A Value Concept for Pavement Construction Pay Adjustment Schedules

ROBERT P. ELLIOTT

ABSTRACT

A value concept is presented that can serve as a basis for developing rational payment schedules for pavement construction. Provisions are made for incorporating both the average and standard deviation of material test results into a pay determination scheme that is based on the relative pavement life effects. the concept is based on the recognition that at the time a pavement is considered to have failed, only a small percentage of the surface actually exhibits severe distress. As a result, the life of the pavement is controlled not by the average or fiftieth percentile of the material, but by a lower percentile representative of the actual surface distress.

In an effort to develop asphalt construction pay adjustment schedules on a rational basis that would be fair to both the contractor and the highway agency, a research study was undertaken at the University of Illinois for the Illinois Department of Transportation (1). The study consisted of laboratory testing, analysis of construction quality control data from previous construction projects, and the development of a rational basis for establishing payment schedules. This paper contains a discussion on the portion of the study that was undertaken to develop a general concept for the development of pay adjustment schedules for pavement construction.

The result was the development of the "value concept." The major emphasis in developing the value concept was to identify a method for incorporating both the average and the variability of quality control test results into the pay determination in a manner that reflects their impact on pavement performance. As developed, the basic concept can be applied to any type of pavement construction if the appropriate pavement life-material property relationships are developed.

NEED FOR A VALUE CONCEPT

A recent survey conducted for the Oregon Department of Transportation contained the finding that, of the 47 highway agencies responding, 43 accepted "out-of-specification" construction in some situations, and 39 of these had formal methods or schedules for establishing pay adjustments for the work (2).

Nevertheless, there is no method for establishing these schedules that is generally accepted by all or even a significant number of agencies. Further, there appears to be a general consensus that the currently used schedules are not fully rational or fair. In the Oregon survey, for example, only 12 of the 39 agencies with pay adjustment schedules indicated a belief that their pay adjustments were equivalent to the value of the reduced pavement serviceability; and the majority of these stated that their belief was based solely on engineering judgment. Similarly, the following statement was made in an NCHRP Synthesis "All of the present systems for determining the amount of reduction in price are arbitrary to some extent" (3).

The lack of a rational basis for the pay adjustment schedules currently in use is also evidenced by the fact that most schedules consider only the mean or average value of the material properties in question. Of the 68 different pay reduction schedules summarized in Reference 3, 43 of the schedules based payment on only the average of test values with no consideration given to the range or any other measure of the overall material variability. Obviously, a construction feature can be acceptable "on the average" while still being unacceptable because of extreme variability (e.g., an acceptable average concrete compressive strength resulting from low strengths that are compensated for by high strengths).

Some of the earliest work in developing payment schedules and quality assurance specifications was conducted by the Commonwealth of Pennsylvania in conjunction with the FHWA (4). This work established payment schedules and sampling procedures based on statistical approaches commonly used in industrial applications. These approaches typically establish limits of acceptability and categorize a product as either "acceptable" or "unacceptable". The payment schedule using this approach is based on the percentage of the completed work that is within the limits of acceptability (percent within limits). Although this incorporates a consideration of material variability, the developed payment schedules do not consider and, consequently, do not necessarily reflect, the relative effect of the deviations from the target properties on the service life or value of the completed facility.

VALUE CONCEPT DEVELOPMENT

The value concept was based on the recognition that the overall performance of a pavement is a function, not of just the average value of a material property, but of the entire distribution of the property. This concept provides a framework within which laboratory testing data, theoretical and empirical pavement life relationships, and field construction variability data can be combined in developing payment schedules.

The value concept establishes the worth of any construction as a function of its effect on the service life of the pavement. In this respect, pavement service life is identified as that period (or number of load applications) from completion of construction until the condition of the pavement surface is considered to be unacceptable and rehabilitation or resurfacing is needed. The value concept was developed with the recognition that at the time, the entire pavement surface had not failed. In fact, only a small percentage of the surface area can be categorized as "failed". However, it is important to note that the amount failed is enough to give the rider a feeling that the entire pavement is bad and that something must be done to improve its characteristics.

The value concept can be explained in a general fashion by considering Figure 1. Figure 1(a) shows a general relationship between material properties and material service life such as might be established by laboratory fatigue testing and mechanistic modeling. For explaining the concept development, this relationship is illustrated as being linear and the general concept was developed accordingly. However, more complex relationships could be incorporated if warranted by data and future analysis considerations. The material property referred to on the horizontal axis may be any appropriate property such as asphalt content, density, or gradation. The expected life may be in terms of time, number of load applications, or any other appropriate measure.

Figure 1(b) represents the distribution and variability of material from a pavement construction project. At this point, it should be noted that the distribution of material properties is depicted as being normally distributed. As developed, this distribution is assumed to be a reasonable representation for highway materials. Data reported in the literature show this assumption to be reasonable. Kennedy, Hudson, and McCullough reported in a study of material variability that the distribution of various properties of asphalt concrete and portland cement concrete are approximately normal (5). Darter and Hudson reported that the distribution of the properties of several other materials also conform closely to the normal distribution (6). Nevertheless, if some other distribution was found to better represent some material property, the general concept could be reworked to incorporate that distribution.

Based on the normal distribution, the development of failures in the material depicted can be represented by a curve such as is shown in Figure 1(c). Such a curve can be developed by using the relationship represented by Figure 1(a) with the variability and distribution of material property shown as Figure 1(b). From Figure 1(c), it is apparent that although the pavement is usually considered to have a single service life, there is no "one" service life for the material in the pavement. Instead, there is a continuous distribution of lives depending on the amount of pavement failed which, in turn, depends on the range and variability of the material properties. It is this distribution of lives that contributes to, and controls the life of, the pavement and that must be evaluated to establish a value relationship.

In this respect and considering the development of failures in a pavement surface such as is represented in Figure 1(c), the pavement service life is

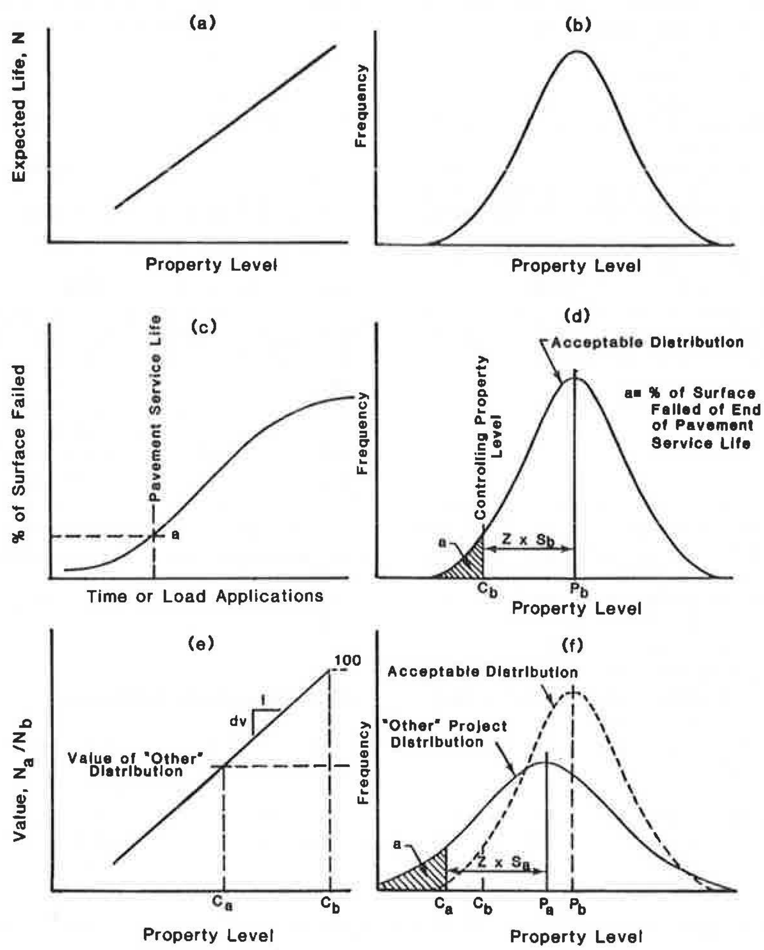

FIGURE 1 The value concept.

that period (or number of load applications) that lasts until the percentage of failed area [represented as "a" on Figure 1(c)] becomes unacceptable. Considering this in relation to Figure 1(d), it can be seen that the mix property level that controls pavement life is not the average or fiftieth-percentile level, but rather some lower percentile that is consistent with the percent of the surface area actually failed in an unacceptable pavement. For purposes of this report, this level will be referred to as the "controlling property level."

Although the a's in Figures 1(c) and 1(d) are not the same, they are related; and, if it is assumed that all of the failures are of the same type and related to the same material property, the two a's will have the same numerical value. Although this is an admitted simplification of reality, it is deemed to be an acceptable simplification for purposes of developing the general value concept.

Assuming the variation in the mix property is to be normally distributed, the controlling property level can be identified as shown in Figure 1(d) as some number, Z, of standard deviations, Sb, away from the mean. The number of standard deviations is a function of the failed area percentage, a. In developing the value concept, this percentage was left undefined with the number of standard deviations represented by Z.

To establish a base condition for the value concept, the distribution depicted in Figure 1(d) is considered to represent the variability from a "good" or "acceptable" project having some acceptable degree of variability (standard deviation = Sb) and with a mean property level denoted as Pb. From the preceding discussion, the material property level that will control the performance (or life) of this project is a value that is Z standard deviations away from the mean. The controlling property level is then

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

By using this property level with the relationship represented by Figure 1(a), a relative value for other controlling property levels (from projects having different means and standard deviations) can be established based on the ratio of life expectancies. This requires the establishment of some relationship between "value" and the life expectancy ratio. Weed has suggested a relationship based on future rehabilitation costs (7). Others have suggested using the life expectancy ratio directly. That is, if Nb represents the life expectancy at the acceptable project controlling property level, Cb, and Na is the expectancy at any other controlling property level, Ca, then the relative value, V, of Ca expressed as a percentage is

$$V = Na/Nb \times 100 \quad (2)$$

For simplicity in developing the value concept, this approach was adopted. However, a more complex relationship could be incorporated into the concept if desired. The value relationship based on the life expectancy ratio is represented in Figure 1(e) as a modified plot of Figure 1(a).

To illustrate application of the value concept, Figure 1(f) is presented. The solid plot on Figure 1(f) represents the distribution of material from some project for which a value, V, is to be established. Because the value concept is primarily of interest for construction lots that exhibit variability and deviations from specification targets that are greater than acceptable, both the mean, Pa, and the standard deviation, Sa, of the material are depicted as being greater than those of the acceptable mix. For clarity, the distribution of this material is shown superimposed over the acceptable project distribution that is represented by the dashed plot. This acceptable distribution is the same as that represented in Figure 1(d). As was established for the acceptable material, the controlling property level, Ca, for this distribution can be defined in terms of its mean, Pa, and standard deviation, Sa, as follows:

$$Ca = Pa - Z \times Sa \quad (3)$$

From Figure 1(e), the value relationship can be expressed as

$$V = 100 - dV \times (Cb - Ca) \quad (4)$$

where dV is the slope of the value relationship. Equation 4 serves as the basic value concept and provides a framework for establishing the value of any pavement construction.

It may be noted that when the actual property level, Ca, is better than the acceptable level, Cb, the value determined from the equation will exceed 100 percent. As a result, the value concept can be used for establishing bonus pay for exceptional work as well as penalties for inferior work.

CONCLUSION

The value concept presented in this paper provides a basis for developing realistic pay schedules for pavement construction that consider both the average and the variability (standard deviation) of the construction. The concept is based on the fact that when a pavement becomes "unacceptable," only a small percentage of the pavement is truly failed. Consequently, the life of the pavement is controlled not by the average value of the material properties, but by some lower percentile consistent with the percentage of failed pavement surface. The value concept provides a way to develop pay schedules based on this lower percentile and pavement life relationships.

The concept, as presented up to this point, is not complete. It considers, for example, a material property-life relationship that decreases in only one direction, and is based on population parameters without taking into account the fact that these parameters will be unknown and must be estimated from the results of a small number of tests. In addition, the concept gives no clue as to how an acceptable distribution can be identified, nor how the property-life relationship can be established.

Nevertheless, the concept, as presented, can be used to establish realistic pay schedules for pavement construction. A practical approach for applying the concept to small samples and without fully defining the acceptable distribution has been demonstrated (1,8). (This demonstration involved laboratory testing, analysis of field quality control data, and the application of theoretical pavement behavior models.)

The laboratory testing was used to identify the effects of variations in contractor-controlled material properties on the material's structural characteristics. These effects were evaluated using theoretical pavement models to establish relationships between material variability and relative pavement life. Field quality control data were used to select a range of normal variability based on actual contractor performance. Penalty and bonus pay schedules were then developed for construction variability that is "poorer" and "better" than this "normal" range based on the variability-life relationships.

In this way, the value concept provides a means for combining real-world construction variability with laboratory and theoretical pavement life relationships for use in establishing useable and fair payment schedules.

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 and conducted as a cooperative study between the Department and the University of Illinois.

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