring
1	Oct 10	2	MTV	SLX_S	Method 1	ICTS, PQI, RDM-GPR, Coring
Day 2 Main Focus: *Effect of Different Compaction Methods*						
2	Oct 11	3	MTV	SLX_S	Method 1	ICTS, PQI, RDM-GPR, Coring
2	Oct 11	4	MTV	SLX_S	Method 2	ICTS, PQI, RDM-GPR, Coring
2	Oct 11	5	MTV	SLX_S	Method 3	ICTS, PQI, RDM-GPR, Coring
2	Oct 11	6	MTV	SLX_S	Method 4	ICTS, PQI, RDM-GPR, Coring
2	Oct 11	7	MTV	SLX_S	Method 5	ICTS, PQI, RDM-GPR, Coring
Day 3 Main Focus: *Effect of Different Asphalt Mixtures*						
3	Oct 15	8	MTV	SLX_M_40-40_R50%	Method 1	PQI, RDM-GPR, Coring
3	Oct 15	9	MTV	SLX_S_58V-34_0.5	Method 1	PQI, RDM-GPR, Coring
3	Oct 15	10	MTV	SLX_S	Method 1	PQI, RDM-GPR, Coring
Day 4 Main Focus: *Effect of Different Asphalt Mixtures*						
4	Oct 16	11	MTV	SLX_M_52-40_R50%	Method 1	PQI, RDM-GPR, Coring
4	Oct 16	12	MTV	SLX_M_58V-34_LCR10%	Method 1	PQI, RDM-GPR, Coring
4	Oct 16	13	MTV	SLX_S	Method 1	PQI, RDM-GPR, Coring

The climate conditions for each of the sections were recorded at the approximate midpoint of time during the paving of each section and are listed in Table 5. A ‘Real Feel’ factor was calculated by simply adding 10 °F to the calculated wind chill on sunny days for solar temperature gain. There was no allowance for solar gain on cloudy days. The 10 °F allowance was just an estimate. Note that the last two rows do not have a wind chill value, as by definition, a wind chill value cannot be calculated for temperatures greater than 50 °F. While the weather conditions varied, some of the coldest paving occurred on the first and second days, which worked out well for research purposes, as these were the 2 days that infrared continuous thermal scanner (ICTS) was used (the manufacturer had other obligations after the first 2 days). The warmest day of paving was the 4th day (Oct 16, 2018-section 13), with a high of 66 °F and sunny. Based on NDOT specification a minimum temperature of 45 °F is required for paving, and 32 °F when Warm Mix Additives (WMA) are used, and this mix contained a WMA additive (see mix design, Appendix A)

Table 5. Climate conditions for each section at the midpoint of paving.

Day	Date[1]	Section	Real Temperature (°F)	Wind (mph)	Direction	Wind Chill[2] (°F)	Sky[3]	Real Feel[4] (°F)
1	Oct 10	1	37	19	N	27	C	27
1	Oct 10	2	43	21	N	34	C	34
2	Oct 11	3	32	6	N	26	C	26
2	Oct 11	4	35	10	N	27	S	37
2	Oct 11	5	40	12	N	33	S	43
2	Oct 11	6	46	12	N	40	S	50
2	Oct 11	7	46	12	N	40	S	50
3	Oct 15	8	32	8	W	25	C	25
3	Oct 15	9	41	11	W	34	S	44
3	Oct 15	10	43	7	W	39	S	49
4	Oct 16	11	36	7	W	30	S	40
4	Oct 16	12	55	11	NW	-	S	-
4	Oct 16	13	66	11	NW	-	S	-

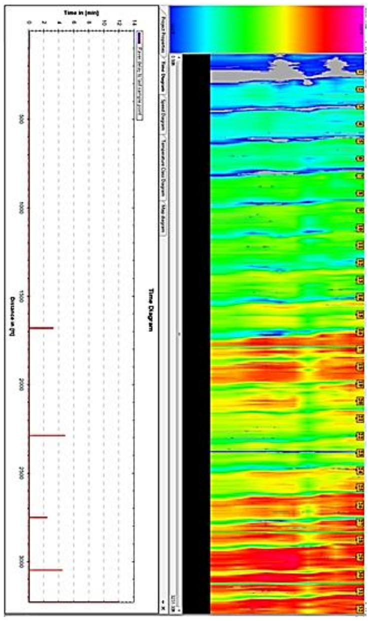
[1]Year: 2018
[2]Wind Chill (°F) = $35.74 + (0.6215 \times T) - (35.75 \times Wind_{sfc}^{0.16}) + (0.4275 \times T \times Wind_{sfc}^{0.16})$, T = air temperature (°F), $Wind_{sfc}$ = wind speed (mph)
[3]Sky: C = Cloudy and S = Sunny
[4]Real Feel: if the sky is cloudy, it is equal to wind chill otherwise it is wind chill plus 10 °F.

Chapter 3. Results and Discussion

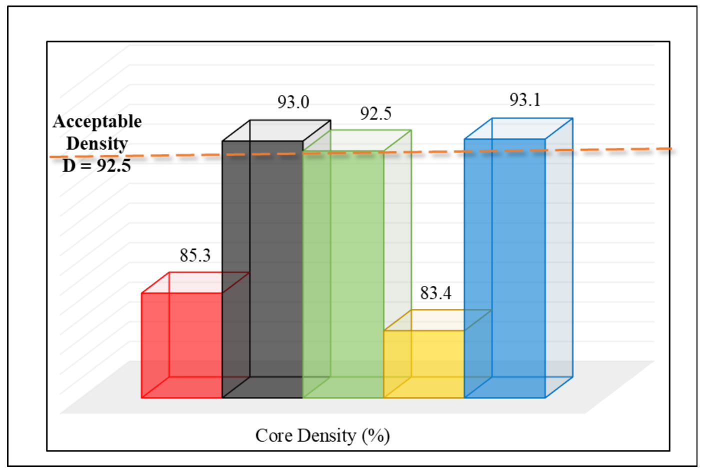
Thirteen different sections were constructed on the four days of the demonstration project. Two different delivery methods investigated in this study were: (1) Standard Pick-up Machine (SPM), and (2) Material Transfer Vehicle (MTV). In addition, different compaction methods (see Table 3) and measuring devices (i.e., ICTS, PQI, and RDM-GPR) were employed. It should be noted that the PQI and RDM-GPR both required a correction factor for density measured by each device. This correction factor is defined as "the average difference in density of cores for each section compared to that measured by each device (i.e., PQI and RDM-GPR) for the same section". It is important to note that the density cores were biasedly sampled based on either high or low densities and were not sampled randomly. The only random cores were those taken under the regular project acceptance system RSS (Random Sampling Schedule) which is a random sampling system that provides sampling for every 1000 ton sub-lot, five per lot for a 5000 ton lot size. Acceptance is based on minimum lot average of 92.5% of the theoretical maximum mixture density.

3.1 Day 1: Standard Pick-Up Machine vs Material Transfer Vehicle

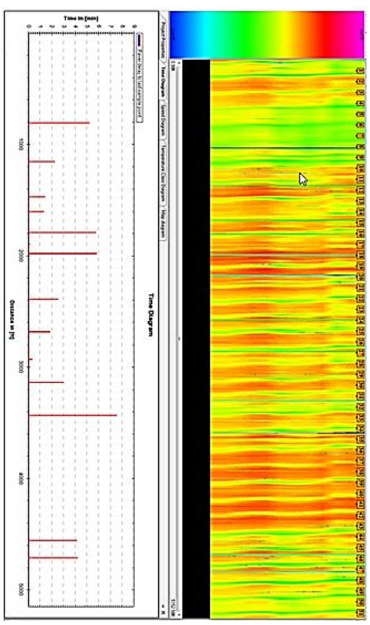
Day 1 began after a delay to wait for temperatures to rise above 32 °F. Two segments (section 1 and 2, see Table 4) were constructed. The weather conditions were very cold and windy, the weather conditions are listed in Table 5. Two different delivery machines were tested, a Standard Pick-up Machine (SPM) was used for the first half of construction and a Material Transfer Vehicle (MTV) was used on the second half. In both scenarios, attaining density was difficult and not achieved at several locations in biased (largest differential temperature) sampling. To obtain a real-time thermal profile of the road during the construction process, an ICTS was used. Figure 5 shows an example of the obtained thermal profile for the mixtures delivered by either SPM or MTV and the density of cores. The largest color variation would be from blue (coldest) to pink (hottest) as shown in the color legend at the top of each page of the scan. The images clearly show the SPM had the largest thermal segregation and also yielded the largest variance in density as shown in the bar graph to the right of the scan. Both bar graphs show the line of minimum average density of 92.5. For a 'single point' density, generally a density of 90 or above would be considered acceptable, conversely the two tests showing 83.4 and 85.3% would be considered not acceptable by all industry standards.



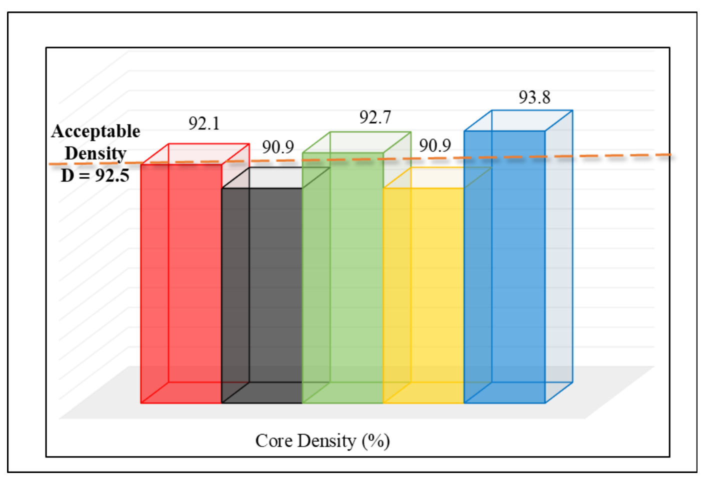
(a) SPM ICTS profile



(b) SPM In-Place Core density



(c) MTV ICTS profile



(d) MTV In-Place Core density

Figure 5. ICTS profile and single core density for mixtures delivered by SPM and MTV.

The ICTS thermal test segments were evaluated in 150′ sections. Sections with less than a 25 °F differential were rated as good, sections with 25 to 50 °F differential rated moderate and those over 50 °F rated as being severe. These criteria were based on manufacture's recommendation and typically used by DOTs. For the SPM, 22 sections were evaluated; zero sections rated good, 12 were moderate and ten were severe. For the MTV, 35 sections were evaluated; 13 sections rated good, 19 were moderate and three were severe (Table 6). Figure 6 provide this graphically, and illustrates the largest differences in 'good' versus 'severe' sections for each delivery method.

Table 6. Thermal profile results summary.

# of Profiles	**Good** Differential<25°F		**Moderate** 25°F<Differential≤50°F		**Severe** Differential>50°F	
	Number	%	Number	%	Number	%
SPM						
22	0	0	12	55	10	45
MTV						
35	13	37	19	54	3	1

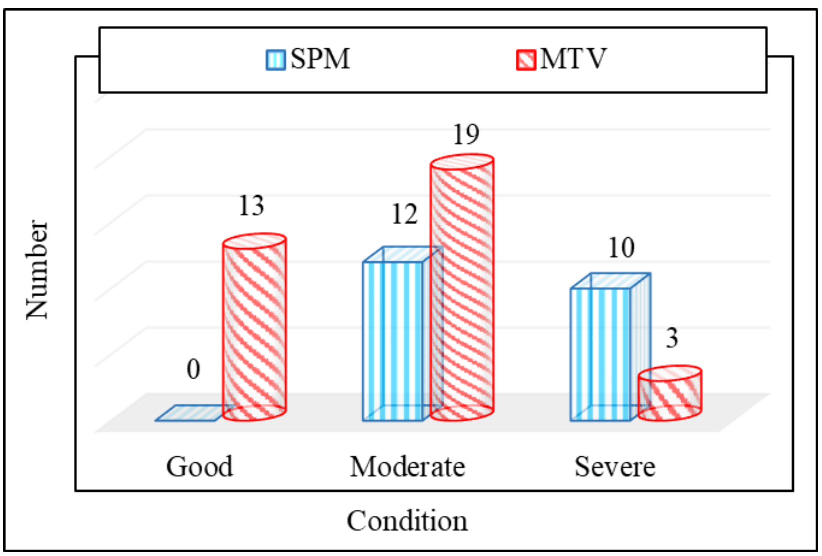


Figure 6. Comparison between MTV and SPM based on thermal differential rate.

Table 7 summarizes the results of each measuring devices' density against the actual roadway cores along with the thermal measurements for mixtures delivered by SPM and MTV. It should be noted that the RDM-GPR readings were not taken during the MTV section because of some battery issues that occurred for the RDM-GPR, due to the morning delays from the cold weather. The batteries ran out of power and there were no back up batteries. The results indicate that a sharp drop in temperature leads to a decrease in density. Table 7 also shows that the performance of MTV was much better than the SPM delivery system.

Table 7. Core density information measured by different techniques and relevant temperatures.

Core Number	Density			Infrared Continuous Thermal Scanner (ICTS)	
	RDM-GPR (Corrected Density)	PQI (Corrected Density)	6" Core	Temperature (°F)	Temperature Differential (°F)
SPM					
1	89.5	89.6	85.3	216	38.7
2	89.2	90.2	93.0	250	38.7
3	89.2	90.2	92.5	244	48.8
4	90.1	87.3	83.4	190	66.8
5	89.3	90.1	93.1	269	66.8
Average	**89.5**	**89.5**	**89.5**	-	
MTV					
6	N.R	92.1	92.1	273	26.5
7	N.R	91.3	90.9	279	26.5
8	N.R	92.6	92.7	270	14.4
9	N.R	91.7	90.9	278	29.5
10	N.R	92.9	93.8	275	34.9
Average	**-**	**92.1**	**92.1**	-	

Figure 7 plots temperature versus density measured using the standard/conventional coring technique. Figure 7 displays a linear correlation with R^2 equal to 0.76 between density and temperature. It suggests that, under these paving and temperature conditions, a minimum material temperature of 250 °F (critical minimum) during compaction may promote densities of 90% or greater.

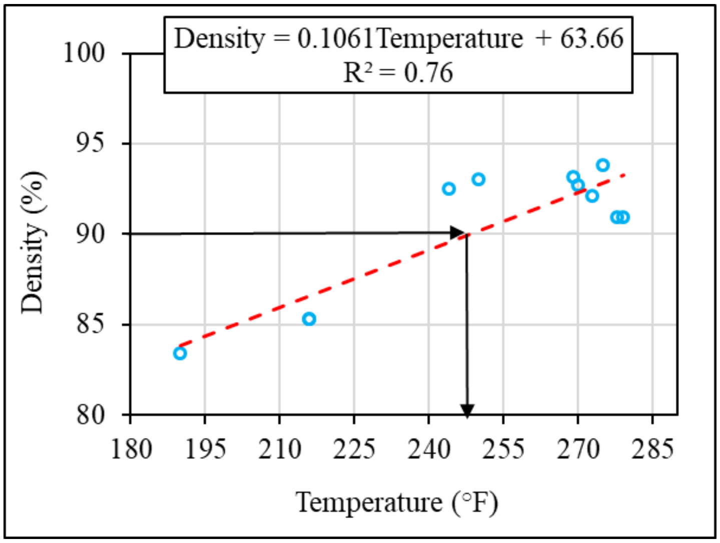


Figure 7. Correlation between temperature and in-place density of core samples.

3.2 Day 2: Compaction Equipment and Rolling Sequences

Day 2 began after temperatures rose above 32 °F. Five segments were constructed in these very cold temperatures. Each segment is defined in Table 4, sections 3 through 7. Same mixture type SLX was used in all segments. Different rollers were used in various combinations: (1) double drum steel rollers, (2) 7 tire pneumatic roller and (3) combination of double drum steel and 7 tire pneumatic roller. The average densities shown in Table 8, indicate that the pneumatic rollers help increase density. It was observed that the combination roller (CR, method 4 and 5 in Table 3) consistently increased density during all of spot checks during each roller pass, these readings were taken during compaction. The density results for the sections are listed in Table 8.

Table 8. Core density information measured by different techniques and the relevant temperatures.

Core Number	Density			Infrared Continuous Thermal Scanner (ICTS)	
	RDM-GPR (Corrected Density)	PQI (Corrected Density)	6" Core	Temperature (°F)	Temperature Differential (°F)
Compaction Method 1 *(see Table 3)*					
11	90.6	92.4	89.7	269	11.7
12	92.5	93.1	95.3	283	17.6
13	N.R	92.9	93.4	275	18
Average	**92.8**	**92.8**	**92.8**	-	
Compaction Method 2 *(see Table 3)*					
14	90.6	92.1	93.8	281	13.3
15	91.1	92.4	92.3	276	13.7
16	91.5	88.7	87.3	274	20.7
Average	**91.1**	**91.1**	**91.1**	-	
Compaction Method 3 *(see Table 3)*					
17	93.1	94.1	95.4	287	18
18	93.6	93.6	93.1	283	14.4
19	93.8	92.7	92.1	286	21.4
Average	**93.5**	**93.5**	**93.5**	-	
Compaction Method 4 *(see Table 3)*					
20	93.6	94.2	94.3	288	16.9
21	93.1	93.0	93.3	277	16.2
22	94.0	93.3	93.0	302	18.4
Average	**93.6**	**93.5**	**93.5**	-	
Compaction Method 5 *(see Table 3)*					
23	94.2	94.7	94.7	280	22.3
24	94.6	93.5	92.7	281	14.9
25	93.7	94.5	95.2	287	18
Average	**94.2**	**94.2**	**94.2**	-	

Another area that is worthy of discussion is thermal mass, which is equivalent to thermal capacitance or heat capacity; the ability of a body to store thermal energy. The importance of thermal mass in this study would be the function of heat loss. Heat loss is defined as the amount of heat per unit weight that a material loses or cools, the focus being on the heat loss during construction (before and during compaction). The heat loss can significantly affect the density of the asphaltic layer. It means that the higher heat loss may result in lower density and vice versa. For this study, the heat loss calculation is simplified by assuming all effective parameters do not change during construction, except mixture temperature during delivery and compaction. In general, Figure 8 shows that a decrease in heat loss results in an increase in density. There were a few results that varied from that (i.e., core number 19, 22, 23 and 24), but most followed that assertion. The green dash line in the Figure 8 shows the acceptance density based on the current standard of 92.5%. Without going into a detailed thermal analysis and assuming all other variables, (e.g., mix delivery temperature, environmental conditions - air, pavement temperature, wind speed, solar gain and etc.) are held constant, the thermal mass would then be simply based on temperature and mass. As a result, an increase in lift thickness from 1.5 to 2″ will essentially lead to 25% more heat mass. This provides a 25% longer compaction time before the material drops to the critical minimum compaction temperatures (i.e., 250 °F) as suggested in the earlier discussion (see Figure 7).

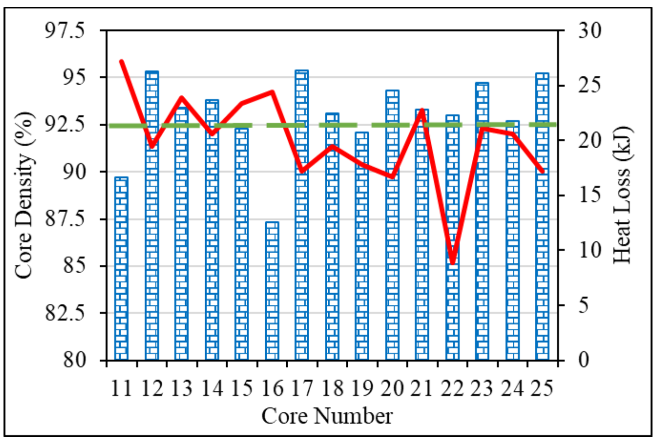


Figure 8. Core density (blue bars) versus heat loss (red line).

3.3 Day 3: Modified Mix Design and Binders

Similar to the first two days of paving, day 3 began after waiting for temperatures to rise above 32 °F. In this section the ‘Standard’ paving operations were used - Paver, MTV, and three steel double drum rollers. Three segments were constructed and the density readings of each segment are shown in Table 4 (sections 8 through 10).

In the first section, the SLX mixture was modified by using a PG 40-40 and 50% RAP (SLX_M_40-40_R50%). These modifications exhibited a visual appearance-change to the mix that added a very glassy black shiny look to the mix. In addition, there was a noticeable change to the fumes from the windrow, what could be described as a reduced petroleum-based smell. However, after compaction, this section appeared visually similar to the control sections. Increasing the RAP to 50% in the mixture, seemed to have reduced the softer binder effects to the combined mix. Therefore, the first section really did not experience a significant improvement to compaction. The decision to increase the RAP to 50% was based on preliminary laboratory testing that yielded similar indirect tensile strength results when compared to the standard/control mix, and resulted in very similar field workability and compaction. The standard SLX mix with 0.5% increased binder above the design target was used in the second section, this change did not provide significant changes to laydown or compaction. The density results for the sections are listed in Table 9.

Table 9. Core density information measured by different techniques.

Core Number	Density		
	RDM-GPR (Corrected Density)	PQI (Corrected Density)	6" Core
SLX_M_40-40_R50% *(see Table 1)*			
26	91.7	91.1	91.8
27	90.6	92.6	93.9
28	92.0	90.4	88.5
Average	**91.4**	**91.4**	**91.4**
SLX_S_58V-34_0.5 *(see Table 1)*			
29	91.3	89.2	86.3
30	90.6	91.2	92.0
31	90.3	91.6	93.7
Average	**90.7**	**90.7**	**90.7**
SLX_S *(see Table 1)*			
32	92.0	91.3	91.4
33	90.6	90.8	90.4
34	91.3	91.9	92.1
Average	**91.3**	**91.3**	**91.3**

3.4 Day 4: Modified Mix Design, Modified Gradation, and Binders

Day 4 began with no delay for temperatures. This section again used the ‘Standard’ paver, MTV, and three steel double drum rollers. Three segments were constructed and each segment built as defined in Table 4 (section 11 through 13). The SLX mixture was modified by using a PG 52-40 and 50% RAP (SLX_M_52-40_R50%). Similar to Day 3, the following observations were reported by field engineers, however, there may have been a slight reduction in density with the slightly stiffer 52-40 and 50% RAP as shown in Table 10.

(1) A visual appearance producing a glassy black shiny look to the mix.

(2) A noticeable change to the fumes from the windrow, seemed less petroleum-based smell.

(3) Similar appearance compared to the control sections after compaction.

In the second section, the coarse crushed rock was reduced by 10% and added 10% fine natural sand (SLX_M_58V-34_LCR10%). The obtained in-place density results, shown in Table 10, are in good agreement with field observations indicating that the laydown and compaction of SLX_M_58V-34_LCR10% mixtures were fairly similar to control mixture (SLX_S).

Table 10. Core density information measured by different techniques.

Core Number	Density		
	RDM-GPR (Corrected Density)	PQI (Corrected Density)	6" Core
SLX_M_52-40_R50% *(see Table 1)*			
35	91.7	91.2	90.2
36	91.5	90.9	90.7
37	91.1	92.0	93.4
Average	**91.4**	**91.4**	**91.4**
SLX_M_58V-34_LCR10% *(see Table 1)*			
38	93.0	93.8	93.3
39	93.5	93.9	93.6
40	94.5	93.5	94.2
Average	**93.7**	**93.7**	**93.7**
SLX_S *(see Table 1)*			
41	93.8	93.4	91.4
42	92.6	95.6	96.9
43	94.2	91.6	92.3
Average	**93.5**	**93.5**	**93.5**

3.5 **Correlations between Measuring Devices**

The sequence used in all of the measurement testing was as follows:

1) ICTS mapped all of the thermal imaging with GPS and stationing on day 1 and day 2.
2) During compaction the spot check of densities using the PQI were performed to see the effect of each compactor and help to establish rolling patterns.
3) After compaction was completed, the ICTS scan was used to identify high and low temperature thermal segregation areas which could result in high and low densities,
4) Then PQI was employed to verify the densities.
5) After PQI densities were completed, the RDM-GPR dielectric reading at each density location were recorded to verify the other readings/findings.
6) The standard 6" density cores were taken at each location.

It should be noted, on the first day of the Demo Project, intelligent compaction GPS device/screen (Figure 9) was used on the first two rollers, but only used for demonstration purposes.

Figure 9. GPS device used on Day 1 for demonstration only.

The average densities for each section measured by different techniques are shown in Figure 10. The results indicate that there is linear correlation between density measured using core samples with the other two techniques (i.e., RDM-GPR and PQI); however, the PQI technique shows better correlation compared to the RDM-GPR based on R^2 value.

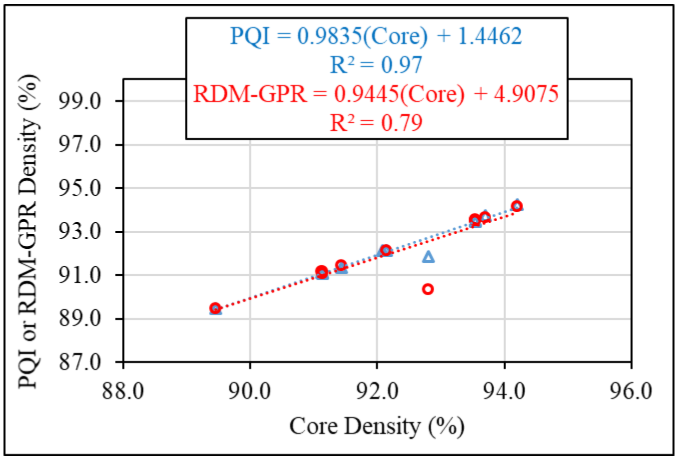


Figure 10. Comparison between core density and measured density using PQI (blue triangular), and RDM-GPR (red circle).

Although the PQI and RDM-GPR techniques showed good correlation with averaged densities, an evaluation of individual core densities, as shown in Figure 11, reveals that further testing and evaluation will be required.

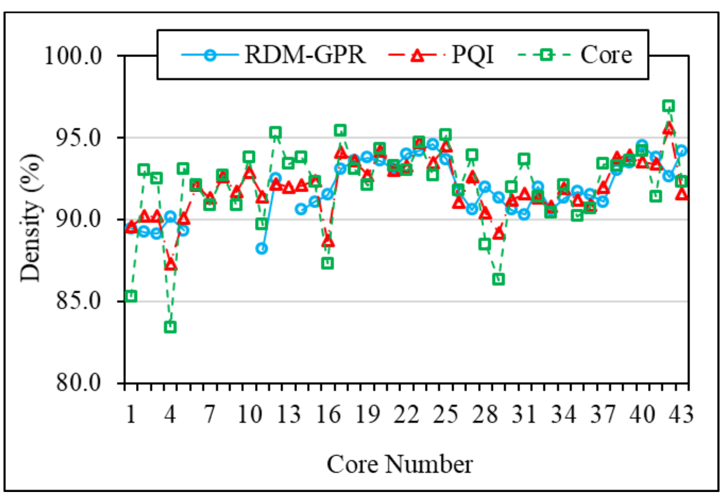


Figure 11. Comparison between measured density using Coring, PQI, and RDM-GPR.

3.6 **Performance of ICTS**

The ICTS performed satisfactory regarding locating thermal segregation and correlated with both high- and low-density areas. Figure 12 shows the correlation between asphalt layer temperature before compaction and density measured by coring.

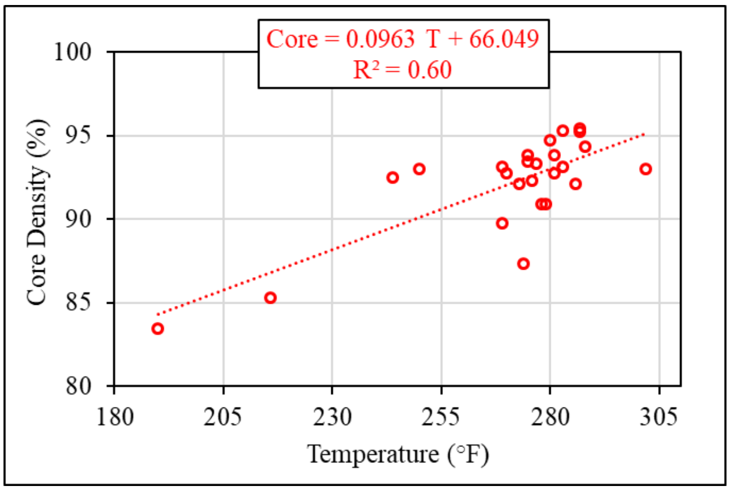


Figure 12. Correlation between temperature recorded by ICTS and density measured by coring.

3.7 **The Effects of Environmental Conditions on the Average Pay Factor**

Another finding was a parallel trend of better compaction with better environmental conditions. This was evaluated with a 'Real-Feel' factor that took into account solar gain along with temperature, and wind chill. For example, on a 'sunny' day, a 'Real-Feel' factor of +10 °F was added to the calculated wind-chill temperature. This was plotted against the lot average pay factor, as shown in Figure 13. As one would expect, better environmental conditions can provide better compaction.

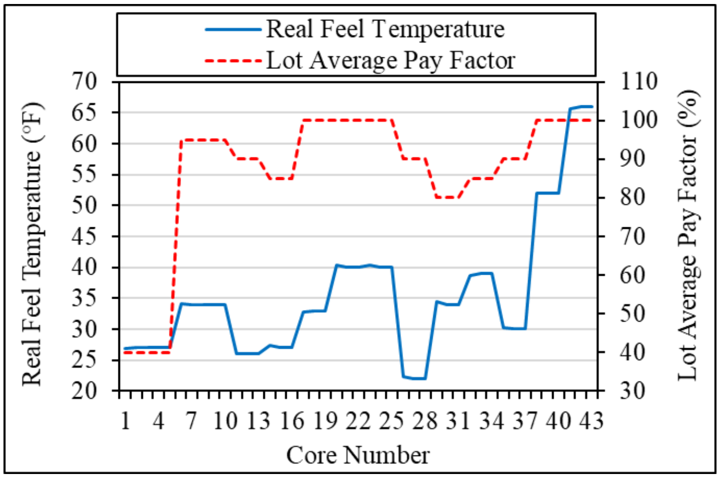


Figure 13. Trend of compaction with the environmental conditions.

3.8 **Current In-Place Density Acceptance Specifications**

The current Nebraska acceptance standard for in-place density requires that one test per 1000 tons of mixture is randomly sampled and the pay factor is based on a five test average for a 5000 ton lot. The result of this research revealed that the current acceptance methods could be strengthened. For example, the demo project was constructed during lot 6 and 8 resulting in a 100% pay factor according to the project specifications. However, selective/biased sampling density test results showed that there were several areas with substandard densities. For instance, in sub-lot sample 6-4 the density was 94.3% which is very good density which would be considered 100% pay in a full lot, however, the selective/biased sampling of this lot shows that the corresponding core number 16 has a density of 87.3% which is considered a failed density according to the current acceptance criterion (i.e., 92.5%). Table 11 summarizes the random project cores that coincided with the research sections.

Table 11. Comparison between densities measured for bias core and random core.

Core #	6" Core	Lot 6 Density	Lot 8 Density	Sample #	Core #	6" Core	Lot 6 Density	Lot 8 Density	Sample #
1	85.3				23	94.7			
2	93.0				24	92.7	94.0		6-5
3	92.5	91.3		6-2	25	95.2			
4	83.4				**Ave**	**94.2**			
5	93.1				26	91.8			
Ave	**89.5**				27	93.9			
6	92.1				28	88.5			
7	90.9				**Ave**	**91.4**			
8	92.7	92.1		6-3	29	86.3			
9	90.9				30	92.0		91.6	8-3
10	93.8				31	93.7			
Ave	**92.1**				**Ave**	**87.3**			
11	89.7				32	91.4			
12	95.3				33	90.4			
13	93.4				34	92.1			
Ave	**92.8**				**Ave**	**91.3**			
14	93.8				35	90.2			
15	92.3	94.3		6-4	36	90.7			
16	87.3				37	93.4			
Ave	**91.1**				**Ave**	**91.4**			
17	95.4				38	93.3			
18	93.1				39	93.6			
19	92.1				40	94.2			
Ave	**93.5**				**Ave**	**93.7**			
20	94.3				41	91.4			
21	93.3				42	96.9		94.1	8-5
22	93.0				43	92.3			
Ave	93.0				**Ave**	**93.5**			

Chapter 4. Summary, Overall Findings, and Conclusion

4.1 Summary

The in-place density of asphalt pavement is a major factor that prevents pavement distresses that may occur during its service life. Late season paving is common and often must be performed in colder temperatures, which is the most challenging environment for attaining optimal in-place density/compaction. This research project aimed to study and compare the effectiveness of different compaction, delivery, and mix design characteristics to ensure the optimization of in-place asphalt pavement density constructed in cold paving conditions and measured using different devices, methods, and techniques.

The ICTS, PQI, RDM-GPR, and core data look to be very useful for providing more measurement and testing data to strengthen the acceptance program for asphalt pavements. It was reported that the pneumatic rollers provided a slight increase in density, and the combination roller (CR) provided consistent improvement on every roller pass and provided an improvement to the 'Standard' three double steel drum rollers most commonly used in Nebraska. The research did not yield significant effects from the mix changes, binder changes, or aggregate change, as one would have thought. The use of softer binders, increased binder contents and aggregate changes have been shown to be beneficial in other research, however, some of the soft binder effects were definitely offset by the increased RAP content to 50%. The higher binder content of 0.5% and the gradation modifications did not exhibit noticeable compaction improvement. This is possibly due to the extremely cold conditions and/or that the modifications made in the control mixtures were not significant enough on the mix design to provide improvement to the in-place density.

4.2 Overall Findings

1) MTVs provide an effective method to minimize thermal segregation and therefore provide improved temperature and density consistency.

2) Pneumatic rollers provide an improved mode of compaction. More specifically the combination roller (CR) provided a consistent improvement compared to the 'Standard' three double drum steel roller compaction method.
3) Infrared continuous thermal scanning (ICTS) is an effective measuring technique that provides real-time information to the producer for improving temperature consistency that will result in more uniform densities.
4) RDM-GPR provides a continuous density measurement of the entire roadway. Further research and implementation studies with the R06C SHRP-2 research project that is currently underway at NDOT, will continue throughout 2019.
5) Heat loss is directly proportional to material mass, i.e., lift thickness. Therefore, lift thickness requirements need to be re-examined, especially for cold weather paving.
6) Random sample cores with averaging of 5 tests per lot dampens density variability compared to single test results. The use of non-destructive testing equipment could provide opportunities for a more rigorous acceptance procedure.
7) Consideration to the environmental conditions (temperature, wind, solar gain) can provide better pavement densities.

4.3 Conclusion

The Nebraska Department of Transportation (NDOT) is exploring specification improvements to in-place density by focusing on infrared continuous thermal scanning and changes to the in-place density testing, measurement and acceptance methods. These changes may include an increased frequency of density testing, use of single density test values versus lot averages, and a new incentive/disincentive quality pay factor. The NDOT is reviewing current lift thickness practices and making some initial changes. For example, the NDOT is designing multi-lift strategies with minimum 2" lift increments and most importantly top lifts of 2", as compared to the current standard of 1.5", which will improve in-place density in all conditions. Furthermore, for thin-lift strategies (1.5" or less), temperature conditions and delivery specifications need to be revised to include provisions to test thermal segregation along with an increased minimum compaction and ambient temperature requirements. As a result from these changes, an increased use of MTVs is quite probable. However, some restrictions may need to be applied on roadways that have structural weaknesses or have potential structural issues after milling of the pavement. This is due to the potential heavy axle loads of the MTV. For example, the MTV used in this study weighs 64 tons (128,000 lbs) when fully loaded, with a 2-axle suspension. This equates to 32 tons (64,000 lbs) per axle, an extremely high load that can damage pavements and subgrades, possibly breaking through in weak sections. A long-term concern of this would be micro-cracking that may not be visible during construction, but creates future wheel path cracking issues. As an outcome of this research, the NDOT will continue to move forward with these advancements in technologies and paving techniques to provide new opportunities for longer lasting/better performing pavements.

Appendix A

SLX_S

STANDARD MIX

State of Nebraska
Original Design #1-42432-SLX(VMA)RAS-18-MD
Department of Transportation
Asphalt Concrete Design

Project Manager: KEVIN KOHMETSCHER **Date:** 02-08-18 Approved
Project No: NH-34-4(130)
Name of Road: US-34, HASTINGS - DONIPHAN
Type of Asphalt Concrete: SLX

ASPHALT BINDER
Source: FLINT HILLS
Grade: PG 58V-34 w/0.7% AD-here (ArrMaz) LOF 65-00 w/Cecabase RT 945

Design No: 2018-1

GRADATION OF MATERIALS PROPOSED						SIEVE ANALYSIS (WASH)								
MATERIAL	PIT LOCATION					19.0	12.5	9.50	4.75	2.36	1.18	600	300	75
	%	1/4	SEC	T	R	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#200
3/8" DRY CHIPS	20	MARTIN MARIETTA				100.0	100.0	99.8	11.4	4.8	4.1	3.7	3.4	2.7
3A GRAVEL	30		36	9N	10W	100.0	100.0	100.0	92.5	52.3	28.0	16.1	10.1	4.7
WASH SAND	5		36	9N	10W	100.0	100.0	100.0	100.0	99.5	88.4	62.6	24.4	1.0
2A GRAVEL	5		36	9N	10W	99.0	96.0	91.7	60.6	7.1	1.8	0.7	0.4	0.2
RAS	5	MANUFACTURED SHINGLES				100.0	100.0	99.8	99.1	97.7	81.0	59.7	52.3	35.2
RAP	10	CONTRACTOR SUPPLIED				100.0	90.0	84.0	79.0	47.0	38.0	31.0	18.0	8.8
RAP	25	TATE SUPPLIED ON PROJEC				100.0	98.0	92.0	78.0	55.0	29.0	18.0	11.0	4.0
		COMBINED GRADATION				100.0	98.3	95.9	70.4	45.3	28.8	19.3	12.1	5.7
		SPECIFICATION RANGE					98	93	70.0	45	25	15	10	4
						100	100	100	87	65	41	31	21	10

JOB MIX IDENTIFICATION	
JMF #	13
TOTAL BINDER	5.40%

CONSENSUS PROPERTIES		FAA SP.GR.
FAA Results	44.4	2.593
Dust to Asph. Ratio	1.21	
Design Gsb	2.585	

Addition of 2.57% of type PG 58V-34 asphalt binder for a total of 5.40% (by wt.of mix) has been selected by the contractor to be the target asphalt binder content.

*No Hydrated Lime will be necessary for this design due to the use of 0.7% AD-here LOF 65-00 w/Cecabase RT 945.

This constitutes verification of the job-mix gradation and superpave criteria values proposed by the contractor. If it is necessary to change the job mix either before or after the job starts, including the asphalt binder %, the contractor shall notify the P.E. / P.M.

cc: Vontz Paving, Inc.
Cal Splattstoesser
Andy Dearmont
Robert Rea

REMARKS: **Please use a +0.1% correction for the asphalt binder content during construction. RR/jp**

Validated by Robert C. Rea & Materials and Research Division
Fax (402) 479-3882

SLX_M_40-40_R50%

Standard Mix using
Flint Hills PG 40-40 and
Increase RAP to 50%

State of Nebraska
*Experimental Design (See Remarks Section Below
Department of Transportation
Asphalt Concrete Design

Project Manager: KEVIN KOHMETSCHER
Date: 02-08-18 Approved
Project No: NH-34-4(130)
Name of Road: US-34, HASTINGS - DONIPHAN
Type of Asphalt Concrete: SLX
Design No: 2018-1

ASPHALT BINDER
Source: FLINT HILLS
Grade: PG 40-40

GRADATION OF MATERIALS PROPOSED						SIEVE ANALYSIS (WASH)								
MATERIAL	PIT LOCATION					19.0	12.5	9.50	4.75	2.36	1.18	600	300	75
	%	1/4	SEC	T	R	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#200
3/8" DRY CHIPS	15	MARTIN MARIETTA				100.0	100.0	99.8	11.4	4.8	4.1	3.7	3.4	2.7
3A GRAVEL	22		36	9N	10W	100.0	100.0	100.0	92.5	52.3	28.0	16.1	10.1	4.7
WASH SAND	4		36	9N	10W	100.0	100.0	100.0	100.0	99.5	88.4	62.6	24.4	1.0
2A GRAVEL	4		36	9N	10W	99.0	96.0	91.7	60.6	7.1	1.8	0.7	0.4	0.2
25	5	MANUFACTURED SHINGLES				100.0	100.0	99.8	99.1	97.7	81.0	59.7	52.3	35.2
RAP	25	CONTRACTOR SUPPLIED				100.0	90.0	84.0	79.0	47.0	38.0	31.0	18.0	8.8
RAP	25	STATE SUPPLIED ON PROJECT				100.0	98.0	92.0	78.0	55.0	29.0	18.0	11.0	4.0
		COMBINED GRADATION				100.0	96.8	93.6	72.7	46.9	31.2	21.9	13.6	6.4
		SPECIFICATION RANGE					98	93	70.0	45	25	15	10	4
						100	100	100	87	65	41	31	21	10

JOB MIX IDENTIFICATION		
JMF #	13	
TOTAL BINDER	5.40%	

CONSENSUS PROPERTIES		FAA SP.GR.
FAA Results	44.4	2.593
Dust to Asph. Ratio	1.21	
Design Gsb	2.585	

Addition of 1.82% of type PG 40-40 asphalt binder for a total of 5.40% (by wt.of mix) has been selected by the contractor to be the target asphalt binder content.

This constitutes verification of the job-mix gradation and superpave criteria values proposed by the contractor. If it is necessary to change the job mix either before or after the job starts, including the asphalt binder %, the contractor shall notify the P.E. / P.M.

cc: Vontz Paving, Inc.
Cal Splattstoesser
Andy Dearmont
Robert Rea

REMARKS: *Experimental Design using standard mix with Flint Hills PG 40-40 and increase RAP to 50%. RR/jp

Validated by Robert C. Rea & Materials and Research Division
Fax (402) 479-3882

SLX_S_58V-34_0.5

State of Nebraska

Standard Mix w/
BINDER INCREASE BY 0.5%

*Experimental Design (See Remarks Section Below)

Department of Transportation
Asphalt Concrete Design

Project Manager: KEVIN KOHMETSCHER
Date: 02-08-18 Approved
Project No: NH-34-4(130)
Name of Road: US-34, HASTINGS - DONIPHAN
Type of Asphalt Concrete: SLX
Design No: 2018-1

ASPHALT BINDER
Source: FLINT HILLS
Grade: PG 58V-34 w/0.7% AD-here (ArrMaz) LOF 65-00 w/Cecabase RT 945

GRADATION OF MATERIALS PROPOSED						SIEVE ANALYSIS (WASH)								
MATERIAL	PIT LOCATION					19.0	12.5	9.50	4.75	2.36	1.18	600	300	75
	%	1/4	SEC	T	R	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#200
3/8" DRY CHIPS	20	MARTIN MARIETTA				100.0	100.0	99.8	11.4	4.8	4.1	3.7	3.4	2.7
3A GRAVEL	30		36	9N	10W	100.0	100.0	100.0	92.5	52.3	28.0	16.1	10.1	4.7
WASH SAND	5		36	9N	10W	100.0	100.0	100.0	100.0	99.5	88.4	62.6	24.4	1.0
2A GRAVEL	5		36	9N	10W	99.0	96.0	91.7	60.6	7.1	1.8	0.7	0.4	0.2
RAS	5	MANUFACTURED SHINGLES				100.0	100.0	99.8	99.1	97.7	81.0	59.7	52.3	35.2
RAP	10	CONTRACTOR SUPPLIED				100.0	90.0	84.0	79.0	47.0	38.0	31.0	18.0	8.8
RAP	25	STATE SUPPLIED ON PROJECT				100.0	98.0	92.0	78.0	55.0	29.0	18.0	11.0	4.0
		COMBINED GRADATION				100.0	98.3	95.9	70.4	45.3	28.8	19.3	12.1	5.7
		SPECIFICATION RANGE					98	93	70.0	45	25	15	10	4
						100	100	100	87	65	41	31	21	10

JOB MIX IDENTIFICATION	
JMF #	13
TOTAL BINDER	5.90%

CONSENSUS PROPERTIES		FAA SP.GR.
FAA Results	44.4	2.593
Dust to Asph. Ratio	0.97	
Design Gsb	2.585	

Addition of 3.07% of type PG 58V-34 asphalt binder for a total of 5.90% (by wt.of mix) has been selected by the contractor to be the target asphalt binder content.

*No Hydrated Lime will be necessary for this design due to the use of 0.7% AD-here LOF 65-00 w/Cecabase RT 945.

This constitutes verification of the job-mix gradation and superpave criteria values proposed by the contractor. If it is necessary to change the job mix either before or after the job starts, including the asphalt binder %, the contractor shall notify the P.E. / P.M.

cc: Vontz Paving, Inc.
Cal Splattstoesser
Andy Dearmont
Robert Rea

REMARKS: *Experimental Design with 0.5% target binder increase from original approved mix design. RR/jp

Validated by Robert C. Rea & Materials and Research Division
Fax (402) 479-3882

SLX_M_52-40_R50%

Standard Mix using Flint Hills PG 52-40 and Increase RAP to 50%

State of Nebraska
Department of Transportation
Asphalt Concrete Design

*Experimental Design (See Remarks Section Below)

Project Manager: KEVIN KOHMETSCHER **Date:** 02-08-18 Approved
Project No: NH-34-4(130)
Name of Road: US-34, HASTINGS - DONIPHAN
Type of Asphalt Concrete: SLX
Design No: 2018-1

ASPHALT BINDER
Source: FLINT HILLS
Grade: PG 52-40

GRADATION OF MATERIALS PROPOSED						SIEVE ANALYSIS (WASH)								
MATERIAL		PIT LOCATION				19.0	12.5	9.50	4.75	2.36	1.18	600	300	75
	%	1/4	SEC	T	R	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#200
3/8" DRY CHIPS	15	MARTIN MARIETTA				100.0	100.0	99.8	11.4	4.8	4.1	3.7	3.4	2.7
3A GRAVEL	22		36	9N	10W	100.0	100.0	100.0	92.5	52.3	28.0	16.1	10.1	4.7
WASH SAND	4		36	9N	10W	100.0	100.0	100.0	100.0	99.5	88.4	62.6	24.4	1.0
2A GRAVEL	4		36	9N	10W	99.0	96.0	91.7	60.6	7.1	1.8	0.7	0.4	0.2
25	5	MANUFACTURED SHINGLES				100.0	100.0	99.8	99.1	97.7	81.0	59.7	52.3	35.2
RAP	25	CONTRACTOR SUPPLIED				100.0	90.0	84.0	79.0	47.0	38.0	31.0	18.0	8.8
RAP	25	STATE SUPPLIED ON PROJECT				100.0	98.0	92.0	78.0	55.0	29.0	18.0	11.0	4.0
		COMBINED GRADATION				100.0	96.8	93.6	72.7	46.9	31.2	21.9	13.6	6.4
		SPECIFICATION RANGE					98	93	70.0	45	25	15	10	4
						100	100	100	87	65	41	31	21	10

JOB MIX IDENTIFICATION			
JMF #	13		
TOTAL BINDER	5.40%		

CONSENSUS PROPERTIES		FAA SP.GR.
FAA Results	44.4	2.593
Dust to Asph. Ratio	1.21	
Design Gsb	2.585	

Addition of 1.82% of type PG 52-40 asphalt binder for a total of 5.40% (by wt.of mix) has been selected by the contractor to be the target asphalt binder content.

This constitutes verification of the job-mix gradation and superpave criteria values proposed by the contractor. If it is necessary to change the job mix either before or after the job starts, including the asphalt binder %, the contractor shall notify the P.E. / P.M.

cc: Vontz Paving, Inc.
Cal Splattstoesser
Andy Dearmont
Robert Rea

REMARKS: *Experimental Design using standard mix with Flint Hills PG 52-40 and increase RAP to 50%. RR/jp

Validated by Robert C. Rea & Materials and Research Division
Fax (402) 479-3882

SLX_M_58V-34_LCR10%

State of Nebraska

Standard Mix w/
10% LESS CRUSHED ROCK
10% MORE WASH SAND

*Experimental Design (See Remarks Section Below)

Department of Transportation
Asphalt Concrete Design

Project Manager: KEVIN KOHMETSCHER

Date: 02-08-18 Approved

Project No: NH-34-4(130)

Name of Road: US-34, HASTINGS - DONIPHAN

Type of Asphalt Concrete: SLX

Design No: 2018-1

ASPHALT BINDER

Source: FLINT HILLS

Grade: PG 58V-34 w/0.7% AD-here

(ArrMaz) LOF 65-00 w/Cecabase RT 945

GRADATION OF MATERIALS PROPOSED						SIEVE ANALYSIS (WASH)								
MATERIAL		PIT LOCATION				19.0	12.5	9.50	4.75	2.36	1.18	600	300	75
	%	1/4	SEC	T	R	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#200
3/8" DRY CHIPS	10	MARTIN MARIETTA				100.0	100.0	99.8	11.4	4.8	4.1	3.7	3.4	2.7
3A GRAVEL	30		36	9N	10W	100.0	100.0	100.0	92.5	52.3	28.0	16.1	10.1	4.7
WASH SAND	15		36	9N	10W	100.0	100.0	100.0	100.0	99.5	88.4	62.6	24.4	1.0
2A GRAVEL	5		36	9N	10W	99.0	96.0	91.7	60.6	7.1	1.8	0.7	0.4	0.2
RAS	5	MANUFACTURED SHINGLES				100.0	100.0	99.8	99.1	97.7	81.0	59.7	52.3	35.2
RAP	10	CONTRACTOR SUPPLIED				100.0	90.0	84.0	79.0	47.0	38.0	31.0	18.0	8.8
RAP	25	STATE SUPPLIED ON PROJEC				100.0	98.0	92.0	78.0	55.0	29.0	18.0	11.0	4.0
		COMBINED GRADATION				100.0	98.3	96.0	79.3	54.8	37.3	25.2	14.2	5.5
		SPECIFICATION RANGE					98	93	70.0	45	25	15	10	4
						100	100	100	87	65	41	31	21	10

JOB MIX IDENTIFICATION		
JMF #	13	
TOTAL BINDER	5.40%	

CONSENSUS PROPERTIES		FAA SP.GR.
FAA Results	44.4	2.593
Dust to Asph. Ratio	1.02	
Design Gsb	2.585	

Addition of 2.57% of type PG 58V-34 asphalt binder for a total of 5.40% (by wt.of mix) has been selected by the contractor to be the target asphalt binder content.

*No Hydrated Lime will be necessary for this design due to the use of 0.7% AD-here LOF 65-00 w/Cecabase RT 945.

This constitutes verification of the job-mix gradation and superpave criteria values proposed by the contractor. If it is necessary to change the job mix either before or after the job starts, including the asphalt binder %, the contractor shall notify the P.E. / P.M.

cc: Vontz Paving, Inc.
Cal Splattstoesser
Andy Dearmont
Robert Rea

REMARKS: *Experimental Design with 10% less crushed rock and 10% more sand from original approved mix design. RR/jp

Validated by Robert C. Rea & Materials and Research Division
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