Development of an Asphalt Construction Pay Schedule Based on the Value Concept

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ABSTRACT

Pavement construction pay adjustment schedules have generally been based on a somewhat arbitrary selection of "acceptability limits" with the adjusted pay based on a concept of the percentage of construction within these limits. In this paper an alternate approach applied to asphalt paving is presented and demonstrated. Acceptability limits are selected to represent the capabilities of normal, good contractors. To assure this, the limits are established through an analysis of actual construction test data. For this study, these data include more than 2,300 field density and 2,300 field extraction tests conducted on random samples from past construction projects. The pay adjustments for work outside the identified acceptability limits are then set on the basis of the anticipated relative effect of such deviations on pavement service life. This relative life effect was determined by a quasi-theoretical analysis of laboratory data in which the effects of variations in mixture composition and density were studied. The framework around which the schedule is developed is called the value concept. This concept serves as a rational basis for the establishment of pavement construction pay schedules. As such, it provides a means for considering both the average and the variability (standard deviation or range) of construction test results and provides a mechanism for setting pay adjustments that reflect the impact of construction variability on expected pavement life.

Construction pay adjustment schedules are used by many highway agencies. Although primarily thought of in connection with the quality assurance (QA) type of construction contracts, they are also used by many agencies with the more traditional method-oriented specifications to establish payment when it becomes necessary (or at least prudent) to accept construction that does not fully comply with the specifications. Of the 47 highway agencies that responded to an Oregon survey (1), 43 indicated that "out-of-specification" construction is sometimes accepted, and 39 of these indicated that they have a formal method for establishing pay adjustments for such work.

There is, however, no generally accepted method for establishing such schedules, and there appears to be a general consensus that most of the schedules in current use are not fully rational or equitable. For example, of the 39 agencies cited, only 12 indicated a belief that their pay adjustments were equivalent to the value of the reduced pavement serviceability.

Because of a similar concern, the Illinois Department of Transportation sponsored a research study at the University of Illinois (2) for the development of an asphalt construction QA specification pay adjustment schedule that would be fair to both the contractor and the highway agency. The object of the study was to establish a pay schedule that would help assure that the highway user receives a fair value for his tax dollar without unduly penalizing the contractor.

To meet this objective, four basic criteria were adopted to govern the development of the pay schedules:

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1. All work should be judged on the basis of the quality that can normally be produced by good contractors using normal care and effort,
2. "Good" or "acceptable" work should always receive full or 100 percent pay,
3. "Superior" work should be rewarded, and
4. "Inferior" work should be penalized.

Two diverse approaches were employed in the development of the payment schedule: (a) an analysis of past construction data to determine typical ranges of variability and (b) a quasi-theoretical analysis of "value" based on the effects of construction variability on pavement life. The first of these assured that the limits adopted for acceptable and superior construction would reflect the construction quality that can be achieved routinely by typical contractors. The second was used to establish penalties for unacceptable construction that reflects the detrimental effect of the degree of unacceptability on the pavement.

Data from 279 lots of binder mix and 189 lots of surface mix from 23 Illinois QA projects were analyzed. From this analysis, limits were established for acceptable work that is to receive full (100 percent) pay and for superior work that is to receive bonus (>100 percent) pay. For the inferior work falling outside these limits, pay adjustments were established on the basis of a concept of construction value measured in terms of the expected relative effect on pavement life.

PAY SCHEDULE FORMAT

Mix Parameters

Before the pay schedule was developed, a general format and the construction parameters to be used for pay determination were selected. Only those items

over which the contractor has direct and immediate control were considered. These included aggregate gradation, asphalt content, density, thickness, and smoothness.

Of these, thickness and smoothness were not considered to be appropriate because most Illinois QA projects involve resurfacing. Because of the surface irregularities in the existing pavement, the contractor's control over these two parameters is limited. Consequently, only gradation, asphalt content, and density were selected to be included as pay schedule parameters.

Illinois' old QA specification was based on these same parameters. Payment levels were determined for four gradation size fractions (e.g., 1 to 1/2 in. and No. 4 to No. 10), asphalt content, and density. Asphalt content and gradation were considered together to establish a mix pay level. The mix pay level was the lowest of these five individual values. The lot pay was then established as the average of the density and mix pay levels.

In the development of the new pay schedule, the four gradation size fractions from the old specification were retained. However, lot pay would be based on the average of three values: (a) the lowest of the four gradation pay values, (b) the asphalt pay value, and (c) the density pay value.

Inclusion of Standard Deviation

With the exception of bonus pay determination, payment under the old QA specification was based on the average of several (generally five) tests. Quite obviously, any construction feature can be acceptable "on the average" and still be quite unacceptable because of extreme variability. In recognition of this, it was considered imperative that the new pay schedule take into account both the average and the variability of test results. To accomplish this, a value concept (3) was developed that serves as the rational basis for the pay schedule. The value concept provides a rational means for including both the average and the standard deviation of test values in the pay determination and a means for basing the pay on the relative effect of construction variability on the life expectancy of the pavement surface.

VALUE CONCEPT

Development of the value concept has been presented in detail previously (3). The concept recognizes that the overall performance of the pavement is a function not of just the average value of material properties but of the entire distribution. It further recognizes that, at the time a pavement is considered to have failed, the area of actual failure is but a small percentage of the pavement surface. This suggests that the life of a pavement surface is controlled by some lower percentile of the material property distribution consistent with this small percentage of surface failure.

The value concept calls this lower percentile the controlling property level. As illustrated in Figure 1d, the controlling property level (assuming a normal distribution) is defined by the equation:

$$Cb = Pb - Z*Sb \quad (1)$$

where

Cb = controlling property level,
Pb = average value of the material property,
Z = number of standard deviations consistent with the percentage of surface area failed when a pavement is considered unacceptable, and
Sb = standard deviation of the material property distribution.

The controlling property level can be used to establish a general value relationship between an acceptable distribution of construction variability and any other distribution. It is assumed that some relationship exists between the material property and its life expectancy and, initially for simplicity, that that relationship is linear (Figure 1a). A value relationship based on ratios of expected life can be identified. For example, if the controlling property level of an acceptable or "base" distribution (Cb) has a life expectancy of Nb and another distribution (Ca) has a life expectancy of Na, the value of the other distribution is defined as Na/Nb (Figure 1e). This relationship is expressed in terms of controlling property levels by the equation:

$$V = 100 - dV * (Cb - Ca) \quad (2)$$

where

V = value of the other distribution as a percentage of the value of the acceptable distribution;
dV = slope of the value relationship; and
Cb and Ca = controlling property levels for the acceptable and other distributions, respectively (Figure 1f).

To use the value concept in developing a pay schedule, it was necessary (a) to identify acceptable controlling property levels (Cb) for each of the pay control factors (i.e., gradation size fractions, asphalt content, and density) and (b) to establish relationships between the variation of these factors and expected surface life.

SELECTION OF A Z-VALUE

A step that preceded the identification of acceptable controlling property levels and the application of the value concept was the selection of an appropriate value for Z (number of standard deviations). According to the value concept, Z should be based on the percentage of surface area failed when a typical pavement is considered unacceptable. The exact value of this percentage is quite questionable because no consensus has been reached by engineers who have studied it. Nevertheless, many engineers believe that the percentage should be around 10 percent (Z = 1.28). This suggests that a Z-value somewhat greater than 1 would be appropriate.

However, due to the manner in which the acceptable controlling property levels were to be selected and due to the way they would later be used to establish contractor pay, the specific value of Z was found to not be significant as long as it was reasonable. This was examined by analyzing QA test data from 15 previous construction projects. Pay schedules were developed with Z-values ranging from 0.5 to 3.0 (4). These were applied to the project test data to determine the average pay percentage for each project. The results of this analysis are given in Table 1.

The "correct" value for Z is believed to be between 1.0 and 2.0. The data in Table 1 demonstrate that, within this practical range of values, the precise value selected has only a minor impact on the average project pay, generally less than 1 percent. Because of this and for lack of any strong indication of a more appropriate value, 1.0 was selected as the value for Z. This simplified the controlling property level equation to

$$Cb = Pa - Sb \quad (3)$$

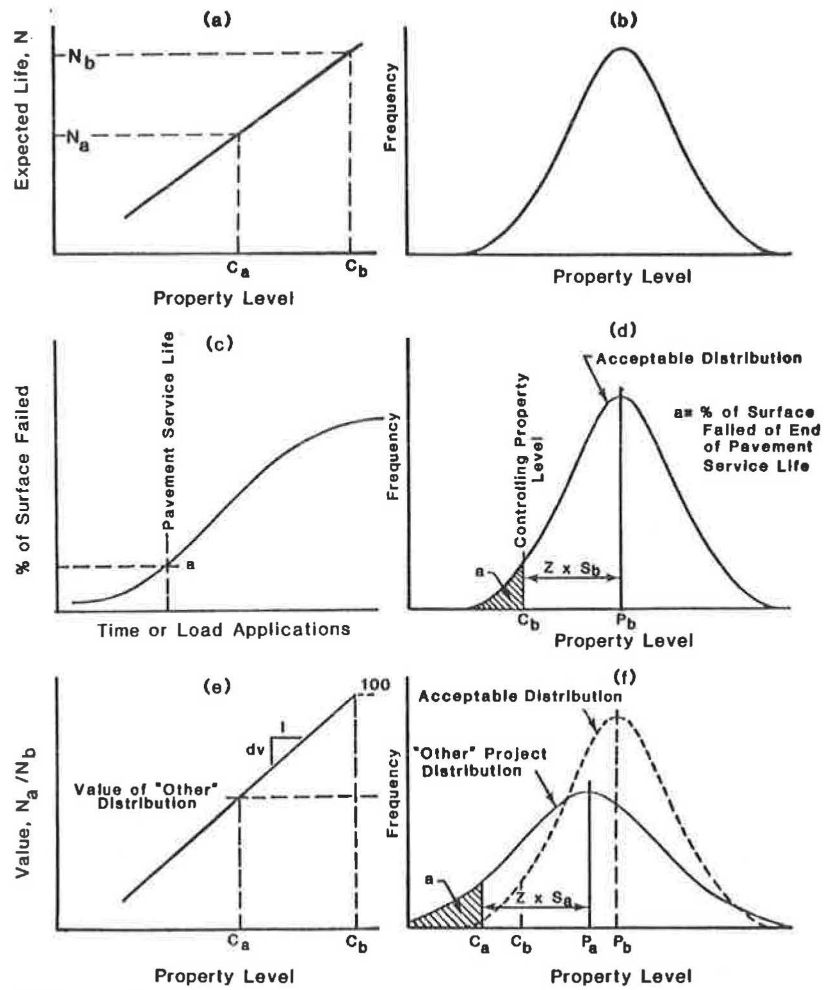

FIGURE 1 Development of the value concept.

USE OF RANGE IN THE VALUE CONCEPT

As a further simplification for practical application, the range of QA test results was substituted into the controlling property level equation as an estimate of the standard deviation (Sb). In actual practice, the true mean and standard deviation of the lot are never known but must be estimated from the results from a small number of test samples. For the mean, the average of the test results is easily calculated and routinely used by field personnel. However, the calculation of standard deviation was considered more complex than what is normally desired for routine field calculation. For small samples, the true population standard deviation can be estimated from the range of test values (difference between high and low) with almost as much efficiency as it can from the more complex calculation (5). The estimate is made by multiplying the range by an appropriate factor that depends on the size of the sample. Table 2 lists the range factors for sample sizes of three through seven.

Substituting the range estimate for the standard deviation in the controlling property level equation, the equation becomes

$$Cb = Pb - f*R \quad (4)$$

where f is the range factor from Table 2 for the number of samples tested in a lot and R is the difference between the high and the low test value.

TABLE 1 Results of Applying Pay Schedules Based on Various Z-Values to Past QA Surface Mix Data

Project	Average Project Pay Percentage for Z-Value					
	0.5	1.0	1.5	2.0	2.5	3.0
A	94.6	95.1	94.6	95.1	95.0	95.0
B	98.6	98.6	98.4	98.8	99.0	99.1
C	100.5	100.7	100.7	101.0	100.2	100.2
D	97.4	96.8	94.8	94.8	94.5	93.8
E	102.5	102.5	102.7	102.7	101.9	100.8
F	100.4	100.4	100.1	99.3	98.7	97.8
G	100.7	101.7	100.9	100.9	100.9	100.2
H	88.8	84.8	84.8	83.1	81.5	81.5
I	99.3	98.8	96.4	94.8	93.1	92.4
J	98.8	98.8	98.5	98.0	98.0	97.6
K	95.7	96.8	96.7	97.1	97.6	97.8
L	98.8	99.6	99.6	99.6	100.0	100.0
M	100.2	100.0	100.2	100.2	100.4	100.4
N	96.3	96.0	94.6	94.4	94.5	93.8
O	96.7	98.3	98.8	99.0	99.0	99.0
Average, all lots	97.9	98.1	97.6	97.5	97.3	97.0
Best job	102.5	102.5	102.7	102.7	101.9	100.8
Worst job	88.8	84.8	84.8	83.1	81.5	81.5

IDENTIFICATION OF PAY DETERMINATION FACTORS

To avoid confusion between the actual pay schedule usage and the value concept as a general basis for pay schedule development, the controlling property

TABLE 2 Factors for Estimating the Standard Deviation from the Range of Test Results *(5)*

Sample Size	Range Factor
3	0.591
4	0.486
5	0.430
6	0.395
7	0.370

level equation was redefined as a pay determination factor (PDF) and modified somewhat to account for the direction of slope of the material property-to-service life (or value) relationship. In developing the value concept, the expected life and value relationships were depicted as increasing with increasing property levels (Figure 1a). With this depiction, the controlling property level was identified as being below the mean resulting in the negative sign in Equation 4. However, for many material properties a reverse trend of decreasing life with increasing property levels exists. For this situation the controlling property level would be greater than the average and the sign would become positive.

Asphalt and Gradation PDFs

For asphalt content and gradation, the deviation from the project's job mix formula was selected as the pay determination parameter. Higher deviations are considered to be associated with shorter life expectancy. Consequently, the PDF equation for asphalt content and the gradation size fractions was defined as

$$PDF = dJMF + f*R \quad (5)$$

where

PDF = pay determination factor,
dJMF = absolute value of the deviation of the lot average from the job mix formula,
f = range factor from Table 2, and
R = range of test results for the lot.

Density PDFs

For density, however, lower values are associated with shorter life expectancies. Therefore the negative sign is retained in the density PDF equation.

The density parameter selected for the pay schedule was the density quality level determined by Illinois' test strip density control method. In this procedure, Illinois uses the nuclear density device correlated to density cores taken from a test strip. The density quality level is defined by the equation:

$$QL = (MLD/TD) * (MCD/0.95D) * 100 \quad (6)$$

where

QL = quality level,
MLD = average of nuclear density tests taken at a site at five specified locations across the paved area,
TD = target nuclear density established as the average nuclear density from the project's compaction calibration test strip,
MCD = average density of cores taken from the calibration strip, and
D = theoretical maximum (zero air voids) mix density.

Using this quality level definition, the density PDF equation was defined as

$$PDF = QL - f*R \quad (7)$$

where QL is the lot average quality level and R is the range of quality level values.

SELECTION OF BONUS AND PENALTY PDFs

Test data representing 279 lots of binder and 189 lots of surface from past QA projects were analyzed to identify PDF values for each of the pay parameters that would represent the limits of acceptable and superior work. The objective of the analysis was to select penalty PDFs that would assure that the bulk of normal construction would be paid for at 100 percent (or greater) of the contract price. A secondary objective was to select bonus PDFs that could be used to identify a smaller percentage of lots for bonus pay.

Penalty and Bonus Frequencies

To make these selections, judgment had to be exercised relative to the number of lots, as represented by the historical QA data, that should be penalized and the number that deserves bonus pay. These numbers must be sufficiently high to encourage quality construction and assure normal acceptable construction but not so high as to affect the cost of construction.

Statistically, deviations from the mean of up to plus or minus one standard deviation are often considered normal and are routinely acceptable in highway construction. Assuming a normal distribution, this would suggest that about 70 percent of all lots might be considered to represent normal, acceptable construction. In this instance, about 15 percent of the lots would be considered at least marginally unacceptable and 15 percent would be superior. This distribution was selected for use in developing the pay schedules--15 percent unacceptable (penalty), 15 percent superior (bonus pay), and 70 percent normally acceptable (100 percent pay).

Actually, of course, any distribution of percentages could be selected. Therefore, to provide complete flexibility to highway administrators who would be responsible for adopting the developed pay schedule, bonus and penalty PDFs were selected based on percentages of 5, 10, 15, 20, and 25. Although the pay schedule developed and presented herein is based on the 15-70-15 distribution, schedules based on other distributions can be established by following the steps used in this paper and using the appropriate bonus and penalty PDFs given in Tables 3 and 4.

Asphalt Content PDFs

In establishing the penalty and bonus levels, the PDF of each lot of past QA data was calculated using either Equation 5 for asphalt content and each gradation sieve size or Equation 7 for density. As an example, for one surface lot, the JMF for asphalt content was 5.5 percent. The average of five samples taken from the lot was 5.74 percent, and the range of test values was 0.26 percent. Using the range factor (f) of 0.43 from Table 2, the PDF for the asphalt content of this lot was

$$(5.74 - 5.50) + 0.43*0.26 = 0.35$$

TABLE 3 Bonus and Penalty Pay Determination Factors for Binder Mixes

Mix Parameter	Pay Determination Factors for Percentage of Lots Expected to Receive Penalties or Bonuses				
	5	10	15[a]	20	25
100% Pay					
Density	97.0	97.3	97.5	97.7	97.9
Asphalt content	0.88	0.70	0.60	0.56	0.48
Size fraction					
1-1/2 in.	11.4	11.1	10.0	9.5	8.7
No. 4-No. 10	5.5	5.3	5.0	4.4	4.05
No. 40-No. 80	4.0	3.3	3.2	3.1	3.0
Minus No. 200	2.7	2.6	2.3	2.1	2.0
Bonus Pay					
Density	100.6	100.3	100.0	99.8	99.6
Asphalt content	0.13	0.19	0.21	0.23	0.25
Size fraction					
1-1/2 in.	4.3	4.6	5.0	5.5	5.9
No. 4-No. 10	1.7	2.0	2.2	2.3	2.5
No. 40-No. 80	1.2	1.4	1.5	1.6	1.8
Minus No. 200	0.8	0.9	1.0	1.05	1.1

[a]15% was selected for use in developing the pay schedule presented in this paper.

TABLE 4 Bonus and Penalty Pay Determination Factors for Surface Mixes

Mix Parameter	Pay Determination Factors for Percentage of Lots Expected to Receive Penalties or Bonuses				
	5	10	15[a]	20	25
100% Pay					
Density	95.9	96.1	96.6	97.1	97.4
Asphalt content	0.60	0.47	0.43	0.39	0.36
Size fraction					
1/2 in.-No. 4	9.0	7.5	7.2	7.0	6.7
No. 4-No. 10	6.0	5.8	5.3	5.2	4.9
No. 40-No. 80	4.0	3.3	3.0	2.8	2.7
Minus No. 200	2.3	2.2	2.05	1.95	1.8
Bonus Pay					
Density	100.3	99.9	99.5	99.3	99.0
Asphalt content	0.12	0.17	0.18	0.19	0.21
Size fraction					
1/2 in.-No. 4	3.2	3.6	3.7	4.0	4.5
No. 4-No. 10	1.8	2.0	2.2	2.5	2.7
No. 40-No. 80	1.2	1.3	1.5	1.7	1.8
Minus No. 200	0.75	0.9	0.95	1.05	1.15

[a]15% was selected for use in developing the pay schedule presented in this paper.

The PDFs were determined for all controls (sieve sizes, asphalt content, and density quality level) for each of the 279 binder lots and the 189 surface lots. As one example, the distribution of the various lot PDFs for asphalt content of binder mixes is shown in Figure 2.

The bonus and penalty PDFs for asphalt content were finally selected by examining the lot PDFs and selecting the values that would cause penalties to be assessed to 15 percent of the lots from past QA projects and that would provide bonus payment to another 15 percent. The remaining 70 percent of the lots would receive payment at the full contract price (100 percent pay). As an example, 15 percent of the 279 binder lots is (0.15*279) 42 lots. The PDF for asphalt content of binder mixes was found to be 0.21 or less for 42 of 279 lots and 0.60 or greater for another 42 of 279 lots (see Figure 2). Therefore these values (0.21 and 0.60) were selected as the binder bonus and penalty PDFs, respectively. The PDFs for surface mix lots were selected by the same procedure using (0.15*189) 28 lots as the divider.

Density PDFs

The PDFs for density were selected in a similar fashion. However, the selection process was modified slightly to accommodate the decision to retain the old specification's limits that are intended to prevent excessive density, which can contribute to bleeding and rut development. These limits prohibit bonus pay for any lot that has a sublot quality level of 103 or greater (average air voids of about 2 percent or less) or a lot quality level of 102 or greater (average air voids of about 3 percent or less). To account for this, any lot of previous QA data having a sublot quality level of 103 or greater or an average lot quality level of 102 or greater was deleted from the analysis. This reduced the number of binder lots from 279 to 241 and the number of surface lots from 189 to 176. The bonus and penalty PDFs for density were determined from these reduced numbers of lots.

Gradation PDFs

For gradation, the selection process was complicated because payment is controlled by four values. For example, if the pay percentages for the four different size fractions were 100, 95, 100, and 90, the gradation pay would be the minimum value of 90. Similarly, all four pay percentages must be in the bonus category for bonus pay to be received. With this situation, the PDFs for gradation were selected so that each of the four size fractions has equal likelihood of causing a penalty or permitting bonus payment.

Various combinations of gradation PDF values were applied to the data. The objective in applying these values was to identify those values that would result in the desired number of lots being penalized (or receiving bonuses) with the cause of the penalties evenly distributed among the four size fractions. For example, at the binder mix PDFs for the 15 percent penalty level (42 of 279 lots being penalized), 13 lots fell into the penalty category for each of the four size fractions. (Some of the lots fell into the penalty category on more than one of the size fractions.)

The PDF values selected from the analysis are given in Tables 3 and 4 for binder and surface mixes, respectively.

VALUE RELATIONSHIP SLOPES

The PDFs for 100 percent pay provided the Cb terms to be applied to the basic value concept equation (Equation 2). Completion of the development of the payment schedule required the determination of value relationship slopes (dV in Equation 2) and the computation of PDFs (Ca in Equation 2) for the pay percentages less than 100 percent.

Value relationship slopes were adopted for asphalt content, density, and gradation on the basis of analysis of data in the laboratory phase of the project. This phase was conducted to identify the relative life effects of variations in asphalt content, density, and gradation in terms of the load-associated modes of failure of fatigue cracking and rut development. Details of this work have been reported elsewhere (6).

Figures 3 and 4 show the relationships found for asphalt content and density variation. The fatigue relationships were developed for two extreme strain conditions that were believed to bracket the probable range of effects. As shown in Figures 3 and 4, the rutting relationships were found to fall between the fatigue extremes. Value relationship slopes for

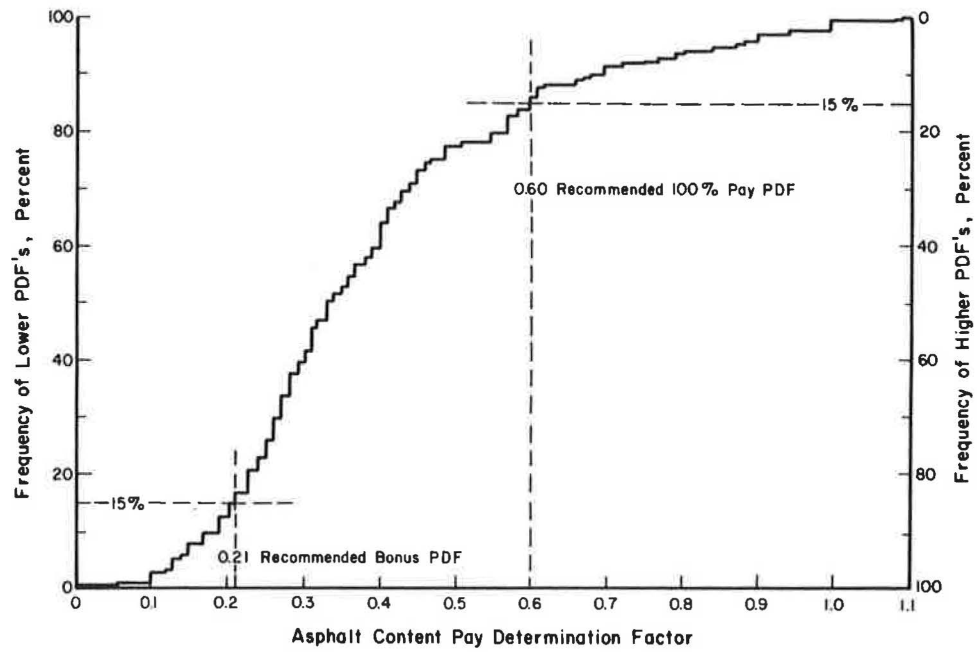

FIGURE 2 Frequency plot of asphalt PDFs for binder mix from previous QA projects.

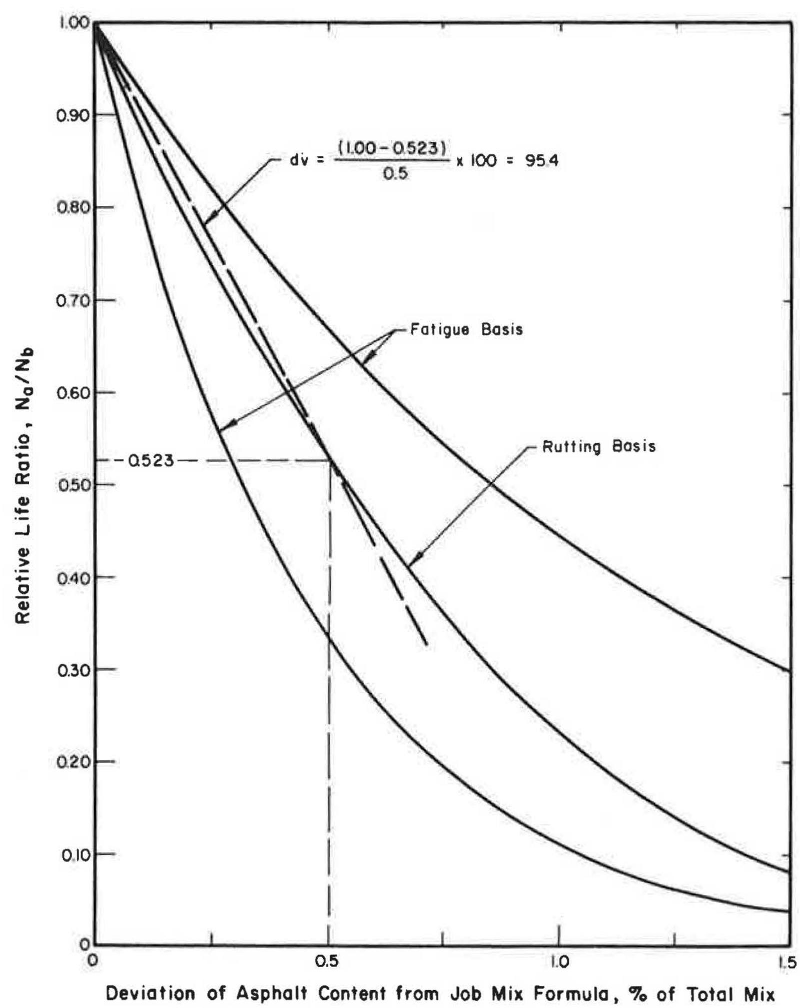

FIGURE 3 Selection of the value relationship slope (dV) for asphalt content.

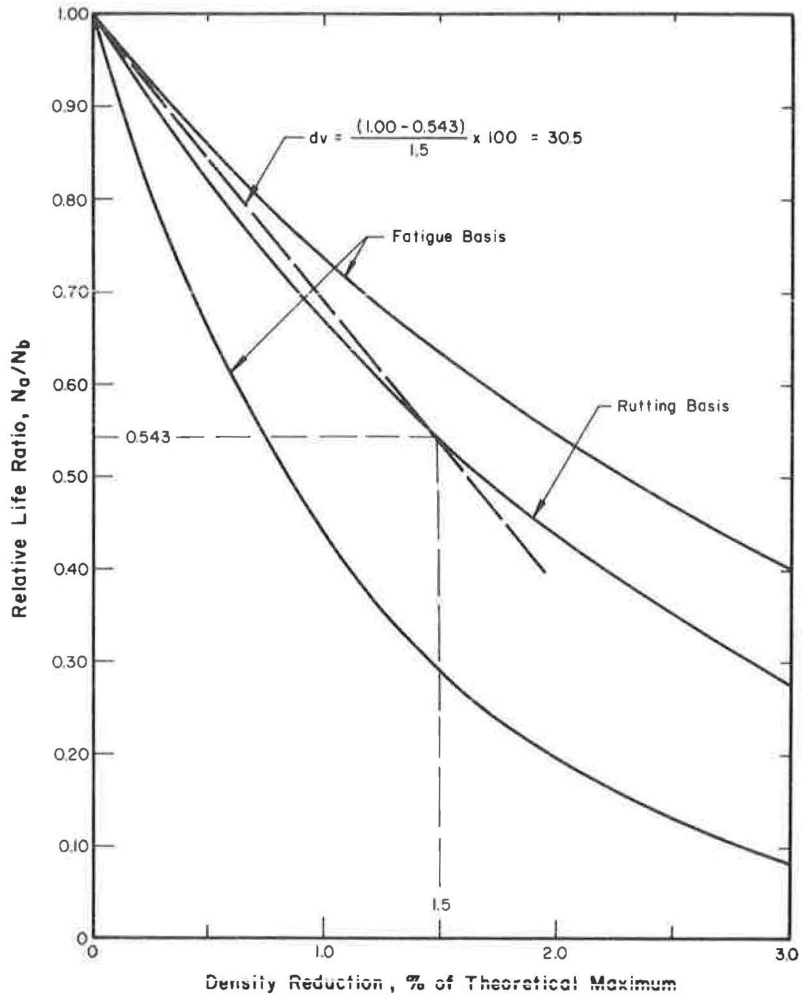

FIGURE 4 Selection of the value relationship slope (dV) for density.

asphalt content and density were selected on the basis of the rut development relationships. Consequently these slopes are considered representative of both fatigue and rutting effects. As shown in these figures, the value relationship slopes were selected as straight line approximations of the initial portion of the rut development curves. These were

dV = [(1.00 - 0.523)/0.5]*100 = 95.4
for asphalt content

and

dV = [(1.00 - 0.543)/1.5]*100 = 30.5 for density

The value relationship slope for gradation variation was selected on the basis of the finding that the fine and coarse gradation specimens exhibited a relative fatigue life ratio of between 0.33 and 0.60 compared with job mix formula specimens. The middle of this range (0.50) was selected and used to select value relationship slopes for the various gradation size fractions.

The gradation variations used in the testing (difference between the job mix formula percentage and either the coarse or the fine gradation) were 5.7 percent for the 1/2-in. to No. 4 material, 3.8 percent for the No. 4 to No. 10 material, 3.2 percent for the No. 40 to No. 80 material, and 1.9 percent for the material finer than the No. 200 sieve. With these percentages the value relationship slopes were found to be

dV = [(1.00 - 0.50)/5.7]*100 = 8.8
for 1/2-in. to No. 4 material,

dV = [(1.00 - 0.50)/3.8]*100 = 13.2
for No. 4 to No. 10 material,

dV = [(1.00 - 0.50)/3.2]*100 = 15.6
for No. 40 to No. 80 material, and

dV = [(1.00 - 0.50)/1.9]*100 = 26.3
for minus No. 200 material.

These slopes were considered characteristic of surface mixes because only surface mixes were tested with gradation variations. However, it would appear that these values can also be applied to binder mixes. The effects of variations in the other mix parameters (asphalt content and density) were not found to be significantly different for binder and surface. Thus the same slopes for gradation were used for both surface and binder mixes with one exception, the 1- to 1/2-in. binder material. Because that material size is not used in surface mixes, its value slope was not established by the testing. To select a value, a plot of the value slopes versus sieve size was developed. A smooth curve was passed between the points and a value

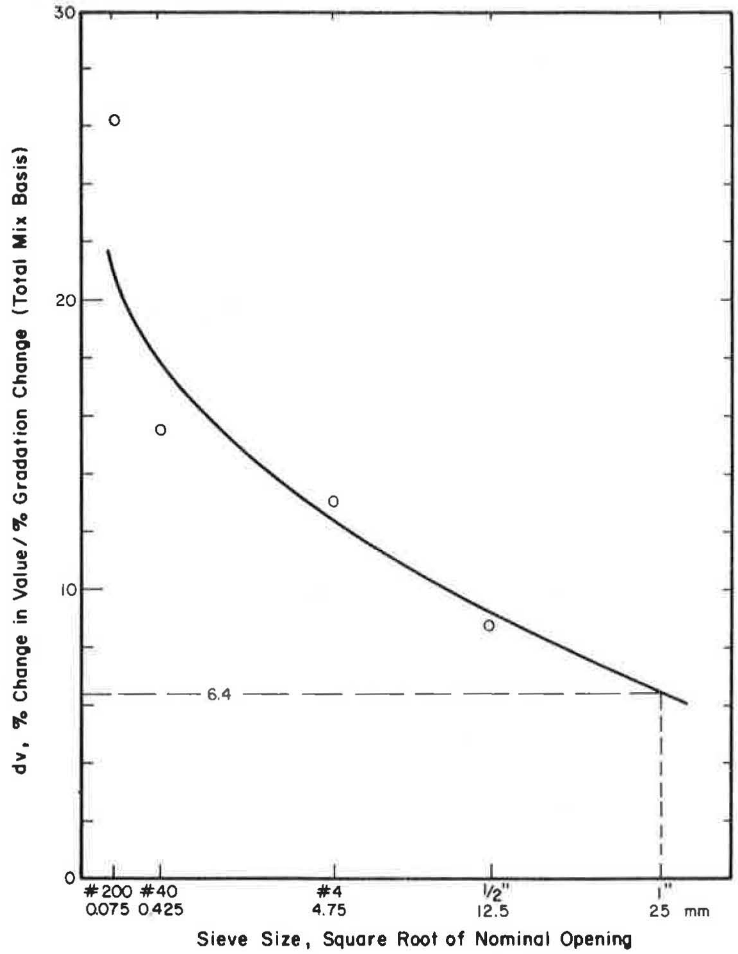

FIGURE 5 Selection of the value relationship slope (dV) for 1- to 1/2-in. material.

relationship slope of 6.4 was selected for the 1- to 1/2-in. material. This plot is shown in Figure 5.

PAY ADJUSTMENT INTERVALS

With bonus and penalty PDFs identified and with value relationship slopes selected, PDFs for pay levels other than 100 percent and bonus could be determined. However, instead of directly computing PDF values, pay adjustment intervals were determined based on the (Cb - Ca) portion of the value equation (Equation 2). These, coupled with the bonus and penalty PDF values identified for various percentages of lots to receive penalties (or bonuses), provide the flexibility needed to permit officials of any highway agency to apply their engineering judgment in accepting or modifying the recommended pay schedule. This flexibility is demonstrated in the next section.

Pay adjustment intervals were established for payment at 95, 90, 85, 80, 75, and 70 percent of the contract price. Based on the value concept, the pay adjustment intervals were determined from the equation:

$$(Cb - Ca) = (100 - P)/dV \quad (8)$$

where (Cb - Ca) is the pay adjustment interval for the payment percentage P.

Pay adjustment intervals were subsequently determined by applying the value relationship slopes to Equation 8. For example, the asphalt content pay adjustment interval for 95 percent pay (P = 95, dV = 95.4) was found by

$$(Cb - Ca) = (100 - 95)/95.4 = 0.05$$

The pay adjustment intervals found are given in Table 5.

PAY SCHEDULE

The recommended payment schedule was developed as a combination of the pay adjustment intervals (Table 5) and the PDFs for 100 percent and bonus pay (Tables

TABLE 5 Pay Adjustment Intervals

	Payment According to Percentage of Contract Price					
Mix Parameter	95	90	85	80	75	70
Density	0.16	0.33	0.49	0.66	0.82	0.98
Asphalt content	0.05	0.11	0.16	0.21	0.26	0.31
Size fraction						
1-1/2 in. (binder)	0.78	1.56	2.34	3.13	3.91	4.69
1/2 in.-No. 4 (surface)	0.57	1.14	1.70	2.27	2.84	3.41
No. 4-No. 10	0.38	0.76	1.14	1.52	1.89	2.27
No. 40-No. 80	0.32	0.64	0.96	1.28	1.60	1.92
Minus No. 200	0.19	0.38	0.57	0.76	0.95	1.14

3 and 4). For example, for asphalt content of binder mixes the 100 percent PDF was found to be 0.60 and the 95 percent pay adjustment interval was found to be 0.05. The PDF for 95 percent pay therefore is

0.60 + 0.05 = 0.65

Thus 95 percent pay would be given if the PDF value for a binder lot were between 0.61 and 0.65. For bonus pay, the PDF is simply the value for bonus pay listed in Table 3 (binder) or 4 (surface). As an example, bonus pay would be given for asphalt content of a binder mix if the lot PDF were 0.21 or less.

The complete pay schedule developed for binder mix is given in Table 6. Table 7 gives the pay schedule for surface mix.

The reader will recall that the payment schedules given in Tables 6 and 7 are based on 15 percent of all lots being penalized and 15 percent receiving bonus pay. In developing the schedule, it was recognized that other percentages of bonus or penalty (including no provision for bonus) may be deemed more appropriate. Therefore the pay schedule data were developed and presented in a manner that would permit the highway administrator to easily modify the schedule for other percentages.

Pay schedules based on other percentages can easily be developed by combining the pay adjustment intervals (Table 5) with the appropriate 100 percent and bonus PDF values from Tables 3 and 4. For example, the 100 percent pay PDF for asphalt content in binder mixes at 10 percent penalized is 0.70 (Table 3). Combining this with the 95 percent pay adjustment interval (0.05), the 95 percent pay PDF for 10 percent penalized is found to be 0.75. The bonus pay PDF for this case would be 0.19 (Table 3).

EFFECT OF SCHEDULE ON PROJECT PAY

A natural question to be asked is, "How will this payment schedule affect the average pay of the typical construction project?" To answer this, the schedule was applied to the 279 lots of binder data and 189 lots of surface data from the previous QA projects. For comparison, the previous Illinois QA payment schedule was also applied to these data. For both schedules, 50 percent pay was assigned for any item (density, gradation, or asphalt content) found to not qualify for at least 70 percent pay. According to Illinois' specification, this is the pay percentage used if the test results are beyond the schedule pay limits but the material is not removed and replaced. Also in accordance with the Illinois specification, bonus pay was awarded at 105 percent of the contract price.

The results of the analyses are summarized in Table 8. The upper portion of the table gives the average pay percentages for all lots based on (a) the current Illinois specification pay schedule; (b) the developed pay schedule that follows a 15-70-15 distribution of penalty, 100 percent, and bonus pay; and (c) a similar pay schedule based on a 10-80-10 pay distribution. Comparison of the old and newly developed schedules shows that the average pay for all projects would be slightly lower (98.1 versus 99.4 for surface and 98.1 versus 100.7 for binder) under the new payment schedule. The lower portion of Table 8 gives the percentage distribution of penalty, 100 percent, and bonus pay for each of the three pay schedules.

Examination of the results indicates that the primary reason for the lower average pay under the new schedule would be a reduction in the number of bonus payments. This is particularly true with regard to density. Actual payment data for QA jobs completed in 1979-1980 show that bonus payment was awarded for 38 percent of all surface lots and for 44 percent of all binder lots. Only 12 percent of surface lots and 9 percent of binder lots were penalized because of density. Similarly, the same data show that 20 percent of all surface lots and 42 percent of all binder lots received a bonus based on gradation and asphalt content. The penalty percentages were 23 and 7, respectively. In contrast the new pay schedule was formulated so that 15 percent of all lots would be

TABLE 6 Pay Adjustment Schedule for Binder

Mix Parameter	Pay Determination Factors for Pay Percentage 105	100	95	90	85	80	75	70
Density[a]	100.0	97.5	97.34	97.17	97.01	96.84	96.68	96.52
Asphalt content	0.21	0.60	0.65	0.71	0.76	0.81	0.86	0.91
Size fraction								
1-1/2 in.	5.0	10.0	10.78	11.56	12.34	13.13	13.91	14.69
No. 4-No. 10	2.2	5.0	5.38	5.76	6.14	6.52	6.89	7.27
No. 40-No. 80	1.5	3.2	3.52	3.84	4.16	4.48	4.80	5.12
Minus No. 200	1.0	2.3	2.49	2.68	2.87	3.06	3.25	3.44

[a]For lots having a sublot quality level of 103 or greater or an average lot quality level of 102 or greater, the pay percentage will be reduced to the next lower pay percentage.

TABLE 7 Pay Adjustment Schedule for Surface

Mix Parameter	Pay Determination Factors for Pay Percentage 105	100	95	90	85	80	75	70
Density[a]	99.5	96.6	96.44	96.27	96.11	95.94	95.78	95.62
Asphalt content	0.18	0.43	0.48	0.54	0.59	0.64	0.69	0.74
Size fraction								
1/2 in.-No. 4	3.7	7.2	7.77	8.34	8.90	9.47	10.04	10.61
No. 4-No. 10	2.2	5.3	5.68	6.06	6.44	6.82	7.19	7.57
No. 40-No. 80	1.5	3.0	3.32	3.64	3.96	4.28	4.60	4.92
Minus No. 200	0.95	2.05	2.24	2.43	2.62	2.81	3.00	3.19

[a]For lots having a sublot quality level of 103 or greater or an average lot quality level of 102 or greater, the pay percentage will be reduced to the next lower pay percentage.

TABLE 8 Results of Applying the Current and Recommended Payment Schedules to Data from 189 Surface Lots and 279 Binder Lots

	Pay Schedule					
	Surface Mix			Binder Mix		
	Current Specification	Recommended 15% P&B	10% P&B[a]	Current Specification	Recommended 15% P&B	10% P&B[a]
Average Pay Percentages						
All lots	99.4	98.1	98.6	100.7	98.1	98.9
Best job	103.2	102.5	102.5	103.1	101.9	101.0
Worst job	92.5	84.8	86.5	86.1	87.5	92.9
Percentage of All Lots						
Pay > 100%	51	28	24	60	27	22
Pay = 100%	24	38	51	25	44	59
Pay < 100%	25	34	25	15	29	19

Note: P&B = penalty and bonus and current specification is the pay schedule in Illinois' current QA specification.

[a]Effect of using a schedule based on a 10-80-10 percentage distribution of penalty, 100% pay and bonus.

penalized and 15 percent would receive a bonus in each of the pay determination categories (density, asphalt content, and gradation).

To compensate for this and to perhaps enhance the incentive capability of the bonus provision, an increase in the bonus pay to 110 percent of contract price was recommended. An alternative or possible additional method for compensating for the lower pay would be to adopt a schedule that would award bonus pay more frequently than it would penalize (e.g., 10 percent penalty and 15 percent bonus). As demonstrated, the schedule was developed in a manner that would easily facilitate adjustment to implement such an administrative decision.

In examining the lower portion of Table 8, the reader may question why the penalty and bonus percentages under the developed schedule were found to differ from 15 percent. Recall that in developing the pay schedule the 15 percent was applied to each of the three pay determination categories. Therefore 15 percent of all lots are penalized (or receive bonus) for density, 15 percent for asphalt content, and 15 percent for gradation. Lot pay, however, is the average of the pay for the three categories. A penalty (or bonus) in any one category could cause the average to be less than (or more than) 100 percent.

EXAMPLE USE OF THE PAY SCHEDULE

Table 9 gives an example use of the pay schedule. The upper portion of the table lists the target job mix formula followed by test results from five sublot

TABLE 9 Example Application of the Payment Schedule

	Job Mix Formula	Binder Mix Sublot Test Results					Avg	dJMF	Range
		1	2	3	4	5			
Size fraction									
1-1/2 in.	28.6	24.2	26.8	23.4	30.8	24.7	26.0	2.6	7.4
1/2 in.-No. 4	25.7	26.3	24.6	27.3	24.2	28.4			
No. 4-No. 10	6.5	9.0	7.3	6.3	8.8	7.1	7.7	1.2	2.7
No. 10-No. 40	13.9	12.8	14.4	16.7	11.7	13.0			
No. 40-No. 80	10.9	12.1	11.1	10.2	11.7	10.4	11.1	0.2	1.9
No. 80-No. 200	5.3	5.6	6.5	7.5	3.6	6.0			
Minus No. 200	4.3	5.0	4.0	3.9	4.7	4.9	4.5	0.2	1.1
Asphalt content	4.8	5.0	5.3	4.7	4.5	5.5	5.0	0.2	1.0
Density quality level		99.0	101.8	98.6	99.3	100.8	99.9		3.2

Note: Gradation and asphalt content

PDF = dJMF + f*R

Density

PDF = QLavg - f*R

where

dJMF = absolute difference (always positive) between the job mix formula and the average of the test values;
QLavg = lot or average density quality level;
f = range factor from Table 2, 0.43 for five samples; and
R = range, difference between the high and low test values.

PDF(1-1/2 in.) = (2.6) + 0.43(7.4) = 5.78 Pay = 100%[a]
PDF(#4-#10) = (1.2) + 0.43(2.7) = 2.36 Pay = 100%[a]
PDF(#40-#80) = (0.2) + 0.43(1.9) = 1.02 Pay = 105%[a]
PDF(< #200) = (0.2) + 0.43(1.1) = 0.67 Pay = 105%[a]
Gradation pay = 100%[b]
PDF(asphalt) = (0.2) + 0.43(1.0) = 0.63 Asphalt pay = 95%[a]
PDF(density) = 99.9 - 0.43(3.2) = 98.52 Density pay = 100%[a]
Lot pay = (100 + 95 + 100)/3 = 98.3%

[a]From Table 6.
[b]Lowest pay of the four gradation size fractions.

samples. The last three columns display the average, the deviation of the average from the job mix formula (dJMF), and the range of these test results for asphalt content, density quality level, and each of the gradation size fractions that are considered relative to pay determination. The PDF equations and definition of the terms included in the equations are shown below the test result listing. This is followed by the application of the test results in determining the PDFs and the resulting payment percentage for the lot.

It will be noted that the PDFs are determined for each of the four gradation sizes using the deviation of the average test value from the job mix formula and the range of the test values. The pay percentage for each size is determined from Table 6 with the lowest percentage being used as the gradation pay. The pay percentages for asphalt content and density are determined similarly except that for density the average quality level is used and the range has a negative impact on the PDF value. The lot payment is the average of the pay percentages determined for gradation, asphalt content, and density.

SUMMARY AND CONCLUSIONS

The developed pay schedule is based on the value concept (3), which provides a rational means for combining "real world" variability with laboratory and theoretical pavement life relationships in order to establish the value of any construction project. With this concept, both the average and the variability of the construction are taken into account.

To assure that the resulting schedule would not result either in requiring an unwarranted costly improvement in quality or in permitting a reduction in quality from current levels, data from previous QA projects were analyzed to identify the limits of acceptable and superior construction. For inferior work falling outside these limits, pay adjustments were established by using the concept of construction value as measured in terms of the expected relative effect on pavement life. The relative life effect was identified through analysis of laboratory test data and pavement behavior theory (6).

The payment schedule given in Tables 6 and 7 was developed so that 15 percent of the lots from the previous projects would have been penalized and another 15 percent would have received bonus pay. However, the schedule was developed in such a fashion that it can be easily modified to accommodate other percentages of bonus and penalty that may be considered more appropriate.

Application of the schedule to past QA project data (Table 9) indicated that, on the average, contractors would receive slightly less pay with this schedule than they would have with the QA pay schedule previously used in Illinois. To compensate for this and to provide added incentive for quality construction, it was recommended that bonus pay be increased from 105 to 110 percent of the contract bid price. At the same time, however, it is possible to use the contents and data presented to establish a pay schedule that would include no provision for bonus pay.

Based on this work, it was concluded that the value concept provides a rational, practical means for establishing pavement construction pay adjustment schedules that are fair to both the contractor and the contracting agency.

ACKNOWLEDGMENTS

This paper is based on the results of Project IHR-411, Quality Assurance Specifications.

IHR-411 was sponsored by the Illinois Department of Transportation as a cooperative study between the department and the University of Illinois. Planning of the project was a joint effort. Field data and the materials used in the testing phase were provided by the department. The laboratory testing and data analyses were performed by the university.

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Publication of this paper sponsored by Committee on Quality Assurance and Acceptance Procedures.