Development of Price-Adjustment Systems for Statistically Based Highway Construction Specifications

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This paper presents a methodology that can be used to develop price-adjustment systems for use in statistically based highway construction specifications. Three approaches are proposed for the development of a price-adjustment system: (a) the serviceability approach, (b) the cost of production approach, and (c) the operating characteristic curve approach. The three approaches are discussed and compared, and their most appropriate applications are recommended. A fourth approach, the cost of quality control approach, is also discussed but is not fully developed because of the limited cost data available.

The advent in recent years of statistically based highway construction specifications has resulted in many highway agencies incorporating various systems of price adjustment into their specifications so as to take into consideration the degree to which the finished product conforms to requirements. A price-adjustment system forms an important part of the specifications, but few guidelines have been made available for the development of an equitable system. As a result, many of the initial price-adjustment systems have been developed primarily through judgment, and further adjustments that have been made have been dictated by experience under actual contract conditions. Unfortunately, such an evolution often occurs at the expense of one or more of the contractual parties that have agreed to proceed under the specifications. In addition, because the desired operating level may not have been decided in advance, it becomes difficult to determine objectively just when an equitable price-adjustment system has been attained.

This paper presents a methodology that may be used by highway agencies to establish effective price-adjustment systems for their statistically based specifications. The methodology can be applied in conjunction with the development and the implementation of a new set of specifications, or it can be applied as a means of establishing the adequacy of the price-adjustment system currently used by the agency.

SPECIFICATIONS

The suitability or effectiveness of a price-adjustment schedule, viewed by itself, is impossible to determine. (Here, a price-adjustment schedule is defined as a tabular, graphical, or formular representation that establishes, for a given material characteristic, the payment factors associated with estimated quality levels of that characteristic; a price-adjustment system, on the other hand, is composed of the various schedules that together are used to determine the contractor's final payment for a given material.) The schedule is but a small part of the specifications, and its merit can only be determined by viewing it in the entire context of the specifications.

Welborn (1), in a report summarizing the statistically based bituminous concrete specifications of several agencies, points out that many differences exist in the specifications in the following areas: responsibilities assigned to the agency and to the contractor, mix design criteria, quality control tolerances, and acceptance plans (specifically, acceptance quality characteristics, basis for acceptance, lot size, and number of samples). When the implementation of statistically based specifications for other materials (e.g., portland cement concrete paving, structural concrete, and soils) becomes as extensive as it is for bituminous concrete today, these specifications too will probably vary widely from agency to agency.

A price-adjustment system must be tailor-made for the specifications in which it will be contained. Therefore, a necessary first step in the design of a price-adjustment system is that of examining and understanding the specifications. Several questions about the agency's statistically based specifications must be answered before a price-adjustment system can be developed:

1. What are the quality characteristics that are to be used as a basis for acceptance? What properties do these characteristics measure? Are all the desired properties taken into account? How are the characteristics related?
2. What procedures are to be used to determine the degree of acceptability of material submitted by the contractor?
3. How have the acceptance limits been determined? What is the relation between the acceptance limits and the statistical parameters of the material?
4. What risks are being taken by the contractor? What risks are being taken by the highway agency? What are the operating characteristic curves of the acceptance plans? (This set of questions applies only to the case in which the adequacy of a price-adjustment system already contained in the specifications is to be determined.)

Acceptance Quality Characteristics

Each quality characteristic that is to be used for acceptance must provide a measure of one or more of the significant properties that are desired in a completed product. Not all of the desired properties must be taken into account by the acceptance quality characteristics; some of them can be adequately controlled by requirements or guidelines placed on the contractor's daily process-control activities. But all properties that are considered desirable must be adequately controlled either through acceptance or process-control testing of the quality characteristics.

Because of the large number of quality characteristics that can be used in various combinations as acceptance characteristics, the number of possible price-adjustment systems is also large. In other words, once a decision is made as to what properties are to be controlled, the designer has a number of quality characteristics from which to choose in establishing the basis for acceptance. In addition, as will be discussed later in this paper, several rational approaches for the establishment of a price-adjustment schedule for a given acceptance characteristic may be available to the designer. The choice of acceptance characteristics that are to be used should therefore take into account the effects that will be created by the implementation of the overall price-adjustment system. Two of the more important effects that should be considered are (a) the interdependency among acceptance quality characteristics (which may need to be minimized) and (b) effects on the relation among the highway agency, the contractor, and the material supplier (a relation that should be optimized).

Acceptance Plans

An acceptance plan is generally defined as an agreed-on method of making measurements for the purpose of determining the acceptability of a lot of material or construction. Although many different statistically based acceptance plans are currently in use, they should all have a common denominator in that they should each define

1. Lot size,
2. Number of samples or measurements,
3. Sampling or measurement procedure,
4. Point(s) of sampling or measurement,
5. Numerical value of acceptance or specification limit(s), and
6. Method of evaluating acceptability.

Each of these items affects the subsequent development of individual price-adjustment schedules. For example, if the number of measurements is small, the uncertainty associated with an estimate of lot quality will be greater than if the number of measurements is large. On the other hand, if the specification limits are wide (in the case where both a lower and an upper limit exist), more material can be expected to fall within those limits and the price-adjustment schedule would appear to be strict in comparison to one based on narrow specification limits. It is important, therefore, that each of the above items be known before an attempt is made at establishing a price-adjustment schedule.

Acceptance Limits and Statistical Parameters

There are basically two approaches for establishing realistic acceptance limits (2, 3). The first approach involves assigning numerical values based solely on engineering requirements. This means that the permissible range for the specific quality characteristic must be determined. It may be possible in some cases to derive the permissible range by means of a theoretical or experimental procedure, but this is often difficult. A more practical approach for setting realistic acceptance limits is to measure the properties (statistical parameters) whose existing construction is satisfactory. Limits are then established so that the material quality will at least stay at the present acceptable level. This is the approach used by most highway agencies that have adopted statistically based specifications.

There are two generally recognized methods for determining the statistical parameters of acceptable construction: (a) Statistical analyses can be performed on historical data, or (b) a separate sampling system can be installed to obtain data under a controlled procedure. If statistical analyses are to be performed on historical data, caution must be exercised in making sure that the data were actually obtained by random sampling. Because few historical data have been collected by random sampling, many highway agencies have introduced separate sampling systems on typical projects under construction. If the data collection system is properly controlled, this method will result in more up-to-date and reliable data.

When the statistical parameters that typify existing construction are known for a given acceptance characteristic, they can be related to the acceptance limit(s) to establish a reference by means of which various levels of quality can be compared. For example, if the typical relative density of bituminous concrete pavement is 100 percent with a standard deviation of 2 percent, then, by calculating the appropriate area under a normal distribution, 97.72 percent of the tests on submitted lots that are of a quality equivalent to that of existing construction can be expected to result in a relative density greater than 96 percent.

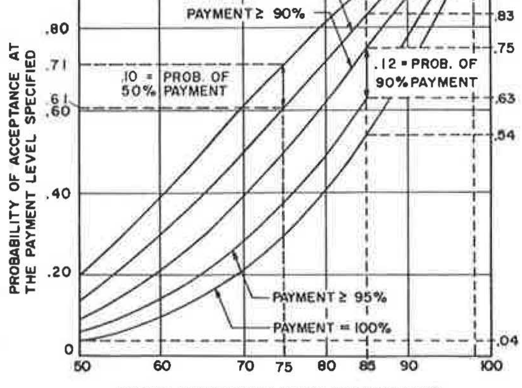
Operating Characteristic Curves

The most common technique used in evaluating the risks that are part of any acceptance plan is the development of operating characteristic (OC) curves. If the adequacy of a price-adjustment system that already exists in the specifications must be checked, it is important to investigate the OC curves.

In its most basic form, an OC curve relates the quality of a lot to the probability of its acceptance. However, when a price-adjustment schedule is part of the acceptance plan, the probability of acceptance associated with various levels of quality does not provide sufficient insight into the risks involved in the acceptance plan. In such a case, it is far more meaningful to think not only in terms of the probability of acceptance of a lot but also in terms of the probability of a lot being assigned any one of the specified payment reductions (or increases). A set of OC curves should thus be drawn to relate the quality of a lot to the probability of its acceptance at each of the specified payment levels. A discussion of the development of such sets of OC curves can be found elsewhere (4).

An example of the type of information that can be provided by OC curves is shown in Figure 1. The set of OC curves shown in the figure was developed from the price-adjustment schedule used by the Pennsylvania Department of Transportation (PennDOT) in its acceptance plan for the density of bituminous concrete pavement. The price-adjustment schedule is given below. For acceptance purposes, a lot of material is divided into five sublots (i.e., n = 5).

Figure 1. Operating characteristic curves for PennDOT acceptance plan for bituminous concrete pavement density.



Estimated Percentage of Lot Above Density Limit	Percentage of Contract Price to Be Paid	Estimated Percentage of Lot Above Density Limit	Percentage of Contract Price to Be Paid
85 to 100	100	70 to 74	80
80 to 84	95	65 to 69	50
75 to 79	90	<65	–

According to the PennDOT schedule, when <65 percent of a lot is estimated to be above the density limit, the lot shall be removed and replaced to meet specification requirements as ordered by the engineer. Alternatively, the contractor and the engineer may agree in writing that, for practical purposes, the lot should be removed and should be paid for at 50 percent of contract unit price.

From Figure 1, it can be seen that a bituminous concrete lot that actually has 85 percent of material above the specified density limit will be accepted 54 percent of the time at full payment, 63 percent of the time at a payment equal to or greater than 95 percent, 75 percent of the time at a payment equal to or greater than 90 percent, and so on. The probability of the lot receiving exactly 90 percent payment, for instance, is found by subtracting the probability of receiving a payment equal to or greater than 95 percent from the probability of receiving a payment equal to or greater than 90 percent.

In Pennsylvania, when statistically based bituminous concrete specifications were being developed, it was determined that a lot having 98 percent of material above the specified density limit typified the level of quality that had been incorporated in acceptable construction in Pennsylvania in the past. Figure 1 shows that lots submitted at this typical quality level will be accepted at full payment approximately 97 percent of the time and will practically never be rejected. Therefore, if the contractor submits the type of material that has normally been submitted in Pennsylvania, the chances are very good that he or she will receive full payment.

The information provided by Figure 1 can also be used to plot the relation between the quality of the contractor's material and the expected payment (or average payment over the long run). The development of this relation for the Pennsylvania density schedule is given in Table 1, and the resulting curve is shown in Figure 2. It can be seen that a contractor who is providing material of a quality typically found in Pennsylvania construction (i.e., lots in which 98 percent of the material is above the specified density limit) can expect an average payment of 99.7 percent. At the other end of the scale, a contractor who is providing material that contains 50 percent material above the limit, for instance, can expect an average payment of 35.6 percent. Other expected payments for various quality levels can be obtained in the same way. The expected payments in this example may be misleading, however, especially at low quality levels, unless the assumptions made in Table 1 regarding the 50 percent payment level are understood. A more detailed discussion of this particular expected-payment curve can be found elsewhere (5).

The OC curves and the curve of expected payment can be used as a basis for determining whether the acceptance plan (with the price-adjustment schedule) is reasonable. Because the answer depends largely on the philosophy of the highway agency, several questions should be posed in analyzing the curves: Is the highway agency satisfied with the performance of roads that have been constructed at the typical quality level? Does the highway agency want the same quality or a higher or lower quality than that provided in the past? If higher (or lower), how much higher (or lower)? What does the highway agency consider to be unacceptable material in relation to the quality characteristic in question? What does the highway agency consider to be good material? What risks are the highway agency and the industry willing to take?

If it is determined that the price-adjustment schedule is not reasonable, then one or more of the following changes can be made:

1. Change the sample size.
2. Loosen or tighten the acceptance or specification limit(s).
3. Increase or decrease payment for a given quality level.
4. Increase or decrease the number of payment levels.

The exact modification to be made depends on the nature of the inadequacy. After the modification has been made, new OC curves and a new curve of expected payment should be drawn and evaluated.

PRICE-ADJUSTMENT APPROACHES

Serviceability

Perhaps the most logical basis for establishing a defensible price-adjustment schedule is the selection of an adjustment in unit price that is commensurate with the expected serviceability or performance of the furnished product. If the acceptance characteristic can be strongly correlated with the serviceability or the performance of the pavement, it may be desirable to relate the payment reductions to the expected losses in pavement performance. For example, assume that it is undesirable to accept bituminous concrete that will result in a pavement with a service life that is less than 75 percent of the design life. If pavement thickness can be shown to be directly correlated with service life, then the value of thickness that is to be considered unacceptable can be determined. Thus, if a 12.7-mm (0.5-in) thickness deficiency reduces service life by 25 percent, bituminous concrete pavement that has a deficiency of 12.7 mm or more should not be accepted. Furthermore, for pavements that are deficient by less than 12.7 mm, a price-adjustment factor related to the expected percentage of design life may be used.

Several state highway agencies have used a serviceability approach for one or more of their price-adjustment schedules. Two examples are the thickness schedule for bituminous concrete pavements of the New Jersey Department of Transportation (6) and the smoothness schedule for portland cement concrete pavements of the New York State Department of Transportation (7).

Developing a price-adjustment schedule based on serviceability is, however, not always possible, for two reasons: (a) The desired precise correlation between the quality characteristic and pavement performance does not exist in many cases, and (b) performance data relating the quality characteristic to the maintenance-free life of pavements are often not available. Therefore, although the serviceability approach is highly desirable, any methodology for the development of a price-adjustment system should also consider alternative approaches.

Cost of Production

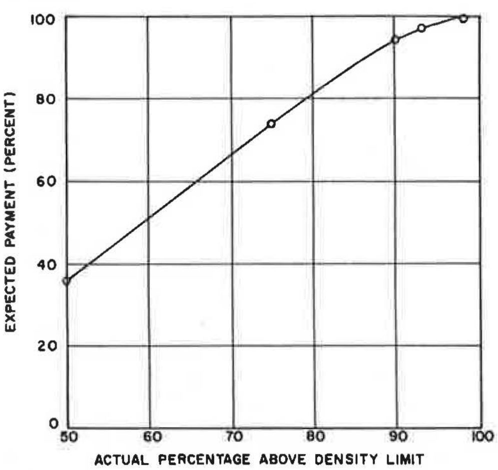
The cost of production approach is limited in use to only a few quality characteristics. In this approach, the payment reduction should be greater than the reduction in cost that results when lower quality material is being produced. For example, if the design thickness of a

Table 1. Calculations of expected payment for PennDOT acceptance plan for bituminous concrete pavement density.

Percentage of Lot Above Density Limit	Percentage Probability of Receiving Payment of 100 Percent	95 Percent	90 Percent	80 Percent	50 Percent[a]	0 Percent	Expected Payment[b] (%)
50	0.04	0.02	0.03	0.05	0.06 + 0.40	0.40	4.0 + 1.9 + 2.7 + 4.0 + 23.0 + 0 = 35.6
75	0.30	0.08	0.12	0.11	0.10 + 0.26	0.03	30.0 + 7.6 + 10.8 + 8.8 + 18.0 + 0 = 75.2
90	0.70	0.09	0.09	0.05	0.03 + 0.04	0	70.0 + 8.6 + 8.1 + 4.0 + 3.5 + 0 = 94.2
93	0.82	0.07	0.06	0.02	0.02 + 0.01	0	82.0 + 6.6 + 5.4 + 1.6 + 1.5 + 0 = 97.1
98	0.97	0.01	0.01	0.01	0	0	97.0 + 1.0 + 0.9 + 0.8 + 0 + 0 = 99.7

[a] The probability of receiving 50 percent payment is the sum of two probabilities: the probability of obtaining a quality estimate that requires 50 percent payment and the probability of receiving 50 percent payment when removal is an alternative. To determine the second probability, it is assumed that material that is actually 50 percent above the density limit will be paid for at half price in 50 percent of the cases where a decision must be made between removal and acceptance; material that is 75 percent above the density limit will be paid for at half price in 90 percent of such cases; and material that is more than 75 percent above the density limit will be paid for at half price in 100 percent of such cases.
[b] Σ(payment) x (probability of receiving payment).

Figure 2. Expected payment curve for PennDOT acceptance plan for bituminous concrete pavement density.



bituminous concrete wearing course is 50.8 mm (2 in) and the average thickness attained is found to be 43.2 mm (1.7 in), the contractor can be said to have incorporated only 85 percent [(1.7 ÷ 2)100] of the material required to do the work. The cost of production is thus assumed to be 15 percent less than it would have been had the required thickness been provided. The contractor's payment should therefore be reduced by 15 percent of the cost of the material. If the payment reduction is any less than 15 percent of the cost of the material, it may be more beneficial for the contractor to place deficient thickness and accept the payment reduction. To make certain that the contractor will not be tempted to place a deficient thickness, the price reduction should be greater than 15 percent of the cost of the material.

In most cases, however, the cost of the material is actually unknown to the purchasing agency. The agency knows only the item bid price, which includes the cost of labor, equipment, and overhead as well as the cost of the material. Although the cost of material has decreased for the contractor who is producing material of deficient thickness, the other costs in the item bid price may have remained essentially constant. If it can be assumed that the cost of material in the example given above is half of the total cost, then the appropriate price reduction should be at least 7.5 percent of the item bid price. A factor of one-half seems to be reasonable for bituminous concrete wearing course (8).

The price reduction thus depends on two ratios:

1. The fractional deficiency ratio (i.e., the deficiency divided by the required amount, or 0.3 ÷ 2.0 = 0.15 in the example); and
2. The ratio of the cost of the material to the item bid price (0.5 in the example).

If these two ratios are multiplied, a minimum price reduction of 0.075 or 7.5 percent of the item bid price is obtained.

Besides being used for the thickness acceptance characteristic as discussed above, the cost of production approach can also be used in bituminous concrete pavements for a characteristic such as asphalt content and in portland cement concrete pavements for thickness and the quantity of portland cement used (bags per cubic meter). It should be noted, however, that the cost of production approach can only be used for acceptance characteristics that have a single (lower) acceptance limit. In the case of asphalt content, the upper acceptance limit would have to be eliminated and replaced in the specifications by an additional acceptance characteristic such as skid resistance, which would function to prevent an excess in asphalt content.

Operating Characteristic Curve

It was indicated earlier that OC curves and curves of expected payment can be used to determine the desirability of a given acceptance procedure and its related price-adjustment schedule. These curves may also be used directly during the course of the development of a price-adjustment schedule. This approach is referred to here as the OC curve approach.

The OC curve approach can be used to develop the entire acceptance plan or the price-adjustment portion of the plan only. If it is used in the development of the entire acceptance plan, two points must be defined on the OC curve graph. In other words, the agency must establish the probability for accepting (or rejecting) two different levels of quality for material. The two quality levels should preferably not be spaced too close to each other. In defining the two points, it is easiest for the agency to think in terms of the probability desired for rejecting material that has been designated as good and the probability desired for accepting material that has been designated as poor. Only one OC curve can pass through the two points—the curve that identifies the sample size and the acceptance limit(s) that are to be used.

Once the sample size and the acceptance limit(s) have been established (whether or not OC curves have been considered to that point), the agency can use OC curves and curves of expected payment to develop a reasonable schedule. A trial schedule should be devised. In the first step, the price reductions can either be designed to increase sharply with decreasing quality or they can be designed to increase linearly with decreasing quality.

Next, OC curves (for the various levels of payment) and curves of expected payment can be drawn. If both the agency and the contractors are pleased with the curves, then the schedule can be incorporated into the specifications. If not, then either the price-adjustment schedule or the acceptance plan must be modified by means of the changes suggested earlier in this paper (changing the sample size, loosening or tightening the acceptance or specification limits, increasing or decreasing payment for a given quality level, and increasing or decreasing the number of payment levels). After the appropriate modification has been made, new OC curves and a new curve of expected payment are drawn and the process is repeated until both contractual parties are satisfied.

Cost of Quality Control

The development of a price-adjustment system that is based on the contractor's cost of quality control was also investigated during the course of this research (4, 5, 9). A price-adjustment system based on the cost of quality control would logically relate the reduction in payment for inferior material to the contractor's reduced spending on quality control. Inherent in the development of such a system is the assumption that there is a direct relation between the contractor's cost of quality control and the quality of the resulting construction.

In an effort to determine whether this approach could be implemented, an attempt was made to gather the data necessary to determine the relation that existed between what a contractor spent on quality control of a project and the resulting quality of that project. This relation seemed to be obscured by variable project conditions—such as weather and the distance from the plant to the project—that influence quality but cannot readily be associated with the cost of quality control. Furthermore, cost data for the Pennsylvania situation were unavailable on a project-by-project basis. Nonetheless, this approach has a certain intuitive appeal and may be found to be workable as more cost data become available.

DEVELOPING AND IMPLEMENTING A PRICE-ADJUSTMENT SYSTEM

Factors for Consideration

Incorporating price-adjustment tables or formulas into specifications is not a simple matter. Even if a rational method could be used to determine price adjustments, many issues must still be considered before the payment factors can be declared acceptable. For instance, the price-adjustment system must be consistent with the highway agency's philosophy regarding the level of quality desired in future construction. In addition, the effect of combining individual price-adjustment schedules to form a price-adjustment system must be considered.

The preceding discussion of the various approaches to price adjustment may have implied that a price-adjustment schedule that involves only judgment is undesirable, but this is not necessarily true. A rational schedule, of course, would be ideal, but it is not essential. DiCocco (10) states that the main function of reduced payment is to provide an alternative means of enforcing the contractual agreement. An entirely rational price-adjustment schedule is not always required to enforce the contractual agreement. Any arbitrary price-adjustment schedule, as long as it is reasonable, can serve that purpose.

Because the four price-adjustment approaches discussed here are based on sound mathematical procedures, they each represent a rational (and therefore defensible) method of determining price adjustments. But when two or more of these approaches can be applied to the same quality characteristic, they will probably not result in the same price adjustment. In the case of pavement thickness, for example, the serviceability, cost of production, and OC curve approaches are all applicable (the cost of quality control approach may also be applicable, but it is disregarded here because it could not be fully developed at the time the research was performed). The question that logically follows is, Which approach should be applied when two or more approaches are possible?

The authors believe that all possible approaches should be considered for a given acceptance characteristic. In the pavement-thickness example mentioned above, a comparison should first be made between the serviceability approach and the cost of production approach. If the price reduction based on the cost of production turns out to be larger than the price reduction based on serviceability, perhaps it is in the interest of the highway agency to use the cost of production approach because the smaller price reduction for serviceability would allow the contractor to benefit by producing deficient material. But it may also be argued that, if at all possible, the highway agency should be primarily concerned with the serviceability approach. In this case, if a contractor can provide the required serviceability at a reduced cost of production, it is an incentive for him or her to do so.

The selection of either the serviceability or the cost of production approach, however, does not ensure that the resulting schedule will be either reasonable or readily acceptable by the industry. It is therefore recommended that the OC curve approach also be adopted (and that either the serviceability or the cost of production approach be used as a trial schedule). Although the OC curve approach cannot be said to be as rational as the other approaches, its primary benefit is that it provides a means by which the highway agency can define the quality level the agency desires. It is also more likely to yield a schedule that will be accepted by all parties involved.

Methodology

In view of the material that has been discussed, the following methodology is suggested for the development of a price-adjustment system:

1. Acceptance characteristics should be chosen so as to ensure that the desirable properties of the material are evaluated. The combination of acceptance characteristics and required process-control characteristics should be inclusive enough to provide adequate protection to the highway agency.
2. Individual price-adjustment schedules should be devised by considering each acceptance characteristic separately.
3. The ideal schedule is probably one that assigns a payment reduction equal to the economic consequences of reduced quality. If the acceptance characteristic being considered correlates strongly with pavement serviceability or performance, such a schedule can be developed. If not, the highway agency should consider the cost of production approach.
4. If the price-adjustment schedule is developed on the basis of serviceability, a schedule based on the cost of production method should also be developed if possible. After the results of both methods are compared, it may be beneficial from the highway agency's point of view to use the cost of production method whenever it

results in a larger price reduction. OC curves and curves of expected payment should also be developed as a check to ensure that the proposed schedule is reasonable and meets the desires of the agency.

5. If neither the serviceability method nor the cost of production method applies to the acceptance characteristic in question, the trial-and-error OC curve approach should be used.

6. The overall effect of combining the individual schedules should be considered. Adjustments should be made to the individual schedules if necessary. When adjustments are made, OC curves and curves of expected payment should be redrawn.

7. The entire system should be carefully monitored under contract conditions. Data related to cost, serviceability, and quality should be gathered continuously as a check on the design assumptions of the price-adjustment system. The effects on the relation among the highway agency, the contractor, and the material supplier should also be examined.

Implementation

Although a properly developed price-adjustment system can do much to improve the relation between the highway agency and the contractor, it must be kept in mind that a price-adjustment system is only as good as the specifications that encompass it. If the specifications are confusing or ambiguous, the price-adjustment system cannot hope to provide equitable treatment for all contractors. If the specifications are not uniformly enforced, the price-adjustment system cannot provide impartiality. For this reason, uniform interpretation and enforcement of statistically based specifications containing price-adjustment systems are more critical than they are under the conventional materials-and-methods type of specifications. The implementation of statistically based specifications containing price-adjustment systems should force highway agencies to make improvements that have been overlooked in the past.

The question of which party is to perform the required acceptance tests during the implementation of statistically based specifications is often debated. Some people reason that, because the highway agency is responsible for acceptance of the product, the highway agency should perform its own acceptance tests. This is sound reasoning only when the highway agency uses a central laboratory to perform all acceptance tests. If individual field inspectors perform the acceptance tests, the same submitted material will not necessarily have the same probability of acceptance. Testing error has been found to be the major source of variation in many quality characteristics (2, 11). For that reason, the determination of payment should not depend on the abilities of highway-agency inspectors. The contractor's technician should be allowed to perform the acceptance tests so that any penalty incurred because of testing errors will be the fault of the contractor.

Another obstacle to the implementation of statistically based specifications seems to be the fear of increased legal complications resulting from the enforcement of the price-adjustment system. Conflicts will undoubtedly arise not only between the highway agency and the contractor but also between the contractor and the subcontractors and suppliers. A contractor who is assigned a sizable price reduction is likely to contest it. The apparent inferior quality may well not be the contractor's fault. The contractor's point of view must be considered: Is the price-adjustment system placing the contractor in a situation that will create legal entanglements?

Clearly, better and more binding contractual agreements will have to be developed between contractors and suppliers. However, the type of price adjustment can also do much to improve the situation. Acceptance characteristics that can potentially create conflicts should not be used. For example, the PennDOT acceptance characteristics for bituminous concrete are asphalt content, density, thickness, and smoothness. This system minimizes legal complications because the responsibility for the control of each characteristic essentially falls on only one party. Asphalt content is clearly the responsibility of the producer. Thickness, smoothness, and density are primarily the responsibility of the contractor.

A price-adjustment system cannot be successful unless all parties are satisfied. The recommendations and the comments of contractors and suppliers should be investigated. The system that is initially implemented will probably have limitations that will only be discovered under contract conditions. Because of constantly changing construction conditions, the effectiveness of the price-adjustment system is also subject to change. The price-adjustment system will need to be reevaluated periodically because of new developments in testing and construction procedures and changes in prices. The highway agency must therefore be flexible enough to correct inequities that become apparent during implementation of the price-adjustment system.

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Statistical Quality Assurance in Highway Engineering in South Africa

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This paper examines the first large-scale application of process and acceptance control plans to a major road construction project in South Africa. The acceptance control scheme used and its background are outlined, and certain controversial features of the scheme are discussed. The variability of typical South African construction materials and processes is indicated. Some economic consequences of the use of the plan are also reported. Because the average quality of the work was well above the minimum standard required, a fully conclusive assessment of the financial advantages or disadvantages of the scheme is not possible. Because of this, a comparison was made between the acceptance decisions of the specific scheme discussed, and those of the engineering judgment approach. It is concluded that the use of the statistical method leads to more consistent interpretation of results, and the continued use of this scheme on highway projects is recommended.

Highway authorities in South Africa, like authorities in other countries, have for several years been concerned about the quality of construction work, particularly about the application of uniform standards of judgment to the acceptance or rejection of such work. The Division of National Roads of the South Africa Department of Transport—aware that differences existed in materials, construction processes, and contractors and that supervisory engineers often applied different criteria to work that did not strictly conform to specifications—decided in 1972 to incorporate statistical principles into certain road contracts. This was done so that the properties of engineering materials could be rationally defined and to assist in providing uniform criteria of judgment for acceptance or rejection decisions. The department primarily wanted to give economic encouragement to contractors who delivered uniform construction work and to reduce as far as possible the risk of having basically acceptable work rejected.

The theory and the design of the acceptance control plans adopted for use by the Division of National Roads are fully described by Kühn, Mitchell, and Smith (1). A document that explains the system and the method of implementation and also contains a typical specification is available (2). In conjunction with the Natal Roads Department, the division decided that the first major contract on which statistically oriented acceptance control procedures would be used in judging certain parameters would be a contract encompassing a portion of National Route 2 on the Durban Outer Ring Road. This $8 million contract consisted of the construction of 4.8 km of six-lane double carriageway freeway including 1.3 million m^3 of earthworks, 66 Gg of asphaltic concrete, and 121 000 m^3 of base and subbase layers.

ACCEPTANCE CONTROL IN SOUTH AFRICA

The decision to use a statistically oriented acceptance control procedure for the National Route 2 contract did not originally meet with enthusiasm from all the road engineers involved in the project. This was not surprising for two reasons: (a) Nearly every change in existing quality control procedures in road construction had met with the same reaction, and (b) most engineers do not possess an in-depth knowledge of the principles of statistics. Statistical methods are helpful, however, in solving problems of quality control and acceptance of completed work in road engineering, provided they are properly applied. It is anticipated that such procedures will come to be recognized as a definite improvement on past methods and that they will become standard practice for quality control.

In the early stages of the development of road construction in South Africa, many of the current specifications and tests were developed on an empirical basis and were largely method-type procedures both to guide contractors and to provide parameters for quality acceptance. One of the major functions of a specification was to convey technical instructions to both the contractor and the resident engineer.

It is hoped that, because of the accent on technological improvements in the contracting industry, it will soon be possible to specify only the significant characteristics of the end product in terms of measurable parameters and use a rational acceptance control procedure for the acceptance of the work. Before this goal can be reached many problems must be overcome, the most important of which is changing the practice of ill-defined joint control of both processes and acceptance by contractor and engineer to separate control of processes by the contractor and control of acceptance by the engineer.

The statistical procedures now being introduced into the South African road construction industry are not new concepts; similar procedures have been successfully applied in road construction in North America for many