Quantifying the Variability of Production of Asphalt Mixtures through newly implemented Performance Tests for the Wisconsin Department of Transportation

by

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Abstract

This study aims to determine an appropriate standard deviation of Balanced Mix Design performance tests for Wisconsin specifications based on field-produced mixes. Identifying variability is an essential aspect of the pavement materials and construction industry. Federal Highway Administration (FHWA) and State Department of Transportation (DOTs) quantify the variability of material properties to manage quality. Typical asphalt mixture properties measured to assess variability have been binder content, aggregate gradation, and mix volumetrics. New performance tests are being used to assess the quality of an asphalt mix. These new performance tests included in the balanced mix design are rutting and cracking indicators on an asphalt mix.

This study used mixtures from ten shadow projects from various locations across Wisconsin to obtain representative production variability data to determine the within-lot pooled standard deviation. For this study, two performance tests, Hamburg Wheel Tracking Test (HWTT) and Indirect Tensile Asphalt Cracking Index (IDEAL-CT), were performed for the mixtures from the ten shadow projects and their representative lots/sublots.

The analysis methods used to quantify the variability include the standard deviation, coefficient of variation, normality, outlier test, and cumulative distribution function of production standard deviations. The final conclusions of this study indicated that asphalt content was the least variable quality characteristic measured with a COV of 2.8%. The most variable quality characteristic measured was HWTT passes to 12.5 mm with a COV of 16.6%. IDEAL-CT had a mean COV of 13.1%. The mean COV for air voids was 10.4%. The mean COV for HWTT CRD20k was 10.9%.

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List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
BMD	Balanced Mix Design
CDF	Cumulative Distribution Frequency
COV	Coefficient of Variation
FHWA	Federal Highway Administration
HMA	Hot Mix Asphalt
HWTT	Hamburg Wheel Tracking Test
IDEAL-CT	Indirect Tensile Asphalt Cracking Test
NCAT	National Center for Asphalt Technology
PWL	Percent Within Limits
QA	Quality Assurance
QC	Quality Control
QI	Quality Index
QMP	Quality Management Program
QV	Quality Verification
WisDOT	Wisconsin Department of Transportation

Chapter 1 – Introduction

1.1 Background

This research aims to quantify the overall variability of asphalt mixture performance test results for Balanced Mix Design (BMD) tests being considered for use in Quality Assurance (QA) by the Wisconsin Department of Transportation (WisDOT). Overall variabilities of traditional quality characteristics such as binder content, aggregate gradation, and mixture volumetrics properties have been well documented in previous studies. Overall production variability is used to measure product quality. However, very little research has been reported on the overall variability of new performance tests used in BMD tests. The WisDOT has selected the indirect tensile asphalt cracking test (IDEAL-CT) and Hamburg wheel tracking test as their two performance tests for BMD.

1.2 Research Objective

The main objectives of this thesis were to:

- Statistically analyze the overall variability of performance test results from ten shadow projects
- Recommend appropriate standard deviations for the BMD performance tests for Wisconsin specifications based on field-produced mixes

1.3 Scope of Work

Several steps were accomplished to meet the research objectives. First, ten shadow projects were selected across Wisconsin from which asphalt mixtures were sampled during production at the same time as traditional QA samples for each sublot for two to three lots. A shadow project is a project on which additional (BMD) tests are conducted at a frequency similar to existing acceptance quality characteristics. The additional test results are only used for research purposes and not used to influence the production process or material acceptance decisions. In total, 134 mixture samples were obtained for this study. These mixture samples were shipped to NCAT for performance testing. These mixture samples were volumetrically verified for specific gravity and air voids, and samples were compacted to specification requirements for performance testing. HWTT and IDEAL-CT tests were conducted on each sublot sample. The data from the performance tests were statistically analyzed using various methods to provide overall variability statistics for developing QA specifications for performance tests in Wisconsin.

1.4 Organization of Thesis

This thesis has been organized into five chapters. Chapter One is the introduction: including the background, research objectives, scope of work, and the organization of this thesis. Chapter Two is a literature review on the background of BMD, variabilities in the production of asphalt paving materials, and test methods on IDEAL-CT and HWTT. Chapter Three focuses on the research plan, explaining the selection of shadow projects, testing plan, and method of analysis. Chapter Four discusses the results and the impact of the outlier analysis on the variability results. Chapter Five provides the conclusions and recommendations for this project.

Chapter 2 – Literature Review

2.1 Background on Balanced Mix Design

Most state highway agencies currently use the Superpave mix design method (AASHTO M 323) and associated criteria for asphalt mix design specifications. Since many of these agencies have been dissatisfied with Superpave mixtures' cracking and durability performance, recent research efforts proposed moving toward a new mix design approach that directly assesses a mixture's resistance to prevalent distresses. Balanced Mix Design (BMD) is defined as "asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate, and location within the pavement structure" (AASHTO PP105-20). BMD usually includes two or more performance tests, such as rutting and cracking tests, to determine how well the mixture resists common forms of distress in asphalt pavements (West, R et al., 2021).

In 2021 the Wisconsin Department of Transportation (WisDOT) developed a draft special provision, the *HMA Pavement Balanced Mix Design,* to implement BMD (Wisconsin, 2021). The performance tests used in the special provision are the Hamburg Wheel-Tracking Test (HWTT) to evaluate the mixture for rutting resistance and moisture resistance and the Indirect Tensile Asphalt Cracking Test (IDEAL-CT) for cracking resistance (Wisconsin, 2021).

2.2 Variability in the Production of Asphalt Materials

Variability in the production of asphalt paving mixtures is an important measure to assess quality. One definition of quality states that "quality is inversely proportional to variability" (Montgomery, D). AASHTO R 9 *Acceptance Sampling Plans for Highway Construction,* recommends quantifying the "overall" variability of quality characteristics for QA programs (AASHTO R 9-05).

Hughes (1996) described overall production variability to consist of four components: testing variability, sampling variability, materials variability, and construction variability. Mathematically, overall variance ($\boldsymbol{\sigma_o^2}$), is the sum of the testing variance ($\boldsymbol{\sigma_t^2}$), sampling variance ($\boldsymbol{\sigma_s^2}$), materials variance ($\boldsymbol{\sigma_m^2}$), and construction variance ($\boldsymbol{\sigma_c^2}$), shown as Equation 1.

$$\sigma_o^2 = \sigma_t^2 + \sigma_s^2 + \sigma_m^2 + \sigma_c^2 \qquad \text{Equation 1}$$

Where:

$\sigma_o^2 = overall\ variance$

$\sigma_t^2 = testing\ variance$

$\sigma_s^2 = sampling\ variance$

$\sigma_m^2 = materials\ variance \sigma_c^2 = construction\ variance$

2.2.1 Previous Measures of Overall Variability in Roadway Construction

Between 1956 and 1962, construction materials tests were conducted at the AASHO Road Test, which documented the overall variabilities of material qualities encountered during the construction of the pavements (Hughes, 1996). After the results of the AASHO Road Tests were published, many highway agencies established statistically based specifications using the variabilities of typical materials and construction processes (Hughes, 2005).

2.2.2 Typical Variability in Asphalt Mixtures

In NCHRP Synthesis 232 completed in 1996, Hughes summarized variabilities of common acceptance quality characteristics such as laboratory compacted, air voids, gradation, and asphalt content based on data obtained through random sampling procedures (Hughes, 1996). By the 1970s, statistically, based-specifications had been incorporated into QA programs with a strong dependence on statistical analysis (Halstead, 1979). Other asphalt material properties often studied include: gradation, asphalt material viscosity, and asphalt binder penetration (Solaimanian et al. 1995).

2.2.3 Uses of Variability to Establish Specification Limits

AASSHTO R 9, Standard Practice for Acceptance Sampling Plans for Highway Construction, explains types of acceptance plans and states that a "statistical acceptance plan is one based on analysis of either variables or attributes" (AASHTO R 9-05). The standard gives an example acceptance plan using the Percent Within Limits (PWL) procedure based on population, estimates of central tendency, and variability (AASHTO R 9-05). The example given in AASHTO R 9 Appendix X1 includes an analysis of "target miss" variability; this is an important case where quality characteristic has a specified target value and upper and lower specification limits are set above and below the target value (West et al., 2023).

2.2.4 Current Quality Control/Quality Acceptance in Wisconsin

WisDOT developed its hot mix asphalt (HMA) quality management program (QMP) in the early 1990s. QMP is considered a best construction practice to ensure that an agency receives quality construction materials produced by a contractor (Faheem et al., 2018). Developing a QMP specification involved identifying key asphalt mixture parameters related to long-term pavement performance and the development of the agency's quality assurance (QA) program, including procedures for quality assurance (QA) and quality verification (QV) (Faheem et al., 2018). The asphalt pavement acceptance quality characteristics in Wisconsin's QMP are aggregate gradation, asphalt content, air voids, voids in the mineral aggregate, and in-place density (Faheem et al., 2018).

2.3 Test Methods

2.3.1 IDEAL-CT

The IDEAL-CT is an asphalt mixture performance test to assess cracking resistance using laboratory-prepared cylindrical specimens developed for mix design and quality assurance testing (Zhou 2019). According to the test method, ASTM D8225-19, a cylindrical specimen is centered in the indirect tensile test fixture, and a load is applied at a rate of 50.0+2.0 mm/min. The load and the vertical displacement measured during the test are used to calculate the CT_{Index} (Figure 2.3.1). The CT_{Index} is calculated from failure energy, the post-peak slope of the load-displacement curve, and deformation at 75% of the peak load (shown in Equation 2.3.1).

$$CT_{Index} = \frac{t}{62} * \frac{l_{75}}{D} * \frac{G_f}{|m_{75}|} * 10^6 \qquad \text{Eq. 2.3.1}$$

Where:

CT_{Index} = cracking tolerance index

G_f = fracture energy (J/m^2)

$|m_{75}|$ = absolute value of the post-peak slope m_{75} (N/m)

l_{75} = displacement at 75% of the peak load after the peak (mm)

D = specimen diameter (mm)

t = specimen thickness (mm)

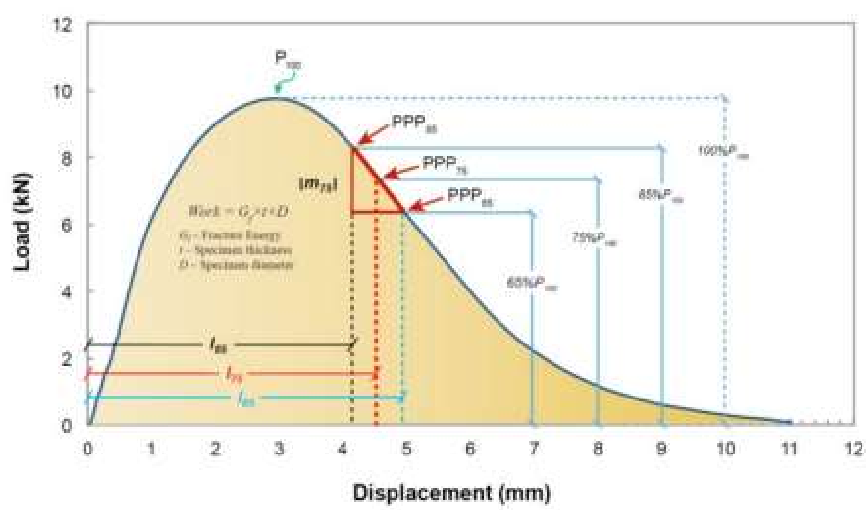


Figure 2.3.1: Load vs. LLD Data (Zhou, 2019)

2.3.2 IDEAL-CT Variability

A Texas A&M Transportation Institute study reported the testing variability (repeatability) of the IDEAL-CT test based on its sensitivity to asphalt mix characteristics and conditions. The CT_{Index} was sensitive to RAP and RAS content, asphalt binder type, binder content, and aging conditions. The highest within-lab COV was 23.5%, and most COVs were less than 20% (Zhou, 2019).

The Utah Department of Transportation conducted a study comparing the IDEAL-CT and I-FIT cracking tests to determine a feasible candidate for the cracking test in their BMD implementation. The study compared within and between lab COVs. They found that the IDEAL-CT COV ranged between 15 and 25% within and between labs and concluded that was an acceptable range of variability for a cracking test (VanFrank et al., 2020).

The National Center for Asphalt Technology (NCAT) compared results from six different IDEAL-CT machines (Moore et al., 2021). They stated that consistent specimen preparation is key to achieving low variability (Moore et al., 2021). The results of tests with different machines were compared using an equivalence limit of 20% of the average CT_{Index} (Moore et al., 2021).

In 2018, NCAT conducted a round-robin study on performance tests being considered for the BMD implementation. This study was broken into two phases, and fifteen different labs completed IDEAL-CT testing. The within-lab COV for phase one was 19.5%, and the between-lab COV was 35.3%. For phase two of this project, the IDEAL-CT within-lab COV was 18.8%, and the between-lab COV was 20.2%. The difference between phase one and phase two was that all of the specimens were made in a single laboratory for phase two, while each laboratory made its own specimens in phase one. The difference in between-lab COV drops between the studies highlights the importance of consistent sample preparation for CT_{index} results (Taylor et al., 2022).

COVs of CT_{index} range from 15% to 35% for within and between-lab. Results were found to be sensitive to RAP content, asphalt content, asphalt binder type, and aging conditions, according to the study completed by the Texas A&M Transportation Institute study. Studies recommended testing an adequate number of replicate samples; the NCAT study did approximately 50 replicate samples per machine when performing statistical analysis on mixes, and that sample preparation is an essential step in reducing variability.

2.3.3 Hamburg Wheel Tracking Test

The Hamburg Wheel Tracking Test (HWTT) is a performance test used to evaluate asphalt mixtures rutting resistance and moisture susceptibility. According to AASHTO T324, a pair of laboratory-compacted specimens, 62mm in thickness and 150mm in diameter, is loaded using a reciprocating steel wheel. The test specimens are submerged in a temperature-controlled water bath, and the total deformation is measured and plotted as a function of the number of wheel passes.

For this study, the HWTT raw data were analyzed for rutting using two methods. The first method, referred to as the corrected rut depth method, isolates deformation due to rutting from deformation due to moisture damage, as illustrated in Figure 2.3.2 (Yin et al., 2014). This separation of the HWTT specimen damage according to the two distress mechanisms is necessary since the remedies for the two distresses are different. Thus, the corrected rut depth at 20,000 passes (CRD_{20k}) is a better indicator of mixture rutting resistance than the traditional HWTT rutting parameters of total rut depth or passes to 12.5mm rut depth (West et al., 2021).

However, to relate the HWTT results of this study to previous research, the total passes to 12.5 mm rut depth was also recorded.

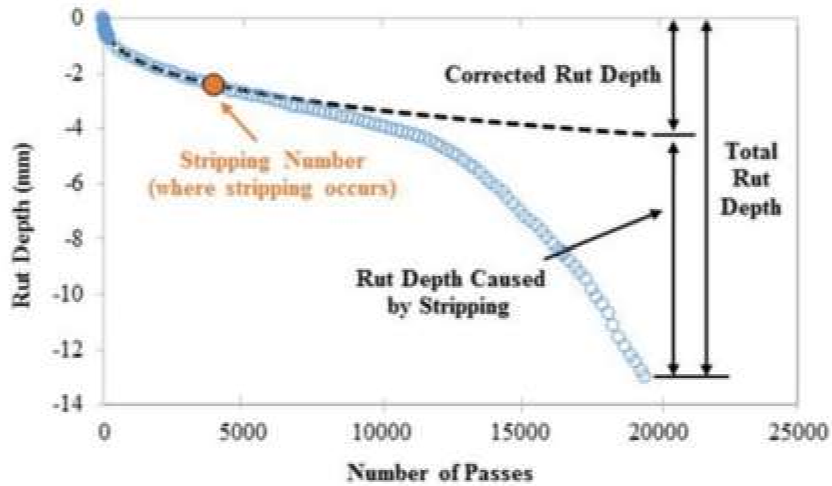


Figure 2.3.2: HWTT Data Analysis, CRD_{20k} (West et al., 2021)

2.3.4 Hamburg Wheel Tracking Test Variability

The Texas Transportation Institute studied the variability of seven HWTT devices, all manufactured by Precision Metal Works, in three laboratories in Texas. The two-way analysis of variance (ANOVA) showed that the variability within and between machines increased with the increase in load cycles (Chowdhury et al., 2004).

A round-robin study conducted by the University of California Pavement Research Center (UCPRC) involved twenty laboratories around California. Each lab conducted four HWTT tests. Two tests were conducted on specimens made by UCPRC and the other two were conducted on specimens compacted by each participating laboratory. The laboratories reported test results at rut depths after 5,000, 10,000, 15,000, and 20,000 passes, the number of passes to 12.5 mm rut depth, creep slope, stripping slope, and stripping inflection point. An outlier analysis was conducted if a lab's average differed considerably from the other labs. An ANOVA analysis was also conducted to determine variance components that influenced test results. The study concluded that the type of HWTT device used was significant only for the rut depth after 5,000 and 10,000 passes. Single-operator variability was measured to be relatively low. Between-lab variability was relatively high for all results measured (Mateos, 2017).

In the 2018 NCAT round-robin study, the HWTT variability was analyzed since this is the most popular rutting performance test being considered for BMD implementation. Thirty-two labs participated in the first phase of the round-robin study; four different HWTT machines were used between the labs. At 10,000 passes, two of the thirty-two labs were shown as outliers; at 20,000 passes, four of the thirty-two labs were shown as outliers. The within and between-lab COV were reported for 10,000 and 20,000 passes. The within-lab COV for 10,000 passes was 9.0%, and for 20,000 passes, it was 9.4%. The between-lab COV for 10,000 passes was 21.1%, and for 20,000 passes, the COV was 25.9%. It is stated in the study that the COV results for within-lab repeatability are good, and the between-lab COV is reasonable (Taylor et al., 2022).

NCHRP project 20-07/Task 361, Hamburg Wheel-Track Test Equipment Requirements and Improvements to AASHTO T 324, evaluated the capabilities of available HWTT devices and identified issues with the AASHTO T 324 standard. The study concluded that there are differences in machines in the waveform, temperature range, and reporting parameters (Mohammad et al., 2015). Recommendations for fixing HWTT devices proposed addressing equipment capabilities, data collection, data analysis, and reporting to address the differences between machines (Mohammad et al., 2015).

A study completed by the AASHTO Materials Reference Laboratory studied the precision estimates for AASHTO T 324. The results proposed several changes to AASHTO T 324 to improve the repeatability and reproducibility of the HWTT machines. These changes included: starting location of the wheel, alignment of the wheel with respect to the specimen, measurement locations used in the analysis, variability in the cutting of the gyratory specimens, potentially increasing the specimen length, designing a new mold in terms of material and reducing the joint space between the two specimens (Azari, 2014). Precision estimates were reported for the number of passes to a threshold rut depth for single-operator COV of 16.6% and for multi-laboratory COV of 24.2% (Azari, 2014).

In summary, HWTT variability increases with increasing cycles based on the Texas Transportation Institute study. AASHTO T 324 has several parameters, waveform, temperature range, and reporting parameters, that can be improved upon to improve the repeatability and reproducibility of HWTT results. The NCAT round-robin study reported within-lab COVs of rut depths at 10,000 passes to be 9.0%, and at 20,000 passes to be 9.4%.

Chapter 3 – Research Plan

3.1 Selection of Shadow Projects

For this study, ten shadow projects were chosen from various locations across Wisconsin to represent the state's diversity in aggregate type, binder grades, and mix types. Wisconsin contractors obtained the surface mixture samples for the research while they also sampled mix for QC testing. For WisDOT, random samples are taken every 750 tons, representing a sublot. A typical lot in Wisconsin consists of five sublots; this gave 10 to 15 mix samples per shadow project. Table 3.1 summarizes the shadow project county locations, the region in Wisconsin, route, mix design number, mix type, and contractor. Figure 3.1 shows a map of the ten shadow project locations. The mix designs for each project can be found in Appendix 1. All of the mixtures were designed using the Superpave method.

Table 3.1 Project Summary

Project	County	Region	Route	WisDOT Mix Design ID	Mix Type	Contractor
1	Ozaukee	Southeast	IH 43	250-0032-2021	4 MT 58-28 S	Payne & Dolan
2	Florence	North Central	STH 139	250-0263-2021	4 LT 58-28 S	Payne & Dolan
3	Grant	Southwest	STH 011	601-21-4MTR301	4 MT 58-28 S	Mathy
4	Kewaunee	Northeast	STH 029	250-0035-2022	4 MT 58-28 S	Northeast Asphalt
5	Waukesha	Southeast	STH 067	250-0051-2022	4 MT 58-28 S	Rock Road
6	Lacrosse	Southwest	STH 016	147-21-4MTR301	4 MT 58-28 S	Mathy
7	Bayfield	Northwest	USH 063	158-22-5MTRW301	5 MT 58-34 V	Mathy
8	Iowa	South Central	USH 018	0-250-0025-2021	4 HT 58-28 S	Payne & Dolan
9	Barron	Northwest	USH 008	360-22-4MTRW301	4 MT 58-34 V	Mathy
10	Waushara	Central	IH 039	250-0107-2022	4 HT 58-28 S	American Asphalt

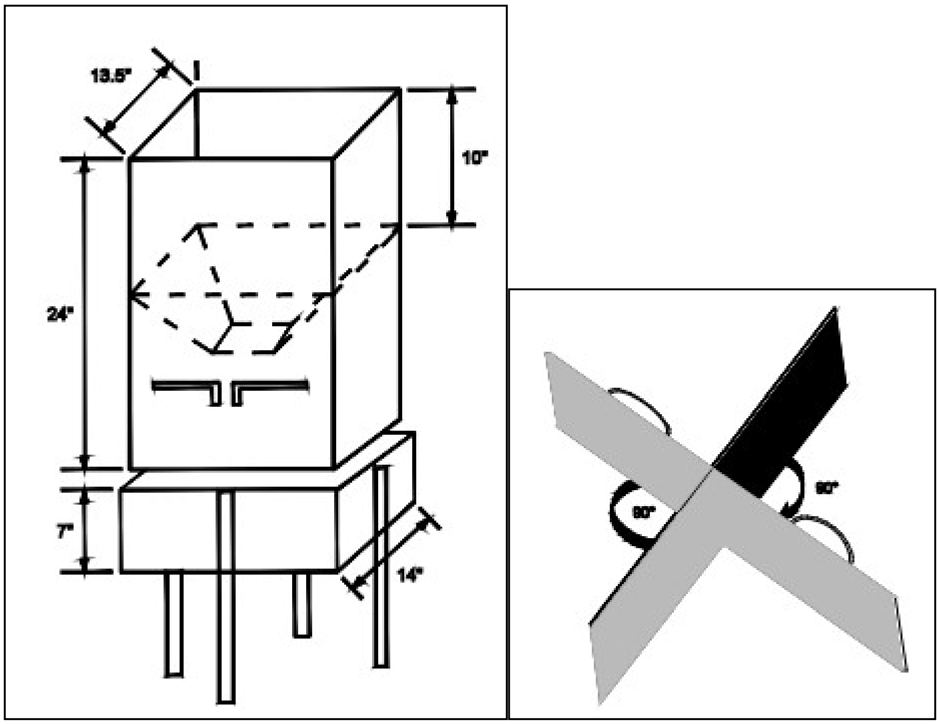
Figure 3.1 Project Locations in Wisconsin

3.2 Testing Plan

Two performance tests were conducted for this study: IDEAL-CT and Hamburg Wheel Tracking Test (HWTT).

3.2.1 Mixture Processing

The asphalt mixtures used in this study were sampled during plant production while the contractor was sampling for regular QC/QA testing for WisDOT projects. For each project, sublots for two to three lots were sampled, resulting in approximately 15 samples per project. Two five-gallon buckets of asphalt mix for each sublot were obtained to ensure sufficient material for testing. The contractors also provided the results of their QC tests corresponding to each sample. The mixes were shipped from their respective Wisconsin contractor to NCAT for performance testing. Each bucket of loose asphalt mix was heated to compaction temperature and reduced to testing size per AASHTO R47-19 *Standard Practice for Reducing Sample of Asphalt Mixtures to Testing Size.* A Quartermaster quartering device, shown in Figure 3.2.1, was used to reduce the sample size while ensuring representative samples for consistent laboratory results. As shown in Figure 3.2.2, a quartering template was used to further reduce the sampled mix to size. This sample-reducing method produced four maximum specific gravity (G_{mm}) samples, two bulk specific gravity (G_{mb}) samples, and approximately fifteen test specimens per sublot.



Figures 3.2.1 and 3.2.2 : Quartering Devices (AASHTO R47-19)

Once the loose plant mix was reduced to the testing size, the samples were stored in sealed, labeled plastic bags to be compacted later. Each specimen was compacted to 62 mm in height and 150 mm in diameter using a gyratory compactor, following ASTM D6925-15. Each sample was made by the same engineer, scale, oven, and gyratory compactor to reduce specimen variability. The theoretical maximum specific gravity (G_{mm}), known as the Rice test, was determined for each mix. A trial specimen was made using the previously reduced samples to determine the mass needed to achieve7.0±.05 air voids, 150 mm in diameter and 62 mm in thickness.

3.2.2 Summary of Testing Plan

Figure 3.2.3 shows a flow diagram of the testing procedure performed. Across the ten projects in this research study, a total of 134 sets of four samples were subjected to IDEAL-CT and HWTT testing. The maximum specific gravity (G_{mm}) and bulk specific gravity (G_{mb}) were verified to be consistent with the contractors' data using the multi-lab d2s limits in AASTO T 209 and T 166, respectively.

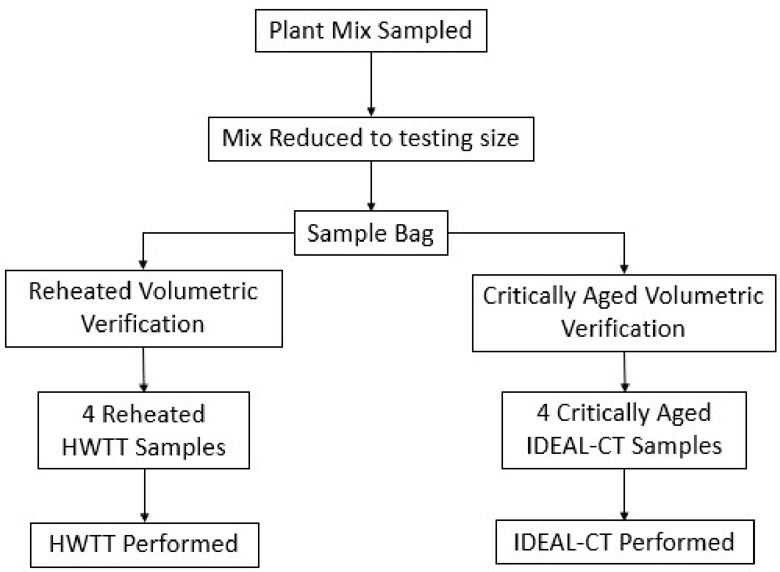


Figure 3.2.3 Testing Plan Flow Diagram

3.2.3 HWTT Testing Procedure

Mix was reheated to the compaction temperature to compact the HWTT specimens. Each specimen's air voids were checked using AASHTO T166, Standard Method of Test for Bulk Specific Gravity (G_{mb}) of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens. Each HWTT specimen was cut to fit into the HWTT mold. All HWTTs were conducted following AASTHO T 324 using the Troxler machine shown in Figure 3.2.4.

Figure 3.2.4 Troxler HWTT Machine at NCAT Laboratory

3.2.4 IDEAL-CT Procedure

For the IDEAL-CT test specimens, the loose plant mix samples were long-term aged for 6 hours at 275°F. This aging procedure was recommended to simulate in-service aging in a previous WHRP project using Wisconsin mixtures in 2018 (Bahia, 2018). This is similar to the "critical aging" procedure recommended by NCAT (Chen et al, 2018). A maximum specific gravity (G_{mm}) test and a bulk specific gravity (G_{mb}) test were performed on asphalt samples produced from the aged mixture. Once the quantity of loose mix needed to produce 150 mm diameter compacted samples to a height of 62 mm with 7.0% +/- 0.5% air voids, four specimens were compacted for IDEAL-CT testing. The IDEAL-CT test was conducted according to ASTM D8225 using the Troxler IDEAL Plus, shown in Figure 3.2.5.

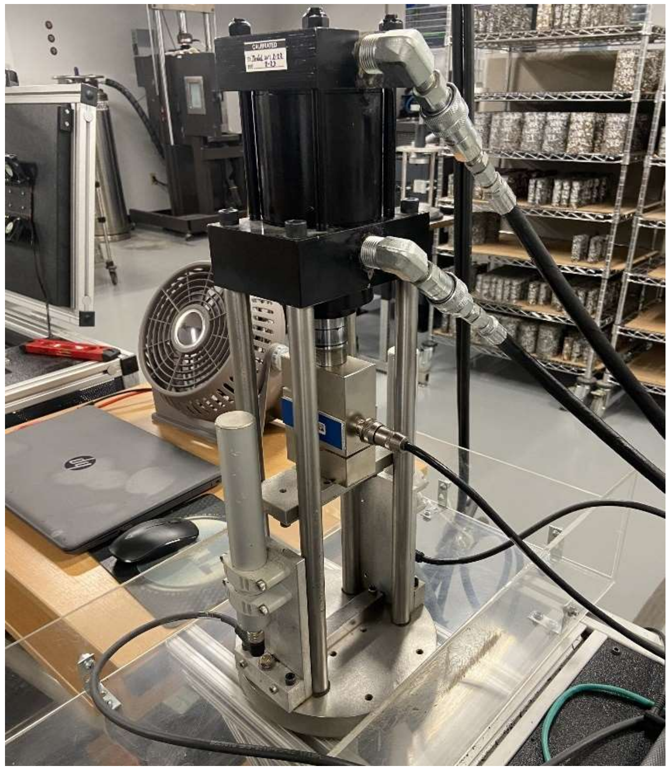


Figure 3.2.5 Troxler IDEAL Plus machine at NCAT Laboratory

3.3 Method of Analysis

For this experiment, statistical analysis was performed on the data collected from the HWTT and IDEAL-CT tests. Statistical analysis was also performed on the percent binder (P_b) and air voids (V_a) from the contractor's QC data. For the IDEAL-CT tests on each sublot, the average and standard deviation was calculated from four replicates. The HWTT data was used to determine the corrected rut depth (CRD) and the number of passes to reach a rut depth of 12.5 mm for the left and right wheels. The results for the left and right wheels were averaged to yield an average CRD, and an average passes to 12.5 mm rut depth for each sublot.

3.3.1 Calculation of Sample Mean, Standard Deviation, and Coefficient of Variation

The sample mean (Eq 3.1), standard deviation (Eq. 3.2), and coefficient of variation (Eq. 3.3) were calculated from the five sublots based on each lot. The calculations are as follows:

$$\overline{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$ Equation 3.1: Sample Mean

$$s = \sqrt{\frac{\sum (x_i - \overline{x})^2}{n}}$$ Equation 3.2: Standard Deviation

$$COV = \frac{\overline{x}}{s}$$ Equation 3.3: Coefficient of Variation

Where:

$\overline{x}$ = Sample Mean

s = standard deviation

COV = coefficient of variation

x_i = each value from the sample population

n = number of items in the sample

3.3.2 Outlier Evaluation of a Lot

An outlier can be defined as "one that appears to deviate markedly from other members of the sample in which it occurs" (ASTM E178-21). This outlier procedure used in this study was developed by the Maine Department of Transportation and is an adaptation from ASTM E178 *Dealing with Outlying Observations*. This calculation procedure is based on a "two-tail t-test" with a level of significance (α) of 5%. The calculation steps are as follows:

1. Calculate the sample average ($\overline{x}$) and standard deviation (*s*) of the results in the lot.
2. Find the critical t value "t_{crit}" from Table 3.2 using the total number of samples (n) in the sample set.
3. Determine the total allowable deviation (D) on either side of the sample average by multiplying 't_{crit}' by *s*.
4. Establish values for Max and Min by adding and subtracting D to and from $\overline{x}$.
5. Any results greater than the Max or less than the Min are determined to be an outlier.

Table 3.2 t_{crit} values for a 5% Significance Level

n	t_{crit}
3	1.155
4	1.481
5	1.715
6	1.887
7	2.020

This outlier evaluation procedure was performed on results from the IDEAL-CT, HWTT, the contractor's reported air voids, and asphalt content for each lot.

3.3.3 Normality Procedure

An Anderson-Darling (AD) test was performed using Minitab software to assess the normality of the results of quality characteristics from each project. This test compares the empirical cumulative distribution function of the data with the distribution expected if the data was normal ("Test for Normality'). The AD statistic measures how well the data follows the normal distribution; the better the distribution fits the data, the smaller the AD statistic. The null hypothesis for the Anderson-Darling test was that the data followed a normal distribution. If the p-value was less than 0.05, the null hypothesis was rejected and it was concluded that the data were found to be not normally distributed. The AD test was performed on the ten projects individual sublot data for IDEAL-CT, HWTT, air voids, and asphalt content.

3.3.4 CDF of Production Standard Deviation and Coefficients of Variation

The cumulative distribution frequency (CDF) for each project's lot standard deviations and coefficients of variation were plotted using Minitab software. Cumulative distribution frequencies are used to evaluate the distribution of a dataset. They can help analyze the percentage of the data that lie above or below a particular value, and the steepness or slope of the CDF can indicate how close the observations are to the mean (Cumulative, 2020).

3.3.5 Percent Within Limits Calculations

Percent within limits (PWL) calculations were conducted on each project's lot for IDEAL-CT and HWTT data based on current WisDOT specification criteria, as shown in Table 3.3. PWL is the percentage of a lot falling within a set specification limit based on simple statistics. Since the HWTT and IDEAL-CT criteria are minimum values (one-sided criteria), only the lower quality index was calculated following Equation 3.4.

$$Ql_L = \frac{(\overline{x} - LL)}{S} \qquad \text{Eq. 3.4}$$

Where:

Ql_L = Lower Quality Index

$\overline{x}$ = mean of test results

LL = Lower specification Limit (tolerance)

S = Standard Deviation

The "Q" table from AASHTO R 42 was used to find the PWL corresponding to each Ql.

Table 3.3 Wisconsin DOT Performance Test Requirements

Binder Designation Level[1]	HWTT $N_{12.5}$	HWTT *SIP*	IDEAL-CT CT_{Index}[2]
S	≥ 10,000	≥ 8,000	≥ 30
H	≥ 15,000	≥ 8,000	≥ 30
V	≥ 20,000	≥ 8,000	≥ 30
E	≥ 20,000	≥ 8,000	≥ 30
Notes: 1. Asphalt binders will be tested against the contract specified traffic level performance requirements, which may not be the same traffic level as classified by AASHTO M332. 2. For SMA, increase the minimum CT_{Index} criterion to 80 for all binder designation levels.			

3.4 Summary

Once the asphalt mixture samples were received at NCAT from the Wisconsin contractors, they were reduced, compacted, and evaluated using various AASHTO procedures. The two performance tests completed on each sublot sample were the IDEAL-CT and HWTT.

All specimen preparation and tests were conducted at NCAT by the same engineer using the same equipment to minimize variability. For each lot on each of the ten mixes, the average, standard deviation, and coefficient of variation were calculated for CT_{index} and HWTT CRD and passes to 12.5 mm rut depth, and the results were analyzed for outliers, normality, cumulative distribution frequency, and percent within limits.

Chapter 4 – Results and Discussion

This chapter summarizes the results from the performance testing conducted at NCAT on mixtures from the ten shadow projects sampled by WisDOT contractors. These mixes were tested using IDEAL-CT and HWTT performance tests, along with the asphalt content and air voids from the contractor's QC data to evaluate the production variability of the properties.

4.1 Summary of Averages, Standard Deviations, and Coefficients of Variation

For mixes of each shadow project, the contractors provided samples for two or three lots, and for each lot, there were five sublots. Therefore, the tests' average, standard deviation, and COV s were calculated from the results of five sublots.

Table 4.1.1 summarizes the asphalt content of each project. The asphalt content has the lowest overall COVs among the evaluated quality characteristics, with an average COV of 2.8%; the maximum COV was observed to be 7.2%.

Table 4.1.2 summarizes the air voids for each project. The air voids had an average COV of 10.4%.

Table 4.1.3 summarizes the CT_{Index} for each project. The average COV for CT_{Index} was 13.1%, with the minimum COV being 1.3% and the maximum COV being 39.7%.

Table 4.1.4 summarizes the CRD_{20k} calculated for each project. The average COV for CRD_{20k} was 10.9%, with a maximum COV of 26.4%, and a minimum COV of 4.1%. Table 4.1.5 summarizes the HWTT passes to reach a 12.5 mm rut depth. The average COV for passes to 12.5 mm was 16.6%, with a maximum of 35.8% and a minimum of 2.8%.

Table 4.1.1 Asphalt Content Summary

Asphalt Content				
Project	Lot	Average	Std. Dev.	COV
1	Lot 1	6.1	0.2	2.6%
	Lot 2	6.3	0.2	3.8%
2	Lot 2	5.6	0.1	1.3%
	Lot 3	5.7	0.1	2.5%
3	Lot 2	5.8	0.2	2.6%
	Lot 3	6.0	0.4	7.2%
	Lot 4	5.9	0.3	5.9%
4	Lot 2	5.9	0.1	1.7%
	Lot 3	6.0	0.1	1.9%
	Lot 4	6.0	0.1	1.4%
5	Lot 4	5.7	0.2	3.4%
	Lot 5	5.8	0.2	3.1%
	Lot 6	5.8	0.1	1.9%
6	Lot 9&11	6.0	0.1	2.2%
	Lot 10	5.9	0.2	2.8%
7	Lot 3&6	6.6	0.1	1.3%
	Lot 4	6.7	0.1	1.8%
	Lot 5	6.8	0.1	1.3%
8	Lot 3	5.8	0.2	4.0%
	Lot 4	5.8	0.1	1.9%
	Lot 5	5.7	0.2	2.7%
9	Lot 8	5.6	0.1	2.1%
	Lot 9	5.6	0.1	2.3%
	Lot 10	5.4	0.3	5.8%
10	Lot 8	6.2	0.2	2.7%
	Lot 9	6.2	0.1	2.1%
	Lot 10	6.2	0.2	3.0%

Table 4.1.2 Air Voids Summary

Air Voids				
Project	Lot	Average	Std. Dev.	COV
1 - P&D Jackson	Lot 1	3.3	0.4	12.8%
	Lot 2	3.1	0.3	10.2%
2 - NEA Popple River	Lot 2	2.8	0.1	4.1%
	Lot 3	2.9	0.2	6.7%
3 - Mathy Plant 1	Lot 2	2.9	0.2	7.9%
	Lot 3	2.9	0.1	4.5%
	Lot 4	2.8	0.4	15.8%
4 - NEA Denmark	Lot 2	2.9	0.3	10.3%
	Lot 3	3.0	0.1	2.9%
	Lot 4	3.2	0.1	1.7%
5 - Rock Road	Lot 4	3.3	0.3	8.3%
	Lot 5	3.2	0.2	6.8%
	Lot 6	3.3	0.3	9.0%
6 - La Crosse	Lot 9&11	2.9	0.3	10.1%
	Lot 10	2.4	0.4	15.5%
7 - Drummond	Lot 3&6	3.1	0.5	16.5%
	Lot 4	2.8	0.5	16.8%
	Lot 5	2.6	0.3	9.9%
8 - Dodgeville	Lot 3	3.0	0.4	14.9%
	Lot 4	2.7	0.6	21.3%
	Lot 5	2.9	0.6	19.5%
9 - Turtle Lake	Lot 8	3.1	0.2	6.2%
	Lot 9	2.8	0.4	14.6%
	Lot 10	3.0	0.3	10.8%
10 - Coloma	Lot 8	3.0	0.1	3.6%
	Lot 9	2.8	0.3	10.6%
	Lot 10	2.8	0.3	10.0%

Table 4.1.3 CT_{Index} Summary

IDEAL CT				
Project	Lot	Average	Std. Dev	COV
1 - P&D Jackson	Lot 1	47.0	7.4	15.6%
	Lot 2	48.0	4.0	8.4%
2 - NEA Popple River	Lot 2	58.2	9.1	15.7%
	Lot 3	62.8	19.6	31.1%
3 - Mathy Plant 1	Lot 2	62.7	6.4	10.2%
	Lot 3	69.7	27.7	39.7%
	Lot 4	73.3	17.8	24.3%
4 - NEA Denmark	Lot 2	86.2	7.6	8.8%
	Lot 3	83.8	10.7	12.8%
	Lot 4	89.0	6.0	6.7%
5 - Rock Road	Lot 4	40.1	4.3	10.7%
	Lot 5	44.3	8.8	19.9%
	Lot 6	51.3	5.2	10.1%
6 - La Crosse	Lot 9&11	46.2	3.6	7.8%
	Lot 10	51.2	7.7	15.1%
7 - Drummond	Lot 3&6	106.7	16.8	15.7%
	Lot 4	113.5	7.8	6.9%
	Lot 5	120.4	8.9	7.4%
8 - Dodgeville	Lot 3	45.1	2.0	4.4%
	Lot 4	51.0	4.6	9.1%
	Lot 5	43.4	0.6	1.3%
9 - Turtle Lake	Lot 8	51.5	8.9	17.2%
	Lot 9	58.9	5.2	8.8%
	Lot 10	57.5	5.5	9.5%
10 - Coloma	Lot 8	113.2	11.6	10.3%
	Lot 9	118.4	14.5	12.2%
	Lot 10	119.5	16.4	13.7%

Table 4.1.4 CRD_{20k} Summary

HWTT - Corrected Rut Depth 20,000 passes				
Project	Lot	Average	Std. Dev	COV
1 - P&D Jackson	Lot 1	10.7	2.2	20.4%
	Lot 2	11.0	1.4	13.1%
2 - NEA Popple River	Lot 2	16.4	2.8	16.8%
	Lot 3	16.2	0.7	4.4%
3 - Mathy Plant 1	Lot 2	9.0	0.4	4.1%
	Lot 3	11.0	0.4	4.1%
	Lot 4	10.6	1.2	11.7%
4 - NEA Denmark	Lot 2	15.9	1.6	10.3%
	Lot 3	16.2	1.3	8.0%
	Lot 4	17.3	3.0	17.6%
5 - Rock Road	Lot 4	10.5	1.0	9.9%
	Lot 5	11.2	0.7	5.8%
	Lot 6	10.5	0.7	7.0%
6 - La Crosse	Lot 9&11	11.3	1.0	8.7%
	Lot 10	11.6	1.6	13.5%
7 - Drummond	Lot 3&6	11.7	0.7	5.6%
	Lot 4	13.1	3.4	26.4%
	Lot 5	16.4	3.3	20.1%
8 - Dodgeville	Lot 3	10.2	1.2	11.9%
	Lot 4	10.2	1.0	10.0%
	Lot 5	8.4	1.2	14.3%
9 - Turtle Lake	Lot 8	9.7	0.9	9.3%
	Lot 9	11.0	1.1	9.6%
	Lot 10	12.0	1.3	10.6%
10 - Coloma	Lot 8	11.6	0.6	4.9%
	Lot 9	13.3	1.4	10.6%
	Lot 10	12.6	0.6	5.1%

Table 4.1.5 Passes to 12.5 mm Rut Depth Summary

HWTT - Passes to 12.5 mm Rut Depth				
Project	Lot	Average	Std. Dev	COV
1 - P&D Jackson	Lot 1	11416	4085.8	35.8%
	Lot 2	9662	3298.4	34.1%
2 - NEA Popple River	Lot 2	5670	952.13	16.8%
	Lot 3	4785	905.8	18.9%
3 - Mathy Plant 1	Lot 2	14580	2752.5	18.9%
	Lot 3	11188	909.21	8.1%
	Lot 4	11642	2575.7	22.1%
4 - NEA Denmark	Lot 2	5682	523.12	9.2%
	Lot 3	6200	734.81	11.9%
	Lot 4	4800	486.16	10.1%
5 - Rock Road	Lot 4	13972	2768.7	19.8%
	Lot 5	10662	2670.8	25.0%
	Lot 6	11266	1864.5	16.5%
6 - La Crosse	Lot 9&11	8460	608.6	7.2%
	Lot 10	9018	1618.3	17.9%
7 - Drummond	Lot 3&6	7192	215.1	3.0%
	Lot 4	6592	1294.2	19.6%
	Lot 5	4726	1197.2	25.3%
8 - Dodgeville	Lot 3	9188	2272.4	24.7%
	Lot 4	9056	1568.8	17.3%
	Lot 5	11278	1973.5	17.5%
9 - Turtle Lake	Lot 8	10870	1189.3	10.9%
	Lot 9	9278	1828.5	19.7%
	Lot 10	9370	1463.9	15.6%
10 - Coloma	Lot 8	9990	1406.6	14.1%
	Lot 9	8302	235.4	2.8%
	Lot 10	8840	553.2	6.3%

4.2 Normality Test

For the Normality Test, the Anderson-Darlington (AD) statistic and the probability plots of the sublot averages of IDEAL-CT, HWTT, asphalt content, and air voids were calculated for each of the ten shadow projects. Figures 4.2.1 through 4.2.5 display the probability plot and the AD test statistic for Project 1 as examples. Tables 4.2.1 through 4.2.5 display the summary results of the AD statistic and the corresponding p-values for all 10 projects.

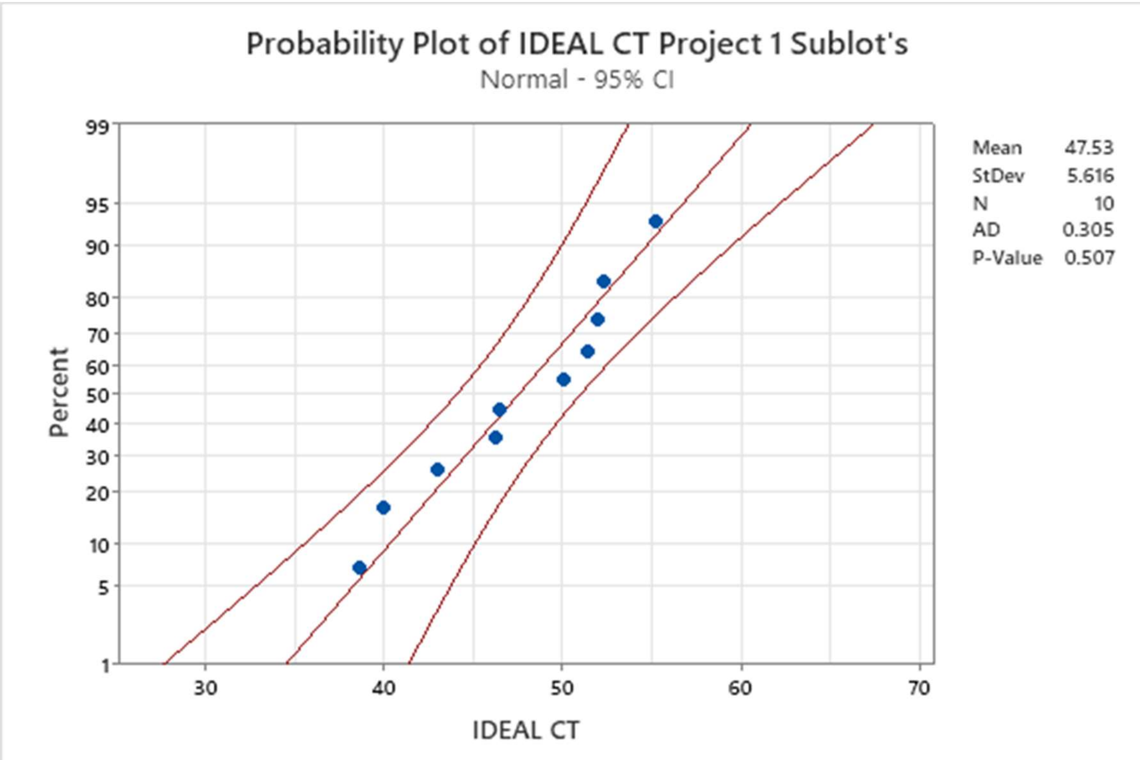


Figure 4.2.1 Probability Plot of CT_{index} Project 1

Table 4.2.1 Normality Test Results for IDEAL-CT Sublots

IDEAL CT			
Project	N (number of sublots)	AD Statistic	p-value
1 - P&D Jackson	10	0.305	0.507
2 - NEA Popple River	9	0.327	0.440
3 - Mathy Plant 1	15	0.891	0.017
4 - NEA Denmark	15	0.251	0.691
5 - Rock Road	15	0.61	0.091
6 - La Crosse	10	0.533	0.128
7 - Drummond	15	0.129	0.978
8 - Dodgeville	15	0.525	0.151
9 - Turtle Lake	15	0.454	0.231
10 - Coloma	15	0.473	0.208

From Table 4.2.1, it can be seen that the p-value for the Anderson-Darling test of normality was greater than 0.05 except for Project 3, indicating that the CT_{index} results from most projects were normally distributed. For Project 3, the AD normality test may have been influenced by the high CT_{index} results from a four sublots compared to the average for all 15 sublots. For this project, the average CTindex for all sublots was 68.6, but CT_{index} results for sublot 3-4, 3-5, 4-2, and 4-3 were 106.2, 92.2, 86.4, and 95.9, respectively. This example brings to light a limitation of assessing normality with small data sets.

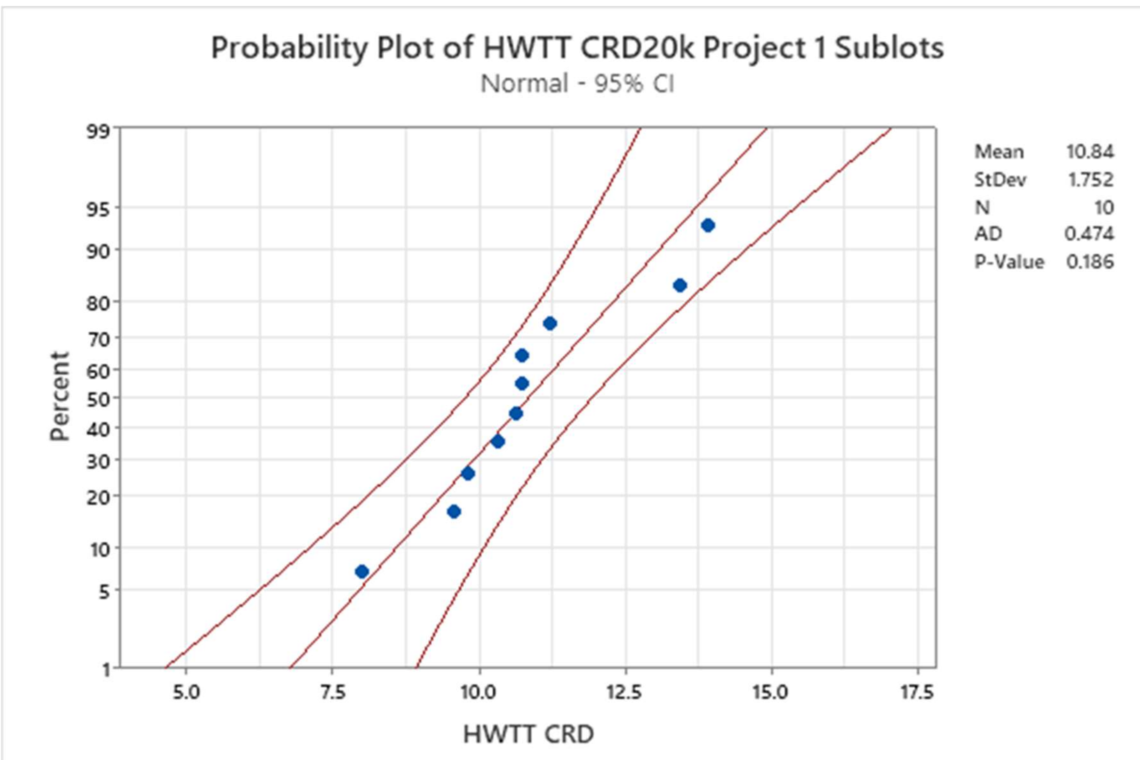


Figure 4.2.2 Probability Plot of HWTT CRD_{20k} Project 1

Table 4.2.2 Normality Test Results for HWTT CRD_{20k}

HWTT CRD20k			
Project	N (number of sublots)	AD Statistic	p-value
1 - P&D Jackson	10	0.474	0.186
2 - NEA Popple River	9	0.282	0.548
3 - Mathy Plant 1	15	0.482	0.196
4 - NEA Denmark	15	0.642	0.076
5 - Rock Road	15	0.389	0.339
6 - La Crosse	10	0.21	0.807
7 - Drummond	15	0.81	0.027
8 - Dodgeville	15	0.305	0.526
9 - Turtle Lake	15	0.357	0.407
10 - Coloma	15	0.725	0.046

Table 4.2.2 shows that the p-value for the Anderson-Darling test of normality for HWTT CRD_{20k} results was greater than 0.05 for all projects except for Project 7, indicating that the HWTT CRD_{20k} results from most projects were normally distributed. For Project 7, the high CRD_{20k} results for sublots 4-5 and 5-1 were 18.8 mm and 21.4 mm, respectively, compared to the average of 13.7 mm for all 15 sublots. This example again demonstrates a limitation of assessing normality with small data sets.

Similarly, Table 4.2.3 summarizes the Anderson-Darling results for HWTT passes to 12.5 mm rut depth. For this quality characteristic, the AD test p-value was less than 0.05 for Project 7 and 10 and was just above 0.5 for Project 3. The other seven projects had p-values well above 0.5 indicating that the HWTT results of the majority of projects were normally distributed.

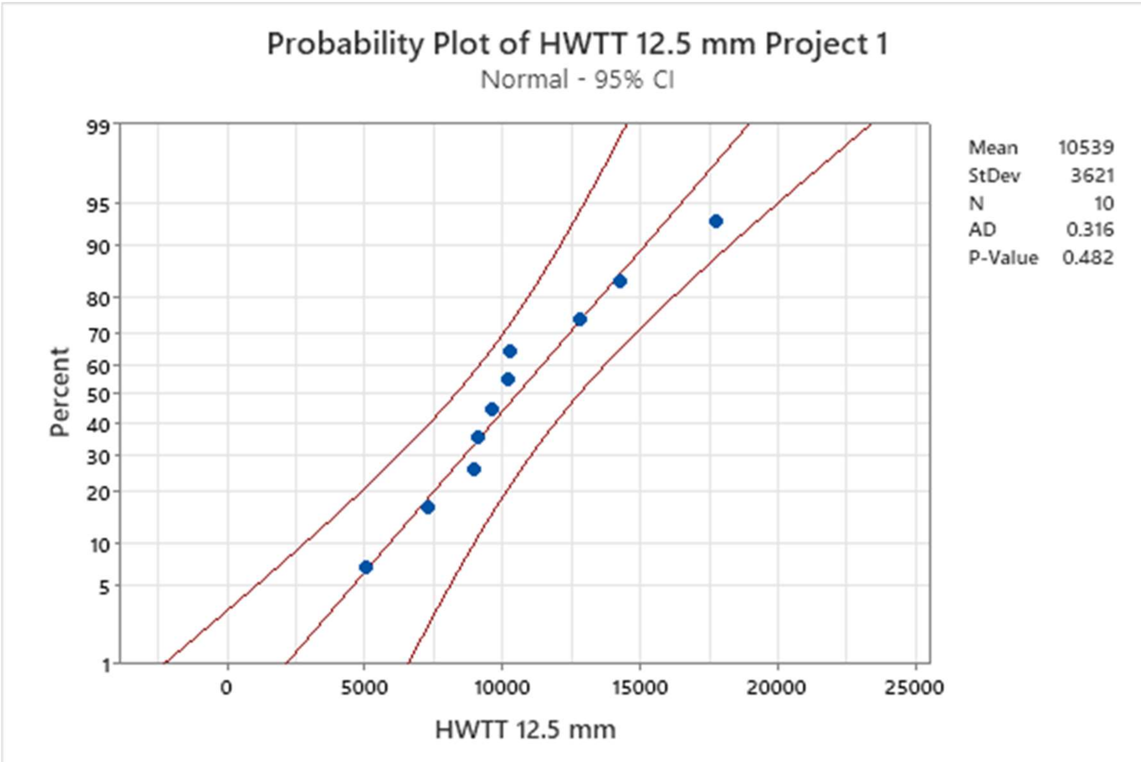


Figure 4.2.3 Probability Plot of HWTT Passes to 12.5 mm Project 1

Table 4.2.3 Normality Test Results for HWTT Passes to 12.5 mm

HWTT Passes to 12.5 mm			
Project	N (number of sublots)	AD Statistic	p-value
1 - P&D Jackson	10	0.316	0.482
2 - NEA Popple River	9	0.338	0.412
3 - Mathy Plant 1	15	0.691	0.056
4 - NEA Denmark	15	0.145	0.958
5 - Rock Road	15	0.329	0.476
6 - La Crosse	10	0.253	0.653
7 - Drummond	15	1.248	0.005
8 - Dodgeville	15	0.400	0.319
9 - Turtle Lake	15	0.263	0.647
10 - Coloma	15	0.964	0.011

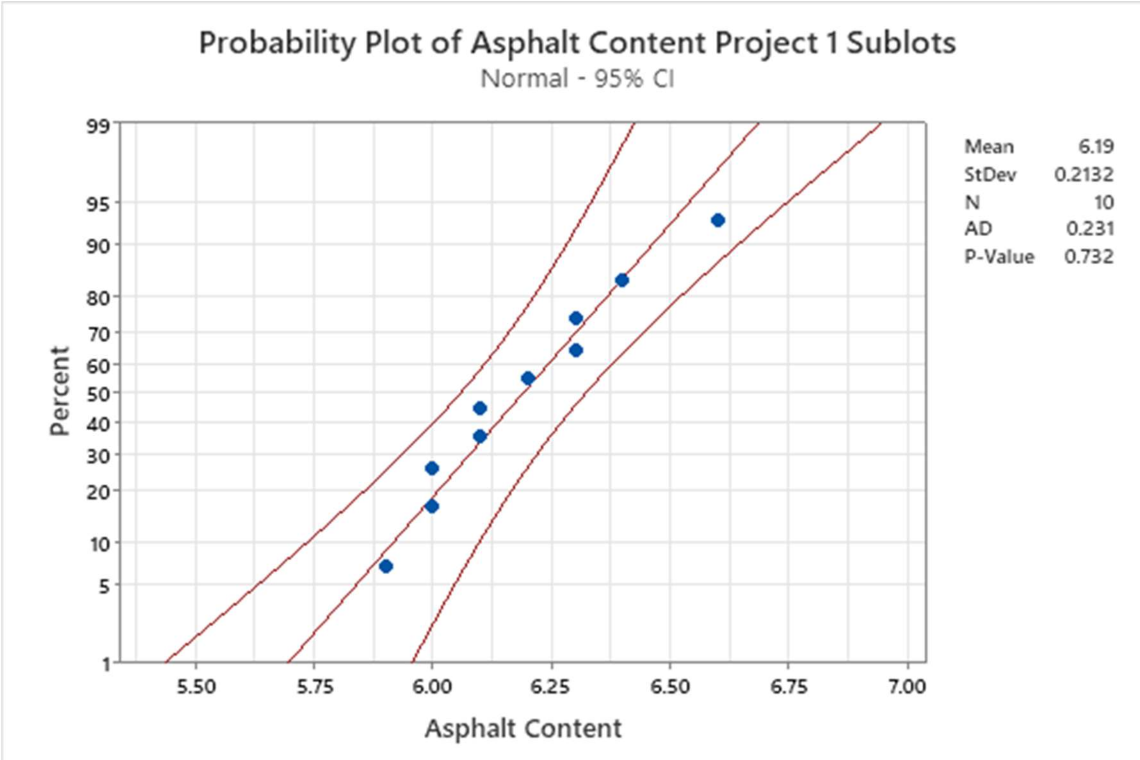


Figure 4.2.4 Probability Plot of Asphalt Content Project 1

Table 4.2.4 Normality Test Results for Asphalt Content

Asphalt Content			
Project	N (number of sublots)	AD Statistic	P-Value
1 - P&D Jackson	10	0.231	0.732
2 - NEA Popple River	9	0.393	0.298
3 - Mathy Plant 1	15	0.46	0.223
4 - NEA Denmark	15	0.759	0.037
5 - Rock Road	15	0.268	0.631
6 - La Crosse	10	0.405	0.285
7 - Drummond	15	0.974	0.010
8 - Dodgeville	15	0.419	0.285
9 - Turtle Lake	15	1.108	0.005
10 - Coloma	15	0.508	0.167

Table 4.2.4 shows that the p-values for the Anderson-Darling test of normality of asphalt content results was greater than 0.05 for seven of the ten shadow projects, indicating that asphalt content results for most projects were normally distributed. Project 4, 7 and 9 had p-values less

than 0.05, indicating that their asphalt content results were not normally distributed. For Project 4, asphalt contents were very consistent with all 15 sublots having asphalt contents between 5.8% and 6.1%. Likewise, Project 7 had very consistent asphalt contents ranging from 6.5% to 6.8%, with six of the 15 sublot results at 6.8%. Project 9's asphalt contents ranged from 5.1% to 5.7% but five of the 15 results were 5.7% which does not seem to follow a normal distribution, but the analysis is limited by the small data set.

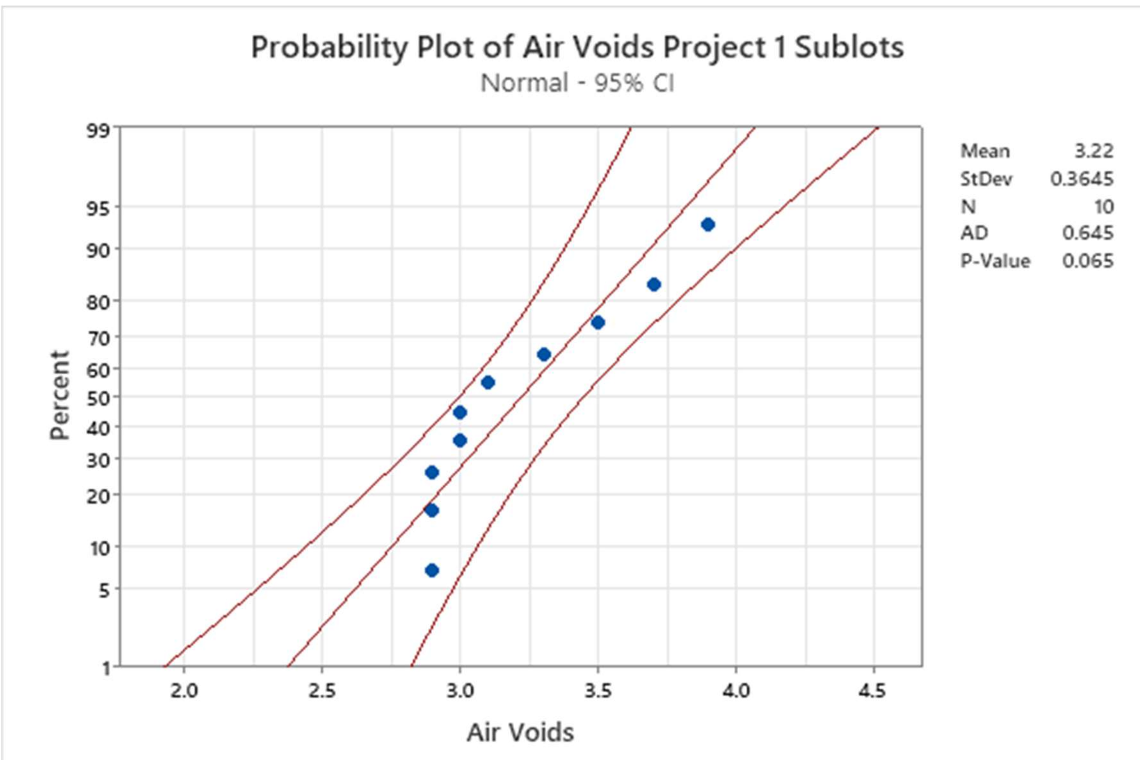


Figure 4.2.5 Probability Plot of Air Voids Average

Table 4.2.5 shows that the p-values for the Anderson-Darling test of normality of air void content results was greater than 0.05 for nine of the ten shadow projects, indicating that air voids were normally distributed for most projects. Only Project 4 had a p-values less than 0.05, indicating that their asphalt content results were not normally distributed. For this project, air voids were very consistent, ranging from 2.7% to 3.3%, with a mean of 3.0%. However, five of the 15 sublots had air voids of 3.1% and four sublots had air voids of 3.2% which does not seem to follow a normal distribution, but the analysis is limited by the small data set.

Table 4.2.5 Normality Test Results for Air Voids

Air Voids			
Project	N (number of sublots)	AD Statistic	p-value
1 - P&D Jackson	10	0.645	0.065
2 - NEA Popple River	9	0.367	0.348
3 - Mathy Plant 1	15	0.458	0.227
4 - NEA Denmark	15	0.873	0.019
5 - Rock Road	15	0.269	0.628
6 - La Crosse	10	0.139	0.960
7 - Drummond	15	0.622	0.085
8 - Dodgeville	15	0.285	0.576
9 - Turtle Lake	15	0.327	0.455
10 - Coloma	15	0.576	0.112

4.3 Evaluation of Outliers

The research project evaluated 27 lots and 134 sublots across the ten shadow projects. Within each sublot, replicates of CT_{index} were evaluated for outliers. Four replicates of IDEAL-CT specimens were individually tested; these four replicates were averaged to obtain the sublot value. The IDEAL-CT data was assessed for outliers within the lot based on the average CT_{index} for each sublot. The HWTT data had a left and right wheel that were averaged to give one value for each sublot.

For air voids, there was only one observed outlier within project one. Table 4.3.1 shows an example calculation for project one, lot two. The green shaded cells mean it is within the outlier range, while the red cell marks the outlier.

Table 4.3.1 Outlier in Air Voids

	Air Voids

		Average
	7-1	3.0
	8-1	3.0
	9-1	3.7
	10-1	3.1
	10-2	2.9
Average		3.140
Standard Deviation		0.321
t critical		1.715
allowable deviation		0.550
Max		3.690
Min		2.590

Overall, one outlier was observed across the projects for all the IDEAL-CT lots tested in project 8, lot 5.

4.4 Examining Potential Relationships between Variability of Asphalt Content and Air Voids with IDEAL-CT and HWTT

To determine if asphalt content and air voids variability influenced the variability of IDEAL-CT and HWTT results, their respective calculated COVs of each lot were plotted against each other in scatterplots. Best-fit linear regression equations were determined for these correlation plots using Excel. The scatterplots of CT_{index} COV versus asphalt content and air voids COVs can be seen in Figure 4.3.1 and Figure 4.3.2, respectively. The scatterplots of HWTT CRD_{20k} COV versus asphalt content and air voids COVs can be seen in Figure 4.3.3 and Figure 4.3.4, respectively. The coefficient of determination (R^2) indicates how well the regression equation explains the relationship between the two variables. R^2 can be interpreted as the percentage of the change in the dependent variable, CT_{index} COV, in this case, which can be attributed to the independent variable, asphalt content COV in this case. In general, the low R^2

indicates that the variabilities of asphalt content and air voids had little to no influence on the variabilities of CTindex and HWTT CRD_{20k}.

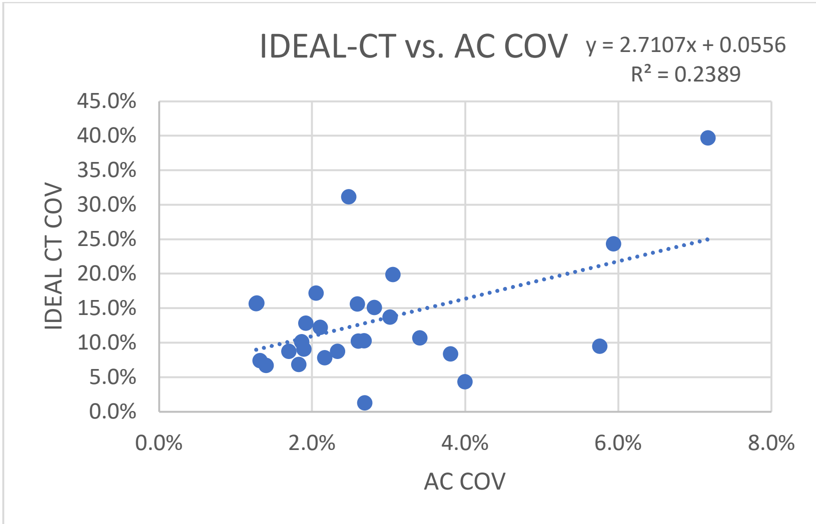


Figure 4.4.1 IDEAL-CT vs. AC COV

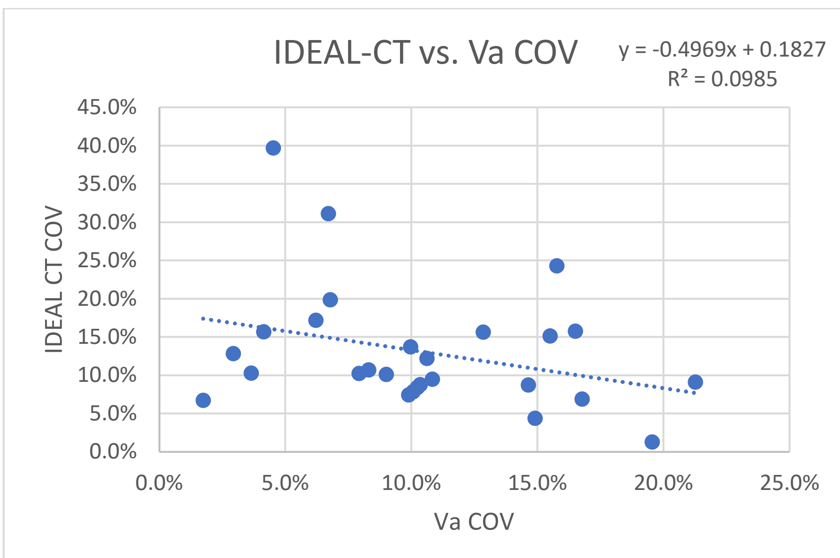


Figure 4.4.2 IDEAL-CT vs. Va COV

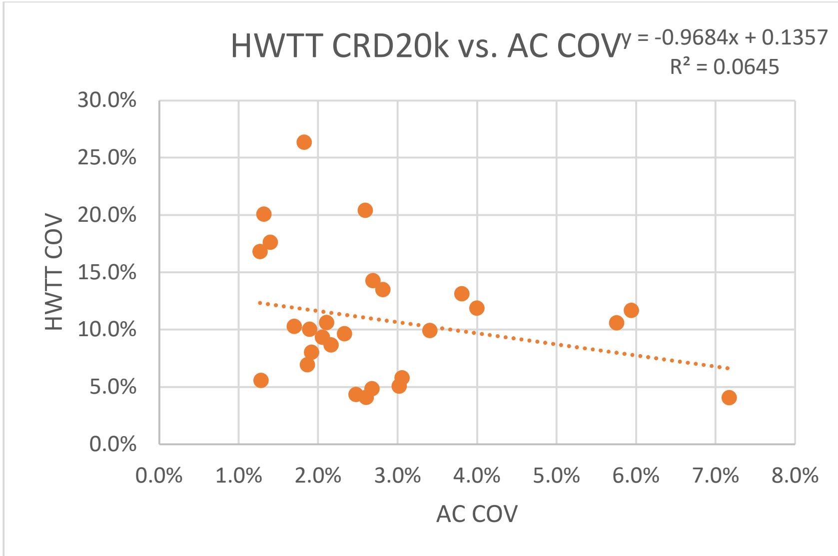


Figure 4.4.3 HWTT CRD20k vs. AC COV

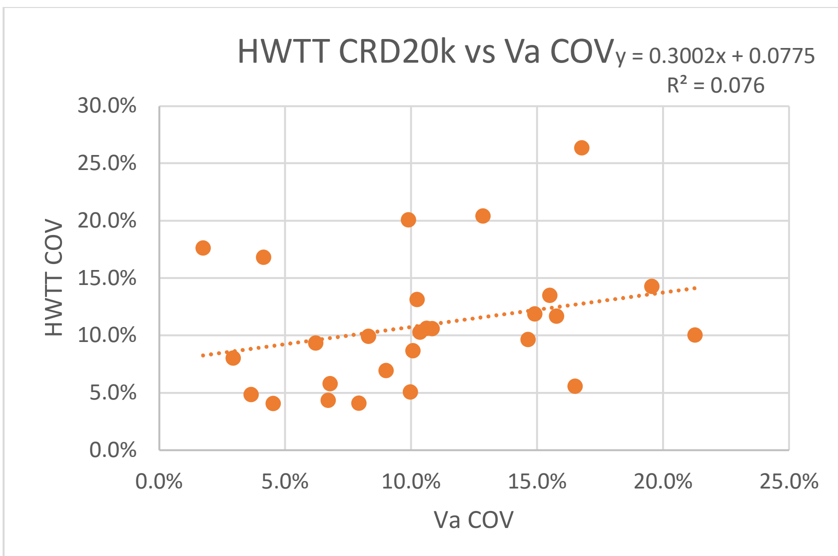


Figure 4.4.4 HWTT CRD 20k vs. Air Voids COV

4.5 Percent Within Limits based on Current WisDOT Specification

Percent within limits (PWL) were calculated for each lot and project based on current WisDOT specifications. For the IDEAL-CT test, the minimum specification limit for CT_{index} was set at 30. Table 4.5.1 summarizes the PWL calculations, where it can be seen that the only lots with PWLs below 100% were projects 3, lot 3 and project 5, lot 5.

Table 4.5.1 IDEAL-CT PWL

IDEAL-CT							
Project		Average	Std. Dev	COV	n	Ql	PWL
1 - P&D Jackson	Lot 1	47.0	7.4	15.6%	5	2.32	100
	Lot 2	48.0	4.0	8.4%	5	4.46	100
2 - NEA Popple River	Lot 2	58.2	9.1	15.7%	5	3.09	100
	Lot 3	62.8	19.6	31.1%	4	1.68	100
3 - Mathy Plant 1	Lot 2	62.7	6.4	10.2%	5	5.09	100
	Lot 3	69.7	27.7	39.7%	5	1.43	94.8
	Lot 4	73.3	17.8	24.3%	5	2.43	100
4 - NEA Denmark	Lot 2	86.2	7.6	8.8%	5	7.44	100
	Lot 3	83.8	10.7	12.8%	5	5.01	100
	Lot 4	89.0	6.0	6.7%	5	9.87	100
5 - Rock Road	Lot 4	40.1	4.3	10.7%	5	2.36	100
	Lot 5	44.3	8.8	19.9%	5	1.62	98.2
	Lot 6	51.3	5.2	10.1%	5	4.09	100
6 - La Crosse	Lot 9&11	46.2	3.6	7.8%	5	4.46	100
	Lot 10	51.2	7.7	15.1%	5	2.74	100
7 - Drummond	Lot 3&6	106.7	16.8	15.7%	5	4.57	100
	Lot 4	113.5	7.8	6.9%	5	10.70	100
	Lot 5	120.4	8.9	7.4%	5	10.12	100
8 - Dodgeville	Lot 3	45.1	2.0	4.4%	5	7.66	100
	Lot 4	51.0	4.6	9.1%	5	4.53	100
	Lot 5	43.4	0.6	1.3%	5	24.14	100
9 - Turtle Lake	Lot 8	51.5	8.9	17.2%	5	2.42	100
	Lot 9	58.9	5.2	8.8%	5	5.61	100
	Lot 10	57.5	5.5	9.5%	5	5.05	100
10 - Coloma	Lot 8	113.2	11.6	10.3%	5	7.15	100
	Lot 9	118.4	14.5	12.2%	5	6.11	100
	Lot 10	119.5	16.4	14%	5	5.46	100

For HWTT, the number of passes to a rut depth of 12.5 mm for both the left and right wheels were recorded and averaged. The WisDOT specification required a minimum of 10,000 passes to reach 12.5 mm rutting for low and medium traffic projects and a minimum of 20,000 passes to reach 12.5 mm for high traffic projects. Table 4.5.2 summarizes the HWTT PWL calculations. In this table, the projects are colored according to traffic category (yellow for low traffic, blue for medium traffic, and green for high traffic). Several projects had failing HWTT results resulting in negative Quality Index (QI) values, and PWL of less than 50% (highlighted in red).

It is important to note that the HWTT machine used for this project differs from the machine used in previous research for Wisconsin. There are a couple of reasons that the HWTT results for the mixtures evaluated in this project are worse than from previous studies. One possible explanation is that a calibration check of the machine used for this project near the end of testing for this study revealed that the wheel paths of this machine did not follow a sinusoidal form as required in the AASHTO standard. Another difference is that the HWTT analysis software programs used with the HWTT machines use different seating passes before the initial rut depth is established. Currently, the AASHTO standard does not address seating passes. It should also be noted that the current WisDOT specification was not the criteria that the previous research completed at NCAT recommended. Even though the mixes here did not meet the WisDOT specifications, this study was conducted on variability.

Table 4.5.2 HWTT PWL

HWTT - Corrected Rut Depth 20,000 passes							
Project		Average	Std. Dev	COV	n	Ql	PWL
1 - P&D Jackson	Lot 1	11416.0	4085.8	35.8%	5	0.35	62
	Lot 2	9662.0	3298.4	34.1%	5	-0.10	50
2 - NEA Popple River	Lot 2	5670.0	952.1	16.8%	5	-4.55	50
	Lot 3	4785.0	905.8	18.9%	4	-5.76	50
3 - Mathy Plant 1	Lot 2	14580.0	2752.5	18.9%	5	1.66	99
	Lot 3	11188.0	909.2	8.1%	5	1.31	92
	Lot 4	11642.0	2575.7	22.1%	5	0.64	72
4 - NEA Denmark	Lot 2	5682.0	523.1	9.2%	5	-8.25	50
	Lot 3	6200.0	734.8	11.9%	5	-5.17	50
	Lot 4	4800.0	486.2	10.1%	5	-10.70	50
5 - Rock Road	Lot 4	13972.0	2768.7	19.8%	5	1.43	95
	Lot 5	10662.0	2670.8	25.0%	5	0.25	59
	Lot 6	11266.0	1864.5	16.5%	5	0.68	74
6 - La Crosse	Lot 9&11	8460.0	608.6	7.2%	5	-2.53	50
	Lot 10	9018.0	1618.3	17.9%	5	-0.61	50
7 - Drummond	Lot 3&6	7192.0	215.1	3.0%	5	-13.05	50
	Lot 4	6592.0	1294.2	19.6%	5	-2.63	50
	Lot 5	4726.0	1197.2	25.3%	5	-4.41	50
8 - Dodgeville	Lot 3	9188.0	2272.4	24.7%	5	-4.76	50
	Lot 4	9056.0	1568.8	17.3%	5	-6.98	50
	Lot 5	11278.0	1973.5	17.5%	5	-4.42	50
9 - Turtle Lake	Lot 8	10870.0	1189.3	10.9%	5	0.73	75
	Lot 9	9278.0	1828.5	19.7%	5	-0.39	50
	Lot 10	9370.0	1463.9	15.6%	5	-0.43	50
10 - Coloma	Lot 8	9990.0	1406.6	14.1%	5	-7.12	50
	Lot 9	8302.0	235.4	2.8%	5	-49.69	50
	Lot 10	8840.0	553.2	6.3%	5	-20.17	50

4.6 Cumulative Distribution Frequency of Production Standard Deviation and COV

Cumulative distribution frequencies were plotted for each lot standard deviation and COV for the CT_{Index}, CRD_{20k}, air voids, and asphalt content.

Figure 4.6.1 and Figure 4.6.2 show the CT_{Index} standard deviation and COV, respectively, for each lot. The 50th percentile for the CT_{index} standard deviation is 7.5 The 50th percentile for CT_{index} COV was 13.2%, with approximately 80% of the lots tested having a COV under 20%.

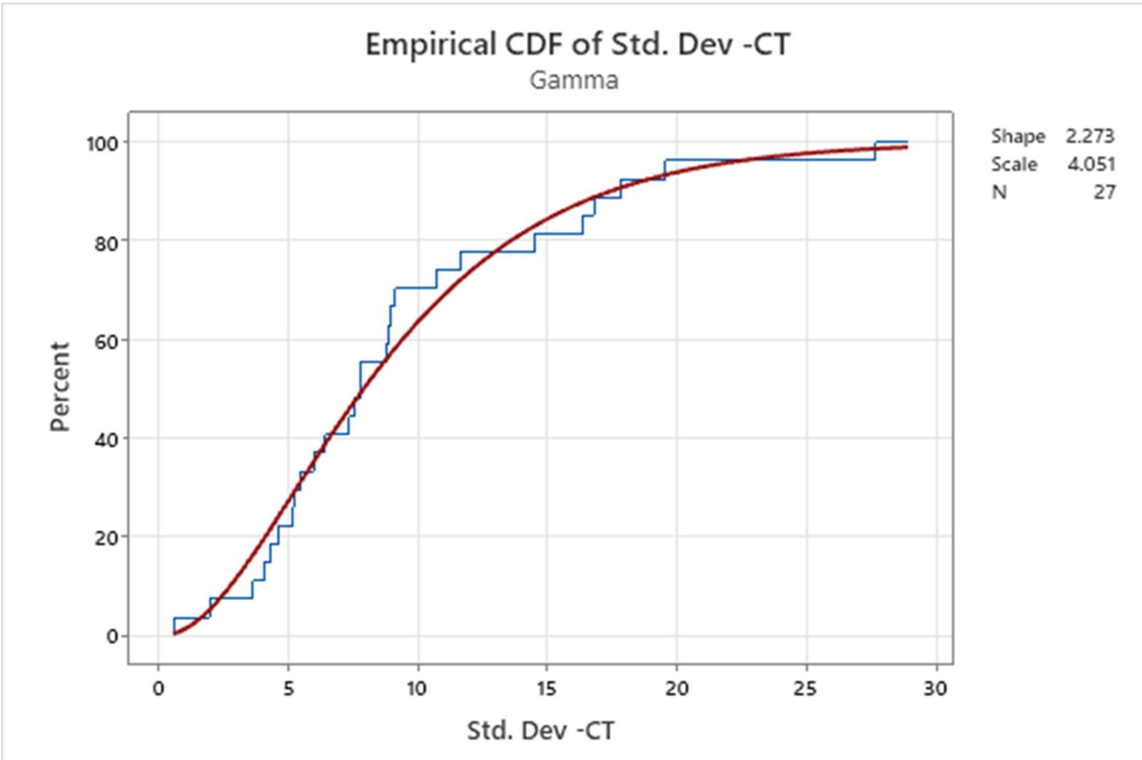


Figure 4.6.1 CDF of Std. Dev. CT_{Index}

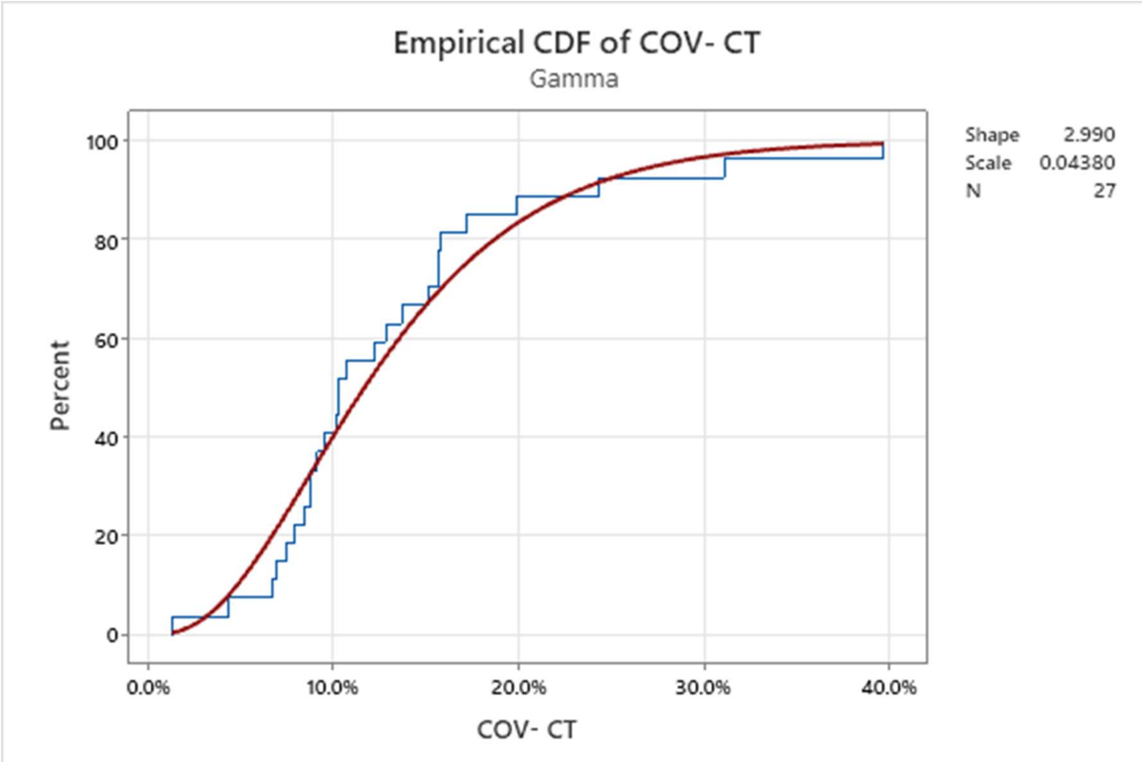


Figure 4.6.2 CDF of COV for CT_{Index}

Figures 4.6.3 and 4.6.4 show the CDF plots of standard deviation and COV for HWTT CRD_{20k}, respectively. The standard deviation had a 50th percentile of 1.3 The COV had a 50th percentile of 10.9%. Figures 4.6.5 and 4.6.4 show the CDF plots of standard deviation and COV for HWTT passes to 12.5 mm, respectively. The standard deviation had a 50th percentile of 1554 passes. The COV has a 50th percentile of 16.6%.

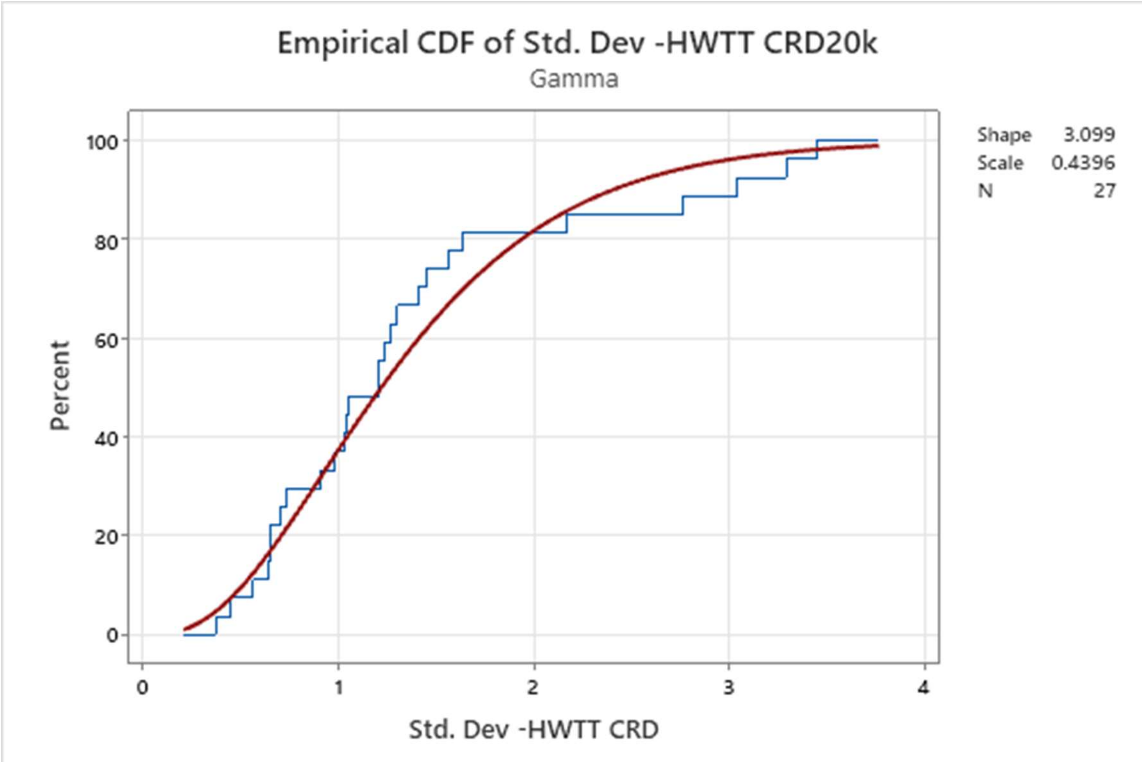


Figure 4.6.3 CDF of Std. Dev. HWTT CRD_{20k}

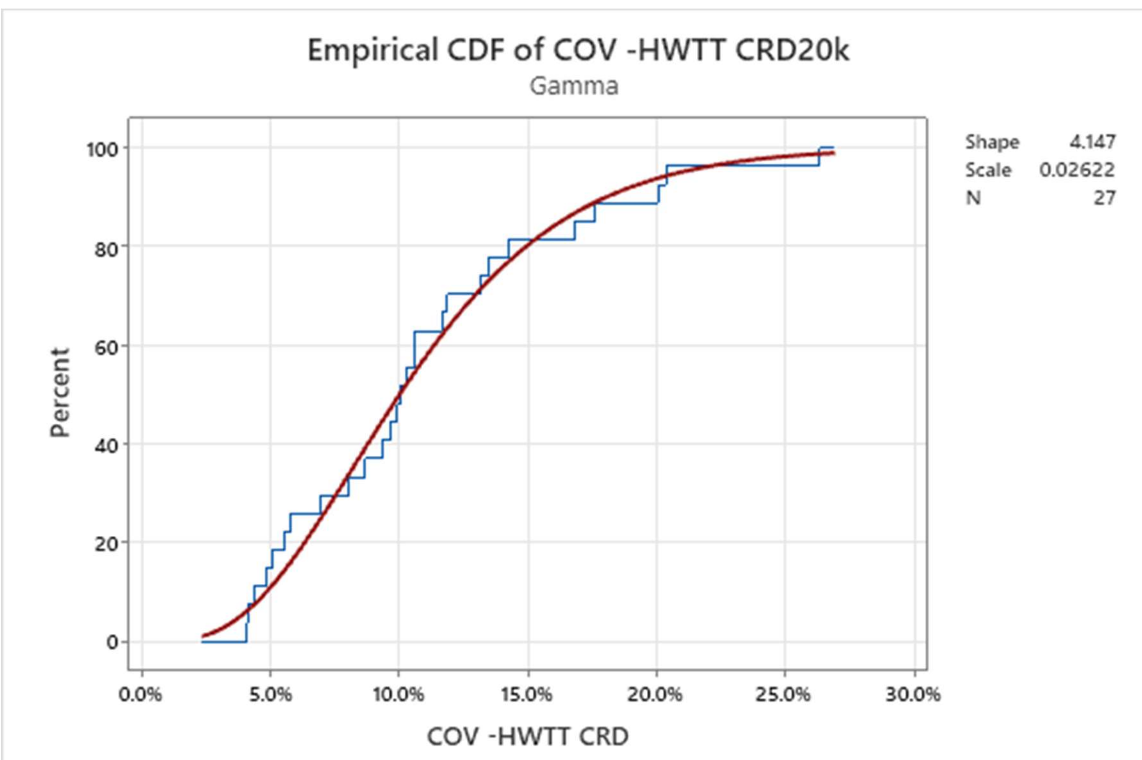


Figure 4.6.4 CDF of COV for HWTT CRD_{20k}

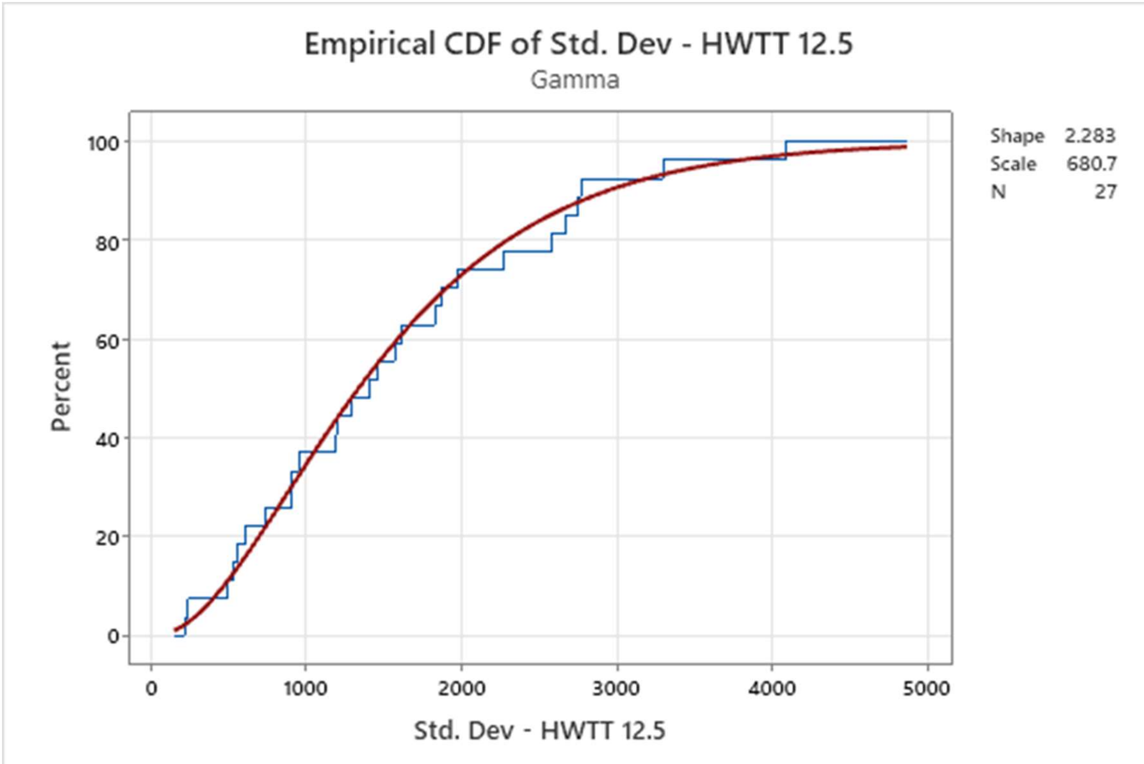


Figure 4.6.5 CDF of Std. Dev. for HWTT passes to 12.5 mm

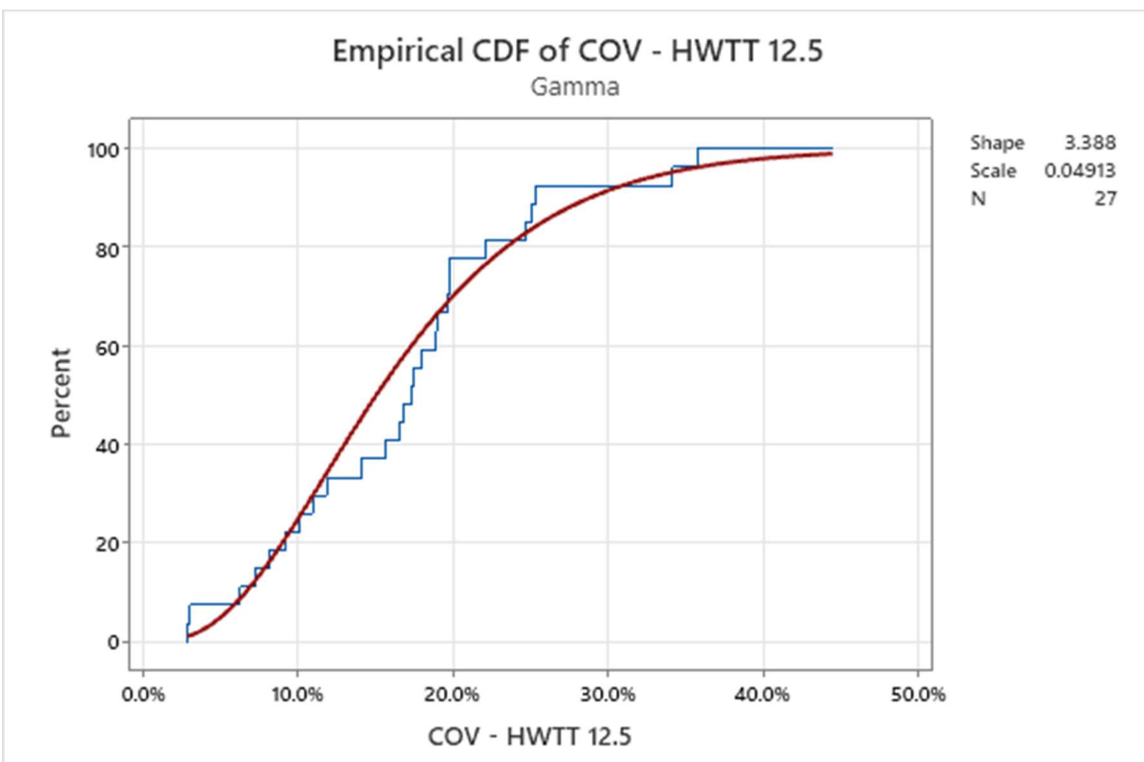


Figure 4.6.6 CDF of COV for HWTT passes to 12.5 mm

Figures 4.6.7 and 4.6.8 display the CDFs of the standard deviation and COV of asphalt content, respectively. Figures 4.6.9 and 4.6.10 show the CDF of the standard deviation and COV of air voids, respectively.

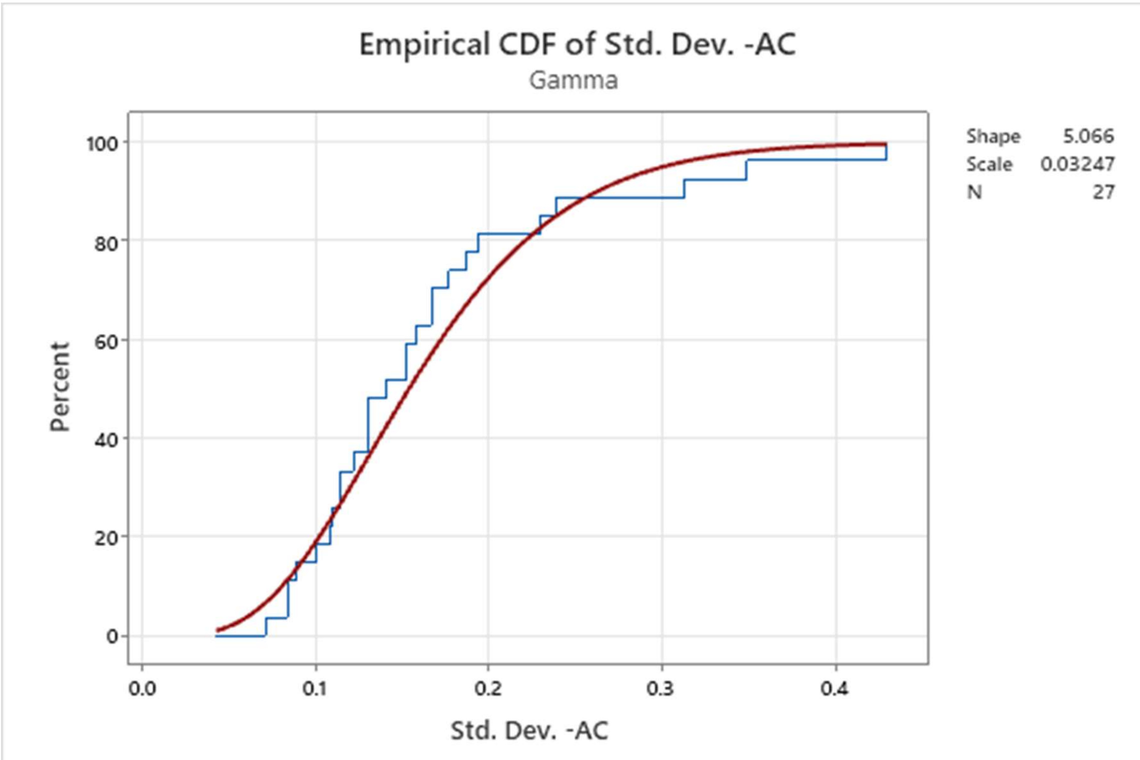


Figure 4.6.7 CDF of Std. Dev. for Asphalt Content

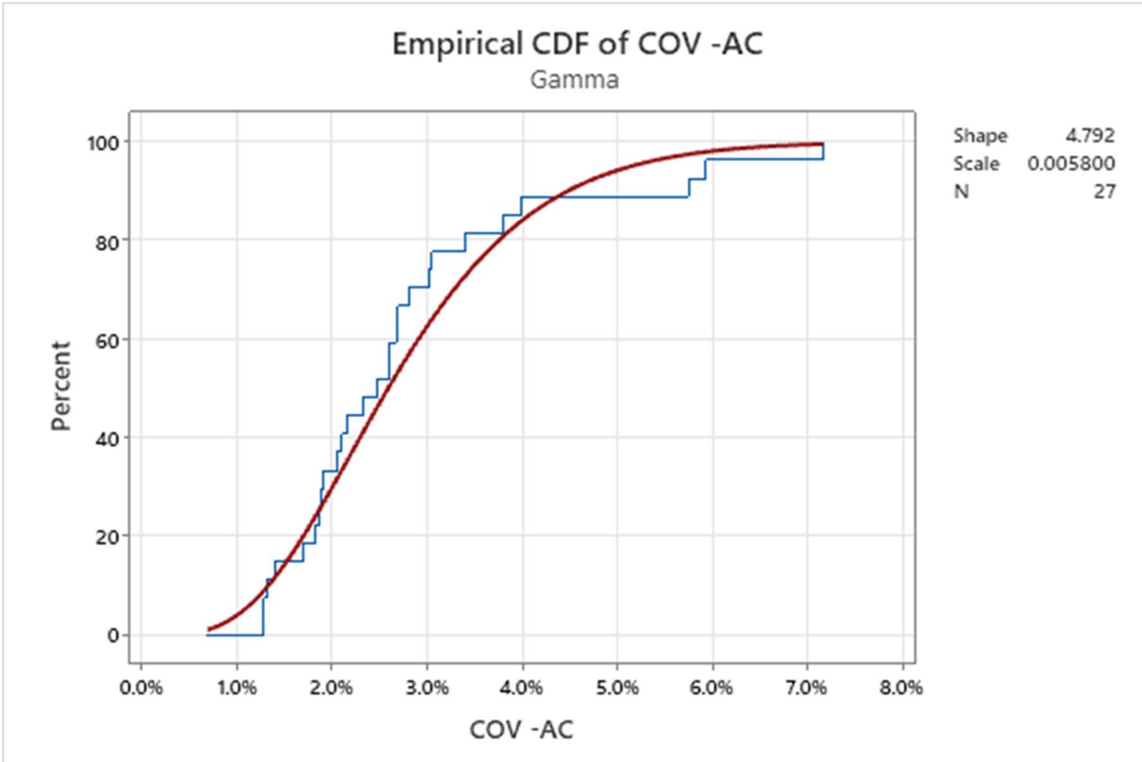


Figure 4.6.8 CDF of COV for Asphalt Content

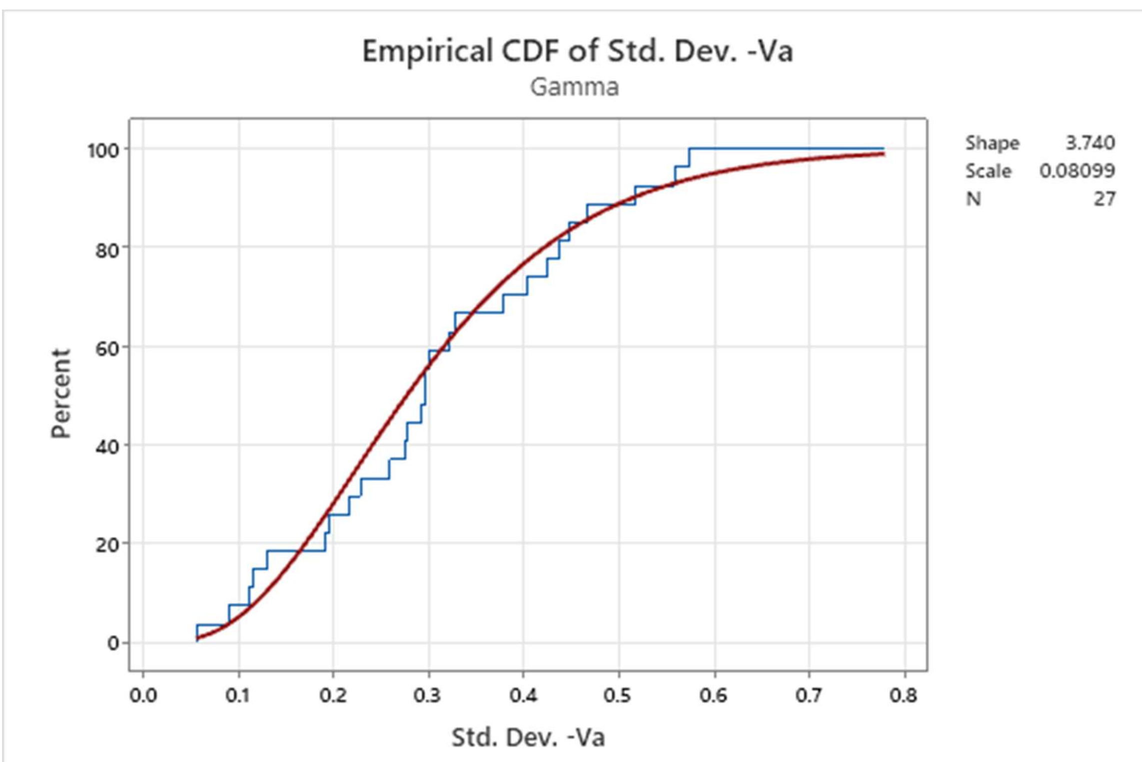


Figure 4.6.9 CDF of Std. Dev. for Air Voids

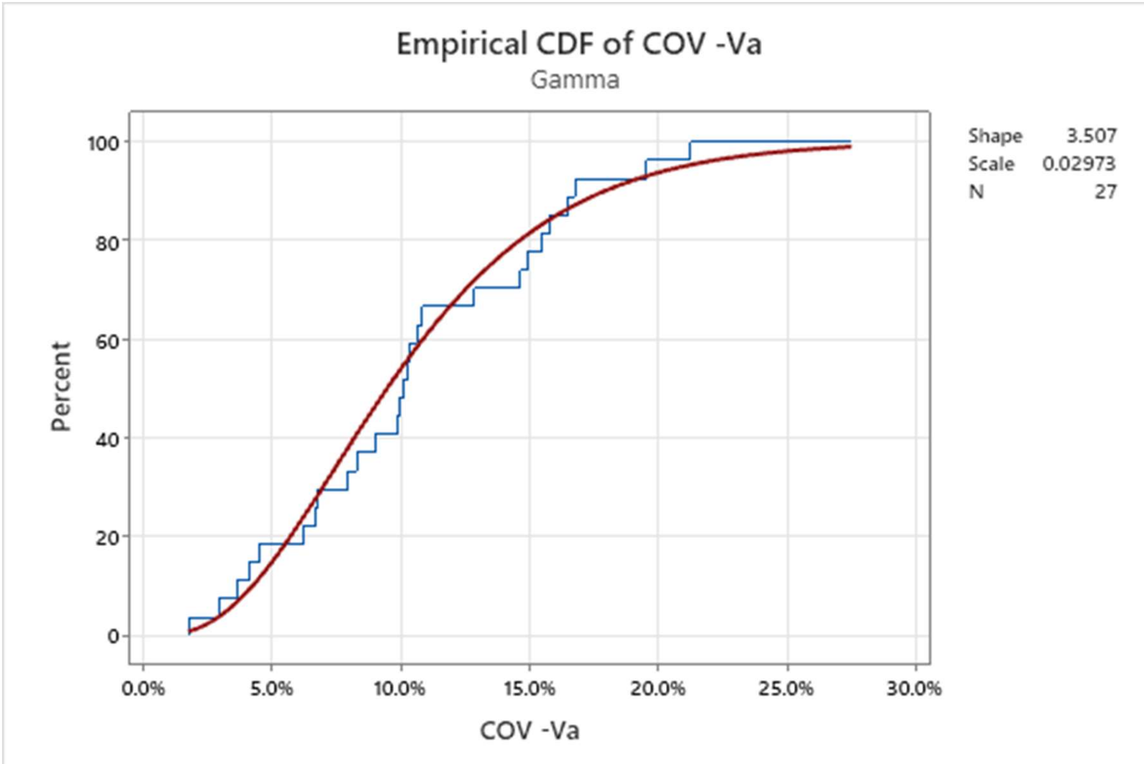


Figure 4.6.10 CDF of COV for Air Voids

A combined plot of CDFs for standard deviations of CT_{index}, HWTT CRD_{20k}, asphalt content, and air voids is shown in Figure 4.6.11. A combined plot of CDFs of COVs of CT_{index}, HWTT CRD_{20k}, HWTT passes to 12.5 mm, asphalt content, and air voids are shown in Figure 4.6.12. It can be seen in Figure 4.6.12 that the asphalt content COV was the lowest, air voids and HWTT CRD_{20k} has very similar COV distributions, and the HWTT passes to 12.5 mm COV was the highest.

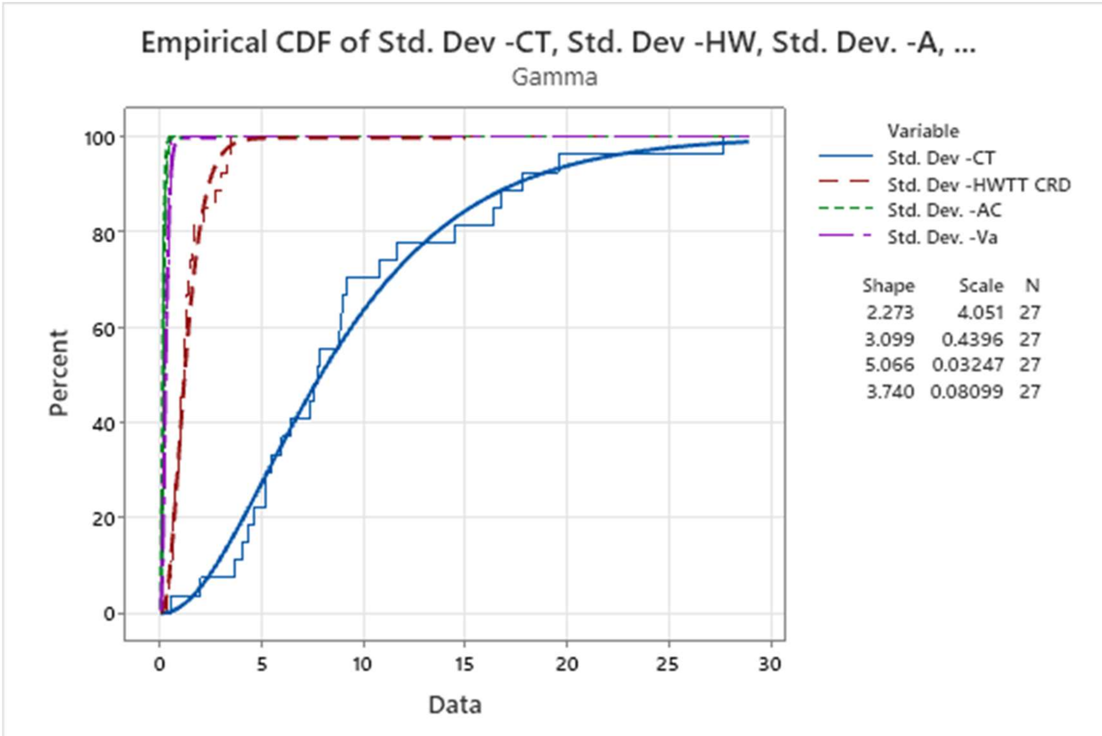


Figure 4.6.11 CDF of Std. Dev. for CT_{Index}, HWTT CRD_{20k}, asphalt content, air voids

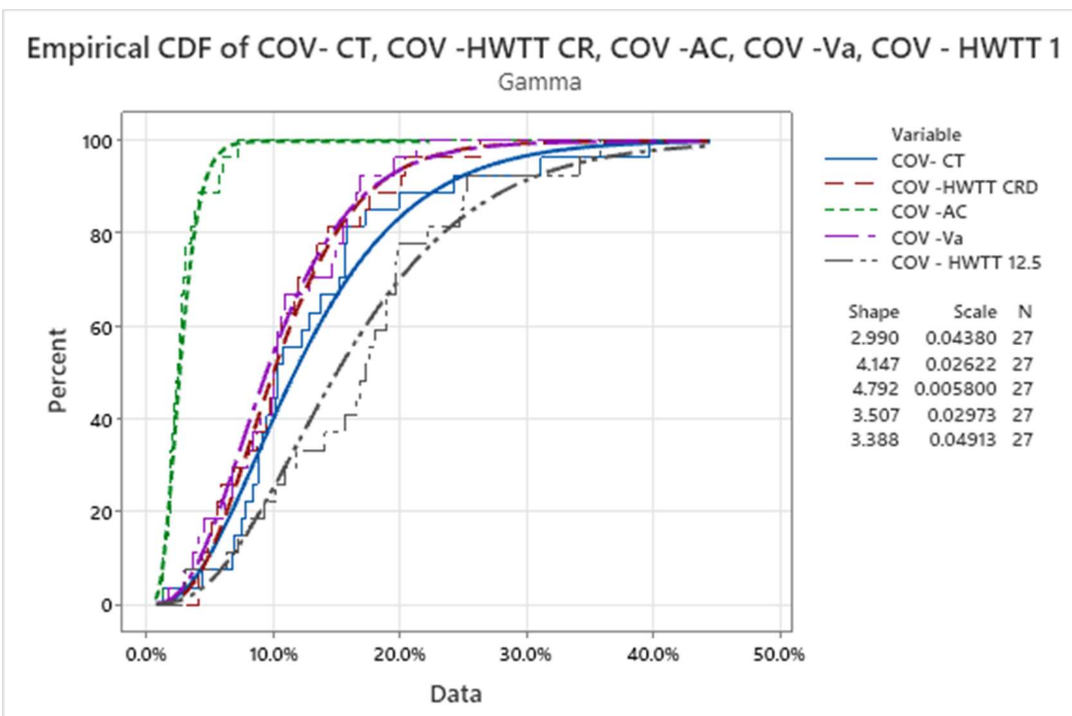


Figure 4.6.12 CDF of COV for CT_{Index}, HWTT CRD_{20k}, HWTT passes to 12.5 mm, asphalt content, air voids

Chapter 5: Conclusions and Recommendations

5.1 Summary

The main objective of this thesis was to statistically analyze the overall variabilities of the performance test results for ten shadow projects. A recommended appropriate standard deviation for the BMD performance test is also provided based on the Wisconsin field-produced mixes. In total, 134 mixture samples were obtained and sent to NCAT for performance testing. The statistical analysis included a summary of the averages, standard deviations, and coefficients of variation. The Anderson-Darlington statistic and probability plots of the ten shadow projects sublots were calculated to check for normality. Results were analyzed to determine outliers on the IDEAL-CT, HWTT CRD_{20k}, asphalt content, and air voids. The percent within limits was calculated based on current WisDOT specifications on the IDEAL-CT and HWTT passes to 12.5 mm. Finally, CDF plots were made on production standard deviations and COVs.

5.2 Conclusions

After statistical analysis, the following conclusions are made:

- AC content was the least variable quality characteristic, with a mean COV of 2.8%. HWTT passes to 12.5 mm rut depth was the most variable quality characteristic with a mean COV of 16.6%. IDEAL-CT had a mean COV of 13.1%. The mean COV for air voids was 10.4%. The mean COV for HWTT CRD_{20k} was 10.9%. From the literature reviewed the COV results achieved at NCAT were lower. These parameters were measured across ten shadow project's production variability, one reason these might be lower is due to the extreme carefulness that was taken during sample preparation.

Another reason is that there was a small sample size going into each shadow project's lot (five sublots).

- Normality testing showed that HWTT passes to 12.5 mm followed the most normal distribution, and the least normal distribution was the CT*index*.
- The PWL analysis of CT_{index} indicated that 25 of the 27 lots had 100% PWL over the ten projects. HWTT passes to 12.5 mm rut depth did not meet the PWL, partly due to the HWTT machine not having a sinusoidal wavelength.

5.3 Plans for Future Research

Studies should follow up with these ten projects over the years to document the field cracking and rutting to determine correlations between lab and field performance.

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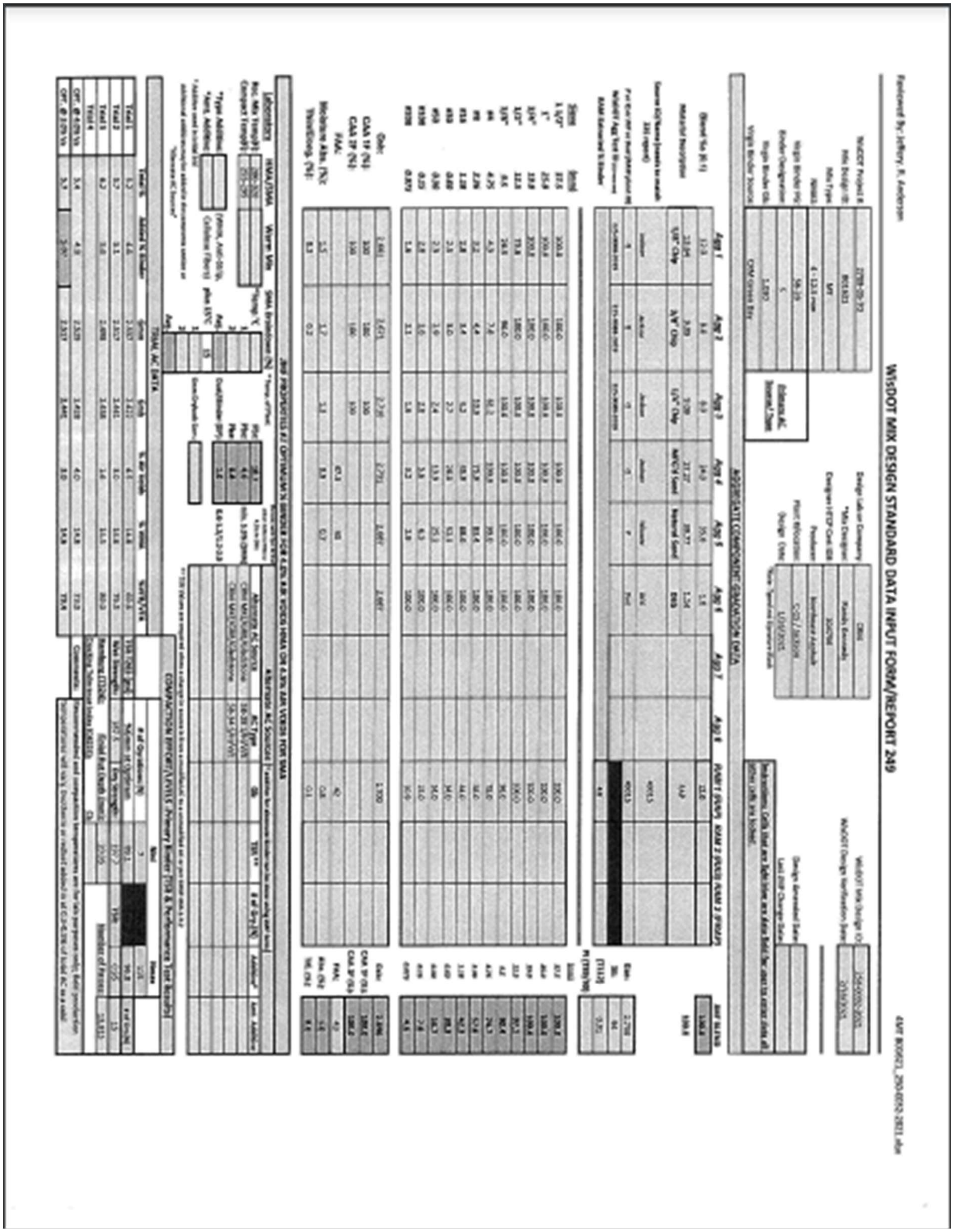
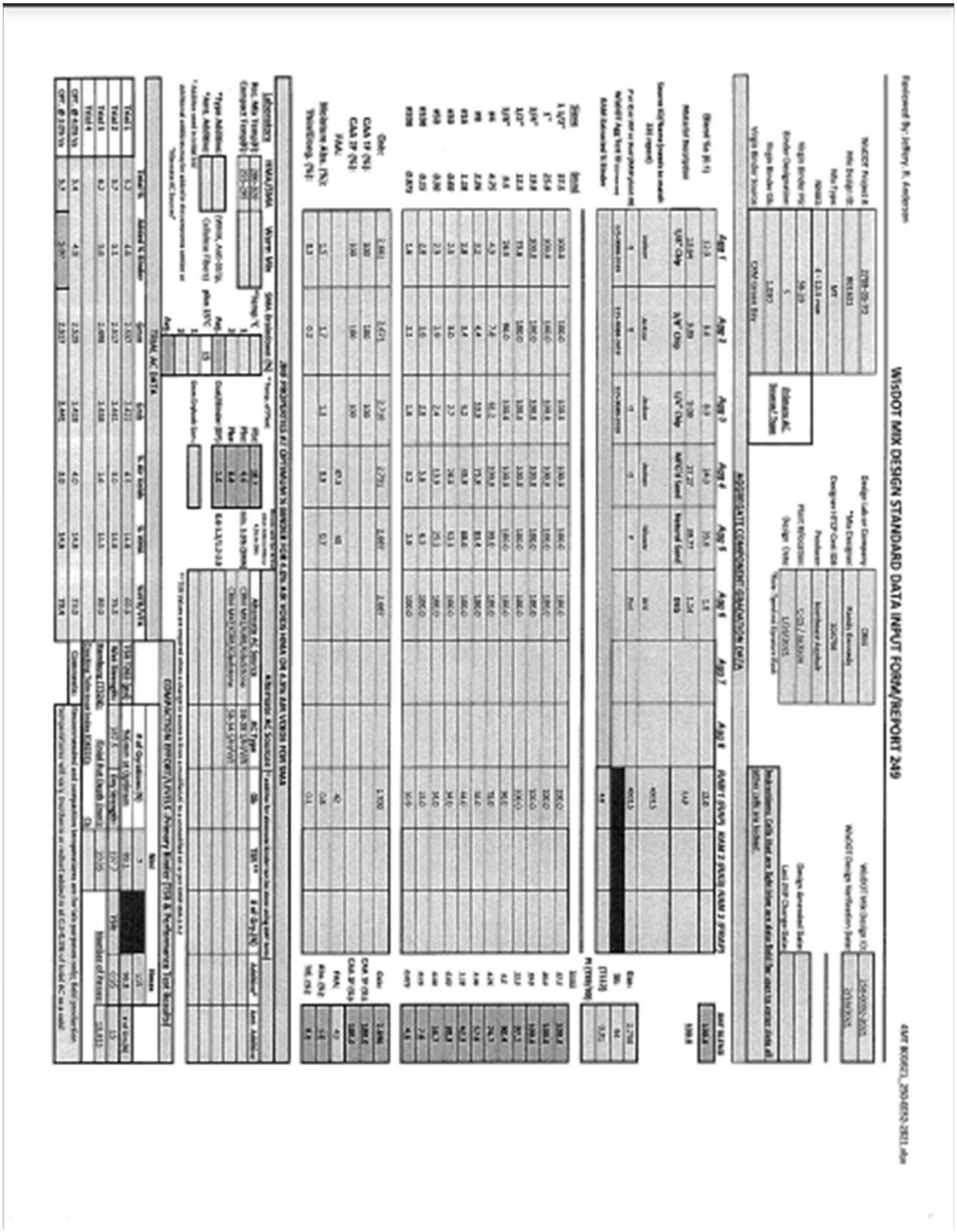
Appendix

Mix Design Project 1


WISDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

Mix Design Project 2


Reviewed By: Jeffery. R. Anderson

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

AGGREGATE COMPONENT GRADATION DATA

Sieve	(mm)
1 1/2"	37.5
1"	25.0
3/4"	19.0
1/2"	12.5
3/8"	9.5
#4	4.75
#8	2.36
#16	1.18
#30	0.60
#50	0.30
#100	0.15
#200	0.075

Gsb:
CAA 1F (%):
CAA 2F (%):
FAA:
Moisture Abs. (%):
Thin/Elong. (%):

TRIAL AC DATA

COMPACTION EFFORT/LEVELS

Mix Design Project 3

MATHY CONSTRUCTION CO.

GENERAL CONTRACTORS

920 10TH AVE N POST OFFICE BOX 189 ONALASKA, WI 54650
PHONE 608-781-4683 FAX 608-781-4694

Report of Bituminous Mix Design

Project Name	Dubuque - Shullsburg STH 11
Date	August 27, 2021
Project #	1706-00-70
Test#	601-21-4MTR301
County	Grant
Specifications	12.5mm MT Design
Course/Layer	

AASHTO R18

Aggregate Sources

	Percent	Material	Location / Source	G_{sb}
1	28	1/2" Washed Chips(1248)	Browns Bottom 24,88,3E Dubuque,IA	2.698
2	33	3/16" Washed Man Sand(1403)	Browns Bottom 24,88,3E Dubuque,IA	2.755
3	17	1/2" Screened Sand(5502)	Tegeler Pit 26,89,3W Deleware, IA	2.616
4	22	RAP(6.0% AC)(7206)	Plant 1 RAP	2.671
5				
6				
7				
8				

	1	2	3	4	5	6	7	8		
Total									Comb G_{sb}	2.696
Virgin Agg Blend	35.90	42.31	21.79						Comb G_{se}	2.734

Aggregate Gradations

Sieve (Std)	Sieve (mm)	Material 1	2	3	4	5	6	7	8	Job Mix	Spec High	Spec Low
2"	50	100.0	100.0	100.0	100.0					100.0		
1.5"	37.5	100.0	100.0	100.0	100.0					100.0		
1"	25	100.0	100.0	100.0	100.0					100.0		
3/4"	19	100.0	100.0	100.0	100.0					100.0		
1/2"	12.5	92.0	100.0	100.0	94.0					96.4		
3/8"	9.5	60.0	100.0	100.0	88.0					86.2		
#4	4.75	13.0	97.0	98.0	69.0					67.5		
#8	2.36	2.1	67.0	86.0	58.0					50.1		
#16	1.18	1.4	42.0	70.0	51.0					37.4		
#30	0.6	1.3	28.0	46.0	41.0					26.4		
#50	0.3	1.2	18.0	14.0	30.0					15.3		
#100	0.15	1.1	8.0	1.8	16.0					6.8		
#200	0.075	1.0	2.7	1.0	9.7					3.5		
Soundness		225-57	225-57								12 Max	
LAR 100/500 Rev		2021	2021								13 & 45 Max	
Crush 1 Face (%)		100.0	100.0	25.0	99.0					99.0	75 Min	
Crush 2 Face (%)		100.0	100.0	23.0	99.0					99.0	60 Min	
Sand Equiv.										88	40 Min	
Flat & Elong (%)		0.9		0.5	0.1					0.7	5 Max	
Fine Agg Ang			49.7	40.5	43.2					43.8	43 Min	
Water Abs.		1.1	0.9	0.7	1.0					0.9		

Test Methods: D312, T176/D2419, T11/C117, T27/C136, D4791, D5821, T304/C1252, T96/C131, T209/D2041, T166/D2726

MATHY CONSTRUCTION CO.

GENERAL CONTRACTORS

920 10TH AVE N POST OFFICE BOX 189 ONALASKA, WI [illegible]

PHONE [illegible] FAX [illegible]

Report of Bituminous Mix Design

Project Name	Dubuque - Shullsburg STH 11
Date	August 27, 2021
Project #	1709-00-70
Test #	501-21-4MTR301
County	Grant
Specifications	12.5mm MT Design
Course/Layer	

AASHTO R18

Mix Properties

Trial #	1	2	3	4	5	6
AC Content (% by Wt)	5.0	5.5	6.0	6.5		5.4
Compaction Level	Design	Design	Design	Design		Max
Air Voids V_a (%)	6.3	3.7	2.2	1.0		4.2
$\%G_{mm}$ @ N_i	89.4	90.6	92.0	92.9		90.8
$\%G_{mm}$ @ N_{final}	94.7	96.3	97.8	99.0		[illegible]
VMA (%)	15.7	15.4	15.2	15.3		14.8
VFA (%)	60.5	76.0	85.6	93.2		71.8
Density (kg/m^3)	2391	2412	2433	2442		2425
G_{mb}	2.391	2.412	2.433	2.442		2.425
G_{mm}	2.525	2.505	2.487	2.468		[illegible]

Gyrations	
N_i	7
N_d	75
N_m	115

Antistrip
None

Mix Design

Note: trials must bracket desired V_a targets.

Property	Value		Specification
V_a	3.0	4.0	
Design P_b	5.7	5.4	
Added P_b	4.4	4.1	
VMA	15.3	15.5	14.5 Minimum
VFA	80.4	74.1	70 - 76
G_{mm}	2.498	2.509	
G_{mb}	2.423	2.409	
P_{be}	5.2	4.9	
P_{ba}	0.5	0.5	
Dust/Binder Ratio	0.7	0.7	0.6 - 1.2
$\%G_{mm}$ @ N_i		90.4	< 89.0 Rec
$\%G_{mm}$ @ N_d		95.8	~ 96.0
$\%G_{mm}$ @ N_m		96.8	98.0 Max
TSR Ratio	85.8		75 Minimum
Rec. Mix Temp.	275-300		

Primary AC Source	AC Type	Gb
M/A - La Crosse	PG 58S-28	1.029
Alternate Sources		
M/A - La Crosse	PG 58S-34	1.023
M/A - La Crosse	PG 58V-34	1.020
M/A - La Crosse	PG 58H-28	1.031

% Binder Replacement

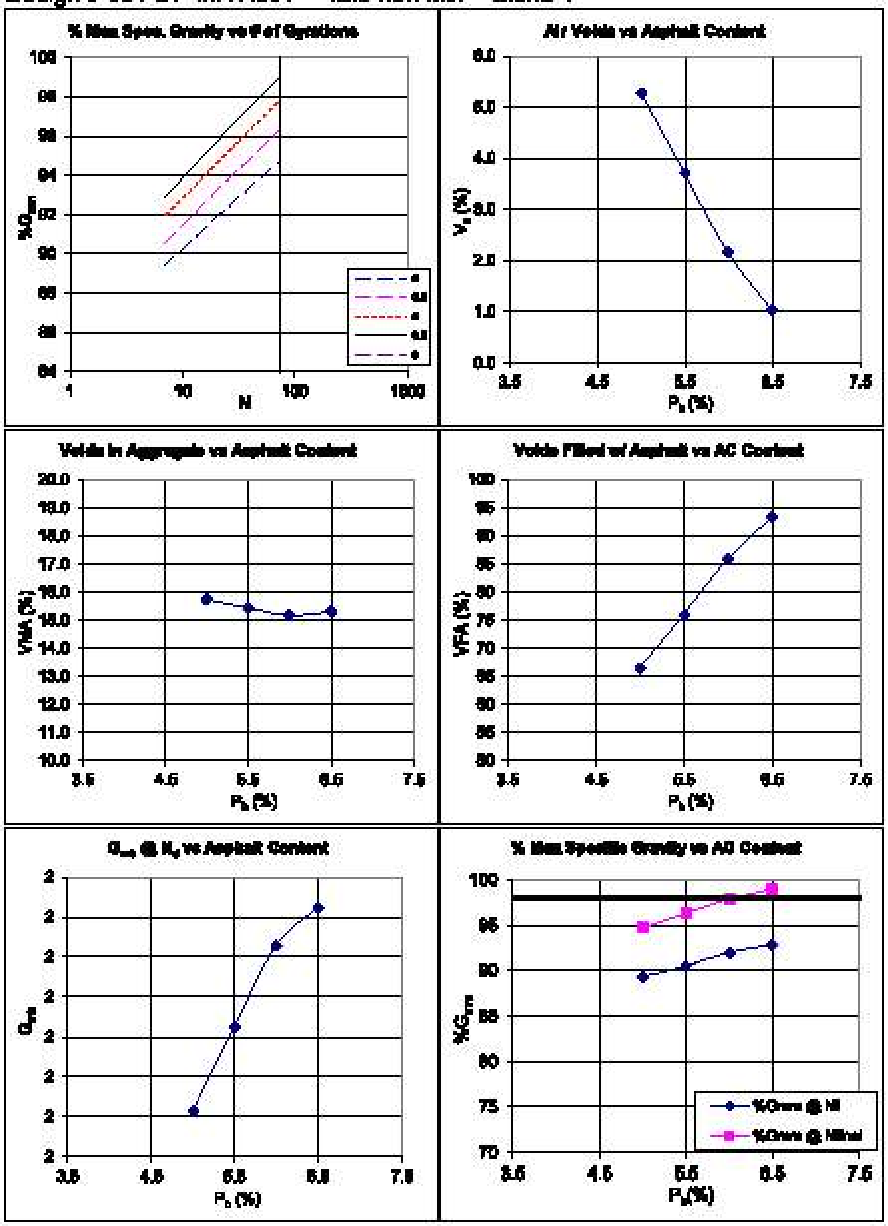
3.0	4.0
22.6%	24.1%

Average # of Gyrations	23

Since this design is material specific, the conclusions and recommendations contained within are obtained from material submitted to and subjected to observations under laboratory conditions.
Adjustments may become necessary when field laboratory data is obtained from plant produced mix.
No guarantee or warranty is implied or offered.
Note: 0.2% Evotherm added as a compaction aid.

Signature: ______ Cert. No. 100163 Date: 8/27/2021

Dubuque - Shullsburg STH 11
Design # 801-21-4MTR301 – 12.5 mm Mix – Blend 1



Mix Design Project 4

Reviewed By: Jeffery. R. Anderson

4MT 802022_25

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	4125-14-80	Design Lab or Company:	CRM	WisDOT Mix Design ID:	250-0005-2022
Mix Design ID:	802023	*Mix Designer:	Randy Kennedy	WisDOT Design Verification Date:	3/21/2022
Mix Type:	MT	Designer HTCP Cert ID#:	104756		
NMAS:	4 - 12.5 mm	Producer:	Northeast Asphalt		
Virgin Binder PG:	58-28	Plant #/location:	Portable / Denmark	Design Amended Date:	
Binder Designation:	S	Design Date:	3/2/2022	Last JMF Change Date:	
Virgin Binder Gb:	1.030				
Virgin Binder Source:	CRM Green Bay				

Primary AC Source/ Type

*Note: Typed not Signature Block

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)	10.0	11.0	20.0	34.5	0.5				24.0				100.0
Material Description	5/8" Chip	3/8" Chip	MFG'd Sand	Natural Sand	DEG				RAP				
Source ID/Name (needs to match 225 report)	Denmark	Denmark	Denmark	Ahmdt PB	DEG				40037				
P or Q or MF or Dust (RAM plant ID)	Q	Q	Q	P	Dust				40037			Gse:	2.758
WisDOT Agg Test ID	225-0008-2020	225-0008-2020										SE:	89
RAM Extracted % Binder									5			(T112)	0.2
												PI (T89/90)	
Sieve (mm)												(mm)	
1 1/2" 37.5	100.0	100.0	100.0	100.0	100.0				100.0			37.5	100.0
1" 25.0	100.0	100.0	100.0	100.0	100.0				100.0			25.0	100.0
3/4" 19.0	100.0	100.0	100.0	100.0	100.0				100.0			19.0	100.0
1/2" 12.5	80.0	100.0	100.0	100.0	100.0				100.0			12.5	98.0
3/8" 9.5	20.0	89.0	100.0	100.0	100.0				97.0			9.5	90.1
#4 4.75	1.6	6.1	90.0	100.0	100.0				75.9			4.75	72.0
#8 2.36	1.3	1.7	46.8	96.3	100.0				58.1			2.36	57.3
#16 1.18	1.2	1.5	22.5	90.6	100.0				45.7			1.18	47.5
#30 0.60	1.2	1.5	11.5	74.6	100.0				36.1			0.60	37.5
#50 0.30	1.1	1.4	6.5	21.3	100.0				23.1			0.30	15.8
#100 0.15	1.1	1.3	3.6	4.0	100.0				16.8			0.15	6.9
#200 0.075	1.0	1.2	1.7	2.3	100.0				11.1			0.075	4.5
Gsb:	2.775	2.765	2.776	2.667	2.667				2.739			Gsb:	2.727
CAA 1F (%):	100	100										CAA 1F (%):	100.0
CAA 2F (%):	100	100										CAA 2F (%):	100.0
FAA:			46	41					44			FAA:	43
Moisture Abs. (%):	0.8	1.0	0.6	1.0					0.7			Abs. (%):	0.8
Thin/Elong. (%):	0.4	1.5										T/E. (%):	0.2

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):	280-320	
Compact Temp(F):	255-295	

*Type Additive: (WMA, Anti-Strip, Cellulose Fibers)

*Amt. Additive:

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%) * Temp. of Plant

*Temp. °C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr:	21.8	
Pbe:	4.7	min. 5.5% (SMA)
Pba:	0.8	
Dust/Binder (DP):	1.0	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
CRM MKE/GRB/Gladstone	58-28 S/H/V/E					
CRM MKE/GRB/Gladstone	58-34 S/H/V/E					

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Total %	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.2	4.0	2.561	2.434	5.0	15.4	67.5
Trial 2	5.7	4.5	2.541	2.452	3.5	15.2	77.0
Trial 3	6.2	5.0	2.521	2.463	2.3	15.3	85.0
Trial 4							
OPT. @ 4.0% Va	5.5	4.3	2.550	2.448	4.0	15.2	73.6
OPT. @ 3.0% Va	5.9	4.72	2.532	2.456	3.0	15.3	80.3

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Ndes	
	# of Gyrations (N)	7	--	115	
TSR T283 (psi)	%Gmm at Optimum	90.4	--	96.9	# of Gry.(N)
Wet Strength:	393.7	Dry Strength: 451.6	TSR:	0.87	15
Hamburg (T324):	Final Rut Depth (mm):	19.10		Number of Passes:	19082
Cracking Tolerance Index (D8225):	CT:	81			

Comments: Recommended and compaction temperatures are for lab purposes only; field production temperatures will vary; Evotherm or rediset added in at 0.3-0.5% of total AC as a cold

Mix Design Project 5

Rock Road Companies Mix Design

* Rock Road Companies * 301 W B R Townline Rd * Beloit, WI 53511 * (608)752-8944 *

Project:	Various WisDOT	Spec.	WisDOT	Plant Location:	389/Delafield	Date:	3/31/2022
Project #:	8250-11-11	RR Mix #:	RR0408	MD Tech Signature:	[illegible]	DOT Ver. Date:	4/5/2022
Mix Type:	4 MT 58-28 S	WisDOT Mix Ver #:	250-0851-2022	MD Tech Print:	Jon Wixom		

Agg #		Rec 1	Rec 2			Agg 1	Agg 2		Agg 3	Agg 4	BHF / MF	ASPHALT
Aggregate Description		WLF 1/2" RAP	WLF RAS			WLF 5/8" ST	WLF 3/8" ST		WLF WMS	WLF Blend Sand	BHF	58-28 S
Source Designation		Wolf	Wolf			[illegible] Waukesha County	[illegible] Waukesha County		[illegible] Waukesha County	[illegible] Waukesha County	Wolf Dousman Plant	Flint Hills Resources, Dubuque, IA
Internal Source #												
Source Quality Data	Test #					225-257-2021	225-257-2021		225-257-2021	225-257-2021	Gb	1.031
	Sound	N/A				2.4	2.4		2.4	2.4		
	LA 100/500	N/A				4.1 / 23.0	4.1 / 23.0		4.1 / 23.0	4.1 / 23.0		
	Freeze	N/A				1.3	1.3		1.3	1.3		

% Aggregate		24.00	3.00			15.00	9.00		24.00	24.00	1.00	Sieve Size		JMF Blend	4 MT (12.5mm N/S)
1 1/2"	37.5mm	100.0	100.0			100.0	100.0		100.0	100.0	100.0	1 1/2"	37.5mm		
1"	25.4mm	100.0	100.0			100.0	100.0		100.0	100.0	100.0	1"	25.4mm		
3/4"	19.0mm	100.0	100.0			100.0	100.0		100.0	100.0	100.0	3/4"	19.0mm	100.0	100
1/2"	12.5mm	99.6	100.0			65.0	100.0		100.0	98.7	100.0	1/2"	12.5mm	97.3	90 - 100
3/8"	9.5mm	95.8	100.0			31.0	96.4		100.0	96.4	100.0	3/8"	9.5mm	87.5	90 max
#4	4.75mm	77.2	99.4			1.9	24.8		100.0	90.3	100.0	#4	4.75mm	70.7	
#8	2.36mm	57.4	98.8			1.7	3.8		65.9	85.9	100.0	#8	2.36mm	54.8	28 - 58
#16	1.18mm	42.2	81.9			1.6	3.1		40.0	79.8	100.0	#16	1.18mm	42.9	
#30	0.6um	30.4	59.2			1.6	2.8		23.0	65.0	100.0	#30	0.6um	31.7	
#50	0.3um	18.7	52.3			1.5	2.6		18.0	25.0	100.0	#50	0.3um	17.8	
#100	0.15um	12.2	44.5			1.4	2.5		6.8	6.4	99.0	#100	0.15um	8.7	
#200	0.075um	8.1	33.4			1.2	2.2		3.9	3.2	91.0	#200	0.075um	5.7	2.0 - 10.0
CAA 1F (%)		97				97.8	100			37		CAA 1F (%)		93.3	75
CAA 2F (%)		92.1				95.9	100			28.6		CAA 2F (%)		90.8	60
Flat & Elongated												Flat & Elongated		0.00	Flat & Elong.
Agg Abs		1.1				1.1	1.4		1.2	1.1		Agg Abs		1.1	Agg Abs
Gsb		2.688	2.501			2.748	2.719		2.717	2.654	2.700	Gsb		2.695	Gsb
FAA		43	45						46	42		FAA		44	43 MIN
RAM % AC		4.9%	24.5%												
														98	Sand Equiv.
														0	Clay Lumps (T112)
														0	PI (T89/90)

% Gmm @ Optimum			
N Level	Nini	Ndes	Nmax
Revs	7	75	115
% Gmm	89.8%	96.3%	97.4%

HMA Mixing and Compaction Temperatures			
Mixing Temp.	300F	Compaction Temp.	270F

HMA Mixture Liquid AC Properties	
Total Pb	5.5%
Virgin Pb	3.6%
Pba	0.8%
Pbe	4.7%
RAM Pb	1.9%

Volumetric Properties at Ndes				
	%AC	%Air Voids	%VMA	%VFA
	4.5%	6.8%	15.5%	56.1%
	5.0%	5.5%	15.4%	64.3%
	5.5%	3.9%	15.1%	74.2%
	6.0%	2.4%	15.0%	84.0%
4% Va Optimum	5.5%	4.0%	15.1%	73.6%

MIX TYPE: 4 MT 58-28 S		Optimum Design Data @ 4.0% Va		MIX#: RR0408	
# of Gyrations	% AC	% Binder Replacement	% Voids	VMA	Gmm
75	5.5%	34.9%	4.0%	15.1%	2.520
Gmb	VFA	Gse	Gsb	Dust/AC	TSR
2.419	73.6%	2.750	2.695	1.21	0.78
				[illegible]	[illegible]

MIX TYPE: 4 MT 58-28 S		Optimum Design Data @ 3.0 % Va		MIX#: RR0408	
# of Gyrations	% AC	% Binder Replacement	% Voids	VMA	Gmm
75	5.8%	32.8%	3.0%	15.0%	2.507
Gmb	VFA	Gse	Gsb	Dust/AC Ratio	TSR
2.432	80.0%	2.750	2.695	1.13	0.78
				* (0.6 - 1.2) Based on Pbe	21 Revs

Mix Type: 4 MT 58-28 S — Mix #: RR0408

Measured Specific Gravity Analysis

Gmm(meas) — Sp. Gravity of AC: 1.031

Mix	AC1	AC2	AC3	AC4	
%AC	4.5	5.0	5.5	6.0	
	Gmm	Gmm	Gmm	Gmm	
Mix Wt. in Air	1536.6	1437.4	1567.9	1530.3	
Wt. Pyc + H2O	1300.8	1300.8	1300.8	1300.8	
Mix + Pyc + H2O	2236.6	2173.7	2246.1	2218.9	
Volume	600.8	564.5	622.6	612.2	
Max Sp. Gravity, Gmm	2.558	2.546	2.518	2.500	Ave of 4
Gse	2.749	2.760	2.749	2.750	2.752

Gmb(meas)

Gyration Level : Nini = 7 Ndes = 75 Nmax = 115

Mixing Temp. °F: 300 Compaction Temp. °F: 275

Mix	AC1		AC2		AC3		AC4	
%AC	4.5		5.0		5.5		6.0	
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5	Spec. 6	Spec. 7	Spec. 8
Spec. Wt. in Air	4846.6	4849.6	4847	4852.6	4847.2	4849.5	4852.7	4854.3
Spec . Wt. In H2O	4854	4855.3	4853.2	4858.9	4850.9	4854.1	4855.8	4857.6
SSD	2821	2819.5	2832.6	2839.6	2846.9	2853.3	2865.6	2866.9
Bulk Volume	2033	2035.8	2020.6	2019.3	2004	2000.8	1990.2	1990.7
Bulk Sp. Gravity, Gmb	2.384	2.382	2.399	2.403	2.419	2.424	2.438	2.438
Av. Bulk Sp. Gravity	2.383		2.401		2.421		2.438	

T-283 TSR Data

Specimen # ——>	1	4	5	2	3	6
Orig. Wt. ——>	3870.7	3875.0	3874.5	3873.4	3873.8	3874.7
SSD WT. ——>	3884.6	3887.7	3885.2	3886.1	3886.0	3883.0
SUB WT. ——>	2218.1	2220.1	2224.4	2216.6	2225.1	2220.1
Volume ——>	1666.5	1667.6	1660.8	1669.5	1660.9	1662.9
SPGR. "d" ——>	2.323	2.324	2.333	2.320	2.332	2.330
%VOIDS ——>	7.3	7.3	6.9	7.5	7.0	7.1
VOIDS (CC) ——>	122.2	121.6	115.1	124.4	115.8	117.3
BIG "D"-	2.507	AV.SPGR-	2.327		AVG. % VOIDS-	7.2

SPECIMEN NO. (S) UNCONDITIONED	1	4	5
SPECIMEN NO. (S) CONDITIONED	2	3	6
WEIGHT FOR 70% SATURATION	3960.5	3954.9	3956.8
WEIGHT FOR 80% SATURATION	3972.9	3966.4	3968.5
FINAL STAURATED WEIGHT	3967.0	3960.6	3960.2
FINAL % SATURATION	75.2	75.0	72.9

AVE.% SAT. 74.4

	CONDITIONED			UNCONDITIONED		
SPEC. NO.(S)	2	3	6	1	4	5
LOAD (kN)	14.8	14.8	15.2	19	19	19.3
TENS.STR. k Pa (psi)	664.9	668.3	685.5	855.1	854.5	871.6

CONDITIONED AV.TENS.STR. 672.9

UNCONDITIONED AVE.TEN.STR. 860.4

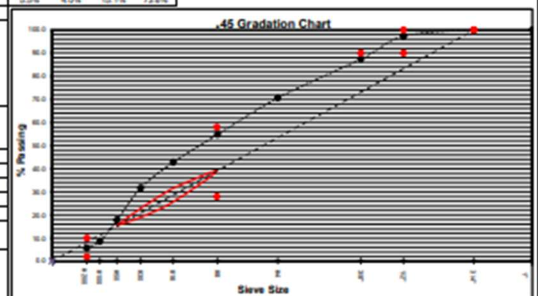
TENSILE STRENGTH RATIO- 0.78

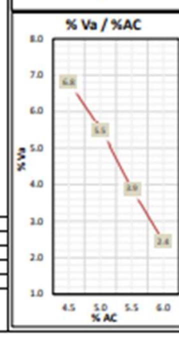
REVS - 21

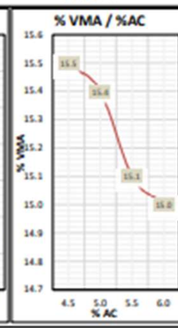
Summary of Compaction Properties at Different Asphalt Contents

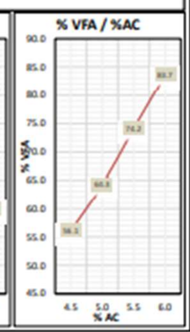
Volumetric Properties at Ndes			
%AC	%Air Voids	%VMA	%VFA
4.5	6.8	15.5	56.1
5.0	5.5	15.4	64.3
5.5	3.9	15.1	74.2
6.0	2.4	15.0	83.7
5.5%	4.0%	15.1%	73.6%

Project	Various WisDOT
Project #	0250-11-11
Mix Type	4 MT 58-28 S









Mix Design Project 6

MATHY CONSTRUCTION CO.

GENERAL CONTRACTORS

920 10TH AVE N   POST OFFICE BOX 189   ONALASKA, WI 54650

PHONE 608-781-4683   FAX 608-781-4694

Report of Bituminous Mix Design

Project Name	La Crosse - Sparta IH-90
Date	August 25, 2021
Project #	1074-00-72
Test#	147-21-4MTR301
County	Monroe
Specifications	12.5mm MT Design
Course/Layer	

Aggregate Sources

	Percent	Material	Location / Source	G_{sb}
1	18	3/4 Xb 3/8 Bit Agg(1221)	Wiedl 29,16,2W Monroe	2.588
2	21	3/16" Washed Man Sand(1403)	Donskey 11,16,3W Monroe	2.650
3	22	1/4" Washed Man Sand(3402)	Merrillan-734 13,23,3W Clark	2.670
4	19	3/16" Screened Sand(5505)	Levis Pines 6,21,3W Jackson	2.620
5	20	RAP(6.1% AC)(7230)	I-90 Millings	2.672
6				
7				
8				

Total	1	2	3	4	5	6	7	8	Comb G_{sb}	2.642
Virgin Agg Blend	22.50	26.25	27.50	23.75					Comb G_{sa}	2.710

Aggregate Gradations

Sieve		Material								Job Mix	Spec	
(Std)	(mm)	1	2	3	4	5	6	7	8		High	Low
2"	50	100.0	100.0	100.0	100.0	100.0				100.0		
1.5"	37.5	100.0	100.0	100.0	100.0	100.0				100.0		
1"	25	100.0	100.0	100.0	100.0	100.0				100.0		
3/4"	19	100.0	100.0	100.0	100.0	100.0				100.0		
1/2"	12.5	63.0	100.0	100.0	100.0	94.0				92.1		
3/8"	9.5	33.0	100.0	100.0	100.0	82.0				84.3		
#4	4.75	8.8	99.0	96.0	97.0	54.0				72.7		
#8	2.36	6.4	73.0	60.0	89.0	40.0				54.6		
#16	1.18	5.9	47.0	31.0	77.0	31.0				38.6		
#30	0.6	5.6	34.0	15.0	51.0	23.0				25.7		
#50	0.3	5.3	26.0	7.0	16.0	16.0				14.2		
#100	0.15	4.4	11.0	3.0	1.8	12.0				6.5		
#200	0.075	3.1	3.0	1.5	0.8	8.2				3.3		
Soundness		225-261	225-18	225-19							12 Max	
LAR 100/500 Rev		2021	2020	2021							13 & 45 Max	
Crush 1 Face (%)		100.0	100.0	100.0	34.0	100.0				98.6	75 Min	
Crush 2 Face (%)		100.0	100.0	100.0	33.0	100.0				98.6	60 Min	
Sand Equiv.										87	40 Min	
Flat & Elong (%)		1.7	0.8	0.5	1.3	0.1				1.1	5 Max	
Fine Agg Ang			49.0	51.7	40.2	53.7				43.5	43 Min	
Water Abs.		2.4	2.2	0.8	0.8	1.0				1.4		

Test Methods: D312, T176/D2419, T11/C117, T27/C136, D4791, D5821, T304/C1252, T96/C131, T209/D2041, T166/D2726

MATHY CONSTRUCTION CO.

GENERAL CONTRACTORS

920 10TH AVE N POST OFFICE BOX 189 ONALASKA, WI 54650

PHONE 608-781-4683 FAX 608-781-4694

Report of Bituminous Mix Design

Project Name	La Crosse - Sparta IH-90
Date	August 25, 2021
Project #	1074-00-72
Test #	147-21-4MTR301
County	Monroe
Specifications	12.5mm MT Design
Course/Layer	

AASHTO R18

Mix Properties

Trial #	1	2	3	4	5	6
AC Content (% by Wt)	5.0	5.5	6.0	6.5		5.6
Compaction Level	**Design**	**Design**	**Design**	**Design**		**Max**
Air Voids V_a (%)	5.9	4.4	3.0	1.8		4.1
$\%G_{mm}$ @ N_i	88.4	89.7	90.6	91.6		89.7
$\%G_{mm}$ @ N_{final}	94.1	95.6	97.0	98.2		**97.1**
VMA (%)	15.2	14.9	14.8	14.8		13.9
VFA (%)	61.2	70.8	79.5	87.9		70.2
Density (kg/m^3)	2357	2378	2393	2406		2410
G_{mb}	2.357	2.378	2.393	2.406		2.410
G_{mm}	2.505	2.487	2.468	2.450		**2.483**

Gyrations	
N_i	7
N_d	75
N_m	115

Antistrip
None

Mix Design

Note: trials must bracket desired V_a targets.

Property	Value		Specification
V_a	3.0	4.0	
Design P_b	6.0	5.6	
Added P_b	4.8	4.4	
VMA	14.8	14.9	14.5 Minimum
VFA	79.8	73.1	70 - 76
G_{mm}	2.468	2.483	
G_{mb}	2.394	2.383	
P_{be}	5.1	4.7	
P_{ba}	1.0	1.0	
Dust/Binder Ratio	0.7	0.7	0.6 - 1.2
$\%G_{mm}$ @ N_i		89.9	< 89.0 Rec
$\%G_{mm}$ @ N_d		95.9	~ 96.0
$\%G_{mm}$ @ N_m		97.1	98.0 Max
TSR Ratio	95.2		75 Minimum
Rec. Mix Temp.	275-300		

Primary AC Source	*AC Type*	*Gb*
MIA - La Crosse	PG 58S-28	1.029
Alternate Sources		
MIA - La Crosse	PG 58H-28	1.030
MIA - La Crosse	PG 52S-34	1.023
MIA - La Crosse	PG 58S-34	1.023
MIA - La Crosse	PG 58H-34	1.020

% Binder Replacement

3.0	4.0
20.0%	21.4%

Average # of Gyrations	23

Since this design is material specific, the conclusions and recommendations contained within are obtained from material submitted to and subjected to observations under laboratory conditions.

Adjustments may become necessary when field laboratory data is obtained from plant produced mix.

No guarantee or warranty is implied or offered.

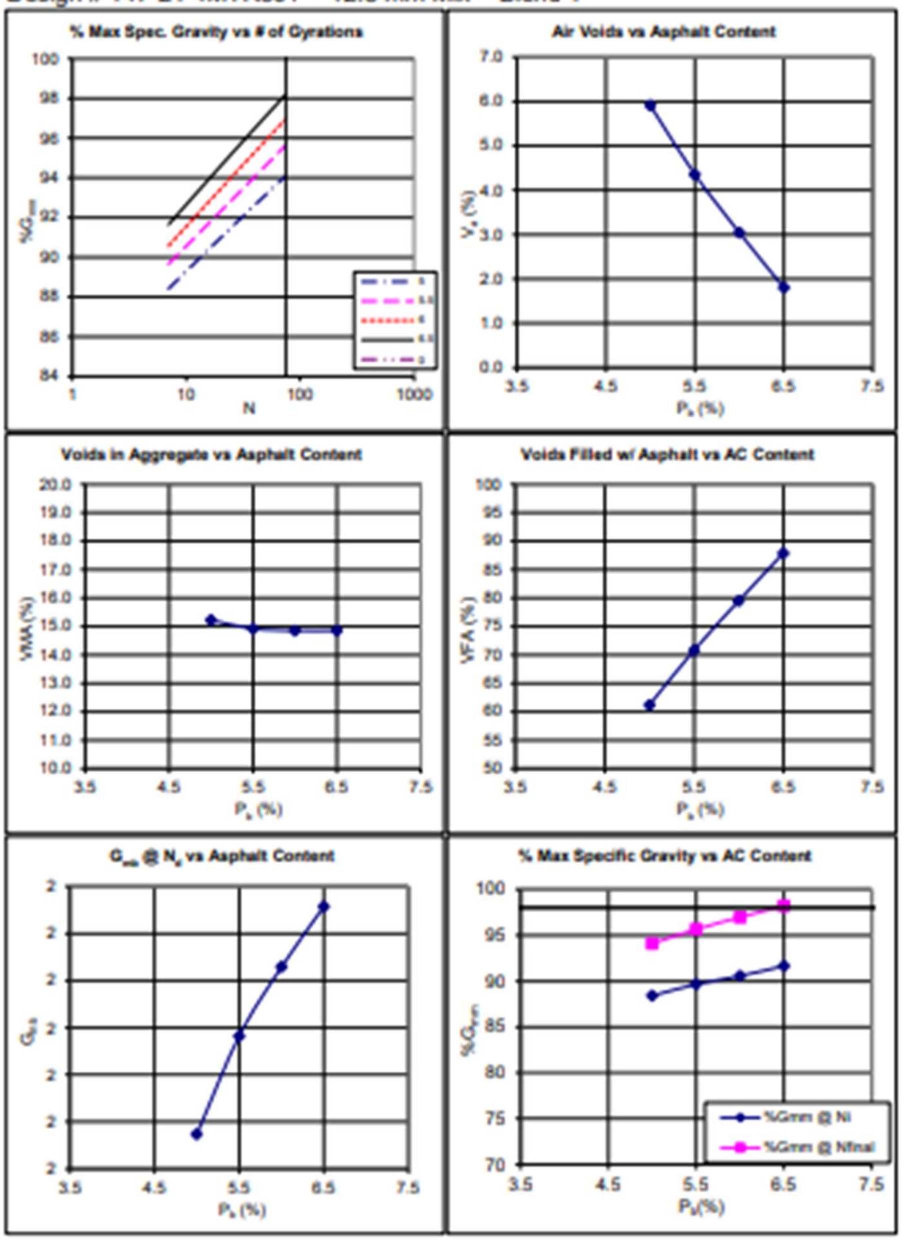
Note: 0.2% Evotherm added as a compaction aid.

Signature [signature] Cert. No. 100163 Date: 8/25/2021

Mathy Construction Co. -- MTE

La Crosse - Sparta IH-90

Design # 147-21-4MTR301 -- 12.5 mm Mix -- Blend 1



Reviewed By: Jeffery. R. Anderson

158-22-SMTRW30

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	1560-00-72	Design Lab or Company:	Mathy Construction	WisDOT Mix Design ID:	
Mix Design ID:	158-22-SMTRW301	*Mix Designer:	John Jorgenson	WisDOT Design Verification Date:	
Mix Type:	MT	Designer HTCP Cert ID#:	100163		
NMAS:	5 - 9.5 mm	Producer:	Northwoods Paving		
Virgin Binder PG:	58-28	Plant #/location:	67/Ashland,WI	Design Amended Date:	
Binder Designation:	S	Design Date:	5/31/2022	Last JMF Change Date:	
Virgin Binder Gb:	1.029				
Virgin Binder Source:	MIA - La Crosse				

Primary AC Source/ Type

*Note: Typed not Signature Block

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)	18.0	26.0	10.0	24.0					22.0				100.0
Material Description	3/8" Washed Chips(3238)	3/8" Bit Agg(3235)	3/16" Washed Man Sand(5400)	Washed Sand(5405)					RAP(7260)				
Source ID/Name (needs to match 225 report)	Highbridge North 16,45,3W Ashland	Highbridge North 16,45,3W Ashland	Crooked Lake 36,47,8W Radfield	Crooked Lake 36,47,8W Radfield					Ashland 1/2" RAP				
P or Q or MF or Dust (RAM plant ID)	Q	Q	P	P					RAP			Gsa:	2.668
WisDOT Agg Test ID	225-33-2020	225-33-2020	225-58-2019	225-58-2019								SE:	81
RAM Extracted % Binder									5.1			(T112)	0.33
												PI (T89/90)	

Sieve	(mm)	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)	(mm)	JMF BLEND
1 1/2"	37.5	100.0	100.0	100.0	100.0					100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0					100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0					100.0			19.0	100.0
1/2"	12.5	100.0	100.0	100.0	100.0					100.0			12.5	100.0
3/8"	9.5	100.0	100.0	100.0	100.0					98.0			9.5	99.6
#4	4.75	25.0	77.0	96.0	99.0					80.0			4.75	75.5
#8	2.36	3.0	52.0	64.0	86.0					66.0			2.36	55.6
#16	1.18	2.5	36.0	41.0	72.0					55.0			1.18	43.3
#30	0.60	2.2	25.0	27.0	49.0					41.0			0.60	30.4
#50	0.30	1.8	17.0	15.0	20.0					25.0			0.30	16.5
#100	0.15	1.5	11.0	4.9	3.5					14.0			0.15	7.5
#200	0.075	1.0	7.2	1.7	1.1					10.0			0.075	4.7

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Gsb:	2.615	2.606	2.819	2.668					2.654			Gsb:	2.653
CAA 1F (%):	100	100	100	73					95			CAA 1F (%):	98.8
CAA 2F (%):	100	100	100	62					91			CAA 2F (%):	98.0
FAA:		49.9	47.7	40.3					41.3			FAA:	43.5
Moisture Abs. (%):	0.6	1	0.2	0.5					1			Abs. (%):	0.7
Thin/Elong. (%):	4.5	3.7	2.2	0.6					0.4			T/E. (%):	0.9

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix	SMA Draindown (%) * Temp. of Plant			
Rec. Mix Temp(F):		220-240	*Temp. °C		Pbr:	20.0
Compact Temp(F):		230	1		Pbe:	5.4
			2		Pba:	0.2
*Type Additive:	Evotherm	(WMA, Anti-Strip,	Avg.		Dust/Binder (DP):	0.9
*Amt. Additive:	0.30%	Cellulose Fibers)	plus 15°C	15		
			1		Gmm Dryback Corr.:	
			2			
			Avg.			

[illegible] min. 5.5% (SMA)

0.6-1.2/1.2-2.0

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
MIA - La Crosse	PG 58H-28	1.035				
MIA - La Crosse	PG 58S-34	1.025				
MIA - La Crosse	PG 58H-34	1.025				
MIA - La Crosse	PG 58V-34	1.027				

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM [illegible]

TRIAL AC DATA

	Total %	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.0	3.9	2.471	2.335	5.5	16.4	66.4
Trial 2	5.5	4.4	2.453	2.350	4.2	16.3	74.1
Trial 3	6.0	4.9	2.435	2.368	2.8	16.1	82.6
Trial 4	6.5	5.4	2.418	2.379	1.6	16.2	90
OPT. @ 4.0% Va	5.6	4.5	2.450	2.352	4.0	16.3	75.4
OPT. @ 3.0% Va	5.9	4.83	2.437	2.364	3.0	16.2	81.5

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	7		115	
TSR T283 (psi)	%Gmm at Optimum	90.4		96.8	# of Gry.(N)
Wet Strength: 94.5	Dry Strength:	103.7	TSR:	0.91	20
Hamburg (T324):	Final Rut Depth (mm):		Number of Passes:		
Cracking Tolerance Index (D8225):	CT:				

Comments: Note: This is a WARM MIX design. 0.3% Evotherm added as a WARM MIX additive.

Mix Design Project 8

Reviewed By: Jeffery. R. Anderson

C-5 4HT 502321

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	0250-11-11	Design Lab or Company:	CRM	WisDOT Mix Design ID:	0-250-0025-2021
Mix Design ID:	502321	*Mix Designer:	Gregory Mamerow	WisDOT Design Verification Date:	2/15/2021
Mix Type:	HT	Designer HTCP Cert ID#:	105762		
NMAS:	4 - 12.5 mm	Producer:	Payne and Dolan		
Virgin Binder PG:	58-28	Plant #/location:	40005/ Fitchburg	Design Amended Date:	
Binder Designation:	S	Design Date:	2/12/2021	Last JMF Change Date:	
Virgin Binder Gb:	1.017	*Note: Typed not Signature Block			
Virgin Binder Source:	CRM Milwaukee				

Primary AC Source/ Type

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

		Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)		14.0	12.0	22.0	25.0	11.5	0.5			15.0				100.0
Material Description		5/8" Chip	3/8" Chip	MFG'D Sand	MFG'D Sand	Natural Sand	DEG			1/2" FRAP				
Source ID/Name (needs to match 225 report)		Oregon	Oregon	Oregon	Waterloo (Michels)	Oregon	40005.00			40005.00				
P or Q or MF or Dust (RAM plant ID)		P	P	P	Q	P	DEG			RAM1			Gsa:	2.703
WisDOT Agg Test ID		225-0050-2017	225-0050-2017										SE:	91
RAM Extracted % Binder										4.8			(T112)	0.6
													FI (T89/90)	
Sieve	(mm)												(mm)	
1 1/2"	37.5	100.0	100.0	100.0	100.0	100.0	100.0			100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0	100.0	100.0			100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0	100.0	100.0			100.0			19.0	100.0
1/2"	12.5	80.0	100.0	100.0	100.0	100.0	100.0			100.0			12.5	97.2
3/8"	9.5	23.0	97.0	100.0	100.0	100.0	100.0			98.0			9.5	88.6
#4	4.75	3.0	19.0	97.0	100.0	94.0	100.0			81.0			4.75	72.5
#8	2.36	2.0	4.0	64.0	77.0	72.0	100.0			63.0			2.36	52.3
#16	1.18	2.0	3.0	41.0	46.0	56.0	100.0			50.0			1.18	35.6
#30	0.60	2.0	3.0	27.0	27.0	42.0	100.0			41.0			0.60	24.8
#50	0.30	1.5	2.0	15.0	13.0	16.0	100.0			27.0			0.30	13.4
#100	0.15	1.5	2.0	5.0	4.0	4.0	100.0			18.0			0.15	6.2
#200	0.075	1.2	1.6	2.4	2.0	1.8	100.0			13.3			0.075	4.1
Gsb:		2.602	2.586	2.639	2.674	2.651	2.651			2.633			Gsb:	2.636
CAA 1F (%):		99	99										CAA 1F (%):	99.0
CAA 2F (%):		97	98										CAA 2F (%):	97.4
FAA:				47	48	41				42			FAA:	46
Moisture Abs. (%):		1.9	2.3	1.3	0.7	0.7				1			Abs. (%):	1.2
Thin/Elong. (%):		0.5	0.5										T/E. (%):	0.1

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):	280-320	
Compact Temp(F):	255-295	

*Type Additive: (WMA, Anti-Strip, Cellulose Fibers)

*Amt. Additive:

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%) * Temp. of Plant

*Temp. °C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr:	13.6	
Pbe:	4.5	min. 5.5% (SMA)
Pba:	1.0	
Dust/Binder (DP):	0.9	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
CRM MKE/GRB/Gladstone	58-28 S/H/V/E					
CRM MKE/GRB/Gladstone	58-34 S/H/V/E					

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.1.1.2

TRIAL AC DATA

	Total %	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.0	4.3	2.496	2.365	5.3	14.8	64.2
Trial 2	5.5	4.8	2.477	2.384	3.8	14.5	73.8
Trial 3	6.0	5.3	2.458	2.416	1.7	13.9	87.8
Trial 4							
OPT. @ 4.0% Va	5.4	4.7	2.481	2.382	4.0	14.5	72.4
OPT. @ 3.0% Va	5.7	4.87	2.471	2.397	3.0	14.3	79.0

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	8	---	160	
TSR T283 (psi)	%Gmm at Optimum	88	---	96.5	# of Gry.(N)
Wet Strength:	103.6	Dry Strength: 93.8	TSR:	1.00	24
Hamburg (T324):	Total Rut Depth (mm):	3.25		Number of Passes:	20000
Cracking Tolerance Index (D8225):	CT:	[illegible]			

Comments: Recommended and compaction temperatures are for lab purposes only; field production temperatures will vary; Evotherm or rediset added in at 0.3-0.5% of total AC as a cold

Mix Design Project 9

MATHY CONSTRUCTION CO.

GENERAL CONTRACTORS

920 10TH AVE N POST OFFICE BOX 189 ONALASKA, WI 54650

PHONE 608-781-4683 FAX 608-781-4694

Report of Bituminous Mix Design

Project Name	Turtle Lake - Cameron USH 8
Date	April 19, 2022
Project #	1570-05-63
Test#	360-22-4MTRW301
County	Barron
Specifications	4 MT WARM MIX
Course/Layer	

AASHTO R18

Aggregate Sources

	Percent	Material	Location / Source	G_{sb}
1	18	3/4" X 3/8" Bit Gravel	McLaine 9,35,13W Barron	2.816
2	22	3/8" Bit Gravel	McLaine 9,35,13W Barron	2.772
3	22	5/16" Washed Man Sand	Safert 1,34,11W Barron	2.713
4	21	5/8" Screened Sand	McLaine 9,35,13W Barron	2.742
5	17	RAP(5.2% AC)	USH 8 Millings	2.706
6				
7				
8				

	1	2	3	4	5	6	7	8		
Total									Comb G_{sb}	2.749
Virgin Agg Blend		26.83	26.83	25.61	20.73				Comb G_{sa}	2.768

Aggregate Gradations

Sieve		Material								Job Mix	Spec	
(Std)	(mm)	1	2	3	4	5	6	7	8		High	Low
2"	50	100.0	100.0	100.0	100.0	100.0				100.0		
1.5"	37.5	100.0	100.0	100.0	100.0	100.0				100.0		
1"	25	100.0	100.0	100.0	100.0	100.0				100.0		
3/4"	19	100.0	100.0	100.0	100.0	100.0				100.0		
1/2"	12.5	70.0	100.0	100.0	95.0	97.0				93.0		
3/8"	9.5	26.0	100.0	100.0	88.0	92.0				82.8		
#4	4.75	1.9	65.0	100.0	74.0	76.0				65.1		
#8	2.36	1.6	40.0	79.0	63.0	63.0				50.4		
#16	1.18	1.4	28.0	53.0	51.0	51.0				37.5		
#30	0.6	1.3	20.0	35.0	32.0	36.0				25.2		
#50	0.3	1.2	14.0	19.0	11.0	20.0				13.2		
#100	0.15	1.0	9.4	6.7	3.8	12.0				6.6		
#200	0.075	0.8	6.3	3.0	2.4	9.2				4.3		
Soundness		225-177	225-177	225-77	225-177						12 Max	
LAR 100/500 Rev		2022	2022	2021	2022						13 & 45 Max	
Crush 1 Face (%)		96.0	100.0		8.0	94.0				82.9	75 Min	
Crush 2 Face (%)		93.0	100.0		7.0	93.0				81.1	60 Min	
Sand Equiv.										84	40 Min	
Flat & Elong (%)		4.0	0.7		1.1	1.5				2.5	5 Max	
Fine Agg Ang			49.2	47.9	42.1	42.0				45.8	43 Min	
Water Abs.		0.9	1.4	1.1	1.0	1.0				1.1		

Test Methods: D312, T176/D2419, T11/C117, T27/C136, D4791, D5821, T304/C1252, T96/C131, T209/D2041, T166/D2726

MATHY CONSTRUCTION CO.

GENERAL CONTRACTORS

920 10TH AVE N   POST OFFICE BOX 189   ONALASKA, WI 54650
PHONE 608-781-4683   FAX 608-781-4694

Report of Bituminous Mix Design

Project Name	Turtle Lake - Cameron USH 8
Date	April 19, 2022
Project #	1570-05-63
Test #	360-22-4MTRW301
County	Barron
Specifications	4 MT WARM MIX
Course/Layer	

Mix Properties

Trial #	1	2	3	4	5	6
AC Content (% by Wt)	4.5	5.0	5.5	6.0		4.9
Compaction Level	**Design**	**Design**	**Design**	**Design**		**Max**
Air Voids V_a (%)	5.3	3.8	2.2	1.3		4.1
$\%G_{mm}$ @ N_i	88.6	89.9	91.1	92.1		89.8
$\%G_{mm}$ @ N_{final}	94.7	96.2	97.8	98.7		**96.6**
VMA (%)	15.4	15.1	14.9	15.2		14.6
VFA (%)	65.7	75.0	85.1	91.2		71.9
Density (kg/m³)	2436	2455	2476	2479		2468
G_{mb}	2.436	2.455	2.476	2.479		2.468
G_{mm}	2.572	2.552	2.532	2.513		**2.556**

Gyrations	
N_i	7
N_d	75
N_m	115

WARM MIX Additive
0.3% Evotherm

Mix Design

Note: trials must bracket desired V_a targets.

Property	Value		Specification
V_a	3.0	4.0	
Design P_b	5.3	4.9	
Added P_b	4.4	4.0	
VMA	15.1	15.1	14.5 Minimum
VFA	80.2	73.5	70 - 76
G_{mm}	2.544	2.556	
G_{mb}	2.468	2.454	
P_{be}	5.1	4.6	
P_{ba}	0.3	0.3	
Dust/Binder Ratio	0.8	0.9	0.6 - 1.2
$\%G_{mm}$ @ N_i		89.6	< 89.0 Rec
$\%G_{mm}$ @ N_d		95.9	~ 96.0
$\%G_{mm}$ @ N_m		96.6	98.0 Max
TSR Ratio	79.4		75 Minimum
Rec. Mix Temp.	220 - 240 F		lab Comp. 230F

Primary AC Source	AC Type	Gb
MIA - La Crosse	PG 58S-28	1.029
Alternate Sources		
MIA - La Crosse	PG 58H-28	1.035
MIA - La Crosse	PG 58S-34	1.025
MIA - La Crosse	PG 58H-34	1.025
MIA - La Crosse	PG 58V-34	1.027

% Binder Replacement

3.0	4.0
17.0%	18.4%

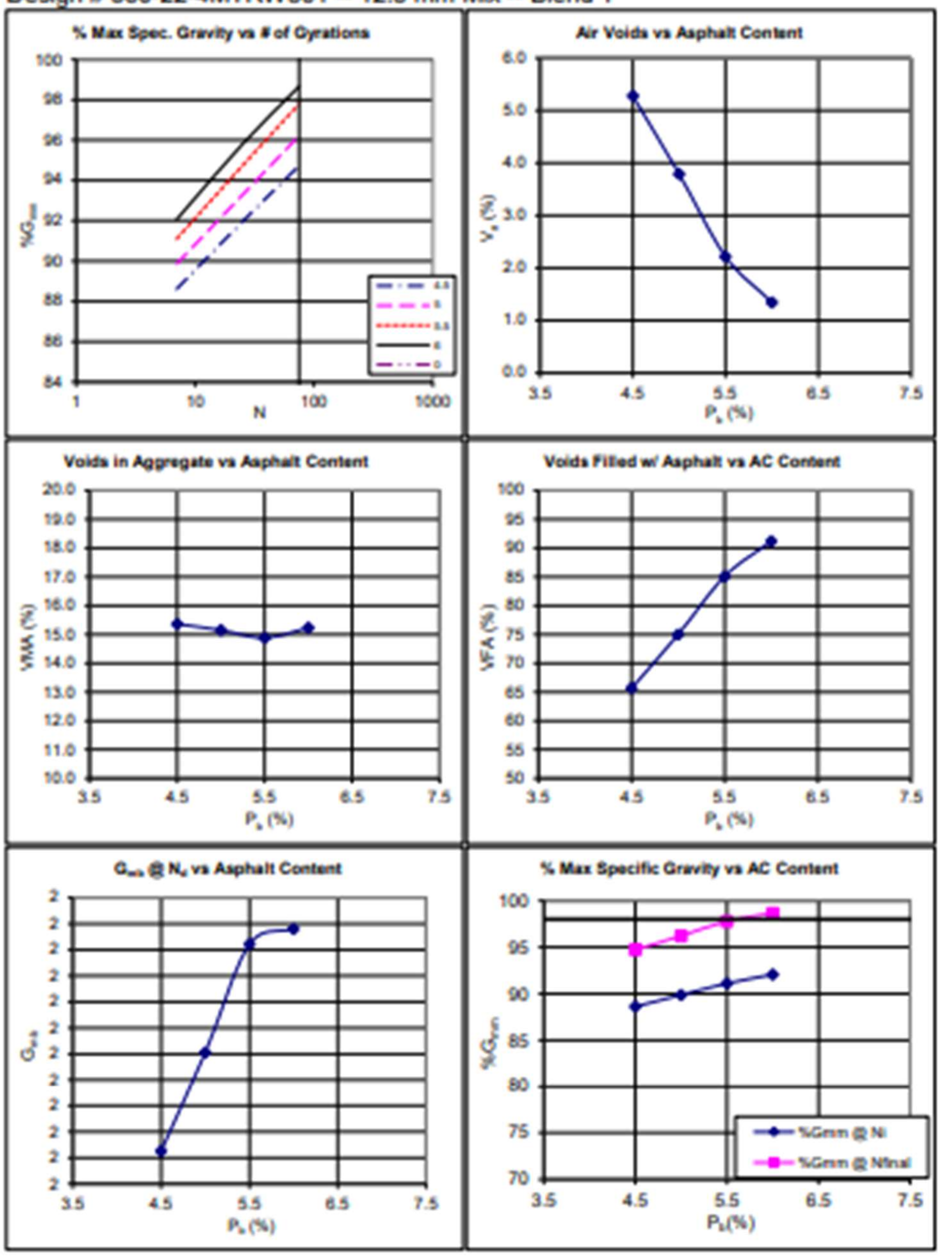
Average # of Gyrations	26

Since this design is material specific, the conclusions and recommendations contained within are obtained from material submitted to and subjected to observations under laboratory conditions. Adjustments may become necessary when field laboratory data is obtained from plant produced mix. No guarantee or warranty is implied or offered.

Signature: [signature]   Cert. No. 100163   Date: 4/20/2022

Turtle Lake - Cameron USH 8

Design # 360-22-4MTRW301 -- 12.5 mm Mix -- Blend 1



Mix Design Project 10

Reviewed By: Jeffery R. Anderson 1145-22-4HT

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	1166-07-79	Design Lab or Company:	American Asphalt	WisDOT Mix Design ID:	250-0107-2022
Mix Design ID:	1145-22-4HTRW001(281)	*Mix Designer:	Kerrie Dassow	WisDOT Design Verification Date:	5/17/2022
Mix Type:	HT	Designer HTCP Cert ID#:	101931		
NMAS:	4 - 12.5 mm	Producer:	American Asphalt		
Virgin Binder PG:	58-28	Plant #/location:	Heyn/Hancock	Design Amended Date:	
Binder Designation:	S	Design Date:	5/12/2022	Last JMF Change Date:	
Virgin Binder Gb:	1.029				
Virgin Binder Source:	MIA-Lacrosse				

Primary AC Source/ Type

*Note: Typed not Signature Block

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)	14.0	15.0	16.0	27.0	13.0				15.0				100.0
Material Description	5/8x3/8-3226	3/8 Bit-3235	3/8x1/8-3250	1/8MS-3404	Washed Sand-5405				Millings-7230				
Source ID/Name (needs to match 225 report)	Seven Sisters 36,20,7 E Adams	Seven Sisters 36,20,7 E Adams	Cisler 5,26,7 E Marathon	Cisler 5,26,7E Marathon	Heyn 22,19,8E Waushara				Plant Stockpile				
P or Q or MF or Dust (RAM plant ID)	Q	Q	Q	Q	P							Gsa:	2.718
WisDOT Agg Test ID	225-0036-2022	225-0036-2022	225-0037-2022	225-0037-2022	225-191-2021							SE:	71
RAM Extracted % Binder									4.8			(T112)	
												PI (T89/90)	

Sieve	(mm)	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)	(mm)	JMF BLEND
1 1/2"	37.5	100.0	100.0	100.0	100.0	100.0				100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0	100.0				100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0	100.0				100.0			19.0	100.0
1/2"	12.5	77.0	100.0	100.0	100.0	100.0				97.0			12.5	96.3
3/8"	9.5	36.0	100.0	100.0	100.0	99.0				93.0			9.5	89.9
#4	4.75	3.2	70.0	34.0	100.0	90.0				73.0			4.75	66.0
#8	2.36	1.9	41.0	9.0	96.0	84.0				54.0			2.36	52.8
#16	1.18	1.7	25.0	4.2	60.0	79.0				41.0			1.18	37.3
#30	0.60	1.5	17.0	2.3	34.0	66.0				33.0			0.60	25.8
#50	0.30	1.4	12.0	1.5	16.0	24.0				24.0			0.30	13.3
#100	0.15	1.3	9.0	1.1	4.9	2.2				15.0			0.15	5.6
#200	0.075	1.1	6.8	1.0	2.6	1.0				10.4			0.075	3.7

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Gsb:	2.697	2.686	2.690	2.668	2.679				2.691			Gsb:	2.683
CAA 1F (%):	100	100	100		82.3				98.3			CAA 1F (%):	99.1
CAA 2F (%):	100	100	100		76.1				96.7			CAA 2F (%):	98.7
FAA:		49.9		48.1	38.3				43.5			FAA:	45.4
Moisture Abs. (%):	0.2	0.35	0.39	0.54	0.3				1.01			Abs. (%):	0.5
Thin/Elong. (%):	1.8	4.5	7.4		0.9				0.13			T&E (%):	1.2

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):		225-245
Compact Temp(F):		230

SMA Draindown (%) * Temp. of Plant	
*Temp. °C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr:	1.1	
Pbe:	5.3	min. 5.5% (SMA)
Pba:	0.5	
Dust/Binder (DP):	0.7	0.6-1.2/1.2-2.0
6mm Dryback Corr.:		

*Type Additive: Evotherm (WMA, Anti-Strip, Cellulose Fibers)

*Amt. Additive: 0.35

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

Alternate AC Sources (*additive for alternate binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
St Paul Park	58-28S	1.035				

**TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.3.3.2

TRIAL AC DATA

	Total %	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.0	4.4	2.512	2.353	6.3	16.7	62.2
Trial 2	5.5	4.9	2.493	2.370	5.0	16.5	70.3
Trial 3	6.0	5.4	2.474	2.384	3.9	16.5	78
Trial 4	6.5	5.9	2.456	2.400	2.3	16.4	86.1
OPT. @ 4.0% Va	5.8	5.2	2.478	2.379	4.0	16.5	75.8
OPT. @ 3.0% Va	6.3	5.68	2.464	2.390	3.0	16.5	81.8

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	8		160	
TSR T283 (psi)	%Gmm at Optimum	88.7		97	# of Gyr.(N)
Wet Strength:	2115	Dry Strength:	2436	TSR:	0.87	27
Hamburg (T324):	Total Rut Depth (mm):			Number of Passes:	
Cracking Tolerance Index (D8225):	CT:				

Comments: Evotherm P-series used for warm mix.