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Assessing Specification Pay Schedules through Monte Carlo Simulation

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ABSTRACT: Objective of highway agencies is to develop rational and defensible specifications for the acceptance of highway materials and transportation structures. Such specifications are often coupled with a pay schedule that rewards higher and penalizes lower quality levels. This study had as objective the development of a methodology examining the production population characteristics and assessing the effectiveness of pay schedules to award appropriate levels of monetary rewards for desired target quality levels. The proposed approach uses the distribution of production quality to generate alternative lots through Monte Carlo simulation and examine the impact on pay factors (PF). Then, the probability of receiving a certain level of PF is estimated for assessing the rationality of the pay schedule in relation to the achieved quality. The suggested approach can also aid in adjusting pay schedules and specification tolerances for accepting higher quality materials. While the results presented in this paper were pertinent to the acceptance of asphalt mixtures, this approach is transferable elsewhere since it can be adapted to assess similar effects for any other materials with acceptance plans that include payment adjustments.

KEYWORDS:Specifications, risk analysis, pay factors, simulation, asphalt mixtures.

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I. INTRODUCTION

With the development and adoption of statistically based specifications for materials and structures agencies need to address (i) the associated risks of acceptance, and (ii) the effectiveness of pay schedules to award appropriate levels of monetary rewards for the delivered quality.

In terms of risk assessment the analysis involves an estimation of the risk of accepting lower quality (β error) and rejecting higher quality (α error) materials. The assessment of risks is associated with the development of operating characteristic (OC) curves which numerically as well as graphically present the relationship between the actual quality of a lot (in terms of percent within specification limits, PWL) and the probability of its acceptance. This aspect has been addressed in the literature for highway materials [1, 2, 3], as well by the investigators at earlier studies for the acceptance of asphalt mixtures [4, 5], granular aggregate base, GAB, [6], and GAB field density [7].

This paper presents a proposed approach to assess the effectiveness of pay schedules to award appropriate levels of monetary rewards for the delivered quality. The proposed approach uses the distribution of production quality to generate alternative lots through Monte Carlo simulation, Figure 1, and examine the impact on pay factors (PF). The probability of receiving a certain level of PF is then estimated for assessing the rationality of the pay schedule in relation to the achieved quality. The OC curves for acceptance plans with pay adjustments presents the relationship between the actual lot quality (PWL) on the x axis versus the probability of that lot receiving a certain PF on the y axis. Different OC curves are identified from the simulation analysis for various PF levels.

II. SIMULATION ANALYSIS & PROPOSED APPROACH

Objective of the simulation analysis was to generate a number of random lots normally distributed for each of the material properties used in the acceptance specification. To achieve so, the population characteristics for these properties are used. In this study Maryland State Highway Administration's, MSHA, acceptance specifications [8, 9] were used along with quality assurance (QA) data for dense graded hot mix asphalt, HMA. The HMA specification includes the following four properties: aggregates percentage passing 0.075mm, 2.36mm, and, 4.75mm sieves; and, asphalt content, AC. The population characteristic for these properties and the specification tolerances are shown in Table 1. The deviations from the target values, "Delta Mean," were considered in these analyses since each project may have a different target value. Thus, the more than 10,000 lots generated from the Monte Carlo simulation were used to calculate the Percent Within Limits (PWL) for each mixture property in relation to the specification tolerances. Subsequently, the Composite Mixture Percent within Specification Limits, CMPWSL, (equation 1), and the mixture pay factor, MF, were calculated for each lot, (equation 2).

Table 1: Population Characteristics& Specification Tolerances

Property	Delta Mean*	Std. Dev.	Tolerances
0.075	0.992	1.20	± 2
2.36	-0.192	3.88	± 5
4.75	0.066	5.60	± 5
AC	-0.002	0.31	± 0.5

*Deviations from the target values

$$CMPWSL = \frac{f1\ PWSL1+f2\ PWSL2+f3\ PWSL3+f4\ PWSL4}{\Sigma f} \qquad \text{EQUATION 3}$$

where: PWSL1 = asphalt content; PWSL2 = aggregate passing 4.75mm / # 4 sieve; PWSL3 = aggregate passing 2.36 mm / # 8 sieve; PWSL4 = aggregate passing 0.075 mm / # 200 sieve; f1 = asphalt content = 62; f2 = aggregate passing 4.75mm / # 4 sieve; f3= aggregate passing 2.36 mm / # 8 sieve; f4= aggregate passing 0.075 mm / # 200 sieve

$$\begin{cases} MF = 0.55 + 0.5CMPWSL \\ if\ CMPWSL < 40\%\ MF = 0 \end{cases} \qquad \text{EQUATION 2}$$

In the proposed approach a simulation code in Matlab was generated for carrying out these analyses and included the following steps, Figure 1:

1- User identifies mixture properties and acceptance specifications (i.e., tolerances, AQL, RQL, CMPWSL and PF equations);
2- User inputs: population characteristics for the mixture properties; number of lots and sublots, n, used in QA; target design values for mixture properties; correlations matrix among mixture properties;
3- User specifies number of random lots generated for mixture properties with Monte Carlo simulation.
4- Using the simulated lots, OC curves relating the actual quality of a lot (PWL) with the probability of its acceptance are defined. These analysis are used for determining acceptance risks (α *error* - rejecting high quality material, and, β *error* - accepting lower quality) for each material property at "acceptance quality level," AQL, and "rejectable quality level," RQL, respectively. AQL is defined as the level of quality a property is fully acceptance, while RQL is the level of quality a property is rejected. Examples of such analysis have been reported elsewhere [5].
5- The simulated lots are then used to obtain CMPWSL for each lot, equation 1.
6- The MF for each lot is then calculated using equation 2.
7- The histograms of MF for all lots are generated for developing the OC curves relating the actual lot quality (PWL) with probability of that lot receiving a certain pay factor PF.

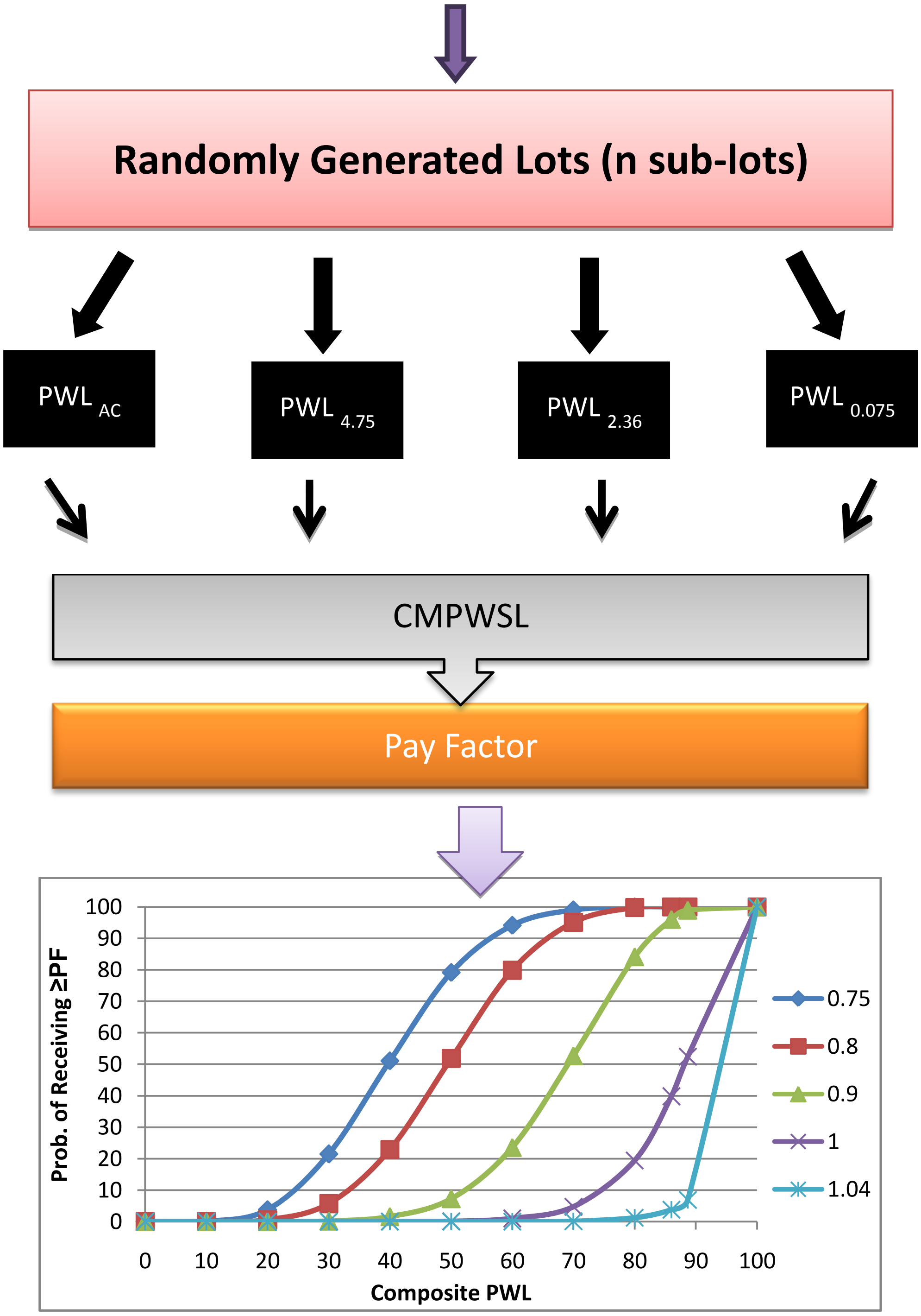


Figure 1: Flow chart of simulation analysis & OC curves development

III. EXAMPLE RESULTS

Figures 2 and 3 show as an example the PWL for the AC and 0.0075 based on the specification tolerances and the population characteristics. As mentioned above the deviations from the target values (i.e., "delta mean") were used since each construction project may have different target values for each mixture property. The tolerances identify the upper and lower specification limits, USL and LSL, respectively. The population distributions were then shifted at levels producing various PWL values. For the 0.0075 mixture parameter, schematically the population was shifted at AQL and RQL so that 90% and 40% of the population is within tolerances, Figures 4 and 5. To notice that in some cases (i.e., 0.075, 2.36, and 4.75) 90PWL cannot be achieved due to the distribution variance (i.e., spread) and the width of the specification tolerances. Thus, the standard deviation of the population had to be adjusted.

The OC curves for acceptance plans with payment adjustments, Figure 5, are represented with the probability of receiving ≥PF (y-axis) in relation to the CMPWL quality level (x-axis). Table 2 summarizes the values obtained at each CMPWSL from the simulation analysis. As it was observed from the results, when the population standard deviations for the four mixture parameters were used the highest achievable CMPWSL was 88.7. Thus, for values above this level the resulting probabilities were interpolated. Furthermore, the simulation analysis have shown that the probability of receiving a PF< 1 when producing at AQL (90CMPWL) is about 40%, while the probability of receiving a PF≥ 1 when producing at RQL (40CMPWL) is 0%. Similarly the expected pay at any other level of CMPWSL, and/or the probability of receiving different levels of PF can be interpolated from these results.

Figures 6 and 7 show the CMPWL and pay factor distribution. At the long run the average pay factor for a 88.7CMPWL is equal to 0.99, while for RQL the average pay factor is 0.40. Table 3 includes the expected pay - EP (PF at the long run) calculations when the population is shifted within the specification tolerances to produce different levels of CMPWSL.

In summary, based on the average pay factors the current pay factor equation fairly awards and penalizes the good and bad quality material and there is no need to modify the pay equation. Typically material produced at AQL is awarded with 100% pay and material below RQL is rejected. Based on the population characteristics of the four HMA mixture parameters only 88.7% of the data are within the specification tolerances. Thus, in order to achieve, at the long run, a 90CMPWSL (AQL value for MSHA spec) either the mixture production variability has to be reduced (higher homogeneity during production, reducing variability and consequently the population standard deviation), or the specification limits have to be widen (if it is concluded that the existing variability represents the best achievable levels of production). Since the expected pay factor (over the long run) at 40 CMPSWL (RQL) is 0.4 the agency bears lower risk for inferior quality material. If the agency is interested in modifying the mix property pay factor specifications a possible approach will be either to modify the AQL and RQL and/or the associated PWL - pay schedule equation.

IV. CONLUSIONS

This study presented a methodology for assessing the ability of specification pay schedules to award appropriate levels of pay factors for various levels of quality. The proposed approach uses production quality data and Monte Carlo simulation to develop pay factor analysis. The probability of receiving a certain level of PF in relation to the quality level can be used to assess the rationality of the specification pay schedule. The suggested methodology can be used to: assess the effects of production variability and specification limits on PWL and PF; identify alternative strategies for fine tuning PF awarded at various levels of production quality; define bonus provisions for promoting higher quality of materials; relate acceptance risks to pay factors; and/or develop new specifications and pay schedules. While the results presented in this paper were pertinent to the acceptance of asphalt mixtures, this approach is transferable to other production processes since it can be adapted to assess similar effects for any other materials with acceptance plans that include payment adjustments.

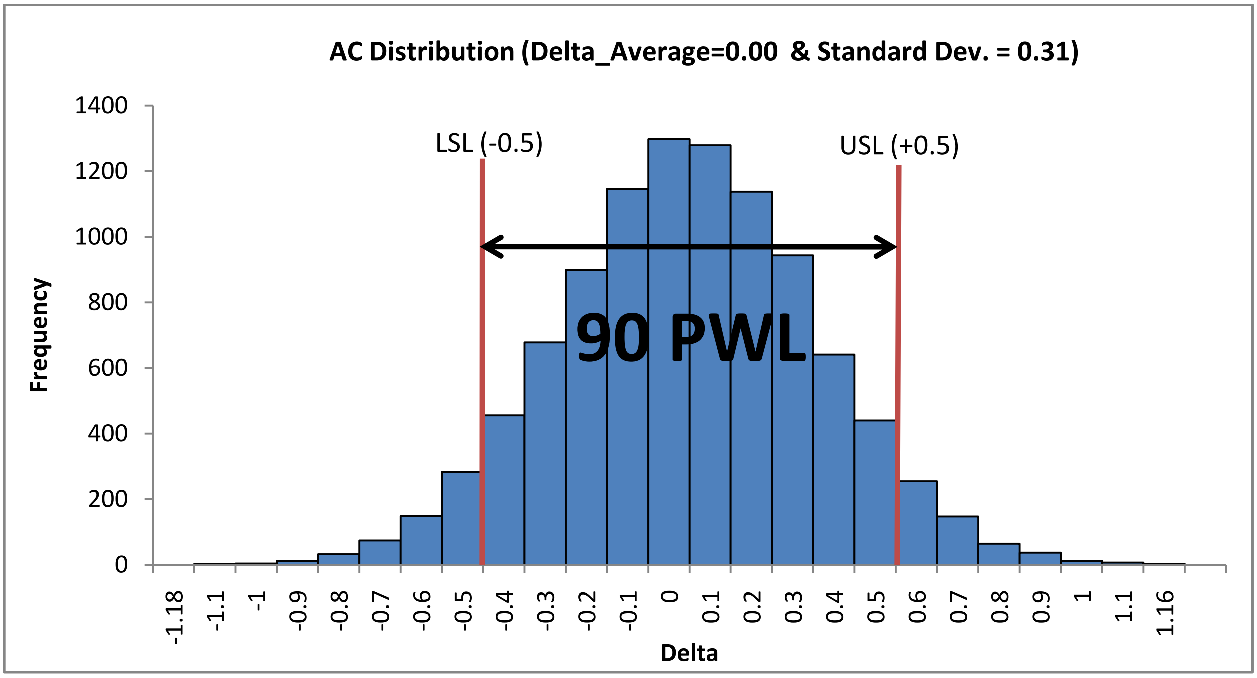


Figure 2: Distribution of asphalt content population and specification tolerances

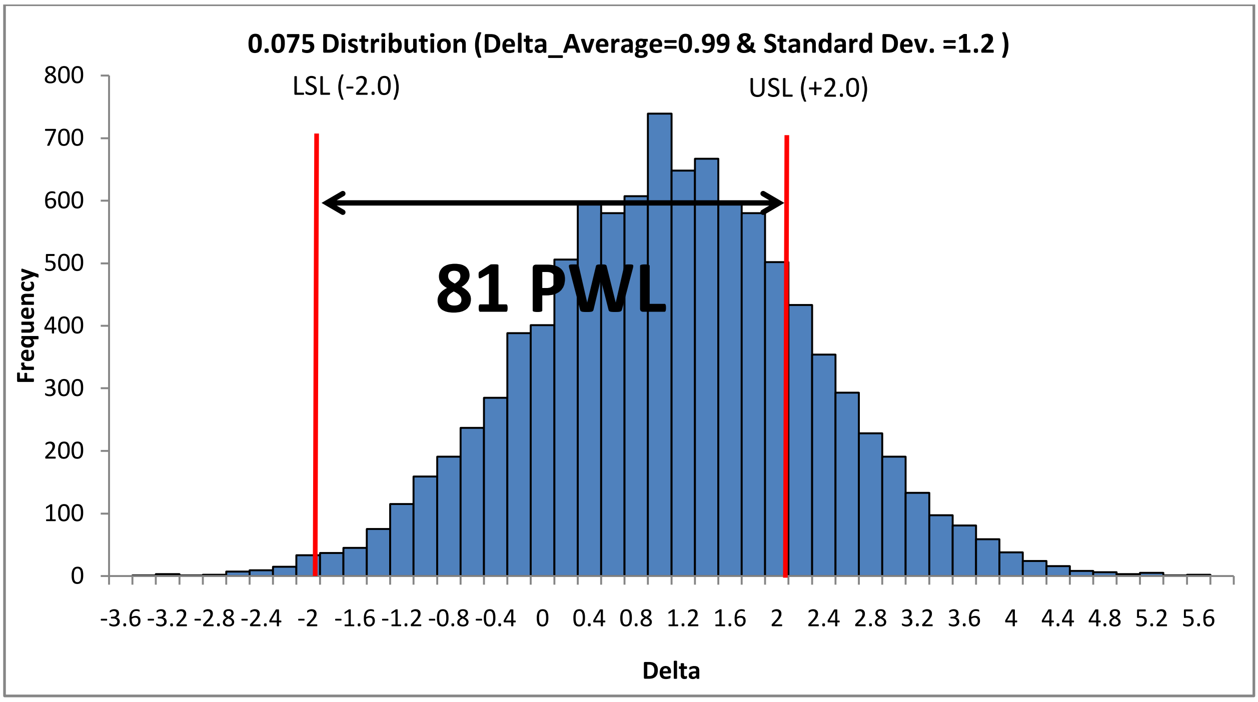


Figure 3: Distribution of % passing 0.075mm population and specification tolerances

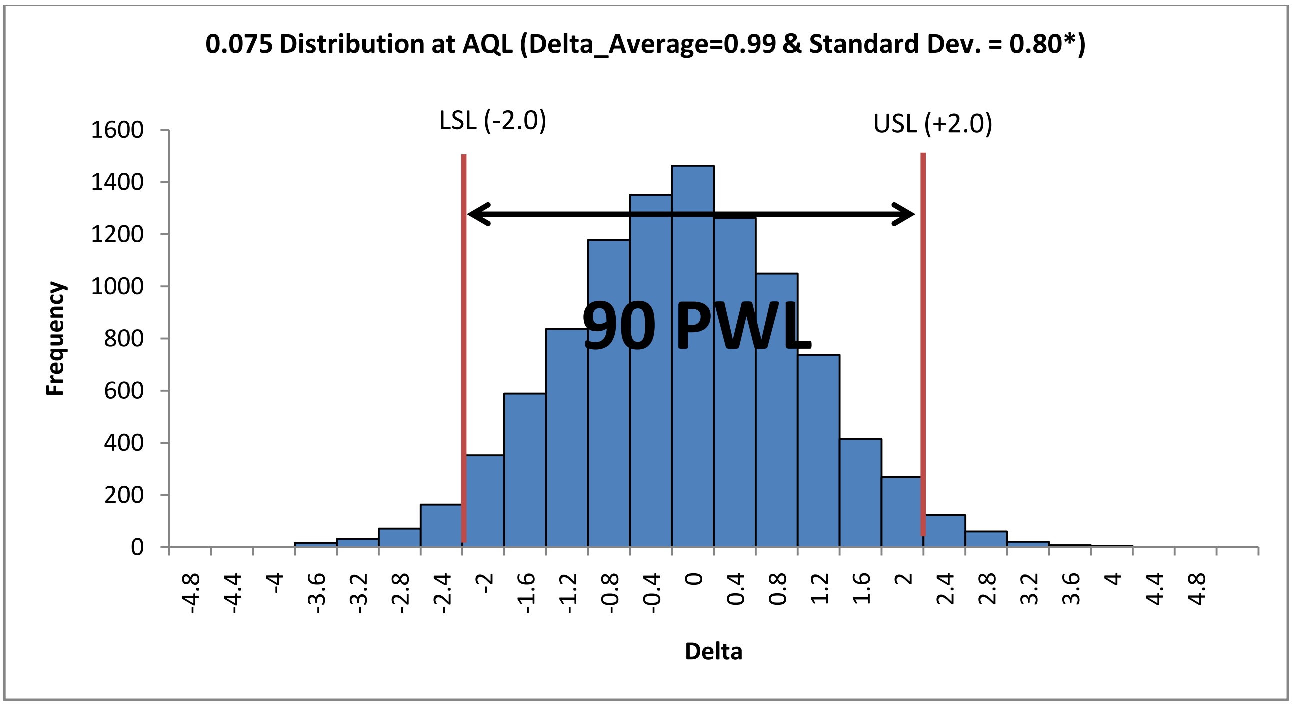


Figure 3: Distribution of Passing 0.075mm at AQL
***Note: In order to achieve 90PWL the standard deviation was reduced by 33%**

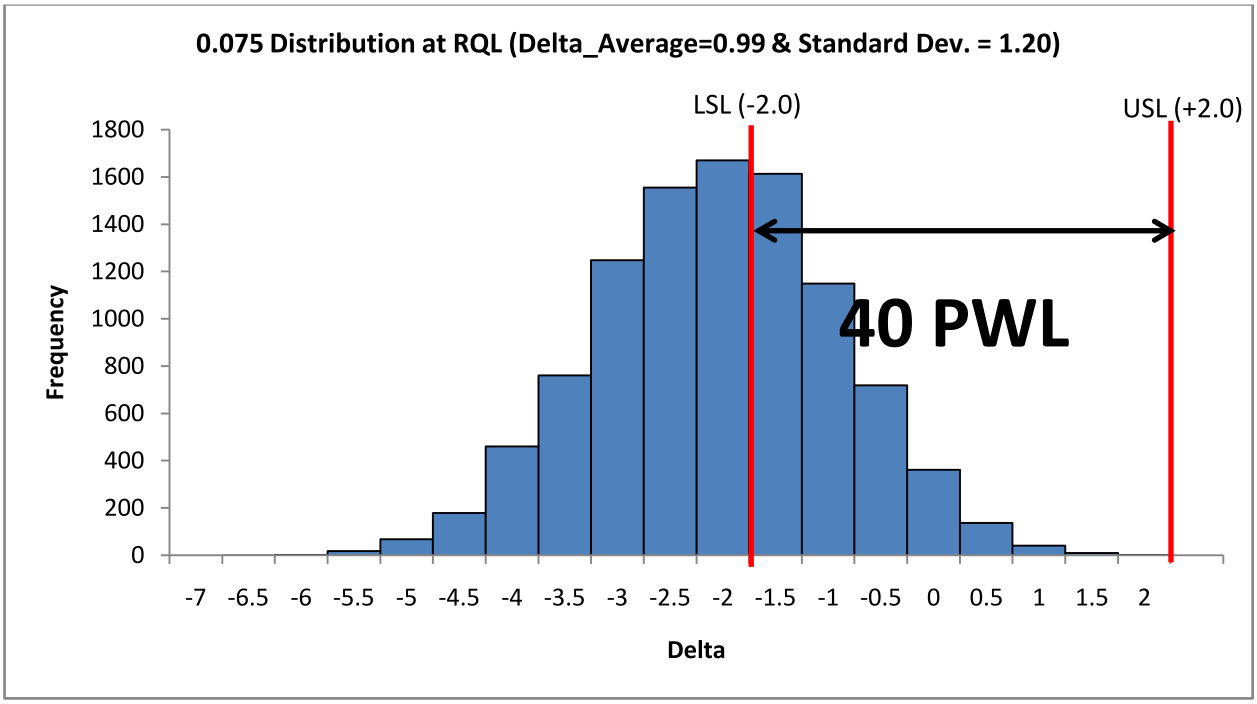


Figure 4: Distribution of Passing 0.075mm at RQL

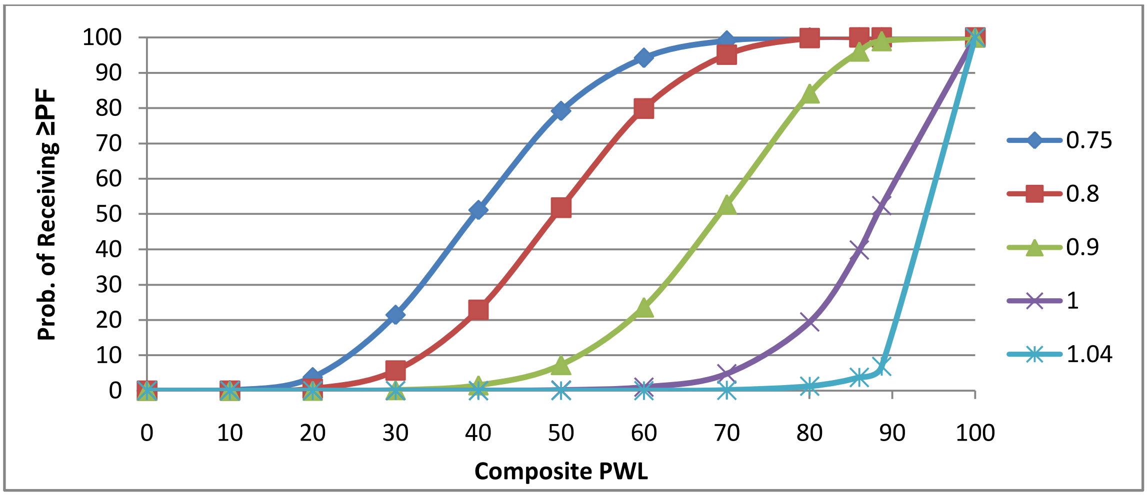


Figure 5: OC curves with Expected PF Using Population Characteristics

Table 2: Probability of Receiving ≥PF at Different CMPWL with Population Characteristics

CMPWL	Prob of Receiving ≥PF				
	0.75	0.8	0.9	1	1.04
0	0	0	0	0	0
10	0.1	0	0	0	0
20	3.81	0.55	0.01	0	0
30	21.47	5.72	0.17	0	0
40	51.11	22.9	1.57	0.01	0
50	79.19	51.82	7.3	0.13	0
60	94.14	79.86	23.57	1	0.02
70	99.04	95.08	52.71	4.76	0.14
80	99.98	99.78	84.15	19.43	1.25
86	100	100	96.02	39.82	3.77
88.7	100	100	98.95	52.41	6.88
100	100	100	100	100	100

Note1: simulation at 10000 iterations for each CMPWL
Note2: assumed values at 100PWL since only 88.7% of the data fits within spec tolerances

Table 4: Expected payment in relation to CMPWL with population characteristics*

CMPWL	EP
100.0	1.05
90.0	1.00
88.7	0.99
80.0	0.95
70.0	0.89
60.0	0.81
50.0	0.65
40.0	0.41

Note: * The maximum achievable CMPWL with population standard deviation is 88.7;
90CMPWL obtained with population standard deviation reduced by 3.6%;
100CPWL obtained by reducing population standard deviation by 55%.

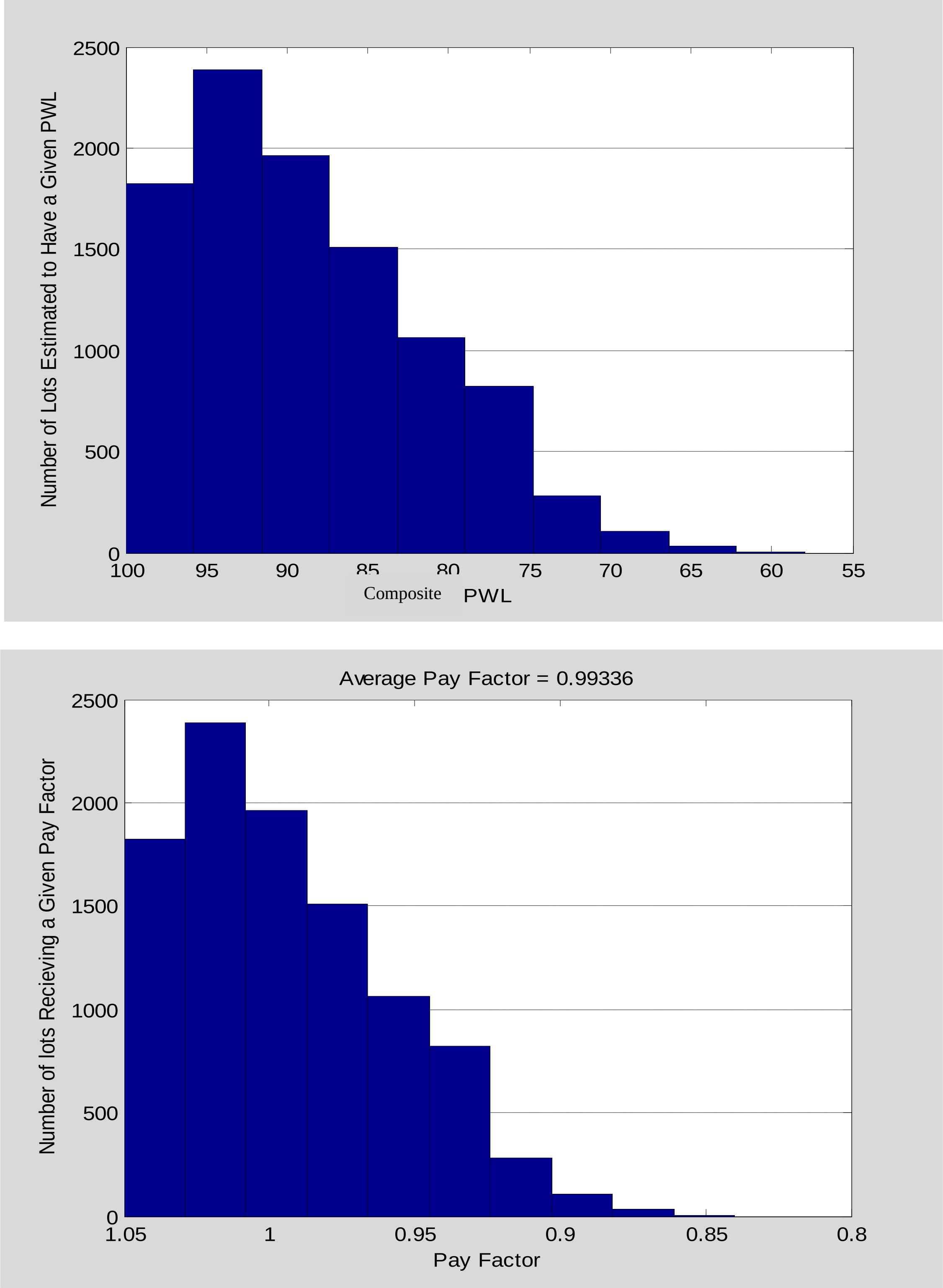
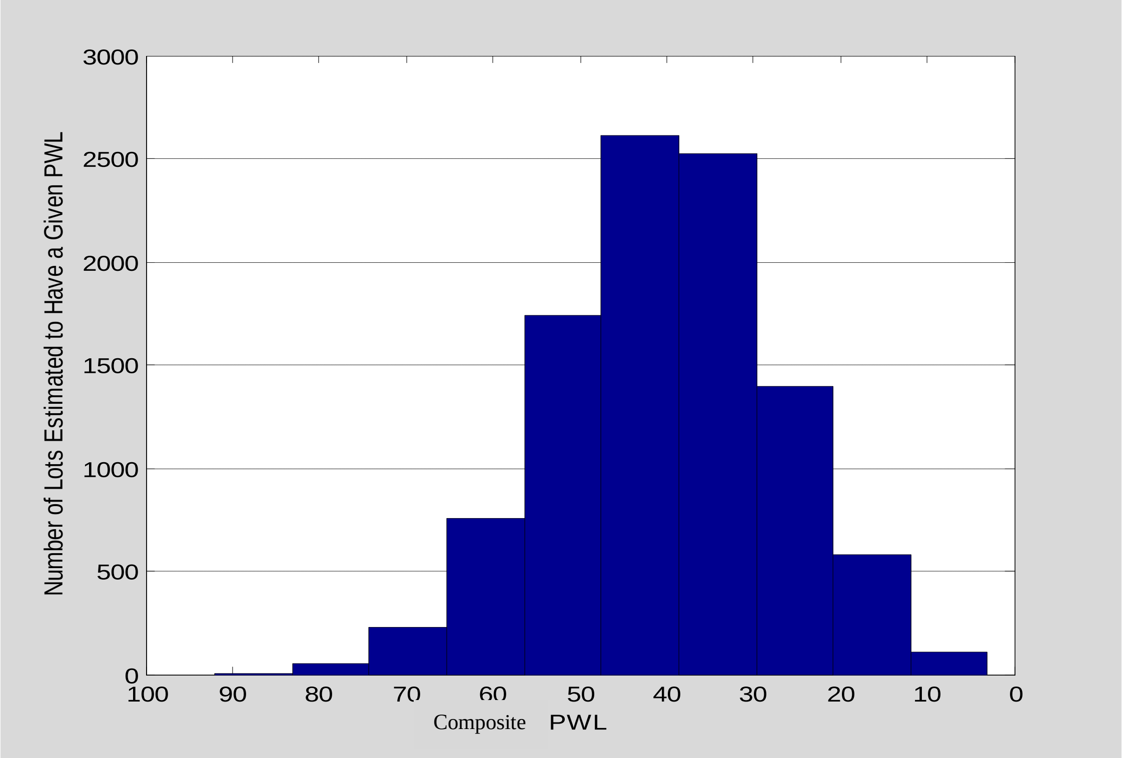


Figure 6: CMPWL and pay factor distribution for production "close to" AQL (max CMPWL = 88.7 using population standard deviation)



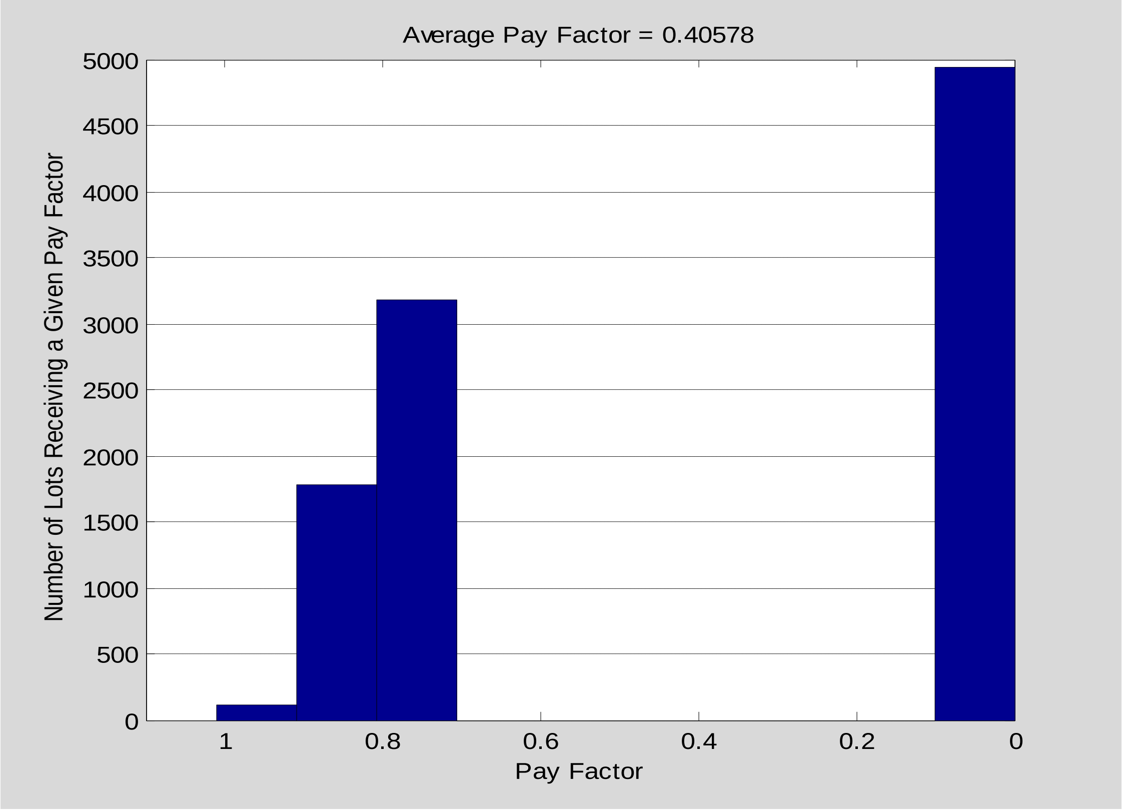


Figure 7: CMPWL and pay factor distribution for RQL (with population standard deviation)

REFERENCES

[1]. Burati J. Risks with Multiple Pay Factor Acceptance Plans, Transportation Research Board, TRR journal No. 1907, pp. 97-42, 2005.

[2]. Sholar G. A., Page G. C., Musselman J. A., Upshaw P. B., Moseley H. L. Development of the Florida Department of Transportation's Percent Within Limits Hot-Mix Asphalt Specification" Transportation Research Bora, TRR Journal No. 1907, pp. 43-51. 2005.

[3]. Villiers C., Mehta Y., Lopp G., Tia M., Roque R. Evaluation of Percent-within-limits- Construction Specification Parameters, IJPE Volume 4, Issue 4, pp. 221-228. 2003

[4]. Karimi, S., Goulias, D., Schwartz, C. Evaluation of Superpave HMA Mixture Properties at the Plant versus behind the Paver: Statistical Comparison of QC and QA Data.' ASCE Journal of Transp. Eng., 138(7), 924–932. 2012.

[5]. Karimi, S., Goulias, D., and Schwartz, C. Risk and Expected Pay Factor Analysis for Assessing Gap and Dense Graded Superpave Mixture Specifications.' IJPE, Vol 16, Issue 1, pp 69-79, 2015.

[6]. Goulias D., Karimi S. Risk Assessment for the Acceptance of Construction Materials, IJERD, Vol 13, Issue 12 pp 54-58, 2017.

[7]. Goulias D., Karimi S. Materials-Quality-Assurance Risk Assessment, MSHA MD-13-SP909B4K Report, pp84. 2013.

[8]. Maryland Department of Transportation. MSMT 735 – Statistical Analysis of Material Using Quality Level Analysis for Determination of Pay Factors. 2009.

[9]. Maryland Department of Transportation. Specifications Section 504 – Hot Mix Asphalt Pavement. 2009.