NDOT Research Report

Report No. 206-10-803

Develop a PWL System for Dense Graded Hot Mix Asphalt Construction, Including Pay Factors

January 2015

Nevada Department of Transportation
1263 South Stewart Street
Carson City, NV 89712

NEVADA DOT SAFE AND CONNECTED

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DEVELOP A PWL SYSTEM FOR DENSE GRADED HOT MIX ASPHALT CONSTRUCTION, INCLDUING PAY FACTORS

NEVADA DEPARTMENT OF TRANSPORATION
Research Division
1263 South Stewart Street
Carson City, Nevada 89712

Research Report No. 3
January, 2015

UNIVERSITY OF NEVADA, RENO

Pavements/Materials Program

Department of Civil and Environmental Engineering
College of Engineering
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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Develop a PWL System for Dense Graded Hot Mix Asphalt Construction, Including Pay Factors		5. Report Date January 6, 2015 6. Performing Organization Code University of Nevada, Reno
7. Author(s) Peter E. Sebaaly, Roger Schlierkamp, Cristian Diaz, Elie Hajj, and Mena Souliman		8. Performing Organization Report No. WRSC-UNR-PWL-201501
9. Performing Organization Name and Address Western Regional Superpave Center Pavements/Materials Program Department of Civil and Environmental Engineering University of Nevada 1664 N. Virginia Street/Mail Stop 258 Reno, Nevada 89557		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Nevada Department of Transportation 1263 South Stewart Street Carson City, Nevada 89712		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes
This report is accompanied by a PWL software which conducts all applicable calculations

16. Abstract
This research project developed a PWL system that the Nevada DOT can effectively implement on the construction of dense graded HMA mixtures. The PWL system includes pay factors that are based on pavement performance indicators such as rutting and cracking. In addition, the developed PWL System is incorporated into a user-oriented software that is capable of analyzing the relevant data, establishing the PWL values, and applying the appropriate pay adjustments. The research was completed over three phases:

Phase I – Review of Existing PWL Specification Systems: this phase reviewed several PWL specification systems for HMA construction. Based on the findings of the review, the research team recommended the general framework of the PWL system to be developed in Phase II.

Phase II – Develop the PWL Specification System: this phase developed the PWL system. The developed system uses several materials and mixtures properties to identify the PWLs for all sublots and lots of HMA mixtures. Weight factors are identified for each of the materials and mixtures properties leading to the development of a single PWL for each lot within a construction project.

Phase III – Implement the Specifications: this phase will implement the developed PWL system on several NDOT projects and uses the data from these projects to fine tune the system.

17. Key Words Hot Mix Asphalt, PWL, Performance		18. Distribution Statement No restriction.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 49	22. Price Free

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When you know**	**Multiply by**	**To find**	**Symbol**
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
ºF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	ºC
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When you know**	**Multiply by**	**To find**	**Symbol**
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
ºC	Celsius	1.8C+32	Fahrenheit	ºF
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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CHAPTER 1. INTRODUCTION

There are three essential steps for the successful construction of hot mix asphalt (HMA) pavements: mix design, production, and quality control/quality assurance (QC/QA). Every State Highway Agency (SHA) has well documented procedures for each of the three steps. However, the processes used in each of the three steps differ significantly among SHAs especially in the area of QC/QA. Since the subject of this report is mainly related to the Percent within Limit (PWL) system, only the QC/QA process will be discussed due to its direct application in the PWL.

Quality control represents the testing program that the contractor is required to conduct in order to assess the uniformity and acceptability of the produced HMA mix. Quality assurance represents the testing program that the SHA conducts in order to assess the conformance of the produced HMA mix with the agency's applicable specifications. For final acceptance of the HMA mix, some agencies use both the QC and QA testing results while others use only the QA testing results. The specific properties measured in the QC and QA programs also vary significantly among SHAs.

In 1998, Schmitt et al conducted a survey on the various properties that are measured through the QA programs in 40 states (1). The survey identified three fundamental measures of acceptance testing: mix properties, density, and smoothness. Tables 1 and 2 summarize the mix properties and density attributes identified by Schmitt et al, respectively. The mix properties that are commonly used for acceptance include: aggregate gradation, asphalt content, and mix volumetrics. The data presented in Tables 1 and 2 show that there are significant variations among the practices used by various SHAs in terms of: size of sublots and lots, sampling location, testing methods, and compliance measure (i.e. method used to measure conformance with the specification).

Tables 1 and 2 show that the majority of the SHAs use the Quality Level Analysis to measure the compliance of the HMA mixtures to the agency's specifications. In addition, the most common Quality Level Analysis is the PWL process. This indicates that the use of the PWL method for evaluating the compliance of HMA mixtures to SHAs specifications has been very popular.

The survey conducted by Schmitt et al also looked at the use of the measured properties to identify pay adjustment that can be applied to the overall cost of the HMA mix (1). Table 3 summarizes the various properties that have been used in the calculations of pay adjustments by various SHAs. A review of the data in Table 3 indicates the followings:

- The majority of the SHAs establish a Factor which may lead to a penalty or bonus for their pay adjustment.
- The majority of the SHAs use aggregate gradation, asphalt content, air voids, field density, and smoothness as measures of compliance with specifications.
- The percent passing #200 is the most commonly used gradation attribute.
- The majority of the SHAs use a weighted approach to combine the impact of the various attributes toward the final pay adjustment.

Table 1. Mix Property Acceptance Attributes for 40 States (1).

Attribute	Number of States Specifying		
	Aggregate Gradation	Asphalt Content	Mix Volumetrics
Sublot Size			
1 per 500 tons to 1 per 900 tons	12	17	9
1 per 1,000 tons to 1 per 2,000 tons	12	10	15
1 per 3 hours	2	6	5
4 samples	1	1	0
Variable	2	2	2
Lot Size			
1 per 500 tons to 5 per 6,000 tons	13	17	15
1 to 4 per day	7	11	7
4 Sublots	2	2	1
Project	1	1	0
Total per Mix Design	4	4	3
Variable	2	2	2
Cumulative	0	1	1
Continuous	0	1	0
Sampling Location[a]			
Coldfeeds or Hot Bins	17	0	0
Plant Discharge	4	7	4
Truck	15	19	15
Windrow	1	2	1
Volume Analysis	1	2	0
Mat	9	11	0
Asphalt Content Testing Methods[b]			
Extraction		20	
Nuclear Gauge		20	
Ignition Oven		18	
Plant Record		11	
Tank Stickings		9	
Specific Gravity		4	
Compliance Measure[c]			
Quality Level Analysis	13	14	10
Absolute Average deviation	7	8	7
Moving Average	6	7	6
Average	5	6	2
Range	3	3	3

Note: 1 ton = 0.91 Mg
[a]States may specify multiple locations for aggregates gradation and asphalt content
[b]States may specify multiple testing options for asphalt content
[c]One or more compliance measures may be specified within a state (i.e. may vary by property being measured)

Table 2. Density Attributes for 40 States (1).

Attribute	Number of States Specifying
Sublot Size	
1 per 80 to 1 per 1,500 tons	19
300 to 600 meters	5
1 to 5 per day	4
Square yards	1
Square meters	1
Variable	1
None	9
Lot Size	
1 per 400 to 1 per 6,000 tons	17
5 to 10 per day	11
300 to 1,500 meters	5
Total per Mix design	4
1 per shift	1
Cumulative	1
Variable	1
Sampling Method	
Nuclear Gauge	16
Core	15
Nuclear Gauge corrected to core[a]	9
Reference [b,c]	
Theoretical Maximum Density	32
Laboratory Maximum Density	9
Test Strip	8
Compliance Measure [b,d]	
Quality Level Analysis	20
Absolute Average deviation	8
Moving Average	4
Average	3
Range	3

Note: 1 ton = 0.91 Mg
[a]Number of cores for correcting nuclear readings ranged from 3 to 12.
[b]When the total number is less than 40, this means that not all agencies provided a response.
[c]States may specify multiple options a density reference.
[d]States may specify multiple options for compliance.

Table 3. Pay Adjustment Attributes for 40 States (1).

Attribute	Number of States Specifying
Type of Adjustment	
Factor	36
Fixed Rate	4
Bonus	21[a]
Aggregate Gradation Sieve Sizes	
12.5mm(1/2”)	15
9.5mm(3/8”)	15
4.75mm(#4)	17
2.36mm(#8)	18
2.07mm(#10)	10
1.18mm(#16)	7
600um(#30)	10
450um(#40)	10
300um(#50)	10
75um(#200)	25
Asphalt and Mixture Properties	
Asphalt Content	31
Air Voids	16
Voids in Mineral Aggregate	7
Stability	2
Voids Filled with Asphalt	1
Asphalt Penetration	1
Anti-strip Additive	1
Moisture Content	1
Theoretical Maximum Density	1
Density	
Percent Theoretical Maximum Density	29
Percent Test Strip Density	6
Percent Laboratory Maximum Density	4
Smoothness	
Profile Index	16
Rolling Straightedge	1
Profilomter/Mays Meter	1
Method of Combination	
Weighted[b]	25
Minimum[c]	12
Density	2
Average	1

[a]Bonus provision is contained within the Factor or Fixed Rate.
[b]Weights summing to 1.0 are multiplied to each property then summed.
[c]Minimum individual pay factor of all measured properties is used.

1.1 Overall Research Objective

The overall objective of the research was to establish a practical PWL system that the Nevada DOT can effectively implement on the construction of dense graded HMA mixtures. The PWL system shall also include pay factors that are based on pavement performance indicators such as rutting and cracking. In addition, the developed PWL shall be incorporated into a user-oriented software that is capable of analyzing the relevant data, establishing the PWL values, and applying the appropriate pay adjustments. Training will be provided to NDOT employees and other entities that will be involved in the implementation of the PWL system.

1.2 Scope of Work

In order to achieve the overall objectives of the research project, the following three phases will be completed:

Phase I – Review of Existing PWL Specification Systems: this phase reviewed several PWL specification systems for HMA construction. The effort concentrated on the review of PWLs implemented by various SHA agencies with similar conditions to NDOT. Based on the findings of the review, the research team recommended the general framework of the PWL system to be developed in Phase II.

Phase II – Develop the PWL Specification System: this phase developed the PWL specification system for dense graded HMA construction that was recommended in Phase I taking into account NDOT and Associated General Contractors (AGC) comments and concerns. The developed system uses several materials and mixtures properties to identify the PWLs for all sublots and lots of HMA mixtures. Weight factors were identified for each of the materials and mixtures properties leading to the development of a single PWL for each lot within the construction project. The PWL system also includes pay factors based pavement performance indicators; rutting and cracking. Finally the developed PWL system has been packaged into a user-oriented software.

Phase III – Implement the Specifications: this phase implemented the developed PWL system on several NDOT projects and uses the data from these projects to fine tune the system.

CHAPTER 2. REVIEW OF EXISTING PWL SPECIFICATION SYSTEMS

This chapter summarizes the findings of a literature review on the applications of PWL system for the acceptance and pay adjustment of dense graded HMA mixtures. Therefore, it will be appropriate to first explain the PWL concept as it relates to the acceptance and pay adjustment of dense graded HMA mixtures.

The Transportation Research Board (TRB) definition of PWL is as follows (2):

> ***PWL*** *– also called percent conforming. The percentage of the lot falling above the LSL, beneath the USL, or between the USL and LSL. [PWL may refer to either the population value or the sample estimate of the population value. PWL = 100-PD.]*

Where:

LSL: lower specification limit
USL: upper specification limit
PD: percent defective

The PWL uses the measured sample average and standard deviation of a specific property of the HMA mix to estimate the percent of the materials, represented by the sample that is within the specification limits. In other words, the PWL process considers both the actual value of the measured property and its associated variability. The PWL tends to reward a producer that manufactures a product that is very close to the target value and has low variability. The low variability part ensures that consistent products are delivered over the duration of the project.

2.1 Distribution of Data

The PWL process assumes that the measured property is normally distributed, i.e. bell shape. Historical data show that most properties of HMA mixtures and pavements follow normal distribution as shown in Figure 1 for asphalt content.

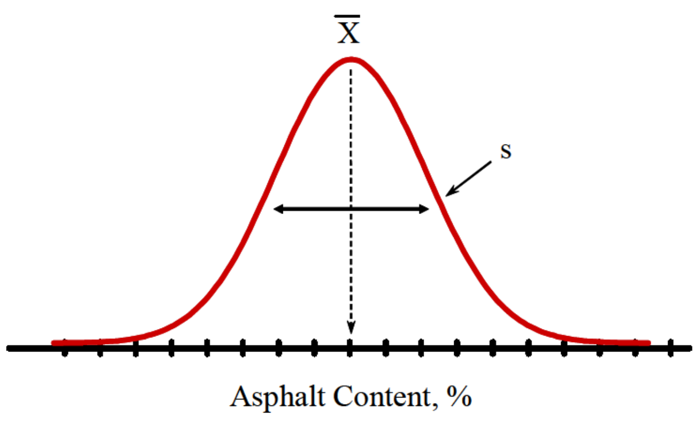


Figure 1. Typical normal distribution of measured asphalt content

The normal distribution is typically described in terms of its average and standard deviation as defined below:

$$\overline{X} = \frac{X_1 + X_2 + \ldots X_n}{n} = \frac{\sum X_i}{n}$$

where:
$\overline{X}$ = sample average,
X_i = each individual value, and
n = number of values in the sample.

$$s = \sqrt{\frac{\sum\left(X_i - \overline{X}\right)^2}{n-1}}$$

where:
s = sample standard deviation,
X_i = each individual value,
$\overline{X}$ = sample average, and
$n-1$ = degrees of freedom, i.e., one less than the sample size.

2.2 Variability of Data

Using the average and standard deviation of a normally distributed data set, the percent of data above or below certain level of the measured property can be estimated. This process is called the Q-statistic or the quality index. For a given HMA property, the quality index is defined for the lower specification limit (LSL) and the upper specification limit (USL) as shown below:

$$Q_L = \frac{\overline{X} - LSL}{s}$$

and

$$Q_U = \frac{USL - \overline{X}}{s}$$

where:
Q_L = quality index relative to the lower specification limit,
Q_U = quality index relative to the upper specification limit,
LSL = lower specification limit,
USL = upper specification limit,
$\overline{X}$ = sample mean for the lot, and
s = sample standard deviation for the lot.

The Q-value indicates the distance in sample deviation units that the sample average is offset from the specification limit. A positive Q-value represents the number of standard deviation units that the sample average falls inside the specification limit. A negative Q-value represents the number of sample standard deviation units that the sample average falls outside the specification limits. These cases are illustrated in Figure 2. Q_L is used when there is only a one-sided lower specification limit. Q_U is used for the one-sided upper specification limit.

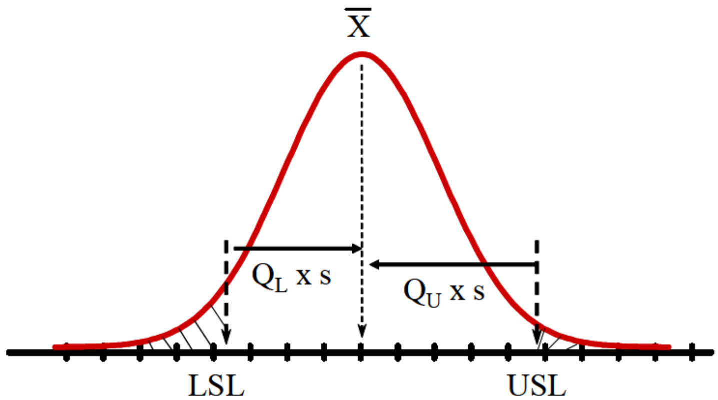


Illustration of the positive quality index.

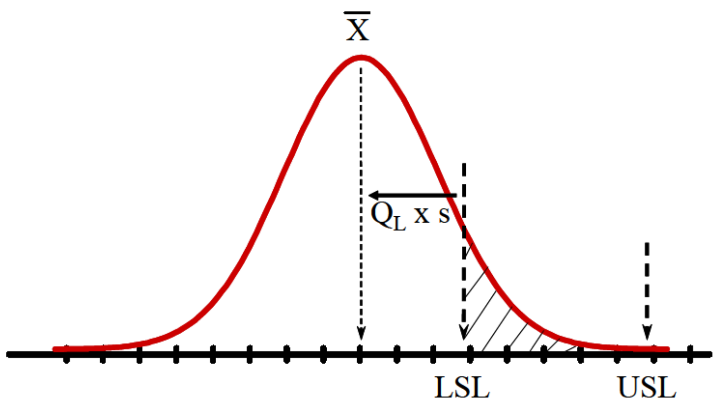


Illustration of the negative quality index.

Figure 2. Illustrations of data variations

2.3 Percent within Limits

The calculated Q_L and Q_U are used in standard statistical tables or in the standard normal distribution function to identify the percent of data that fall above the LSL (i.e. PWL_L) and percent of data that fall below the USL (i.e. PWL_U), respectively. A standard statistical table for number of samples of 5 is shown in Table 4. A complete set of standard statistical tables for sample sizes from 3 to 30 are available in reference 3. The total percent of data that fall between the LSL and USL is estimated using the following relationship:

$$PWL_T = PWL_L + PWL_U - 100$$

Where:

PWL_T = percent within the upper and lower specification limits
PWL_L = percent above the lower specification limits (based on Q_L)
PWL_U = percent below the upper specification limits (based on Q_U)

Table 4. A PWL Estimation Table for Sample Size n = 5 (3).

Q_L or Q_U	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.36	50.71	51.07	51.42	51.78	52.13	52.49	52.85	53.20
0.1	53.56	53.91	54.27	54.62	54.98	55.33	55.69	56.04	56.39	56.75
0.2	57.10	57.46	57.81	58.16	58.52	58.87	59.22	59.57	59.92	60.28
0.3	60.63	60.98	61.33	61.68	62.03	62.38	62.72	63.07	63.42	63.77
0.4	64.12	64.46	64.81	65.15	65.50	65.84	66.19	66.53	66.87	67.22
0.5	67.56	67.90	68.24	68.58	68.92	69.26	69.60	69.94	70.27	70.61
0.6	70.95	71.28	71.61	71.95	72.28	72.61	72.94	73.27	73.60	73.93
0.7	74.26	74.59	74.91	75.24	75.56	75.89	76.21	76.53	76.85	77.17
0.8	77.49	77.81	78.13	78.44	78.76	79.07	79.38	79.69	80.00	80.31
0.9	80.62	80.93	81.23	81.54	81.84	82.14	82.45	82.74	83.04	83.34
1.0	83.64	83.93	84.22	84.52	84.81	85.09	85.38	85.67	85.95	86.24
1.1	86.52	86.80	87.07	87.35	87.63	87.90	88.17	88.44	88.71	88.98
1.2	89.24	89.50	89.77	90.03	90.28	90.54	90.79	91.04	91.29	91.54
1.3	91.79	92.03	92.77	92.51	92.75	92.98	93.21	93.44	93.67	93.90
1.4	94.12	94.34	94.56	94.77	94.98	95.19	95.40	95.61	95.81	96.01
1.5	96.20	96.39	96.58	96.77	96.95	97.13	97.31	97.48	97.65	97.81
1.6	97.97	98.13	98.28	98.43	98.58	98.72	98.85	98.98	99.11	99.23
1.7	99.34	99.45	99.55	99.64	99.73	99.81	99.88	99.94	99.98	100.00

2.4 Sample Calculations

This example shows the calculation process used in the determination of PWL for asphalt content (AC). The following asphalt content data were collected from a lot of HMA mix:

$AC_1 = 4.40\%$
$AC_2 = 4.62\%$
$AC_3 = 4.10\%$
$AC_4 = 4.33\%$
$AC_5 = 4.86\%$

The target asphalt content (AC_T), LSL, and USL are specified as follows:

$AC_T = 4.50$
LSL = 4.10
USL = 4.90

The average AC is: (4.40+4.62+4.10+4.33+4.86)/5 = 4.46%

The standard deviation:
$\{[(4.40-4.46)^2+(4.62-4.46)^2+(4.10-4.46)^2+(4.33-4.46)^2+(4.86-4.46)^2]/4\}^{0.5} = 0.29$

The lower and upper quality indexes are calculated as follows:

$Q_L = (4.46 – 4.10)/0.29 = 1.24$
$Q_U = (4.90 – 4.46)/0.29 = 1.52$

The PWL values are obtained from Table 4 as follows:

$PWL_L = 90.28$
$PWL_U = 96.58$
$PWL_T = 90.28 + 96.58 – 100 = 86.86\% \sim 87\%$

This lot of HMA has 87% of the mix within the limits of the asphalt content. The data show that even-though the average of the asphalt content is very close to the target value of 4.50%, the high variability of the produced mix as represented by the standard deviation of 0.29 resulted in a low percentage of the materials being within the specification limits.

2.5 Review of PWL Systems

This part of the report summarizes the findings of the review of some of the PWL systems that are currently in use for HMA mixtures. Efforts were exerted to identify PWL systems that are being applied by road agencies outside the U.S.; Europe, Japan, and Australia. This search did not identify any applications of the PWL system in these regions. Following this finding, the review focused on the application of the PWL system in SHAs within the U.S. The following eleven PWL systems were reviewed and are summarized in this report:

- Arizona
- California
- Colorado
- Idaho
- Kansas
- Michigan
- New Mexico
- New York
- Utah
- Vermont
- Washington

The review process consisted of identifying the following information from each of the eleven systems:

- Type of data used in PWL: QC, QA, or both
- Definition of lot and sublot
- Measured properties
- Method used to determine overall PWL for a lot

- Method used to determine pay adjustment for a lot
- Specifications limits

2.5.a Type of Data Used in PWL

Table 5 summarizes the type of data used in the PWL systems implemented by the eleven agencies.

Table 5. Type of Data used in PWL.

Agency	QC Data	QA Data	Both QC and QA
Arizona		X	
California	X	X	
Colorado		X	
Idaho	X	X	
Kansas	X		
Michigan	X	X	
New Mexico	X	X	X
New York	X	X	
Utah		X	
Vermont		X	
Washington		X	

Few of the reviewed PWL systems used different data sets for different applications. For example, the California PWL system uses the QC data for asphalt content and the QA data for the in-place compaction. The Idaho system uses both the QC and QA data for acceptance but only the QC data are used for pay adjustment. The Michigan system uses the QC and QA data for acceptance but only the QA data are used for pay adjustment. The New York system uses the QA data for pay adjustment and QC and QA data for mix verification at the plant. Only the New Mexico system fully uses both the QC and QA data sets.

Combining the summary shown in Table 5 and the additional information provided in the previous paragraph indicates that the majority of the reviewed PWL systems use the QA data to establish the percent within limits of the measured properties.

2.5.b Definition of Lot and Sublot

The size of lot and sublot vary significantly among the reviewed PWL systems as shown in Table 6. The majority of the reviewed PWLs uses a lot size and sublot size that are consistent with the AASHTO recommendation for the 19 mm mix. Arizona and Idaho use a production shift which is typically a 1-day production unless contractor runs a continuous operation. Colorado combines all produced mixtures into a continuous lot as long as none of the mixtures properties change which require a change in the job mix formula (JMF).

It should be noted that the number of sublots per lot varies depending on the properties that the agency measures which will be presented in the next section. A typical number of sublots per lot for mix volumetrics and gradation is 4-5 while for compaction it can be as high as 10. The New York PWL system is based on paved feet per day which is not consistent with the other systems.

Table 6. Size of Lot and Sublot of HMA Mix.

Agency	Size of Lot (Ton)	Size of Sublot (Ton)	Sublots/Lot
AASHTO R42: Mix ≥19mm	≥4000	≤1000	4 or more
AASHTO R42: Mix ≤12.5mm	≥2400	≤600	4 or more
Arizona	single production shift	¼ production shift 1/10 production shift	4 for mixtures properties 10 for compaction
California	13500 - 15000	750	18 – 20
Colorado	homogeneous material	1000 for AC 1-day for Va and VMA 2000 for gradation 500 for compaction	Unlimited
Idaho	single production shift	750	3 or more
Kansas	3000	750	4
Michigan	5000	1000	5
New Mexico	15000	3000	5
New York[1]	1-day paving in feet	¼ lot	4
Utah	1-day production	¼ lot for AC ¼ lot for gradation 1/5 lot for compaction	4 for AC 4 for gradation 5 for compaction
Vermont	3000 for Va 1-day paving for compaction	500 for Va 0.6 miles for compaction	6 for Va Min 6 per day for compaction
Washington	12000	800	15

[1] size of lot and sublots is in feet

2.5.c Measured Properties

In general, the reviewed PWL systems use mix volumetrics, gradation, and compaction as measured properties for PWL and pay adjustment. Table 7 summarizes the properties measured by the various agencies. A review of the data presented in Table 7 leads to the following observations:

- All of the reviewed systems use compaction for PWL calculations and pay adjustment. The frequency of measurement varies significantly among the systems (i.e. 80 – 750 tons of mix).
- Eight out of eleven systems use Va for PWL calculations and pay adjustment. Four out of the eleven systems use both Va and VMA for PWL calculations and pay adjustment. The frequency of measurement ranges from 1 per 500 tons to 1 per 1000 tons of mix.
- Seven out of the eleven systems use AC for both PWL calculations and pay adjustment. The frequency of measurement varies from 1 per 500 tons to 1 per 1000 tons of mix.

- Five out of the eleven systems use gradation on multiple sieves for PWL calculations and pay adjustment. The frequency of measurement varies from 4 per day to 1 per 2000 tons of mix.

Table 7. Properties used for PWL and Pay Adjustment.

Agency	Volumetrics		Gradation		AC	Compaction
	Property	**Frequency**	**Property**	**Frequency**	**Frequency**	**Frequency**
Arizona	Va	4 per shift	3/8", #8, #40, #200	4 per shift	4 per shift	10 per shift
California	--	--	½", #8, #200	750 tons	750 tons	750 tons
Colorado	--	--	3/8", #4, #8,#30,#200	2000 tons	1000 tons	500 tons
Idaho	Va, VMA	750 tons	--	--	--	750 tons
Kansas	Va	750 tons	--	--	--	10 per shift
Michigan	Va, VMA	1000 tons	--	--	1000 tons	250 tons
New Mexico	Va, VMA	750 tons	--	--	750 tons	750 tons
New York	--	--	--	--	--	¼ paving length/day in feet
Utah	--	--	topsize, #8, #50, #200	4 per day	4 per day	5 per day
Vermont	Va	500 tons	--	--	--	0.6 miles of paved lane
Washington	Va	800 tons	topsize, #4, #8, #200	800 tons	800 tons	80 tons

2.5.d Determination of Overall PWL and Pay Adjustment

The overall PWL and pay adjustment (PA) refer to the PWL and PA for the entire lot of HMA mix. The following describes the methods used for determining the overall PWL and PA for the reviewed systems.

- **Arizona:**
  - Individual PWL values are determined for gradation, AC, Va, and Compaction.
  - Using the calculated PWLs, the pay factor for each property is determined from Table 8.
  - A single pay factor (PF) is determined for gradation and AC by selecting the lowest of the determined PFs for these properties. Note: multiple PFs are determined for gradation based on the individual sieves.
  - Pay adjustments are calculated as follows:

    Mixture Pay Adjustment = $(PF_{Gradation\&AC} + PF_{Va})$ x Lot Quantity (tons)
    Compaction Pay Adjustment = $(PF_{Compaction})$ x Lot Quantity (tons)

- The following notes apply:
  - Positive mixture properties lot pay factors reduces to zero when the compaction lot is in reject and the material is allowed to be left in place.
  - Positive compaction lot pay factors reduces to zero when the mixture properties lot is in reject and the material is allowed to remain in place.
  - For any mixture properties lot that is in reject due to asphalt content but allowed to remain in place, payment will not be made for asphalt cement quantities in excess of the Upper Limit.

Table 8. Pay Factors for the Arizona PWL System.

PWL	AC/ Gradation	Va	Compaction
100	$0.00	+$1.00	+$1.00
95-99	$0.00	+$0.50	+$0.00
90-94	$0.00	$0.00	$0.00
85-89	$0.00	-$0.25	-$0.25
80-84	-$0.25	-$0.50	-$0.50
75-79	-$0.50	-$0.75	-$0.75
70-74	-$0.75	-$1.00	-$1.00
65-69	-$1.00	-$1.25	-$1.30
60-64	-$1.50	-$1.50	-$1.75
55-59	-$2.00	-$2.00	-$2.25
50-54	-$2.50	-$2.50	-$3.00
< 50	Reject		

- **California:** the CA PWL system uses the percent defection (PD) in place of the PWL; PD = PWL_L+PWL_U.
  - Individual PD values are calculated for gradation, AC, and compaction.
  - The calculated PD values are used in Table 9 to determine the PF which is labeled as "Quality Factor" in the first column.
  - Measured properties are assigned weights as shown below:

Property	**Weight (%)**
AC	30
½" Gradation	5
#8 Gradation	10
#200 gradation	15
Compaction	40

- Individual pay adjustments are determined for AC, gradation, and compaction as follows:

  AC Pay Adjustment = ($PF_{\%AC}$ – 1) x Lot Quantity(tons)xUnit Price x 0.30
  ½" Sieve Pay Adjustment = ($PF_{1/2"}$ – 1) x Lot Quantity(tons)xUnit Price x 0.05
  #8 Sieve Pay Adjustment = ($PF_{\#8}$ – 1) x Lot Quantity(tons)xUnit Price x 0.10
  #200 Sieve Pay Adjustment = ($PF_{\#200}$ – 1)xLot Quantity(tons)xUnit Price x 0.15
  Compaction Pay Adjustment = (PF_{Comp} – 1)xLot Quantity(tons)xUnit Price x 0.40

Table 9. Pay Factors for the California System.

Quality Factors

Quality Factor	Maximum Allowable Percent Defective ($P_U + P_L$)												
	Sample Size (n)												
	5	6	7	8	9	10-11	12-14	15-17	18-22	23-29	30-42	43-66	>66
1.05				0	0	0	0	0	0	0	0	0	0
1.04			0	1	3	5	4	4	4	3	3	3	3
1.03		0	2	4	6	8	7	7	6	5	5	4	4
1.02		1	3	6	9	11	10	9	8	7	7	6	6
1.01	0	2	5	8	11	13	12	11	10	9	8	8	7
1.00	22	20	18	17	16	15	14	13	12	11	10	9	8
0.99	24	22	20	19	18	17	16	15	14	13	11	10	9
0.98	26	24	22	21	20	19	18	16	15	14	13	12	10
0.97	28	26	24	23	22	21	19	18	17	16	14	13	12
0.96	30	28	26	25	24	22	21	19	18	17	16	14	13
0.95	32	29	28	26	25	24	22	21	20	18	17	16	14
0.94	33	31	29	28	27	25	24	22	21	20	18	17	15
0.93	35	33	31	29	28	27	25	24	22	21	20	18	16
0.92	37	34	32	31	30	28	27	25	24	22	21	19	18
0.91	38	36	34	32	31	30	28	26	25	24	22	21	19
0.90	39	37	35	34	33	31	29	28	26	25	23	22	20
0.89	41	38	37	35	34	32	31	29	28	26	25	23	21
0.88	42	40	38	36	35	34	32	30	29	27	26	24	22
0.87	43	41	39	38	37	35	33	32	30	29	27	25	23
0.86	45	42	41	39	38	36	34	33	31	30	28	26	24
0.85	46	44	42	40	39	38	36	34	33	31	29	28	25
0.84	47	45	43	42	40	39	37	35	34	32	30	29	27
0.83	49	46	44	43	42	40	38	36	35	33	31	30	28
0.82	50	47	46	44	43	41	39	38	36	34	33	31	29
0.81	51	49	47	45	44	42	41	39	37	36	34	32	30
0.80	52	50	48	46	45	44	42	40	38	37	35	33	31
0.79	54	51	49	48	46	45	43	41	39	38	36	34	32
0.78	55	52	50	49	48	46	44	42	41	39	37	35	33
0.77	56	54	52	50	49	47	45	43	42	40	38	36	34
0.76	57	55	53	51	50	48	46	44	43	41	39	37	35
0.75	58	56	54	52	51	49	47	46	44	42	40	38	36
	60	57	55	53	52	51	48	47	45	43	41	40	37
	61	58	56	55	53	52	50	48	46	44	43	41	38
Reject	62	59	57	56	54	53	51	49	47	45	44	42	39
	63	61	58	57	55	54	52	50	48	47	45	43	40
	64	62	60	58	57	55	53	51	49	48	46	44	41
Reject Values Greater Than Those Shown Above													

- **Colorado:**
  - Individual PWL values are determined for gradation, AC, compaction, and joint density.
  - Using the calculated PWLs, the pay factor for each property is determined from Table 10 where the PWL is referred to as "QL".
  - A weighted average PF is calculated for each property based on the weight of lot that is represented by the individual PF values.
  - The pay adjustment for the entire project is calculated based on a composite pay factor (CPF) and the following:
    Project Pay Adjustment = (CPF – 1) x lot Quantity(tons) x Unit Price

The CPF is calculated based on the following weights:

Property	**Weight (%)**
AC	25
Gradation	15
Compaction	45
Joint Density	15

Table 10. Pay Factors for the Colorado System.

Table 105-3
FORMULAS FOR CALCULATING PF BASED ON Pn

Pn	When Pn as shown at left is 3 to 9, or greater than 200, use designated formula below to calculate Pay Factor, PF = ...,when Pn is 10 to 200, use formula (1) above:	Maximum PF
3	$0.31177 + 1.57878\ (QL/100) - 0.84862\ (QL/100)^2$	1.025
4	$0.27890 + 1.51471\ (QL/100) - 0.73553\ (QL/100)^2$	1.030
5	$0.25529 + 1.48268\ (QL/100) - 0.67759\ (QL/100)^2$	1.030
6	$0.19468 + 1.56729\ (QL/100) - 0.70239\ (QL/100)^2$	1.035
7	$0.16709 + 1.58245\ (QL/100) - 0.68705\ (QL/100)^2$	1.035
8	$0.16394 + 1.55070\ (QL/100) - 0.65270\ (QL/100)^2$	1.040
9	$0.11412 + 1.63532\ (QL/100) - 0.68786\ (QL/100)^2$	1.040
10 to 11	$0.15344 + 1.50104\ (QL/100) - 0.58896\ (QL/100)^2$	1.045
12 to 14	$0.07278 + 1.64285\ (QL/100) - 0.65033\ (QL/100)^2$	1.045
15 to 18	$0.07826 + 1.55649\ (QL/100) - 0.56616\ (QL/100)^2$	1.050
19 to 25	$0.09907 + 1.43088\ (QL/100) - 0.45550\ (QL/100)^2$	1.050
26 to 37	$0.07373 + 1.41851\ (QL/100) - 0.41777\ (QL/100)^2$	1.055
38 to 69	$0.10586 + 1.26473\ (QL/100) - 0.29660\ (QL/100)^2$	1.055
70 to 200	$0.21611 + 0.86111\ (QL/100)$	1.060
≥ 201	$0.15221 + 0.92171\ (QL/100)$	1.060

- **Idaho:**
  - Individual PWL values are determined for Va, VMA, and compaction.
  - The PF for the Va is calculated as follows:

$$PF_{Va} = [55 + (0.5)PWL]/100$$

  - For VMA and compaction, the PFs are obtained from Table 11. Note: the Quality Level in the table represents the PWL value.
  - Each of the PFs for Va and VMA is weighted 30% while the PF for compaction is weighted 40%.The pay adjustment for the lot is calculated as follows:

    Pay adjustment = $[((PF_{Va} \times 0.30) + (PF_{VMA} \times 0.30) + (PF_{Compaction} \times 0.40))-1]$ xUnit Price x Lot Quantity (tons)

Table 11. Pay Factors for the Idaho System.

Table 106.03-3

Pay Factors

Pay Factor for a given Sample Size(n) and Quality Level

Pay Factor	*n* = 3	*n* = 4	*n* = 5	*n* = 6	*n* = 7	*n* = 8	*n* = 9	*n* = 10 to *n*=11	*n* = 12 to *n*=14	*n* = 15 to *n*=18
1.05	100	100	100	100	100	100	100	100	100	100
1.04	90	91	92	93	93	93	94	94	95	95
1.03	80	85	87	88	89	90	91	91	92	93
1.02	75	80	83	85	86	87	88	88	89	90
1.01	71	77	80	82	84	85	85	86	87	88
1.00	68	74	78	80	81	82	83	84	85	86
0.99	66	72	75	77	79	80	81	82	83	85
0.98	64	70	73	75	77	78	79	80	81	83
0.97	62	68	71	74	75	77	78	78	80	81
0.96	60	66	69	72	73	75	76	77	78	80
0.95	59	64	68	70	72	73	74	75	77	78
0.94	57	63	66	68	70	72	73	74	75	77
0.93	56	61	65	67	69	70	71	72	74	75
0.92	55	60	63	65	67	69	70	71	72	74
0.91	53	58	62	64	66	67	68	69	71	73
0.90	52	57	60	63	64	66	67	68	70	71
0.89	51	55	59	61	63	64	66	67	68	70
0.88	50	54	57	60	62	63	64	65	67	69
0.87	48	53	56	58	60	62	63	64	66	67
0.86	47	51	55	57	59	60	62	63	64	66
0.85	46	50	53	56	58	59	60	61	63	65
0.84	45	49	52	55	56	58	59	60	62	64
0.83	44	48	51	53	55	57	58	59	61	63

Note: Quality Level represents the PWL value

- **Kansas:**
  - Individual PWL values are determined for Va, and compaction.
  - The calculated PWL values are used in the following equations to calculate the PFs:

$$PF_{Va} = [(PWL_{Va} – 100) \times 0.003] – 0.27$$
$$PF_{Compaction} = (PWL_{Compaction} \times 0.004) – 0.36$$

  - The pay adjustments are calculated as follows:

$$\text{Va Pay Adjustment} = PF_{Va} \times \text{Lot Quantity(tons)} \times 40$$
$$\text{Compaction Pay Adjustment} = PF_{Compaction} \times \text{Lot Quantity(tons)} \times 40$$

- **Michigan:**
  - Individual PWL values are determined for Va, AC, VMA, and compaction.
  - PF values are determined based on the following guidelines:
    - If PWL id between 70 and 100: PF = 55 +(0.5 x PWL)
    - If PWL is between 50 and 70: PF = 37.5 + (0.75 x PWL)
    - If PWL is less than 50, the Engineer may elect to do one of the following:
      - Require removal and replacement of the entire lot with new QA sampling and testing and repeat the evaluation procedure.
      - Allow the lot to remain in place and apply an Overall Lot Pay Factor of 50%.
      - Allow submittal of a corrective action plan for the Engineer's approval. The corrective action plan may include removal and replacement of one or more sublots. If one or more sublots are replaced, the sublot(s) will be retested and the Overall Lot Pay Factor will be recalculated according to this special provision. If the Engineer does not approve the plan for corrective action, actions (1) or (2) above will be applied.

  - Weight factors are assigned to the various properties as shown below:

Property	**Weight (%)**
AC	15
Va	30
VMA	15
Compaction	40

  - Using the weight factors, the Overall Lot Pay Factor (OLPF) is calculated as follows:

$$OLPF = (0.4 \times PF_{Compaction}) + (0.30 \times PF_{Va}) + (0.15 \times PF_{AC}) + (0.15 \times PF_{VMA})$$

  - The lot pay adjustment is calculated as follows:

Pay Adjustment = [(OLPF -100)/100] x Lot Quantity(tons) x Unit Price

- **New Mexico:**
  - Individual PWL values are determined for Va, AC, VMA, and compaction.
  - Pay factors are determined for each property from Table 12 using the calculated PWLs for each property.
  - Weight factors are assigned to the various properties as shown below:

Property	**Weight (%)**
AC	10
Va	35
VMA	20
Compaction	35

  - Using the weight factors, the Composite Pay Factor (CPF) is calculated as follows:

$$CPF = (0.35 \times PF_{Compaction}) + (0.35 \times PF_{Va}) + (0.10 \times PF_{AC}) + (0.20 \times PF_{VMA})$$

  - The lot pay adjustment is calculated as follows:

Pay Adjustment = (CPF -1) x Lot Quantity(tons) x Unit Price

Table 12. Pay Factors for the New Mexico System.

Table 901.7:2
Pay Factors

Pay factor	Minimum Required Percent of Work Within Specifications Limits for a Given Pay Factor (Pu+PL) – 100, n=														
	3	4	5	6	7	8	9	10 to 11	12 to 14	15 to 17	18 to 22	23 to 29	30 to 42	43 to 66	67 to ∞
1.05	—	—	—	—	—	100	100	100	100	100	100	100	100	100	100
1.04	—	—	—	—	100	99	97	95	96	96	96	97	97	97	97
1.03	—	—	—	100	98	96	94	92	93	93	94	95	95	96	96
1.02	—	—	—	99	97	94	91	89	90	91	92	93	93	94	94
1.01	100	100	100	98	95	92	89	87	88	89	90	91	92	92	93
1.00	69	75	78	80	82	83	84	85	86	87	88	89	90	91	92
0.99	66	72	76	78	80	81	82	83	84	85	86	87	89	90	91
0.98	64	70	74	76	78	79	80	81	82	84	85	86	87	88	90
0.97	63	68	72	74	76	77	78	79	81	82	83	84	86	87	88

- **New York:**
  - The PWL is determined for compaction.
  - The PF is determined based on the following conditions:
    - PWL > 93, PF = 1.05
    - If the PWL < 93, the density data are grouped into Density Ranges (DR) and a PF is assigned for each DR as shown in Table 13. The PWL for each DR is calculated using the average and standard deviation of the entire data. The PWL is multiplied by the corresponding PF to obtain the Quality Adjustment Factor (QAF) for each DR.
    - The sum of the QAFs is the overall pay factor. Sample calculations are shown in Table 13.

  - The lot pay adjustment is calculated as follows:

Pay Adjustment = [(QAF -100)/100] x Lot Quantity(tons) x Unit Price

Table 13. Pay Factors for the New York System.

Given Values		Calculated Values	
Density Range (DR)	Pay Factor	PWL for DR	QAF for DR
DR ≤ 88.0	0.00	0	0
88.0 < DR ≤ 89.0	0.60	0	0
89.0 < DR ≤ 90.0	0.70	0	0
90.0 < DR≤ 91.0	0.80	0	0
91.0 < DR ≤ 92.0	0.90	11	9.90
92.0 < DR ≤ 93.0	1.00	18 *	18.00
93.0 < DR ≤ 96.0	1.05	53	55.65
96.0 < DR ≤ 97.0	1.00	17	17.00
97.0 < DR ≤ 98.0	0.90	1	0.90
98.0 < DR ≤ 99.0	0.80	0	0
DR > 99.0	0.00	0	0
		Σ PWL = 100	Σ QAF = 101.45 **

- **Utah:**
  - Individual PWL values are determined for AC, gradations, and compaction.
  - Pay factors are determined for each property from Table 14 using the calculated PWLs for each property.
  - The lowest PF determined for AC and gradations is selected to be used for pay adjustment.
  - The total pay adjustment will be the sum of the following two adjustments:

$$\text{Pay Adjustment}_{\text{AC or Grad}} = (\text{PF}_{\text{AC or Grad}}) \times \text{Lot Quantity(tons)}$$
$$\text{Pay Adjustment}_{\text{Compaction}} = (\text{PF}_{\text{Compaction}}) \times \text{Lot Quantity(tons)}$$

- **Vermont:**
  - Individual PWL values are determined for Va, compaction, and roughness.
  - Pay factors are calculated for each property using the following equations:

$$PF_{Va} = [(0.28 \text{ x } PWL + 75)/100] - 1.0$$

$$PF_{Compaction} = = [(0.20 \text{ x } PWL + 83)/100] - 1.0 \quad \text{for } 85 \leq PWL \leq 100$$
$$PF_{Compaction} = = [(0.20 \text{ x } PWL + 83)/100] - 1.0 \quad \text{for } 60 \leq PWL < 85$$

$$PF_{Roughness} = = (-.0029 \text{ x } IRI + 1.15) - 1.0 \quad \text{for Limited Access Highways}$$
$$PF_{Roughness} = = (-.0029 \text{ x } IRI + 1.1786) - 1.0 \quad \text{for Other State Routes}$$

  - Since lot sizes are different, individual pay adjustments are calculated:

Pay Adjustment (Va) = PF_{Va} x Lot Quantity(tons) x Unit Price
Pay Adjustment (Compaction) = $PF_{Compaction}$ x Lot Quantity(tons) x Unit Price
Pay Adjustment (Roughness) = $PF_{Roughness}$ x Lot Quantity(tons) x Unit Price

Table 14. Pay Factors for the Utah System.

%AC/Gradation and Compaction	
PWL (based on an average of minimum of 4 samples)	**PF ($ / ton)**
>99	$1.50
96-99	$1.00
92-95	$0.60
88-91	$0.00
84-87	-$0.26
80-83	-$0.60
76-79	-$0.93
72-75	-$1.27
68-71	-$1.60
64-67	-$1.93
60-63	-$2.27
<60	Reject

- **Washington:**
  - Individual PWL values are determined for Va, AC, gradations, and compaction.
  - Pay factors are determined for each property.
  - Table 15 using the calculated PWLs for each property.
  - The PFs for the Va, AC, and gradations are assigned the following weights:

Pay Factors Constituents	**Factor "f"**
All aggregate passing: 1.5", 1", ¾", and #4	2
All aggregate passing #8	15
All aggregate passing #200	20
AC	40
Va	20

- A Composite Pay Factor (CPF) is calculated for gradations, Ac and Va as follows:

$$CPF = [\sum f_i(PF_i))]/\sum f_i$$

- Pay adjustments are calculated based on a split of 60% for gradation, Va, and AC and 40% for Compaction:

$$\text{Pay Adjustment}_{Grad,AC,Va} = 0.60 \text{ x } (CPF_{Grad,AC,Va} - 1) \text{ x Lot Quantity(tons) x Unit Price}$$
$$\text{Pay Adjustment}_{Compaction} = 0.40 \text{ x } (CPF_{Compaction} - 1) \text{ x Lot Quantity(tons) x Unit Price}$$

Table 15. Pay Factors for the Washington System.

PAY FACTOR	Minimum Required Percent of Work Within Specification Limits for a Given Factor $(P_U + P_L) - 100$													
Category	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10 to n=11	n=12 to n=14	n=15 to n=17	n=18 to n=22	n=23 to n=29	n=30 to n=42	n=43 to n=66	n=67 to ∞
1.05						100	100	100	100	100	100	100	100	100	100
1.04					100	99	97	95	96	96	96	97	97	97	97
1.03				100	98	96	94	92	93	93	94	95	95	96	96
1.02				99	97	94	91	89	90	91	92	93	93	94	94
1.01	100	100	100	98	95	92	89	87	88	89	90	91	92	92	93
1.00	69	75	78	80	82	83	84	85	86	87	88	89	90	91	92
0.99	66	72	76	78	80	81	82	83	84	85	86	87	89	90	91
0.98	64	70	74	76	78	79	80	81	82	84	85	86	87	88	90
0.97	63	68	72	74	76	77	78	79	81	82	83	84	86	87	88
0.96	61	67	70	72	74	75	76	78	79	81	82	83	84	86	87
0.95	59	65	68	71	72	74	75	76	78	79	80	82	83	84	86
0.94	58	63	67	69	71	72	73	75	76	78	79	80	82	83	85
0.93	57	62	65	67	69	71	72	73	75	76	78	79	80	82	84
0.92	55	60	63	66	68	69	70	72	73	75	76	78	79	81	82
0.91	54	59	62	64	66	68	69	70	72	74	75	76	78	79	81
0.90	53	57	61	63	65	66	67	69	71	72	74	75	77	78	80
0.89	51	56	59	62	63	65	66	68	69	71	72	74	75	77	79
0.88	50	55	58	60	62	64	65	66	68	70	71	73	74	76	78
0.87	49	53	57	59	61	62	63	65	67	68	70	71	73	75	77
0.86	48	52	55	58	59	61	62	64	66	67	69	70	72	74	76
Note: If the value of $(P_U + P_L) - 100$ does not correspond to a $(P_U + P_L) - 100$ value in this table, use the next smaller $(P_U + P_L) - 100$ value. **(Continued)**															
0.85	46	51	54	56	58	60	61	62	64	66	67	69	71	72	75
0.84	45	49	53	55	57	58	60	61	63	65	66	68	70	71	73
0.83	44	48	51	54	56	57	58	60	62	64	65	67	69	70	72
0.82	43	47	50	53	54	56	57	59	61	62	64	66	67	69	71
0.81	41	46	49	51	53	55	56	58	59	61	63	64	66	68	70

2.5.e Specification Limits

As summarized in Table 7, every SHA uses a set of mixture properties and field compaction in the determination of PWLs and the pay adjustment. The specification limits for the identified mixtures properties and field compaction vary among the various SHAs. Table 16 summarizes the limits for the mixtures properties and field compaction used in the eleven PWL systems that were reviewed and as required in the NDOT specifications. A review of the data summarized in Table 16 leads to the following observations:

- In general, most of the reviewed specification limits on gradations are very similar.
- The majority of the specification limits on air voids are 3.0 to 5.0% while the NDOT specification allows 4 to 7%.
- The NDOT specification on AC of ±0.40 is within the range of other specifications.
- The NDOT specification on compaction of 92 to 96% is very consistent with other specifications.

Table 16. Specification limits for properties used for PWL and Pay Adjustment.

Agency	Volumetrics			Gradation			AC		Compaction	
	Property	LL	UL	Property	LL	UL	LL	UL	LL	UL
Arizona	Va	-2.0	+1.5	3/8” #8 #40 #200	-6.0 -6.0 -5.0 -2.0	+6.0 +6.0 +5.0 +2.0	-0.5	+0.5	91%	96%
California	--			½” #8 #200	-6.0 -5.0 -2.0	+6.0 +5.0 +2.0	-0.45	+0.45	92%	96%
Colorado	--			3/8” #4, #8 #30 #200	-6.0 -5.0 -5.0 -4.0 -2.0	+6.0 +5.0 +5.0 +4.0 +2.0	-0.3	+0.3	92%	96%
Idaho	Va VMA NMS*: 1.5” NMS: 1” NMS: ¾” NMS:1/2” NMS: 3/8”	3.0 11 12 13 14 15	5.0	--					Cores 92% Nuc. 91	Cores 95% Nuc. 95.5%
Kansas	Va	3.0	5.0	--					92%	
Michigan	Va VMA	3.0 14	5.0 16	--			-0.4	+0.4	92%	
New Mexico	Va VMA	-1.6 -1.6	+1.6 +1.6	--			-0.3	+0.3	92%	97%
New York	--			--					92%	97%
Utah	--			Topsize #8 #50	-6.0 -5.0 -3.0	+6.0 +5.0 +3.0	-0.35	+0.35	90.5%	95.5%

Agency	Volumetrics			Gradation			AC		Compaction	
	Property	LL	UL	Property	LL	UL	LL	UL	LL	UL
				#200	-2.0	+2.0				
Vermont	Va	3.0	5.0	--					92.5%	96.5%
Washington	Va	2.5	5.5	topsize #4 #8 #200	-6.0 -5.0 -4.0 -2.0	+6.0 +5.0 +4.0 +2.0			91%	
Nevada	Va	4.0	7.0	≥ #4 #8 #10 #200	-7.0 -4.0 -4.0 -2.0	+7.0 +4.0 +4.0 +2.0	-0.4	+0.4	92%	96%

*Nominal Maximum Size

2.6 Recommendations of Phase I

Based on the review of the eleven PWL systems and the comments received from NDOT and the AGC, the following recommendations were made for the overall framework of the NDOT PWL for dense graded HMA mixtures.

- Measured properties:
  1. Gradation on multiple sieves using calibrated ignition oven. The critical sieves will be determined based on the analysis of field data presented in Chapter 3.
  2. Asphalt Content using calibrated ignition oven.
  3. In-place Density using nuclear gauge calibrated with cores.

- Weight Factors: each of the measured properties will be assigned a weight factor based on its relative contribution toward the long-term performance of the HMA pavement.

- Percent within Limit: a PWL value will be determined for each of the measured properties for every sublot. An overall PWL will be determined for the entire lot using the appropriate weight factors.

- Sublot and Lot sizes:
  - Size of Sublot: 1,000 tons of HMA mix or end of day whichever comes first for all properties for the duration of the project. However, the size of the sublot for the compaction (i.e., mat density) can range between 100 tons and 1,000 tons. Necessary exceptions will be identified to accommodate construction activities.
  - Size of Lot: 5,000 tons of HMA or 5 sublots whichever comes first for asphalt binder content and gradation and whatever the corresponding number of sublots for compaction for the duration of the project. Necessary exceptions will be identified to accommodate construction activities.

- The following assumptions will be implemented when assigning lot numbers:
  - A job mix revision is not allowed within a lot.
  - An interruption in production of more than one day is not allowed within a lot.

CHAPTER 3. DEVELOPMENT OF THE PWL SPECIFICATION SYSTEM

Phase II was initiated to develop the Percent within Limits (PWL) specification system including pay factors for dense graded HMA construction following the recommendation of Phase I and taking into account NDOT and AGC comments and concerns. This chapter presents the following components of the developed PWL system:

- Collection of measured properties on selected dense graded HMA mixtures constructed by NDOT over the past few years.
- Analyses of the collected data including: statistical analysis, definition of lot and sublot, calculations of PWL values followed by the overall computed bonus or demerit that the contractor would have incurred on each project.
- Development of the PWL software.

3.1 Data Collection

A summary of the nine NDOT contracts that were evaluated in this study is presented in Table 17.

Table 17. Nevada's Contracts Considered in The Study.

	Contract								
	3339	3361	3383	3402	3431	3435	3435 (RAP)	3466 (RAP)	3505 (RAP)
County	Clark	Clark	Clark	Churchill	Pershing	Elko	Elko	Clark	Lyon
Gradation/AC									
Plant start	22-Feb-08	6-Jul-09	30-Sep-09	19-May-10	26-Apr-11	23-Sep-11	25-May-11	4-Apr-12	28-Sep-12
Plant end	28-Apr-09	21-Feb-10	9-Jul-10	11-Aug-10	23-Jun-11	13-Aug-12	18-Sep-12	13-Sep-12	15-Dec-12
Test reports	27	14	55	39	31	30	107	58	33
In-place density									
Start	3-Mar-08	6-Jul-09	30-Sep-09	19-May-10	26-Apr-11	23-Sep-11	25-May-11	22-Mar-12	28-Sep-12
End	17-Apr-09	8-Mar-10	9-Jul-10	11-Aug-10	23-Jun-11	13-Aug-12	18-Sep-12	13-Sep-12	15-Dec-12
Test reports	68	52	124	160	206	141	414	255	106

Figure 3 shows the tonnage production of the selected NDOT contracts. The production rates range from 26,688 up to 119,918 tons representing small and large NDOT projects. The wide distribution of the HMA tonnage among the nine contracts allows the assessment of the application of the PWL system on small and large NDOT projects. In addition, the impact of project size on the conformation of the measured properties with the limits of the JMF would be assessed to identify any impact of project size on the quality of the work. In other words, would contractors pay more attention to quality on large projects versus small projects which would necessitate the implementation of a PWL system that takes into consideration the size of the project.

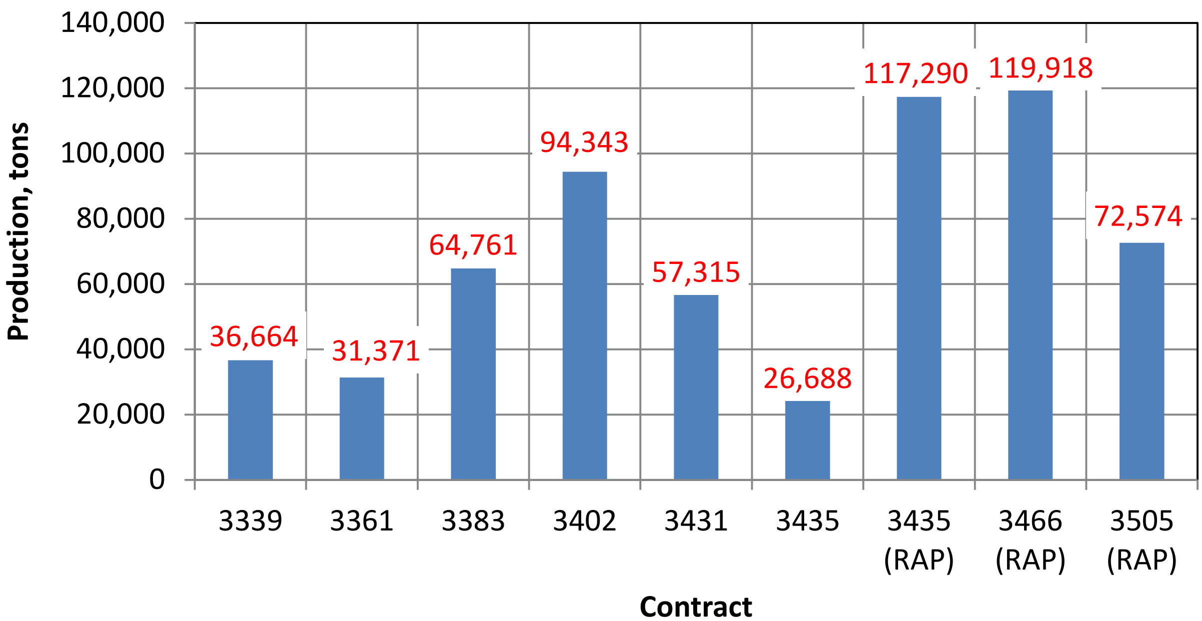
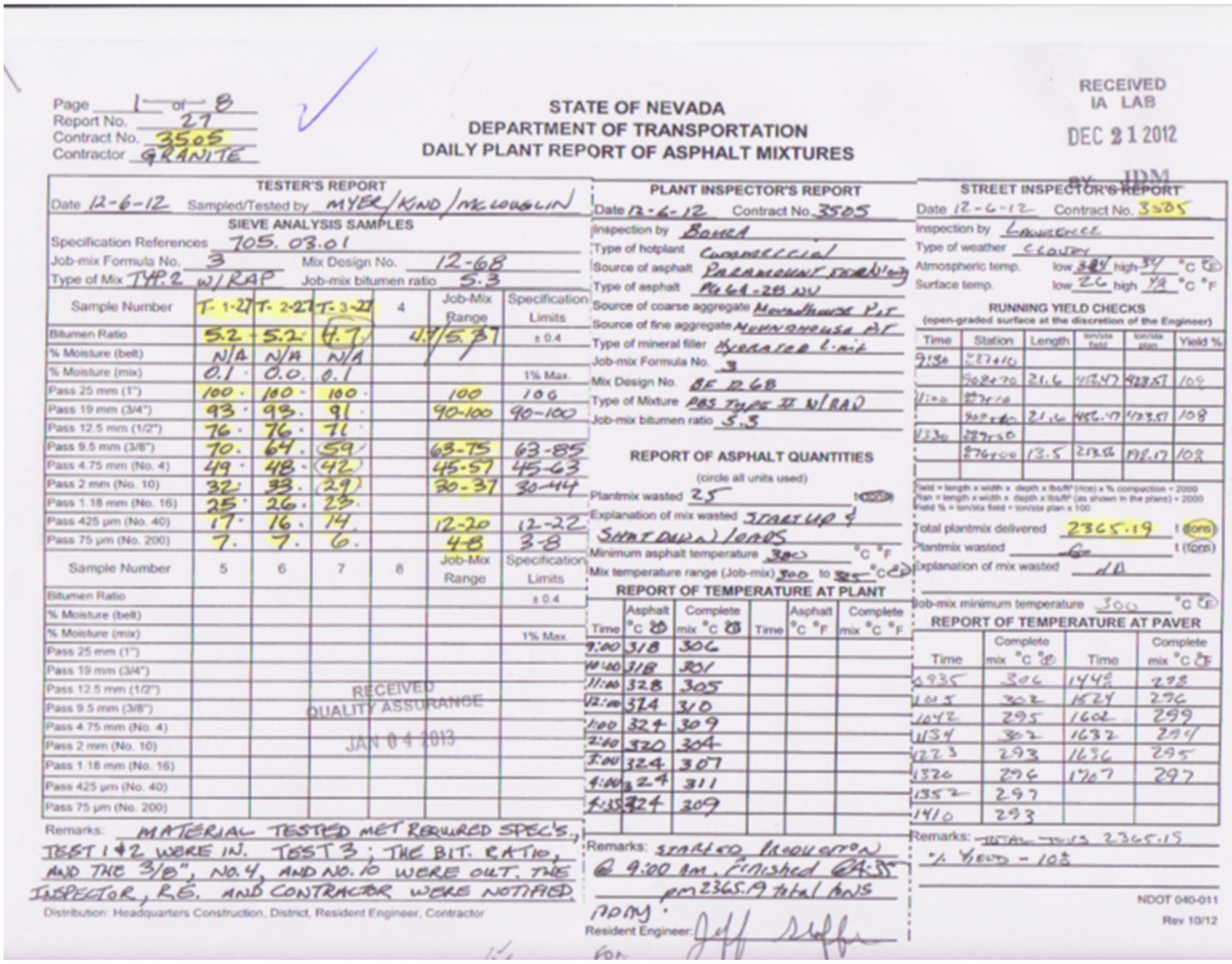


Figure 3. Total HMA production (in tons) for the selected NDOT contracts

Figure 4 shows the standard data collection form that NDOT uses to record the measured properties on HMA mixtures during production: Daily Report of Asphalt Mixtures. Figure 5 shows the standard data collection form that NDOT uses to record the measured properties of HMA mixtures during construction: Nuclear Thin Layer Compaction Report. The combination of data from these two reports covers all the properties that were recommended for inclusion in the NDOT PWL System. The hard copies of the two forms were obtained from NDOT Construction Division for all nine contracts and entered into Excel files in order to facilitate the data analyses.



Page 1 of 8
Report No. 27
Contract No. 3505
Contractor GRANITE

STATE OF NEVADA
DEPARTMENT OF TRANSPORTATION
DAILY PLANT REPORT OF ASPHALT MIXTURES

RECEIVED
IA LAB
DEC 21 2012
BY: IDM

TESTER'S REPORT

Date 12-6-12 Sampled/Tested by MYER/KIND/MCLOUGLIN

SIEVE ANALYSIS SAMPLES

Specification References 705.03.01
Job-mix Formula No. 3 Mix Design No. 12-68
Type of Mix TYP. 2 W/RAP Job-mix bitumen ratio 5.3

Sample Number	T-1-27	T-2-27	T-3-27	4	Job-Mix Range	Specification Limits
Bitumen Ratio	5.2	5.2	4.7		4.9/5.7	± 0.4
% Moisture (belt)	N/A	N/A	N/A			
% Moisture (mix)	0.1	0.0	0.1			1% Max.
Pass 25 mm (1")	100	100	100		100	100
Pass 19 mm (3/4")	93	93	91		90-100	90-100
Pass 12.5 mm (1/2")	76	76	71			
Pass 9.5 mm (3/8")	70	64	59		63-75	63-85
Pass 4.75 mm (No. 4)	49	48	42		45-57	45-63
Pass 2 mm (No. 10)	32	33	29		30-37	30-44
Pass 1.18 mm (No. 16)	25	26	23			
Pass 425 µm (No. 40)	17	16	14		12-20	12-22
Pass 75 µm (No. 200)	7	7	6		4-8	3-8

Sample Number	5	6	7	8	Job-Mix Range	Specification Limits
Bitumen Ratio						± 0.4
% Moisture (belt)						
% Moisture (mix)						1% Max
Pass 25 mm (1")						
Pass 19 mm (3/4")						
Pass 12.5 mm (1/2")						
Pass 9.5 mm (3/8")						
Pass 4.75 mm (No. 4)						
Pass 2 mm (No. 10)						
Pass 1.18 mm (No. 16)						
Pass 425 µm (No. 40)						
Pass 75 µm (No. 200)						

RECEIVED
QUALITY ASSURANCE
JAN 04 2013

Remarks: MATERIAL TESTED MET REQUIRED SPEC'S., TEST 1 & 2 WERE IN. TEST 3; THE BIT. RATIO, AND THE 3/8", NO. 4, AND NO. 10 WERE OUT. THE INSPECTOR, R.E. AND CONTRACTOR WERE NOTIFIED.

Distribution: Headquarters Construction, District, Resident Engineer, Contractor

PLANT INSPECTOR'S REPORT

Date 12-6-12 Contract No. 3505
Inspection by BOHRA
Type of hotplant Commercial
Source of asphalt Paramount Sparks
Type of asphalt PG 64-28 NV
Source of coarse aggregate Moundhouse Pit
Source of fine aggregate Moundhouse Pit
Type of mineral filler Hydrated Lime
Job-mix Formula No. 3
Mix Design No. BF 12 68
Type of Mixture PBS Type II W/RAP
Job-mix bitumen ratio 5.3

REPORT OF ASPHALT QUANTITIES

(circle all units used)

Plantmix wasted 25 t (tons)
Explanation of mix wasted START UP & SHUT DOWN LOADS
Minimum asphalt temperature 300 °C °F
Mix temperature range (Job-mix) 300 to 325 °C °F

REPORT OF TEMPERATURE AT PLANT

Time	Asphalt °C °F	Complete mix °C °F	Time	Asphalt °C °F	Complete mix °C °F
9:00	318	306			
10:00	318	301			
11:00	328	305			
12:00	324	310			
1:00	324	309			
2:00	320	304			
3:00	324	307			
4:00	324	311			
4:35	324	309			

Remarks: Started Production @ 9:00 am, Finished @4:35 pm 2365.19 total tons today.

Resident Engineer: [signature] For

STREET INSPECTOR'S REPORT

Date 12-6-12 Contract No. 3505
Inspection by Lawrence
Type of weather Cloudy
Atmospheric temp. low 34 high 34 °C °F
Surface temp. low 26 high 48 °C °F

RUNNING YIELD CHECKS

(open-graded surface at the discretion of the Engineer)

Time	Station	Length	ton/sta field	ton/sta plan	Yield %
9:30	287+10				
	308+70	21.6	463.47	428.57	108
11:00	287+10				
	308+70	21.6	456.17	423.57	108
1330	289+50				
	276+00	13.5	213.56	198.17	108

Yield = length x width x depth x lbs/ft³ (rice) x % compaction ÷ 2000
Plan = length x width x depth x lbs/ft³ (as shown in the plans) ÷ 2000
Yield % = ton/sta field ÷ ton/sta plan x 100

Total plantmix delivered 2365.19 t (tons)
Plantmix wasted 6 t (tons)
Explanation of mix wasted N/A

Job-mix minimum temperature 300 °C °F

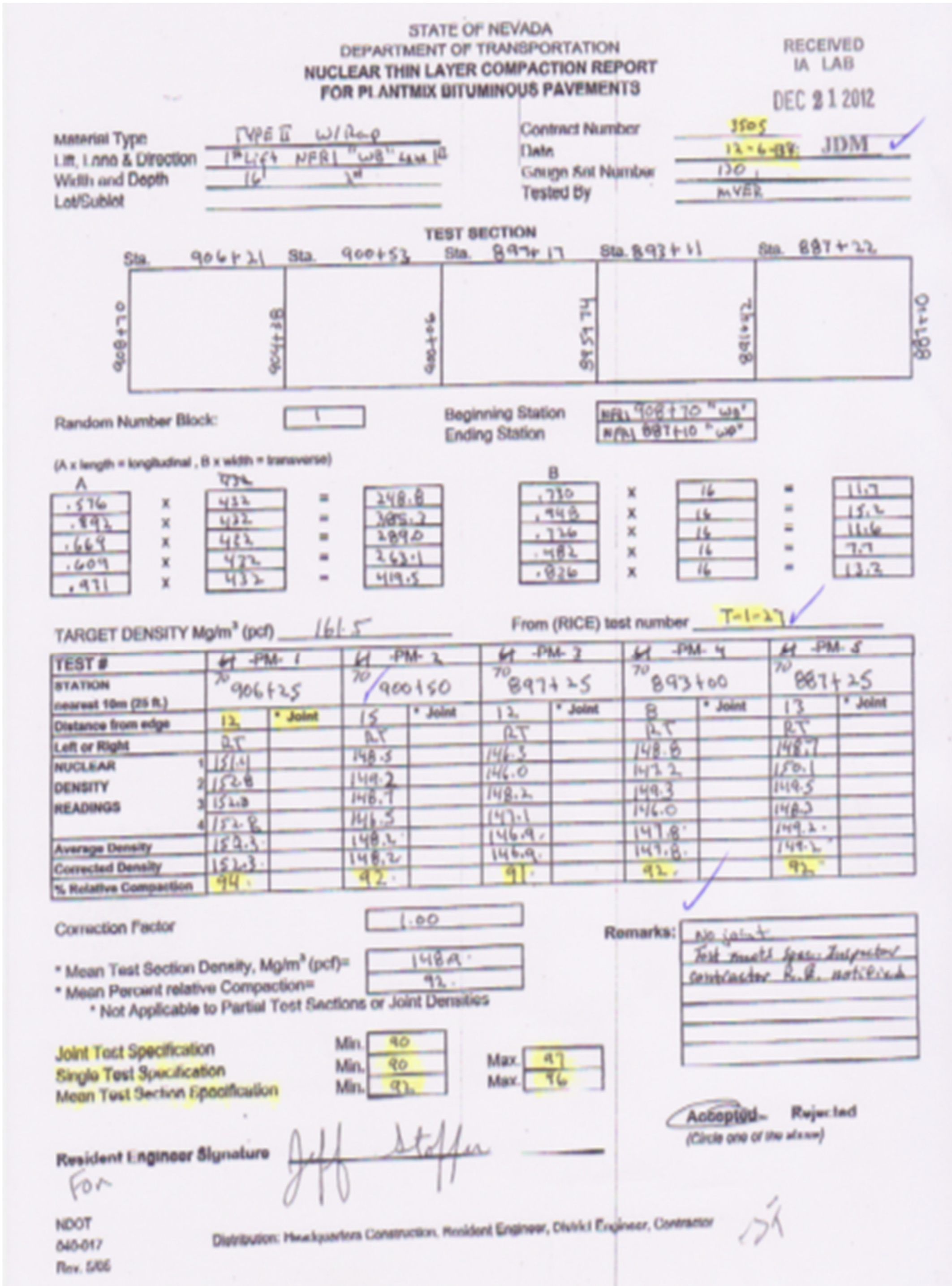
REPORT OF TEMPERATURE AT PAVER

Time	Complete mix °C °F	Time	Complete mix °C °F
0935	306	1448	298
1015	302	1524	296
1042	295	1602	299
1134	302	1632	294
1223	293	1636	295
1320	296	1707	297
1352	297		
1410	293		

Remarks: Total Tons 2365.19 % Yield - 108

NDOT 040-011
Rev 10/12

Figure 4. Daily Plant Report of Asphalt Mixtures (Contract No. 3505 RAP)



STATE OF NEVADA
DEPARTMENT OF TRANSPORTATION
NUCLEAR THIN LAYER COMPACTION REPORT
FOR PLANTMIX BITUMINOUS PAVEMENTS

RECEIVED
IA LAB
DEC 21 2012

Material Type: TYPE II W/RAP
Lift, Lane & Direction: 1st Lift NFRI "WB" Lane 1
Width and Depth: 16' 2"
Lot/Sublot:

Contract Number: 3505
Date: 12-6-12 JDM
Gauge Ser Number: 120
Tested By: MVER

TEST SECTION

Sta. 906+21 | Sta. 900+53 | Sta. 897+17 | Sta. 893+11 | Sta. 887+22

908+70 | 904+48 | 900+06 | 895+74 | 891+42 | 887+10

Random Number Block: 1

Beginning Station: NFRI 908+70 "WB"
Ending Station: NFRI 887+10 "WB"

(A x length = longitudinal, B x width = transverse)

A		432			B				
.576	x	432	=	248.8	.730	x	16	=	11.7
.892	x	432	=	385.3	.948	x	16	=	15.2
.669	x	432	=	289.0	.726	x	16	=	11.6
.609	x	432	=	263.1	.482	x	16	=	7.7
.971	x	432	=	419.5	.826	x	16	=	13.2

TARGET DENSITY Mg/m³ (pcf) 161.5

From (RICE) test number T-1-27

TEST #	H-PM-1		H-PM-2		H-PM-3		H-PM-4		H-PM-5	
STATION nearest 10m (25 ft.)	70 906+25		70 900+50		70 897+25		70 893+00		70 887+25	
Distance from edge	12	* Joint	15	* Joint	12	* Joint	8	* Joint	13	* Joint
Left or Right	RT		RT		RT		RT		RT	
NUCLEAR DENSITY READINGS 1	151.4		148.5		146.3		148.8		148.7	
2	152.8		149.2		146.0		147.2		150.1	
3	152.0		148.7		148.2		149.3		149.5	
4	152.8		146.5		147.1		146.0		148.3	
Average Density	152.3		148.2		146.9		147.8		149.2	
Corrected Density	152.3		148.2		146.9		147.8		149.2	
% Relative Compaction	94		92		91		92		92	

Correction Factor: 1.00

* Mean Test Section Density, Mg/m³ (pcf)= 148.9
* Mean Percent relative Compaction= 92
* Not Applicable to Partial Test Sections or Joint Densities

Remarks: No joint. Test meets Spec. Inspector Contractor R.B. notified

Joint Test Specification: Min. 90
Single Test Specification: Min. 90 Max. 97
Mean Test Section Specification: Min. 92 Max. 96

Accepted - Rejected
(Circle one of the above)

Resident Engineer Signature: Jeff Steffen For

NDOT
040-017
Rev. 5/05

Distribution: Headquarters Construction, Resident Engineer, District Engineer, Contractor

Figure 5. Nuclear Thin Layer Compaction Report (Contract No. 3505 RAP)

3.2 Data Analyses and Results

Phase I recommended the following properties to be included in the PWL system:

1. Gradation using calibrated ignition oven
2. Asphalt Content using calibrated ignition oven
3. In-place Density using nuclear gauge calibrated with cores

The goals of the analyses of the data collected from the nine NDOT contracts are listed below:

- Examine the distribution of the measured properties against the limits of the JMF of each contract.
- Assess the impact of project size on the conformation of the measured properties with the JMF limits.
- Assess the impact of the presence of Reclaimed Asphalt Pavements (RAP) on the conformation of the measured properties with the JMF limits.
- Assess the adequacy of the reported values, in terms of decimals, toward the calculations of PWL parameters.
- In the case of gradations, identify the critical sieves to be included in the calculations of the PWL parameters.
- Identify the appropriate construction limits on the sizes of sublots and lots.

3.2.a Distribution of Measured Properties Against JMF

The purpose of this analysis is to compare the measured properties of the mixtures to the specification limits of the project. Aggregate gradations, asphalt content (AC), and in-place density were examined against their respective upper and lower JMF limits. Each individual measurement was checked against its respective JMF limits (i.e. upper and lower limits). This was followed by estimating the percentage of measured properties that violated the JMF limits relative to the total number of measurements for each property within each contract. For example, Contract 3339 had a total of 41 measured aggregate gradations. For the percentage of aggregates passing sieve size 3/4", it was found that 6 data points out of a 41 were outside the JMF range. This was translated into 15% violations ([6/41]*100) (Figure 6). Similarly, 11 measured asphalt content data points out of 40 were outside the JMF resulting in 28% violations with respect to the asphalt content specifications (Figure 7).

Table 18 summarizes the percent violations for all measured properties on gradation, AC and compaction for all nine Contracts. Examination of the data in Table 18 indicates that the percent of violations in the gradation and AC are significantly higher than the percent violations in the compaction. The significantly lower percent violations in compaction can be attributed to the following reasons:

- Compaction is controlled through a test strip which establishes the appropriate rolling pattern to achieve the desired in-place density.
- The sampling rate for the compaction is much higher than for aggregate gradation and AC which leads to a much larger sample size.

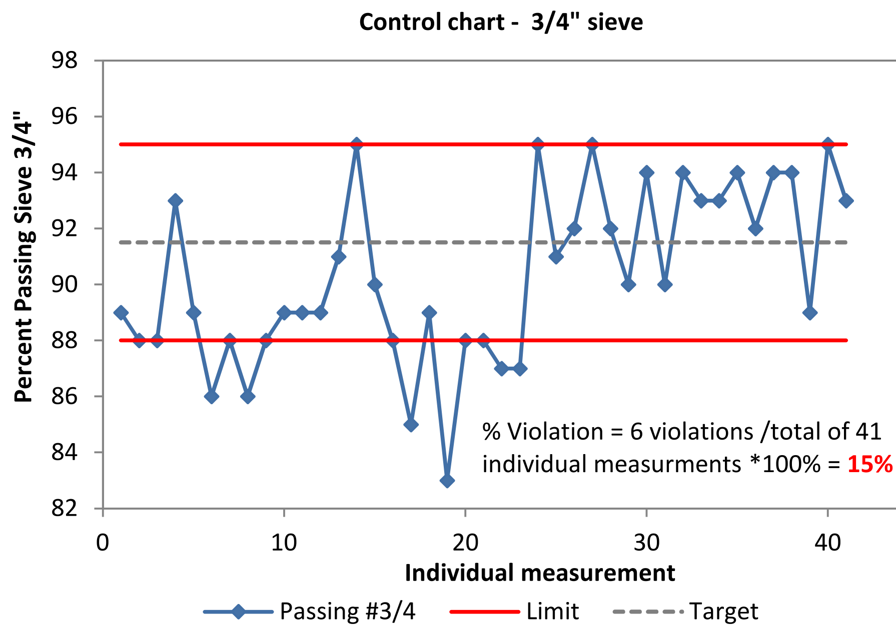


Figure 6. Control chart for percentage of aggregates passing ¾" sieve (Contract 3339)

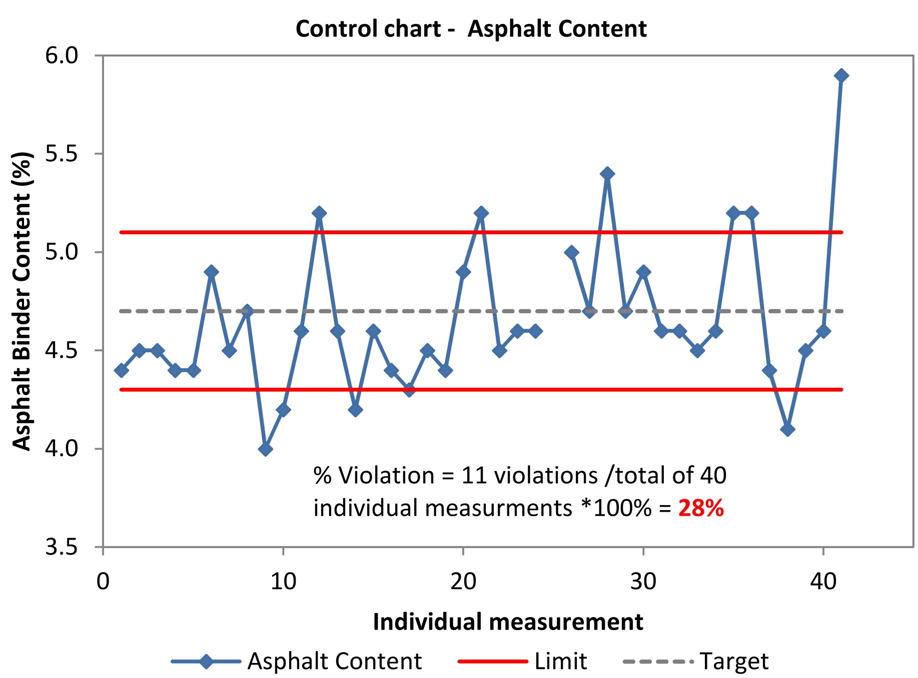


Figure 7. Control chart for asphalt content (Contract 3339)

Table 18. Percentage of Observed Specification Violation.

Sieve	Contract/Tonnage (ton)									Overall Mean (%)
	3339/ 36,664	3361/ 31,371	3383/ 64,761	3402/ 94,343	3431/ 57,315	3435/ 26,688	3435 (RAP)/ 117,290	3466 (RAP)/ 119,918	3505 (RAP)/ 72,574	
	Percentage Violations (%)									
	Gradation									
1"	0	0	0	1	0	0	0	1	0	**0**
3/4"	15	21	6	9	8	18	7	7	3	**10**
1/2"	14	7	10	16	4	10	11	15	-	**10**
3/8"	9	6	5	9	2	5	6	4	5	**6**
#4	14	6	3	17	0	9	4	3	4	**7**
#10	32	10	9	13	8	16	22	18	3	**15**
#40	2	4	0	0	0	5	1	8	0	**2**
#200	2	2	0	1	0	9	7	8	1	**3**
Specification	**Asphalt Content**									
OBC±0.40	28	20	6	4	2	9	7	37	5	**13**
Specification	**Compaction (In-Place Density)**									
Individual <90% or >97%	0.0	0.4	0.0	0.4	0.0	3.2	2.5	0.0	0.9	**0.8**
Average <92% or >96%	0.0	0.0	1.4	0.0	0.0	13	3.3	0.0	0.0	**2.0**

3.2.b Impact of Project Size and Presence of RAP

The selected nine NDOT Contracts spans over a wide range of mixture tonnage and incorporates projects with and without RAP. Using this variations in projects characteristics the analysis can assess the impact of project size and presence of RAP on the quality of the produced and constructed asphalt mixtures.

In order to assess the impact of the project size on the quality of the produced and constructed asphalt mixtures, the evaluated contracts were separated in two groups: contracts with less than 90,000 tons versus contracts with 90,000 tons or more.

Figure 8 compares the percent violations in aggregate gradations, AC, and compaction for the two groups of project sizes. The whiskers represent the 95% Confidence Interval (CI). Overlapping of the CIs for each measurement implies the similarity in the percentage of violations among the two groups of contracts. Examination of the data in Figure 8 indicates that the size of the project did not significantly impact the percent violations of the specification limits for aggregate gradations, AC, and compaction. Therefore, it can be concluded that the size of the project did not impact the quality of the produced and constructed asphalt mixtures.

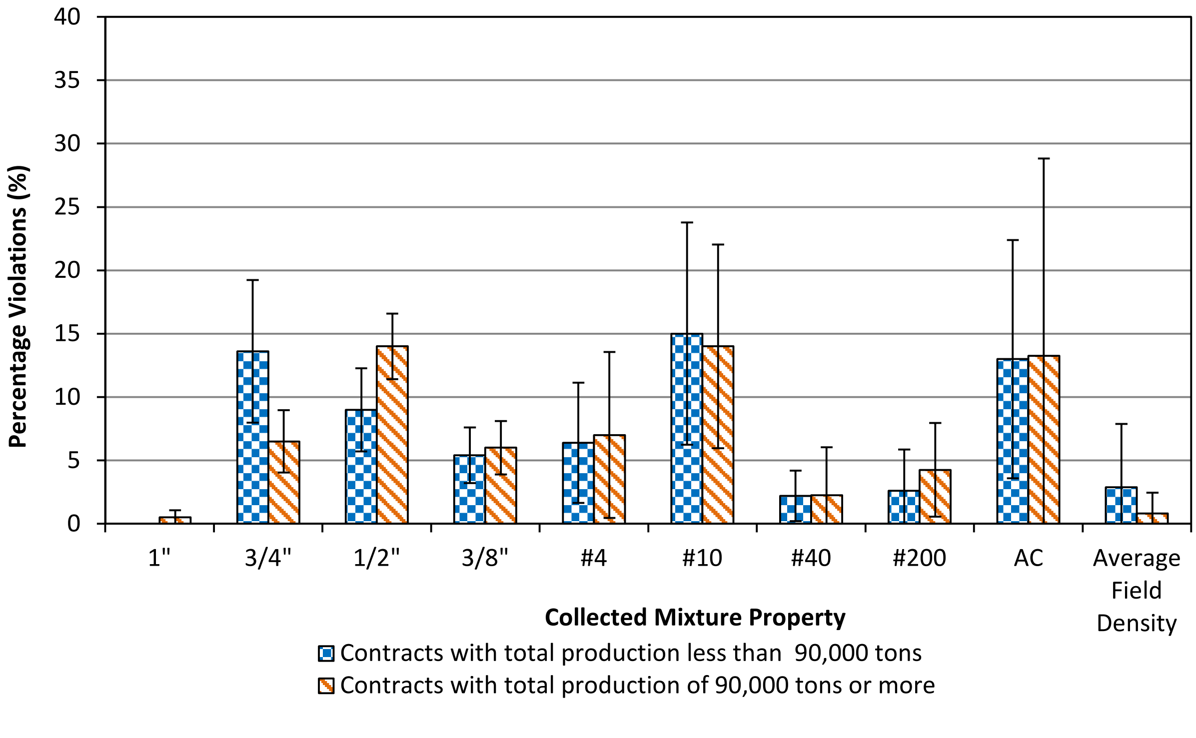


Figure 8. Percentage of violations for contracts with total production less than 90,000 tons versus contracts with total production of 90,000 tons or more

In order to assess the impact of the presence of RAP on the quality of the produced and constructed asphalt mixtures, the evaluated contracts were separated in two groups: contracts without RAP versus contracts with RAP.

Figure 9 compares the percent violations in aggregate gradations, AC, and compaction for the two groups of contracts. The whiskers represent the 95% Confidence Interval (CI). Overlapping of the CIs for each measurement implies the similarity in the percentage of violations among the two groups of contracts. Examination of the data in Figure 9 indicates that the presence of RAP did not significantly impact the percent violations of the specification limits for aggregate gradations, AC, and compaction. Therefore, it can be concluded that the presence of RAP did not impact the quality of the produced and constructed asphalt mixtures.

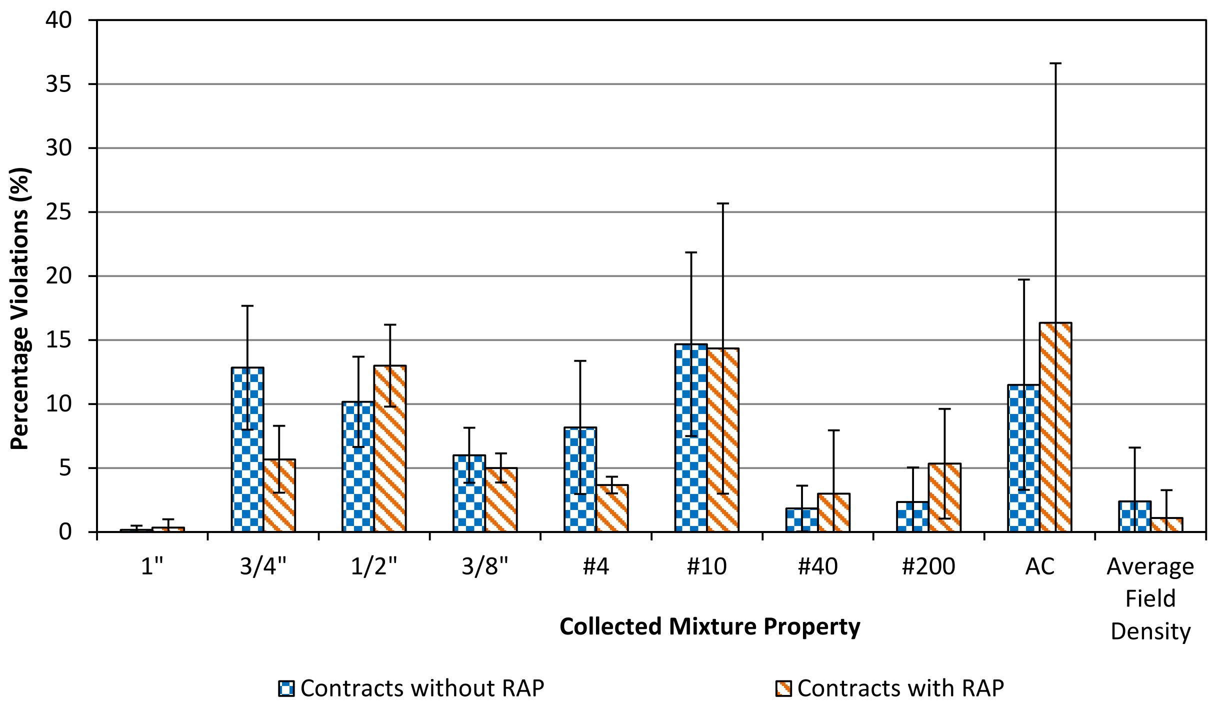


Figure 9. Percentage of violations for contracts without RAP versus contracts with RAP

3.2.c Identify Critical Sieves on Aggregate Gradations

The recommendations from phase I indicated the need to include the gradation of the aggregate in the calculations of PWL and pay factors. The next step is to identify the critical sieves that must be monitored during the production process to generate the data necessary for the calculations of PWL and pay factors. The following guidelines were followed in identifying the critical sieves:

- Multiple critical sieves must be identified in order to control the full shape of the gradation curve.
- A critical sieve in the upper portion of the gradation curve must be identified to control the coarse portion of the aggregates.

- The sieve #200 must be identified as a critical sieve due to the significant impact of the materials passing sieve #200 on the performance and durability of asphalt mixtures.
- One or two critical sieves in the middle portion of the gradation curve must be identified to control the fine portion of the aggregates and to ensure the continuous shape of the gradation curve.

Figure 10 presents the percentage violations on the various sieves for the nine NDOT Contracts. Examination of the data presented in Figure 10 leads to the following observations:

- Among the four top sieve sizes, the 1/2" sieve shows the most consistent and most significant percent violations of the specifications. The 3/8" sieve should be used for Type 2 mixtures.
- Among the middle sieve sizes, sieve #10 shows the most significant percent violations of the specifications.

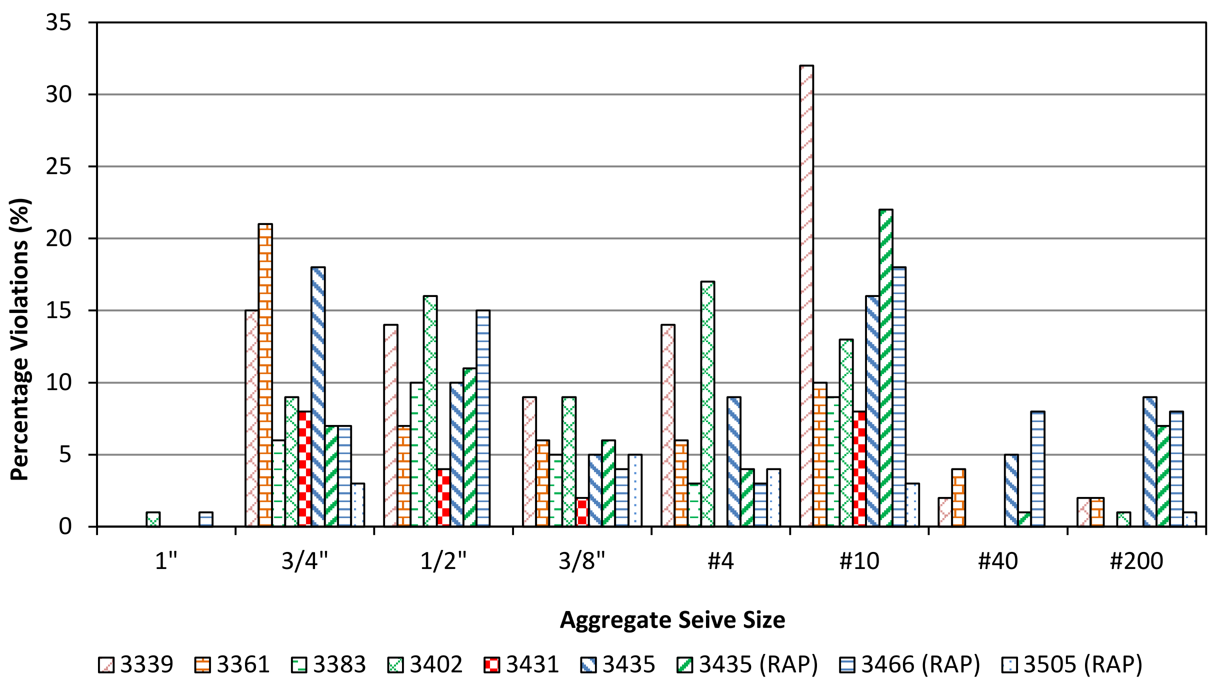


Figure 10. Percentage violations in the aggregate sieve sizes.

Taking into consideration both the basis for selecting the critical sieves and the observations from Figure 10, the following critical sieves were selected to be included in the PWL calculations and pay factors:

- Sieve 1/2" (3/8" for type 2 mixtures) to control the coarse portion of the aggregates.
- Sieve #4 to control the fine portion of the aggregates.
- Sieve #10 to control the shape of the aggregate gradation curve.
- Sieve #200 to control the performance and durability of the asphalt mixture.

3.2.d Adequacy of Measurements and Reported Data Values

The objective of this analysis is to identify the needed level of accuracy in the calculations of the aggregate gradations, AC, and compaction. In other words, do the calculations need to be carried out to three decimals (i.e. 0.001) or only one decimal is sufficient (i.e. 0.1). The importance of this step lies in the fact that the PWL calculations are based on the determination of the average and standard deviation of the measured values for aggregates gradations, AC, and compaction for each lot of asphalt mixtures. In general, the higher the number of decimals, the better accuracy of the calculated average and standard deviation. However, not all measurements requires calculations to three decimals.

It should be noted that the number of decimals that must be carried during the calculations is one higher than the number of decimals that can be reported. For example, in order to report a value with two-decimals, the calculations of the value must be carried out to the three-decimals. In order to assess the need for multiple decimals, sample calculations were conducted with variable number of decimals. Table 19 summarizes the data for the following cases:

- Case 1: the calculations were made with one-decimal and the reported values were rounded to no-decimal.
- Case 2: the calculations were made with two-decimal and the reported values were rounded to one-decimal.
- Case 3: the calculations were made with three-decimal and the reported values were rounded to two-decimal.

For all three cases, the PWL values were calculated for the four critical sieves, AC, and compaction. Examination of the data in Table 19 indicates the following:

- Case 1: the PWL values for Sieve #200 and AC could not be determined due to the fact that all three measurements had the same values when rounded to no-decimal which resulted in a standard deviation of “zero”. It is numerically impossible to calculate the PWL value for a data set with a standard deviation of “zero”.
- Case 2: the PWL values for all measures were determined. There are significant changes in the PWL values for the sieve 1/2” and compaction when measurements are rounded to one-decimal as compared to no-decimal.
- Case 3: the PWL values for all measures were determined. There are no significant changes in the PWL values when measurements are rounded to two-decimal as compared to one-decimal.

Similar analyses were conducted on data from multiple contracts and led to similar findings. Based on the analyses of the impact of decimals in measurements and reported values (i.e. rounding) for gradation, AC, and compaction, the following recommendations are made:

1. Gradations on Sieves 1/2” (3/8” for Type 2), #4, #10, and #200 using calibrated ignition oven measured with two-decimal (0.01) and rounded to the one-decimal (0.1).
2. Asphalt Content using calibrated ignition oven measured with two-decimal (0.01) and rounded to the one-decimal (0.1).

3. In-place Density using nuclear gauge calibrated with cores measured with two-decimal (0.01) and rounded to the one-decimal (0.1).

Table 19. Impact of Decimals on the Calculated PWL Values.

Case 1: Measuring with one-decimal and reporting with no-decimal

					Percentage passing, %									
Date	Lot	Sublot	Report	Job Mix Formula	1"	3/4"	1/2"	3/8"	#4	#10	#40	#200	Asphalt Content, %	Compaction, %
17-Sep-12	56	1	19c	6c	100	95	80	73	55	34	15	7	6	92
17-Sep-12	56	2	19c	6c	100	93	77	72	55	33	15	7	6	93
17-Sep-12	56	3	19c	6c	100	96	82	74	54	33	14	7	6	91
PWL							80		100	100		---	---	50

Case 2: Measuring with two-decimal and reporting with one-decimal

					Percentage passing, %									
Date	Lot	Sublot	Report	Job Mix Formula	1"	3/4"	1/2"	3/8"	#4	#10	#40	#200	Asphalt Content, %	Compaction, %
17-Sep-12	56	1	19c	6c	100.0	95.0	79.9	73.0	55.1	33.4	15.0	6.9	5.9	91.6
17-Sep-12	56	2	19c	6c	100.0	93.0	77.1	72.0	54.6	33.2	15.0	6.7	5.7	92.7
17-Sep-12	56	3	19c	6c	100.0	96.0	82.4	74.0	54.4	32.7	14.0	6.5	5.8	90.9
PWL							76		100	100		100	100	42

Case 3: Measuring with three-decimal and reporting with two-decimal

					Percentage passing, %									
Date	Lot	Sublot	Report	Job Mix Formula	1"	3/4"	1/2"	3/8"	#4	#10	#40	#200	Asphalt Content, %	Compaction, %
17-Sep-12	56	1	19c	6c	100.00	95.00	79.90	73.00	55.14	33.40	15.00	6.92	5.85	91.65
17-Sep-12	56	2	19c	6c	100.00	93.00	77.06	72.00	54.65	33.19	15.00	6.66	5.72	92.73
17-Sep-12	56	3	19c	6c	100.00	96.00	82.44	74.00	54.38	32.66	14.00	6.54	5.84	90.94
PWL							75		100	100		100	100	43

3.2.e Sizes and Construction Limits on Sublots and Lots

As part of the PWL system, the sizes of sublots and lots must be well defined in order to ensure consistency in the implementation among the various projects. Typically, the sizes of sublots and lots are defined in terms of tonnage of mixture being constructed. However, the implementation of the recommended sizes of sublots and lots must accommodate actual construction activities on every project. Therefore, additional guidance is needed in order to ensure that uniform materials are being considered in each sublot and lot for every project.

The guidelines will set the practical limits of sublots and lots based on the actual construction activities on a specific project. For example, when a change occurs to the job mix formula (JMF), the sizes sublots and lots must be adjusted to accommodate this event. Another case that might differentiate assigning sublots and lots is the number of days when construction activities are interrupted. It is recommended that when production is interrupted by more than one day, the sublots and lot must be terminated and their sizes adjusted accordingly. Based on these considerations, the following guidelines are recommended for determining the sizes of sublots and lots for the NDOT PWL system:

1. Size of Sublot: 1,000 tons of HMA mix or end of day whichever comes first for the asphalt content and gradations for the duration of the project. The size of the sublot for the compaction (i.e. in-place density) shall be controlled by the current NDOT sampling rate which may generate compaction sublots as low as 100 tons. The following exceptions shall be applied:

a. When the amount of materials produced after the last full size sublot of a given day is less than 500 tons, these materials should be added to the last sublot of the day.
b. When the amount of materials produced after the last full size sublot of a given day is equal or more than 500 tons, these materials should be tested as a separate sublot.

2. Size of Lot: 5,000 tons of HMA or 5 sublots whichever comes first for asphalt binder content and gradation and whatever the corresponding number of sublots for compaction for the duration of the project. The following exceptions shall be applied:
   a. When the number of sublots is less than 3 and the production of materials is interrupted for more than one day or the JMF is changed, these materials cannot be included in the PWL calculations.
   b. When the number of sublots is 3 – 4 and the production of materials is interrupted for more than one day or the JMF is changed, the size of lot should be reduced to represent the actual number of sublots.
   c. When the number of sublots exceeds 5 but less than 8 and the production of materials is interrupted for more than one day or the JMF is changed, the size of lot should be increased to accommodate the additional sublots.

Figure 11 presents the data from one of the evaluated NDOT Contracts. Figure 11 shows that JMF1 was used for the first week of production on Friday with a total production of 224 tons only. On the following Monday, a new JMF2 was utilized and only 234 tons were produced. Production was interrupted for two days and started again on Thursday under the same JMF2. A new JMF3 was utilized starting Friday of the same week. Under the conditions presented in Figure 12, the following assignments of sublots and lots will be followed:

- The 224 tons produced on Friday under JMF1 are too little to be considered as a single lot and too far to be combined with the next lot on Monday *(exception 2.a)*. Therefore, these materials will not be included in the PWL calculations.
- The 234 tons produced on Monday under JMF2 are too little to be considered as a single lot and too far to be combined with the next lot on Thursday *(exception 2.a)*. Therefore, these materials will not be included in the PWL calculations.
- The 4,769 tons produced on Thursday should be divided into 5 sublots with the fifth sublot having 769 tons *(exception 1.b)* to constitute a single lot with 5 sublots.
- The 4,271 tons produced on Friday should be divided into 4 sublots with the fourth sublot having 1,271 tons *(exception 1.a)* to constitute a single lot with 4 sublots *(exception 2.b)*. These materials cannot be combined with the materials produced on Monday due to existence of the two-day weekend where production was interrupted.
- The 2,407 tons on Monday should be divided into 2 sublots with the second sublot having 1,407 tons *(exception 1.a)* and combined with the 3,041 tons produced on Tuesday divided into 3 sublots with the third sublot having 1,041 tons *(exception 1.a)* to constitute a single lot with 5 sublots.
- The 2,670 tons on Wednesday should be divided into 3 sublots with the third sublot having 670 tons *(exception 1.b)* and combined with the 1,968 tons produced on Thursday divided into 2 sublots with the second sublot having 968 tons *(exception 1.b)* to constitute a single lot with 5 sublots.

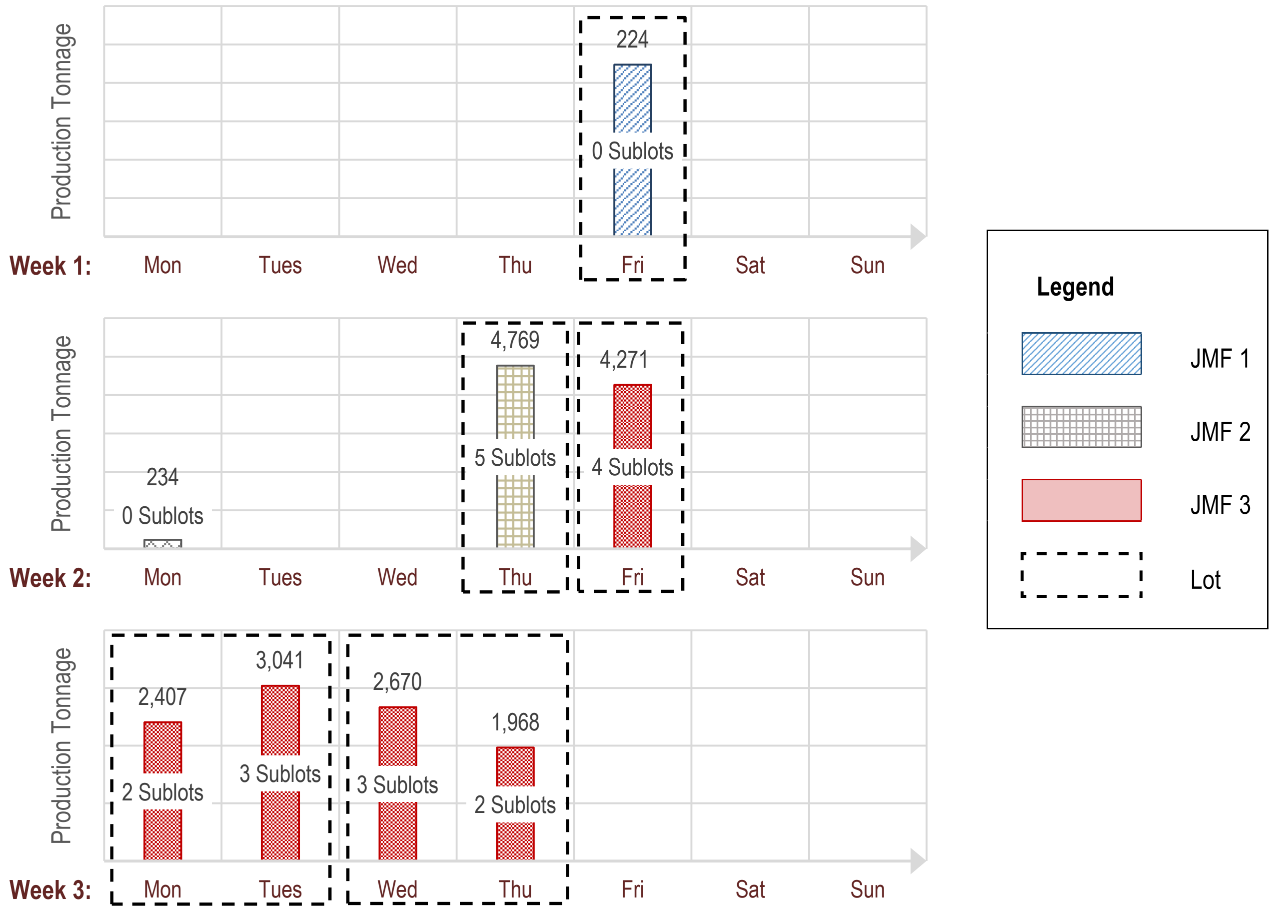


Figure 11. Continuity of production versus lot definition: Example 1

Figure 12 shows the data from another NDOT Contract where three different JMFs were utilized. During the first week, the production under JMF1 was interrupted for two days while only a one-day weekend was observed. Under the conditions presented in Figure 12, the following assignments of sublots and lots will be followed:

- The 2,356 tons produced on Tuesday should be divided into 2 sublots with the second sublot having 1,356 tons *(exception 1.a)* and combined with the 1,960 tons produced on Wednesday divided into 2 sublots with the second sublot having 960 tons *(exception 1.b)* to constitute a single lot with 4 sublots *(exception 2.b)*. These materials cannot be combined with the materials produced on Saturday due to existence of the two days interruption in production.
- The 1,874 tons produced on Saturday should be divided into 2 sublots with the second sublot having 874 tons *(exception 1.b)* and combined with the first three sublots (1,000 tons each) from the 3,968 tons produced on Monday since the interruption was only for one day to constitute a single lot with 5 sublots.
- The remaining 968 tons produced on Monday should be assigned as a sublot *(exception 1.b)*, combined with the three sublots from the 3,307 tons produced on Tuesday with the

third sublot having 1,307 tons *(exception 1.b)* and three sublots from the 2,747 tons produced on Wednesday with the third sublot having 747 tons *(exception 1.b)* to constitute a single lot with 7 sublots *(exception 2.c)*. Note that the additional 2 sublots produced on Wednesday cannot be combined with the materials produced on Thursday due to the change in the JMF.

- The 1,315 tons produced on Thursday should be assigned as a sublot *(exception 1.b)*, combined with 3 sublots from the 2,825 tons produced on Friday with the third sublot having 825 tons *(exception 1.b)* and two sublots from the 2,437 tons produced on Saturday with the second sublot having 1,437 tons *(exception 1.a)* to constitute a single lot with 6 sublots *(exception 2.c)*. Note that the additional sublot produced on Saturday cannot be combined with the materials produced on Monday due to a change in the JMF.
- The 3,639 tons produced on Monday should be divided into 4 sublots with the fourth sublot having 639 tons *(exception 1.b)* combined with the 2 sublots from the 2,337 tons produced on Tuesday with the second sublot having 1,337 *(exception 1.a)* to constitute a single lot with 6 sublots.

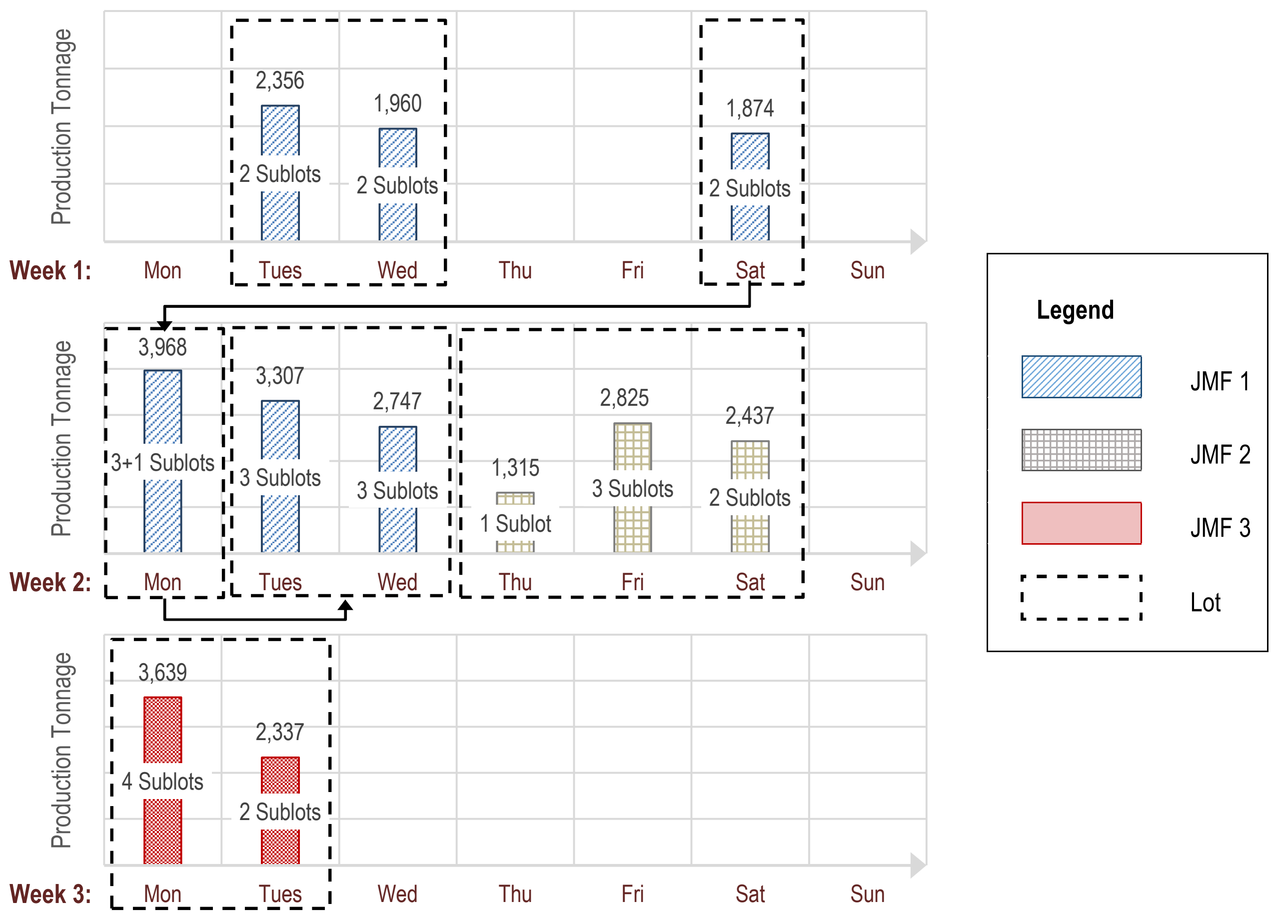


Figure 12. Continuity of production versus lot definition: Example 2

3.3 Determination of Weight Factors

The final step in the development of the PWL system is to identify the weight factors for the identified critical sieves, AC, and compaction. This step is divided into parts: 1) determining the weight factors for each critical sieve within the aggregate gradations and 2) determining the weight factors for aggregate gradations, AC, and compaction. The following principles apply for determining the weigh factors for both parts:

- The weight factor should reflect the relative contribution of the individual measure.
- The sum of the weight factors should be 100.

3.3.a. Part 1: Weight Factors for Critical Sieves

The weight factors for each of the critical sieves are required for the calculation of the PWL value for gradation and were selected as follows.

- Gradation on Sieve 1/2": 10% (Sieve 3/8" for Type 2)
- Gradation on Sieve #4: 35%
- Gradation on Sieve #10: 35%
- Gradation on Sieve #200: 20%

Higher and equal weight factors were assigned to the #4 and #10 sieves. This is mainly due to the following reasons: (1) The two sieves highly control the overall shape of the aggregate gradation; (2) For a given mix, the largest number of violations was generally observed on the #10 sieve; and (3) The observed increased variability in the percent passing #4 and #10 sieves during production. The PWL value for the aggregate gradation is then determined using the weight factors for each of the critical sieves as follows.

$$\mathbf{PWL}_{Gradation} = \mathbf{0.10 \times PWL}_{1/2\ or\ 3/8\ inch} + \mathbf{0.35 \times PWL}_{\#4} + \mathbf{0.35 \times PWL}_{\#10} + \mathbf{0.20 \times PWL}_{\#200}$$

3.3.b. Part 2: Weight Factors for Gradations, AC, and Compaction

A performance related approach was followed to determine the weight factors for aggregate gradations, AC, and compaction. The approach makes use of the findings from a study conducted by Sebaaly and Bazi (4) in 2005 to evaluate the impact of construction variability in aggregate gradation, asphalt binder content, and air-voids, on the performance of HMA pavements. The performance of HMA pavements was measured in terms of their resistance to rutting, fatigue cracking, and thermal cracking using advanced laboratory testing techniques. Materials were selected to cover common sources used in northern and southern Nevada and typical mix designs.

Two aggregate sources were identified, one source in northern Nevada (Lockwood) and one source in southern Nevada (Sloan). The study was conducted in two phases. In Phase I, unmodified AC-20 binder from Paramount Petroleum Company and AC-30 binder from Koch Performance Asphalt were used with the north and south aggregates, respectively. In Phase II, polymer-modified PG64-28NV binder from Paramount Petroleum Company and PG76-22NV binder from Koch Performance Asphalt were used with the north and south aggregates, respectively. The findings from the Phase II were used in this study to determine the performance related weight factors for the various properties.

A total of four sources of variability in a given HMA mix were evaluated: gradation on #4 sieve, gradation on #200 sieve, asphalt binder content, and air-voids (Table 20). Each variability source was simulated at three levels of: Low, medium, and high. The "medium" level represents the job mix formula (JMF) value (i.e. control mixture) while the "low" represents below the JMF level and the "high" represents above the JMF level.

Table 20. Sources of Variability and Violation Levels Considered in the Impact of Construction Variability Study.

Sources of variability	Allowable range (NDOT Specs)	Violation	Levels
% $P_{\#4}$	± 7%	± 10%	L, M, and H
% $P_{\#200}$	± 2%	+ 4%	M and H[1]
% AC	± 0.4% dwa	± 0.6% dwa	L, M, and H
% AV	4 to 8 %	3 to 11 %	L, M, and H

[1] the below JMF level (i.e., L) was not evaluated since no violation was observed.

The impacts of construction variability on the performance of the HMA laboratory mixtures were measured using the Asphalt Pavement Analyzer (APA) for rutting resistance, the flexural beam fatigue for fatigue cracking resistance, and the thermal stress restrained specimen test (TSRST) for the low temperature cracking resistance (TSRST was conducted on northern mixtures only). Table 21 summarizes the effect of the single factor violations on the performance of the evaluated mixtures. All presented trends are based on the statistical significance relative to the control mixture at the JMF values.

The information in Table 21 was used to develop the performance related weight factors for aggregate gradation, AC, and compaction using the following steps. The associated calculations are summarized in Tables 22 and 23 for the northern and southern mixtures, respectively.

- Assign a representative weight factor (WF) to each of the considered distresses according to the historical performance of HMA pavements in Nevada. Consequently, since fatigue and thermal cracking are more prone to occur in northern Nevada while rutting is more prone in the southern part of the state the following weight factors were selected for the considered type of distresses.
    - Northern Nevada: 40% for rutting, 30% for fatigue, and 30% for thermal cracking (total of 60% for cracking)
    - Southern Nevada: 60% for rutting and 40% for fatigue cracking.
- Determine the percent of incidence when the violation resulted in a positive (i.e. increase in performance) or negative (i.e. reduction in performance) effect on the resistance of the mixture to a specific type of distress. A zero value is assigned when no significant effect for the violation was observed on the mixture property. For example, in the case of the northern mixtures, two out of the three violations in aggregate gradation resulted in a reduction of the mixture resistance to fatigue cracking. Hence, the percent of incident to have a positive and a negative effect is $1/3 \times 100 = 33$ and $2/3 \times 100 = 67$, respectively.

- Calculate the overall weighted percent of incidence for the negative effect by multiplying the individual percent of incidence by the corresponding weight factor for each of the distresses.
- Calculate the weight factor for each property by dividing the overall weighted percent of negative incidence for a given property by the total sum of the overall weighted percent of negative incidences for all properties. For example, in the case of the northern mixtures, the performance related weight factor for gradation is equal to 20.1/90.1 × 100 = 22.3%.

Accordingly, the following performance related weight factors were determined for each of the properties.

- Northern mixtures:
  - Gradation: 22.3%
  - Asphalt Binder Content: 33.3%
  - Compaction (i.e., Mat Density): 44.4%
- Southern mixtures:
  - Gradation: 26.7%
  - Asphalt Binder Content: 33.3%
  - Compaction (i.e., Mat Density): 40.0%

Table 21. Effect of the Single Factor Violations on the Performance of Polymer-Modified Asphalt Mixtures.[1]

Single Factor Violations	Northern Nevada Mixtures			Southern Nevada Mixture[2]	
	Rutting Resistance	Fatigue Cracking Resistance	Thermal Cracking Resistance	Rutting Resistance	Fatigue Cracking Resistance
Low on # 4-Sieve	↔	↓	↔	↔	↓
High on # 4-Sieve	↔	↑	↔	↑	↓
High on # 200-Sieve	↔	↓	↔	↔	↓
Low on Percent AC	↔	↓	↓	↑	↓
High on Percent AC	↔	↑	↔	↓	Not Tested
Low on Percent AV	Impractical[3]				
High on Percent AV	↓	Not Tested	Not Tested	↓	Not Tested

[1] Statistical significance relative to the control mixture (i.e., at the JMF values): "↔" no significant effect to the violation on the mixture resistance; "↓" significant reduction in the mixture resistance as a result of violation; "↑" significant increase in the mixture resistance as a result of violation.
[2] The resistance of southern mixtures to thermal cracking was not evaluated.
[3] The HMA mixture that is low on the air-voids, and meeting the specification limits on the #4 and #200 sieves, and on the binder content was considered impractical because of the observed high compaction effort required to reach the 3% air-void level.

Table 22. Performance Related Weight Factors for Northern Mixtures.

Property	Rutting (W_R = 40%)		Fatigue Cracking (W_{FC} = 30%)		Thermal Cracking (W_{TC} = 30%)		Overall Weighted Percent of Incidence		Perf. Related Weight Factor
	Percent of Incidence (P = Positive Effect; N = Negative Effect)								
	P	N	P	N	P	N	P	N	
Gradation	0	0	33	67	0	0	9.9	20.1	22.3%
AC	0	0	50	50	0	50	15.0	30.0	33.3%
Compaction	0	100	0	0	0	0	0.0	40.0	44.4%
Sum							24.9	90.1	100.0%

Table 23. Performance Related Weight Factors for Southern Mixtures

Property	Rutting (W_R = 60%)		Fatigue Cracking (W_{FC} = 40%)		Thermal Cracking (W_{TC} = 0%)		Overall Weighted Percent of Incidence		Perf. Related Weight Factor
	Percent of Incidence (P = Positive Effect; N = Negative Effect)								
	P	N	P	N	P	N	P	N	
Gradation	33	0	0	100	Not Applicable		19.8	40.0	26.7%
AC	50	50	0	50			30.0	50.0	33.3%
Compaction	0	100	0	0			0.0	60.0	40.0%
Sum							49.8	150.0	100.0%

For both, the northern and southern mixtures, the highest weight factor was for the compaction, followed by the asphalt binder content, then the gradation. The determined weight factors for the northern and southern mixtures were relatively similar for each of the properties. Therefore, the average values for the weight factors were calculated and recommended for the State of Nevada as follows:

- Gradation: 25%
- Asphalt Binder Content: 33%
- Compaction (i.e., Mat Density): 42%

The overall PWL value for each lot shall be determined from the individual PWL values for aggregate gradation, AC, and compaction using the following equation.

$$\mathbf{PWL}_{\mathit{Overall}} = \mathbf{0.25 \times PWL}_{\mathit{Gradation}} + \mathbf{0.33 \times PWL}_{\mathit{AC}} + \mathbf{0.42 \times PWL}_{\mathit{Compaction}}$$

3.4 Applications of the AASHTO Pay Factors

The objective of this analysis was to apply the current AASHTO Pay Factor (PF) recommendation shown below with the recommended PWL calculations on the data from the nine NDOT Contracts.

PF = 55 + (0.5 x PWL)

The AASHTO PF assumes a 100% pay will be provided to the contractor at a PWL of 90% while the maximum pay will be at 105%. Figure 13 illustrates the calculated pay factors for all collected nine NDOT Contracts.

The following steps were completed using the data from each of the nine NDOT Contracts:

- Identify the sublots and lots.
- For each lot, calculate the individual PWL values for gradations, AC and Compaction.
- For each lot, calculate the overall PWL value using the weight factors for gradations, AC, and Compaction as shown in Figure 13.
- For each lot, calculate the Pay Factor following the AASHTO recommendation as shown in Figure 14.

Based on the calculated PF for each lot, the overall computed bonus or demerit that the contractor incurred along the duration of the project can be calculated according to the following equation:

$$\textbf{PWL bonus or demerit} = \frac{\boldsymbol{PF - 100}}{\mathbf{100}} * \boldsymbol{tonnage\ amount\ per\ lot} * \boldsymbol{cost\ of\ each\ ton}$$

For example, the computed individual bonus and demerit for the 45 lots in contract 3466 (RAP) is presented in Figure 15. It can be noticed that six lots (1, 9, 17, 23, 31, and 32) had high performance (PWL >100) resulting in considerable bonus that ranged from $1,088.85 (lot number 9) to $8,542.79 (lot number 31). On the other hand, three lots (21, 22, 37) had low performance (100<PWL<70) resulting in associated demerit costs that ranged from $1,989.81 (lot number 22) to $11,417.12 (lot number 21). In addition, Figure 16 shows the accumulated bonuses and demerits along the entire duration for contract 3466 (RAP). The data in Figure 16 indicate that a total of accumulated bonus of $3,641.17 was achieved by the end of the project. Note that the lots that had a PWL less than 70 are not considered in the PWL bonus/demerit analysis and are marked as rejected lots.

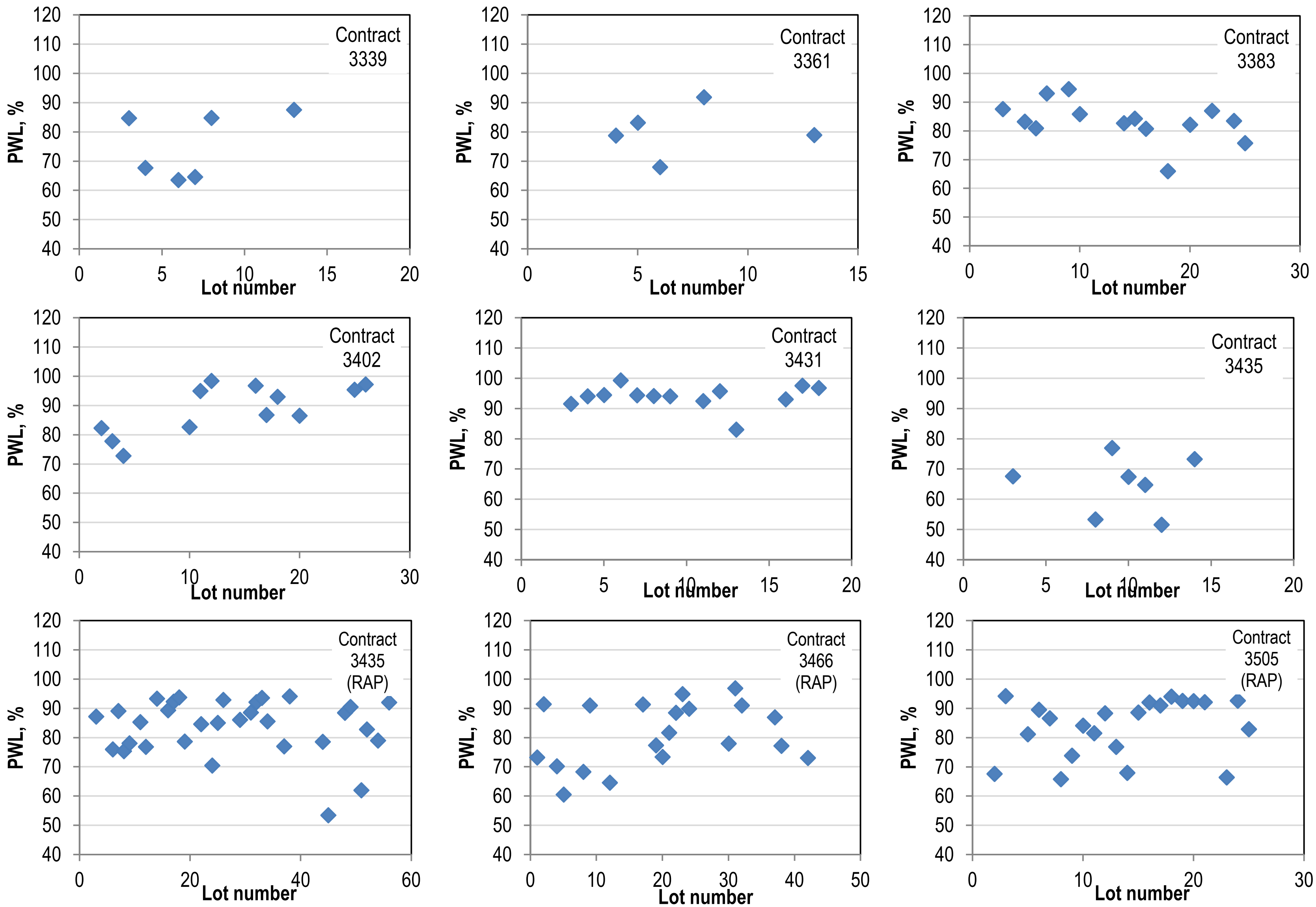


Figure 13. Calculated PWL (%) for all nine NDOT contracts

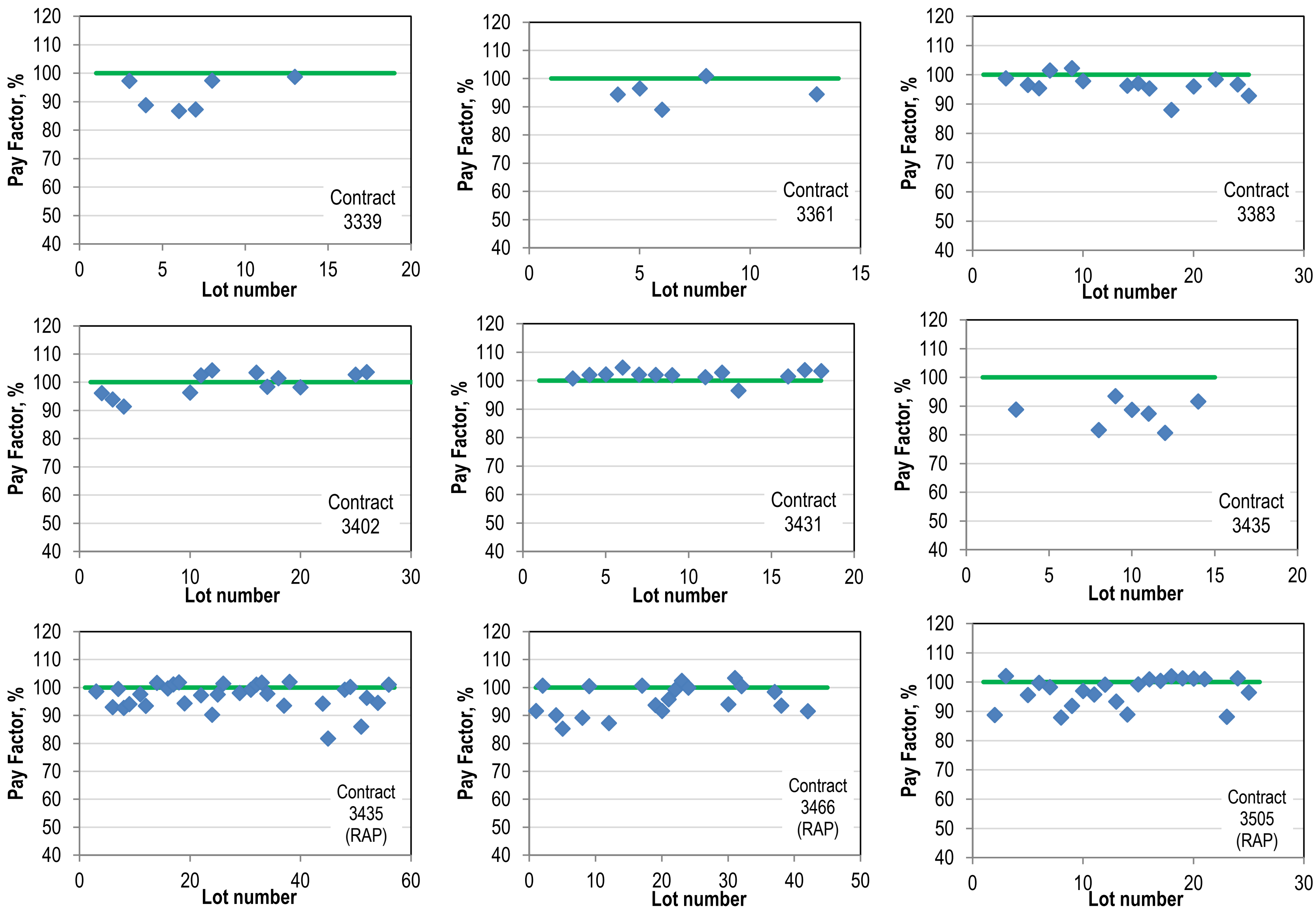


Figure 14. Calculated pay factors (%) for all nine NDOT contracts

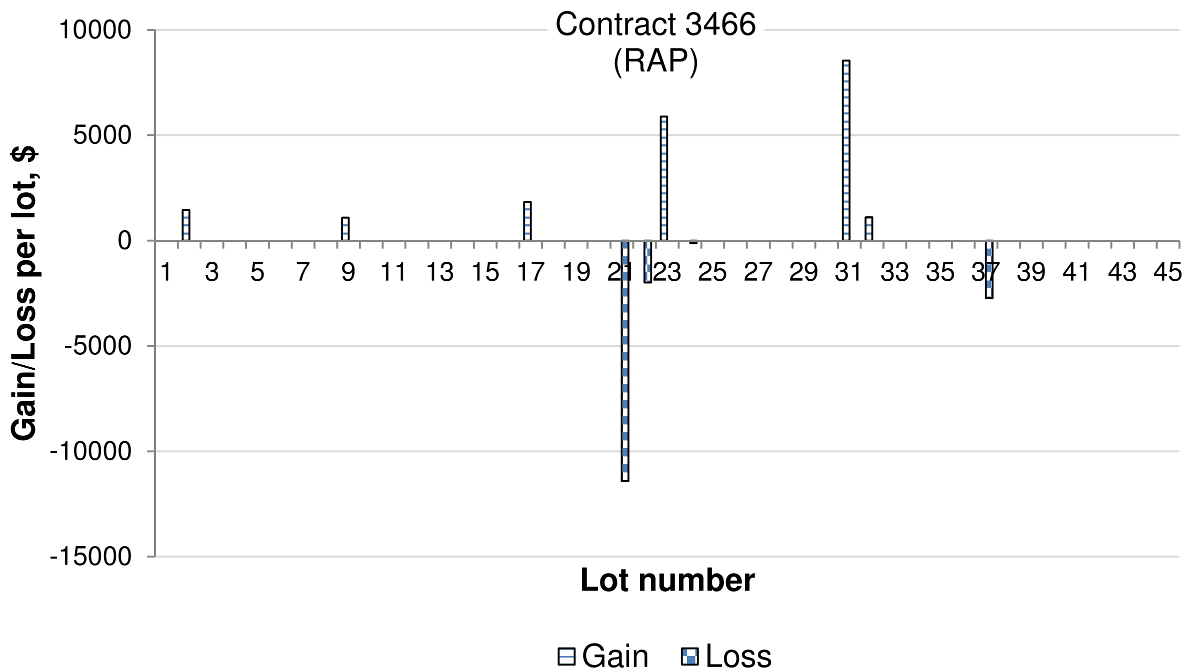


Figure 15. Gain/loss per lot ($) versus lot number (Contract 3466 RAP)

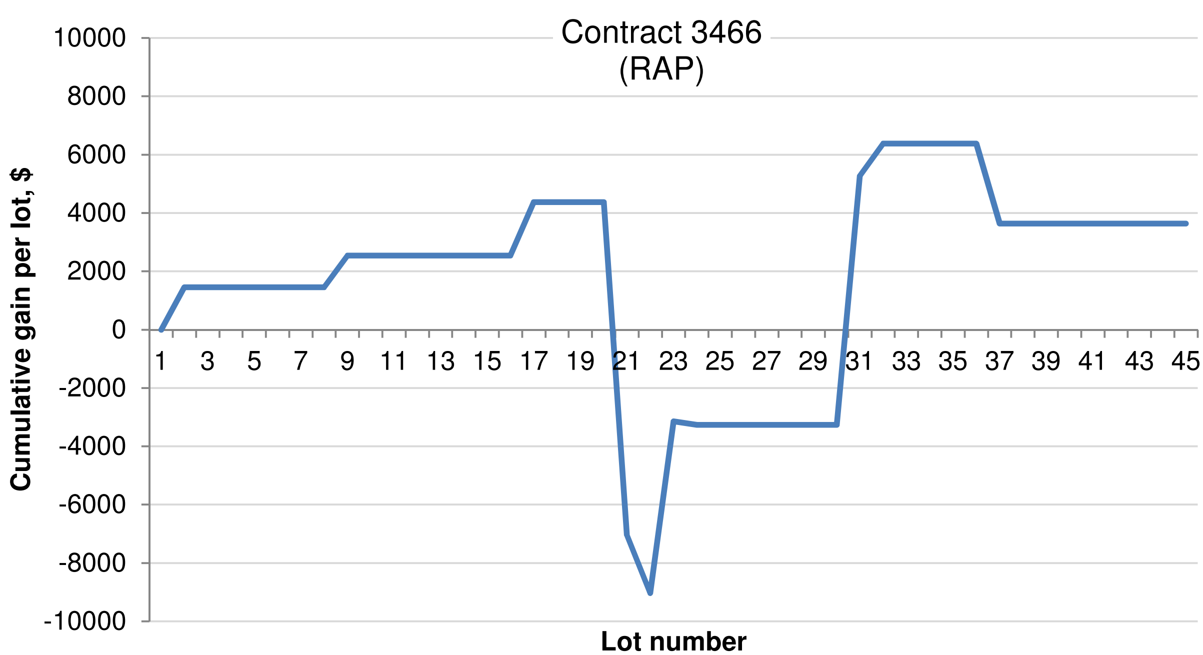


Figure 16. Cumulative gain per lot ($) versus lot number (Contract 3466 RAP)

CHAPTER 4. IMPLEMENTATION OF THE PWL SYSTEM

4.1 Implementation Plan

Phase III of the project calls for the implementation of the developed PWL system on NDOT projects. The following implementation plan will be followed:

- The PWL System will be implemented under the following conditions:
  - Dense graded asphalt mixtures.
  - Projects larger than 25,000 tons.
  - Mixtures constructed on main-lines.

- Year 2014: The PWL System will be applied on pilot projects, however the pay factors will not be implemented.

- Year 2015: The 100% pay will be provided at an overall **PWL of 70**. The maximum pay factor is fixed at 105%. The following payment procedure will be used:
  - If PWL for any of the measured properties (i.e. Gradations, AC, Compaction) is less than 50, the lot is considered rejected.
  - For $50 \leq PWL_{Overall} \leq 80$, $PF = 65 + 0.5(PWL_{Overall})$
  - For $PWL_{Overall} > 80$, $PF = 105\%$

  For example:
  PF at ($PWL_{Overall} = 100$) = 105%
  PF at ($PWL_{Overall} = 80$) = 105%
  PF at ($PWL_{Overall} = 70$) = 100%
  PF at ($PWL_{Overall} = 50$) = 90%

- Year 2016: The 100% pay will be provided at an overall **PWL of 80**. The maximum pay factor is fixed at 105%. The following payment procedure will be used:
  - If PWL for any of the measured properties (i.e. Gradations, AC, Compaction) is less than 60, the lot is considered rejected.
  - For $60 \leq PWL_{Overall} \leq 90$, $PF = 60 + 0.5(PWL_{Overall})$
  - For $PWL_{Overall} > 90$, $PF = 105\%$

  For example:
  PF at ($PWL_{Overall} = 100$) = 105%
  PF at ($PWL_{Overall} = 90$) = 105%
  PF at ($PWL_{Overall} = 80$) = 100%
  PF at ($PWL_{Overall} = 60$) = 90%

- Year 2017: The 100% pay will be provided at an overall **PWL of 90**. The maximum pay factor is fixed at 105%. The following payment procedure will be used:
  - If PWL for any of the measured properties (i.e. Gradation, AC, Compaction) is less than 70, the lot is considered rejected.
  - For $PWL_{Overall} \geq 90$, $PF = 55 + 0.5(PWL_{Overall})$

  For example:
  PF at ($PWL_{Overall} = 100$) = 105%
  PF at ($PWL_{Overall} = 90$) = 100%

$$PF \text{ at } (PWL_{Overall} = 70) = 90\%$$

- Once the PWL system is fully implemented, a lot is considered rejected if the calculated **PWL** for any of the measured properties (i.e. Gradations, AC, Compaction) **is less than 70**.

- Currently all JMFs must match the broadband specification ranges for aggregate gradations. These specification ranges are the minimum and maximum numbers allowed when establishing the job-mix operational range for the combined percent passing targets. The job-mix operational range must be within the broadband specifications. NDOT will reassess this process and make a recommendation whether the full range on the individual sieves will be allowed regardless of the broadband specification.

- The accuracy of the ignition oven for the measurements of asphalt content and aggregate gradations shall be evaluated on each project and the necessary actions shall be taken as shown below:
  - If a constant off-set is occurring between the ignition oven data and the JMF but the Va, VMA, Stability, TS, and TSR are within the specification, then the PWL shall be adjusted accordingly.
  - If a constant off-set is occurring between the ignition oven data and the JMF but any of the Va, VMA, Stability, TS, and TSR are outside the specification, then a new mix design shall be conducted.

4.2 PWL Software

The developed PWL System for Dense Graded Mixtures has been incorporated into a Microsoft Excel software. The developed PWL Software consists of a user-friendly spreadsheet along with a User Manual. The PWL Software incorporates all parts of the NDOT PWL system including: critical measures on gradations, AC, and compaction, determination of subolts and lots, calculations of individual PWL values and overall the PWL value for each lot, determination of pay factors and calculations of bonuses and demerits for each lot and for the entire project.

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