Utility Decision Analysis to Select Aggregates for Asphalt Pavements

PODURU M. GANDHI and ROBERT L. LYTTON

ABSTRACT

Several recent studies have indicated that significant aggregate shortages can occur in about one-third of the states. One important factor contributing to this shortage is that the current aggregate specifications in some states generally tend to disqualify some marginal aggregates that could otherwise give satisfactory service under certain conditions. The research reported in this paper was undertaken to assist in alleviating the aggregate shortage and broaden the base of\aggregate supply by selecting suitable aggregate evaluation methods. The research was conducted in two phases, each of which studied a different aspect of the problem. Phase I was concerned with the overall aggregate evaluation procedures that are used in various states. Phase II dealt with the evaluation of the laboratory tests and petrographic examinations that are used to determine whether aggregates meet specifications. A literature review and a survey of current state practices resulted in the identification of four alternative schemes that are used in the states for evaluating the quality and performance of aggregates. The schemes mainly differ in the relative emphasis put on the aggregate tests, asphalt mix tests, service experience, and the prequalification of aggregate sources based on certain aspects. The relative usefulness of the four schemes was evaluated by means of the utility decision analysis. It is also noted that there is a need to consider other factors such as aggregate reserves, production costs, haul distances, environmental factors, and energy use in addition to the evaluation of quality of an aggregate.

It is generally understood in the highway profession that significant shortages of quality aggregates are imminent in many states (1). One important factor contributing to this shortage is that current aggregate specifications in some states generally tend to disqualify many marginal aggregates that could otherwise give satisfactory service under certain conditions. This research was undertaken under the sponsorship of the National Cooperative Highway Research Program (NCHRP) mainly to address this problem. The main objective was to develop procedures for selecting aggregates for bituminous paving mixtures that may permit the use of marginal aggregates when warranted. The study was conducted in two phases. Phase I dealt with the identification and the development of a systematic procedure to aid in the selection process. Because the estimation of several of these factors involves some uncertainties, a methodology based on utility decision analysis was used. Phase II concentrated on the evaluation of various aggregate and asphalt mix test procedures that can be related to actual performance in the field. In this paper the work done during Phase I is summarized. Results of the Phase II study are reported elsewhere (2).

The current state of the art of methods for evaluating and selecting bituminous paving mix aggregates was assessed on the basis of the published literature and a national survey of state practices. A complete analysis of the national survey can be found in the interim report submitted to NCHRP (3). A summary of the prequalification requirements for aggregate selection in various states is given in Table 1. In addition, during visits to state highway materials offices, information was collected on their aggregate evaluation procedures. An analysis of current state practices and other factors resulted in the formulation of four possible alternative schemes for the evaluation of the quality and performance of bituminous mix aggregates. The schemes differ essentially in the relative emphasis placed on the laboratory testing of aggregates, testing of bituminous mixes, prequalification of sources of aggregates, and evaluation of in-service performance of aggregates. The four schemes are as follows:

TABLE 1 Summary of State Prequalification Requirements for Bituminous Mix Aggregate Sources

Requirement	No. of States Listing Requirement
No prequalification requirement	14
Qualification by laboratory and field tests	3
Qualification by general petrologic examination	2
Carbonate aggregates specifically limited or excluded	12
Other limitations[a]	6

[a] Limatations such as exclusion of all sedimentary rocks, serpentine, degraded basalt, weathered granite, scoria, coral, and shale.

Scheme I: Evaluation of aggregate performance based primarily on physical and chemical tests on representative aggregate samples, and a few tests on bituminous mixes.

Scheme II: Prequalification of aggregate sources based on relatively complex laboratory and field evaluation of bituminous mixes made with the aggregate.

Scheme III: Prequalification of aggregate sources based primarily on petrographic examination of samples coupled with field performance data on bituminous paving mixes.

Scheme IV: Same approach as Scheme I, but supplemented by prequalification evaluation for specific characteristics such as polish, stripping resistance, and durability.

Typical aggregate evaluation and test procedures making up each of these schemes are summarized in Table 2. How these evaluation schemes fit the practices in the states visited is described in Table 3.

TABLE 2 Procedures Considered for Alternative Bituminous Mix Aggregate Quality and Performance Evaluation Schemes

Procedure Category	Scheme I	Scheme II	Scheme III	Scheme IV
Aggregate tests	Gradation, soundness, abrasion, friable particles, sand equivalent value, polish resistance	Gradation, abrasion	Gradation	Gradation, soundness, abrasion, friable particles, sand equivalent value, polish resistance
Tests on aggregate-asphalt systems	Moisture damage (Lottman's test), mechanical behavior (Marshall and Hveem), mix workability	Moisture damage (Lottman's test), mechanical behavior (Marshall and Hveem), fatigue resistance, polish resistance	Mechanical behavior (Marshall and Hveem)	Moisture damage (Lottman's test), mechanical behavior, mix workability
Service and tests on pavement experience	Data collection on performance of aggregates for future improvements in the scheme	Formal data collection to correlate aggregate quality to performance	More detailed and formal data collection to correlate pavement performance to petrology (heavy emphasis)	Performance data related to skid resistance and stripping and performance of marginal materials
Petrographical examinations	None	Deleterious materials, chemical tests, lithology, petrographic examination in special cases (low emphasis)	Deleterious materials, chemical tests, lithology, detailed petrographic examinations (heavy emphasis)	Examinations mainly to identify carbonate rocks and those susceptible to stripping (low emphasis)

TABLE 3 Outline of Typical Aggregate Evaluation Schemes and Source Control in States Visited

	Rating of Relative Importance of Procedures in Aggregate Evaluation Scheme[a]						
State	Tests on Aggregate Samples	Tests on Bitominous Mixes	Petrology	Pavement Test Section Results	Service Experience	Estimate of Alternate Scheme[b]	Control of Aggregate Sources
Colorado	3-4	5	1	0	3	IV	Designated source; state controlled
Florida	–	–	–	–	–	IV	Privately owned pits or quarries
Georgia	2	4	1	0	2	I	Privately owned pits or quarries
Idaho	4	2-3	0-1	0	1	IV	Designated source; state controlled
New York	0	0	5	0	5	III	Privately owned pits or quarries
North Carolina	–	–	–	–	–	IV	Privately owned pits or quarries
Ohio	2	1	3	1	4	III	Privately owned pits or quarries; some by paving contractors
Pennsylvania	3	4	2-3	1	2	II	Privately owned pits or quarries
Texas	4	2	0-1	0	1	IV	Privately owned pits or quarries
Utah	1-2	4	1-2	0	3	II	Designated source; state controlled
Virginia	4	2	1	2	1	IV	Privately owned pits or quarries
Washington	4	1	1	0	1	IV	Designated source; state controlled

[a]Numbers indicate relative importance of procedure category in evaluation scheme: 0 = no importance and 5 = major factor in evaluation.
[b]Refers to alternate scheme designation defined in the text.

ANALYSIS OF AGGREGATE EVALUATION SCHEMES

The four aggregate evaluation schemes previously outlined were compared by means of utility decision analysis. Utility as used in this context is a measure of relative usefulness of the schemes and has a range from 0 to 1. A computer program developed at the Texas Transportation Institute was modified and used in this project for computing the utilities of various schemes. In this analysis the relative power (utility) of each scheme to meet four objectives (attributes)--namely, practicality, significance of evaluation procedures, cost, and implementation--were evaluated. Each attribute was further subdivided into several decision criteria that contribute to satisfying the objective. The details of utility decision analysis and the procedures used for quantifying and evaluating the decision criteria are explained in detail in the following sections.

Utility Decision Analysis

Utility decision analysis is a systematic procedure for considering all of the pertinent factors that influence a decision-making process. It is based on utility theory, a subject about which several textbooks (4-7) have been written. It has been used successfully in the analysis of several engineering applications, especially in the field of transportation (8). The advantage of the utility analysis lies in the fact that it allows the use of different types of information, subjective or objective, to make useful comparisons.

In utility decision analysis all of the factors that affect a decision-making process are carefully outlined and evaluated on a rational basis. A final choice is made based on the utility (power) of an alternative to meet certain objectives, usually called attributes. Each attribute is further subdivided into several decision criteria that contribute to satisfying the objective. Hence the first step in the analysis is to carefully define the attributes of the decision-making process and the criteria that comprise each attribute. The attributes and decision criteria for evaluating aggregate selection schemes are given in Table 4. Decision criteria 7, 8, and 9 also have some subdecision criteria, as shown in the table. The detailed definitions of decision criteria are presented in a later section of this paper.

The next step in this analysis involves establishing utility curves for each of the decision criteria. Utility is a measure of preference and it ranges between 0 and 1, depending on the value of a decision criterion. The shape of the curve generally depends on personal preferences of the decision maker and how much risk he is willing to take with respect to the value of that particular decision criterion. However, typical curves can be drawn by carefully considering opinions of experts in the field. A typical utility curve developed in this study is shown in Figure 1. There is always some uncertainty in estimating the decision criterion

TABLE 4 Attributes, Decision, and Subdecision Criteria for Aggregate Evaluation Schemes

Attribute	Decision Criteria	Subdecision Criteria
Practicality	1. Simplicity of evaluation scheme	
	2. Level of effort to evaluate an already developed source	
	3. Level of effort to evaluate a new or recently developed source	
	4. Personnel requirements	
	5. Level of technical training	
	6. Evaluation time	
Significance of procedures	7. Probability of rejecting an unsuitable aggregate	(i) Strength (ii) Durability (iii) Fatigue resistance (iv) Stripping (v) Skid resistance
	8. Potential for identifying marginal aggregates	Same subdecision criteria as above
	9. Repeatability of results	(i) Aggregate tests (ii) Tests on aggregate-asphalt systems (iv) Petrographic evaluations
Cost	10. Equipment	
	11. Field pavement evaluation	
	12. Laboratory evaluation	
	13. Field geological evaluation	
Implementation	14. Status of development	
	15. Degree of standardization	
	16. Required change from current practice	
	17. Additional training of personnel required	

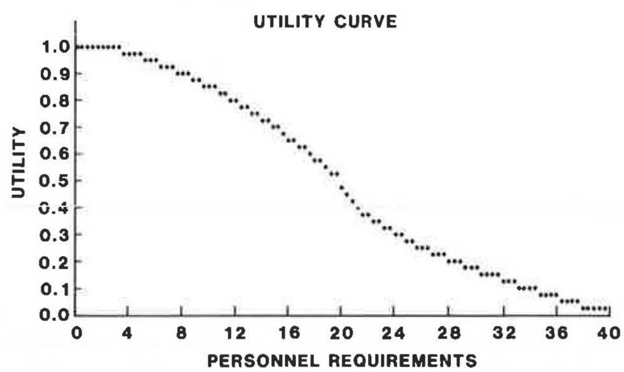

FIGURE 1 Typical utility curve fitted by the program.

input values. To estimate utility under conditions of uncertainty, each decision variable was assumed to have a probability density, f(x). For this study, a beta probability density function was chosen (Figure 2). The beta distribution for each decision criterion can be determined by simply assigning three values [optimistic (O), most probable (M), and pessimistic (P)]. To estimate these three values (O, M, and P) on a rational basis, detailed work sheets must be prepared for each decision criterion.

The expected value of the utility of a decision criterion is obtained by integrating the product of the probability density function and utility function over the range of decision criterion values:

$$E(u) = \int_{x_{min}}^{x_{max}} u(x)\, f(x) dx = u_i \tag{1}$$

where u_i is the mean utility of the decision criterion i. The variance of utility is given by

$$Var\,(u) = \int_{x_{min}}^{x_{max}} f(x)\, u^2(x)\, dx - u_i^2 \tag{2}$$

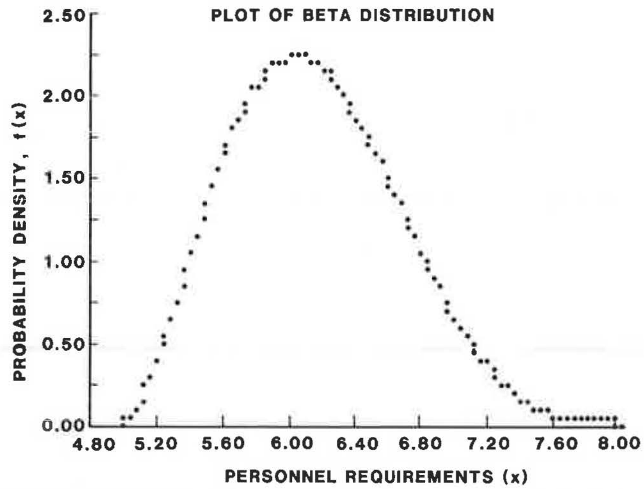

FIGURE 2 Typical beta-distribution curve fitted by the program.

The utility of a scheme is obtained by combining the individual utilities of decision criteria and attributes using a hierarchial additive weighting method, as follows:

$$\text{Utility of attribute } j = u_j = \sum_{i=1}^{n} = w_i\, u_i \tag{3}$$

where n, w_i and u_i refer to the number of decision criteria within an attribute, normalized weight, and utility of the decision criterion, respectively. The mean overall utility of the scheme (K) is given by

$$U_K = \sum_{j=1}^{n_1} w_j\, u_j \tag{4}$$

where n_1 and w_j refer to the number of attributes and normalized weight of the attribute, respectively. The utilities of the K schemes can be compared to aid in the final decision of choosing a particular scheme.

Variances multiplied by the square of their normalized weights, all added together, give the overall variance. For example, the overall variance is given by

$$Var\,(U_K) = \sum_{j=1}^{n_1} w_j^2\ Var\,(u_j) \tag{5}$$

From the mean overall utility U_K and the variance of U_K for any given scheme, confidence limits on the mean (mean ± 2 σ) can be established, which will indicate the variability expected in the estimation of the mean.

A computer program (UDAREM) developed recently at the Texas Transportation Institute on another project (9) was modified extensively and used to carry out various computations involved in Equations 1-5. From the input data, this program fits a utility curve to the sample points, fits a beta distribution to the three estimates (O, M, P), multiplies the two curves together, carries out the integration numerically using Simpson's rule, and finally arrives at the grand total utility and variance for the entire scheme.

Definitions of Attributes and Decision Criteria

Four attributes and 17 decision criteria, as listed in Table 4, were considered essential for judging the utility of aggregate evaluation schemes. The definitions of all of the attributes and decision criteria are outlined in the following sections. These definitions formed the basis for obtaining optimistic, most probable, and pessimistic estimates of the decision criteria on a quantitative basis. (Note that supporting data sheets were prepared to quantify the estimates of all decision criteria described in the following sections.)

Practicality Attribute

Practicality is an important attribute in judging any aggregate evaluation scheme. Schemes that involve complex equipment and testing procedures requiring highly skilled personnel will be considered impractical. Practicality may also depend on cost. However, because cost is a major factor to consider in evaluating any scheme, it is kept as a separate attribute. The following decision criteria were considered under practicality.

Simplicity of Evaluation Scheme

In order to determine whether a given scheme is simple or complex, the examination procedures in each scheme and their complexities have to be considered individually. A given evaluation scheme may involve laboratory tests, lithological and petrographic examinations, field performance evaluation procedures, and so forth. Depending on the nature of equipment needed, complexity of testing procedures, and the time involved in the evaluation, a complexity factor (F_1) may be assigned to each procedure in the scheme. Summation of these factors (F_1) for each scheme is a good measure of the relative complexity of the entire scheme.

Level of Evaluation Effort

The effort involved in any evaluation scheme depends on the number of sources and the degree of detail used in the evaluation of each source. A scheme that provides for different degrees of detail, depending on the number of aggregate sources, will be more practicable than a scheme that provides for a uniform degree of detail. Degree of detail may be defined as total complexity of the scheme. Optimistic, most probable, and pessimistic estimates of the number of aggregate sources can also be obtained for any given state. The product of the number of sources (s) and the degree of detail (d) can be considered as a measure of the evaluation effort.

Personnel Requirements

This criterion was used to evaluate the total number of personnel needed for the complete evaluation of a source using a given aggregate evaluation scheme.

Level of Technical Training

This is the average academic qualification and job experience of personnel needed for various phases of evaluation that are included in the scheme. A scale of 1 to 10 was used for rating the qualification and experience of personnel.

Evaluation Time

This criterion represents the total time required (in weeks) to completely evaluate an aggregate source with a given scheme.

Significance of Procedures Attribute

It is important that the procedures used in an evaluation scheme ultimately reflect the quality and performance of pavements. The evaluation procedures may include laboratory tests on aggregate samples, performance-oriented tests on aggregate-asphalt systems, judgment on the basis of service experience, results from pavement test sections, and interpretation of petrographic information. Finally, an evaluation scheme must be able to distinguish clearly between good, marginal, and poor aggregates. The quality of information obtained during the evaluation should have the potential for identifying problems associated with marginal aggregates and suggest suitable methods of upgrading them. Variability in test results should be low when the test is repeated on the same material. The following decision criteria were used to estimate the utility of this attribute.

Probability of Rejecting an Unsuitable Aggregate

An aggregate may be rejected on the basis of evaluations that are related to performance factors such as strength, durability, stripping, polish resistance, fatigue resistance, and skid resistance, which form subdecision criteria. The procedures provided in a scheme must be able to reject an unsuitable aggregate with high probability.

Potential to Identify Marginal Aggregates

In addition to rejecting a poor aggregate, an evaluation scheme will be still more useful if it can discriminate between poor aggregates and marginally acceptable aggregates. The ability to discriminate depends on the quality of the information provided by the laboratory and the field data gathered on a given aggregate. Depending on local conditions, suitable weight can be placed on this ability of an evaluation scheme to discriminate between acceptable, unacceptable, and marginal aggregates (i.e., aggregates that can be treated, improved, or used in other ways).

Repeatibility of Results

The testing procedures used in a scheme will have more validity and thus more significance if the variation is low when the test is repeated on the same material. This requires that the methods used are proven in practice for several years, and that records are available. A good measure of variability in test results is the coefficient of variation (CV).

Cost Attribute

Cost is an important factor in any evaluation scheme. Other factors being equal, a less expensive scheme will be more acceptable. The decision criteria included in this attribute cover all costs of transportation, personnel, equipment, and materials for various phases of laboratory and field investigations required to evaluate one source of aggregate. The exception to this is the cost of equipment, which is treated separately.

Cost of Equipment

Cost of all field and laboratory equipment and transportation vehicles are included in this criterion. This represents a one-time expense and is not prorated as cost per source because the decision may rest on the total initial expense involved in the purchase of equipment that is required for a particular aggregate selection scheme.

Field Pavement Evaluation Cost

This criterion includes personnel costs, transportation costs (excluding cost of vehicles), and materials costs for conducting various types of field evaluations related to in-service experience of existing pavements or performance of test pavement using a particular source. The evaluations may include visual rating of pavements, roughness measurements, skid resistance measurements, and taking field cores for laboratory tests.

Laboratory Evaluation Cost

This criterion includes costs related to various types of tests on aggregates, asphaltic mix tests, tests on field pavement cores, and laboratory petrographic analysis to evaluate one source. The costs include personnel and materials costs for all the procedures involved in a given scheme.

Field Geological Evaluation Cost

Personnel costs, transportation costs, and materials costs related to field geological investigation to evaluate one source are included in this criterion. Depending on the source, geological investigations may include making test pits and drilling cores for collection of samples and simple field tests for identifications of rocks.

Implementation Attribute

Successful implementation of a given aggregate evaluation scheme mainly depends on its acceptance by a state highway department. A scheme that has been proven effective uses standard tests that are well-known or easily taught, has a large amount of data and experience behind it, and can be implemented quickly. The scheme will have a better chance of acceptance if it represents only a small change from current practice in the state. The following decision criteria were used to evaluate this attribute.

Status of Development

This criterion is a rating of how completely developed a particular scheme is in a given state. A completely developed scheme should have a manual that defines the selection procedures in detail, a set of well-established acceptance criteria (specifications) for aggregates, good correlation with in-service experience for the evaluation procedures employed in the scheme, and all the equipment required for testing is available on the market. Subjective ratings were given on a scale of 0 to 10 for each scheme based on how the scheme satisfies these four elements in a given state.

Degree of Standardization

This criterion is a rating of the degree of standardization of the testing procedures used in the evaluation scheme. The implementation of any testing method is made much easier if it has been proven in practice, accepted as a standard by one of the standards associations (e.g., ASTM, AASHTO), and described in detail in the publications of one of these associations. The rating of the degree of standardization was done subjectively based on how the tests included in a scheme meet the criteria.

Required Change from Current Practice

If a suggested evaluation scheme deviates sharply from the current practice in a state, it may find little acceptance. Each item in the evaluation scheme is assigned a value between 0 and 1 (0 for no change and 1 for complete revision from the existing practice). The degree of change was obtained by summing up the score for various items and dividing it by the maximum applicable points.

Additional Training of Personnel

This criterion is a rating to determine the additional training of personnel that would be necessary to implement the scheme. New and complex procedures may require training of personnel to familiarize them with the procedures. The evaluation of the degree of additional training was obtained subjectively, similar to the criterion previously cited.

Utility Curves

As stated earlier, the shape of a utility curve depends mostly on the personal preferences of the decision maker and how much risk he is willing to take with respect to a particular value of the decision criterion. If the utility curve is a straight line, the decision maker has an expected value attitude (neutral) toward risk; if the utility curve is concave, the decision maker has a risk-averse attitude; and if the utility curve is convex, he has a risk-prone attitude (8). However, S-shaped curves appear to be most suitable for engineering-type decisions; the point of inflection associated with S-curves indicates the change of attitude of a person from risk prone to risk aversiveness. For example, an increase in cost might be tolerated up to a certain level, but beyond that level the decision maker may become aversive to taking risk. The computer program fits the utility curve for a given odd number of data points. About five data points are generally sufficient to plot the curves.

Data points were assumed for the 17 decision criteria, based on subjective judgment on each. However, for a different set of situations, these points can be changed. The computer program is written flexibly to permit such changes in the utilities and weights of decision criteria.

Weighting Factors

In this analysis three levels of weighting factors were assigned separately for attributes, decision criteria, and subdecision criteria in a descending hirerarchical order. The weights selected should reflect the actual preference of the decision makers. Presumably the weights can change, depending on the attitudes of the decision makers and the conditions in a state. For example, a state with a modest highway budget may place a heavy weight on cost. To take this factor into consideration, states were classified into different groups. The basis of classification is given in the next section.

The easiest way to determine weights is to put a 1.0 weight on the attribute or criterion considered to be most important and establish the remaining weights relative to this one. In the computer program the weights are normalized so that their sum is 1.0. Typical weights, initially assumed for the attributes and later modified by the consensus of a committee, are given in Table 5. Similarly, weights were also assigned for different decision criteria.

TABLE 5 Weights for Attributes

		Consensus Weights[a]	
Attribute	Original Weights	States A and B	States C and D
Practicality	0.9	0.7	0.9
Significance of procedures	0.7	1.0	1.0
Cost	1.0	0.5	0.8
Implementation	0.8	0.5	0.7

[a]While taking the consensus poll it was agreed by all those who attended that the cost of evaluation is a minor factor compared with the failure of a highway, and that the significance of procedures is the most important factor. Consensus weights are the averages of weights given by five staff members who attended the meeting. State classifications are as per Table 6.

State Classifications

Results of the national survey and discussions with several state highway materials agencies clearly indicated differences among the states with respect to their approach to aggregate evaluation; therefore aggregate availability should be taken into account when making a utility decision analysis. For this purpose, the states were classified into four different groups, depending on the estimated level of support for highway materials evaluation (assumed to be proportional to the annual highway budget for each state) and the potential number of aggregate sources to be evaluated, as indicated in Table 6.

The main effect of this classification was a variation in the weights assigned to the different attributes. The weights for decision and subdecision criteria were not changed in this analysis because they belong to a lower hierarchical order. However, these weights could be also changed if considered necessary. It was also assumed that in states with larger budgets, the status of development can be high and it will be easier to implement an aggregate evaluation scheme. Thus the input values for the decision criteria related to implementation were different for the two budget classifications. The classification based on number of sources mainly affected the input values for the level of evaluation effort, the effort being higher where the number of sources is large.

Comparison of Utilities of Different Schemes

The utility of each scheme was evaluated as the weighted sum of the utilities of its attributes, as explained earlier. The expected or mean utilities of the four schemes in different state classifications are given in Table 7. The relative rankings of the four schemes are also shown at the right of the table. It can be seen that the same rankings are maintained in all four state classifications.

It is apparent that aggregate evaluation Scheme I is preferred in all states to any of the other alternatives. After Scheme I, Schemes IV, III, and II are preferred in that order. This immediately raises the question: Are there any circumstances under which any other scheme would be preferred to Scheme I? To investigate the answer to this question, the following sensitivity studies were made:

1. A study of confidence limits to see if the same order of preference was maintained at 2 standard deviations above or below the mean;
2. A study of the sensitivity of the means to the relative weights of attributes;
3. A study of the sensitivity of the means to a biased estimate of the decision criteria, and
4. A study of the effect of implementing an entirely new evaluation scheme in a given state as opposed to implementing a variation of an evaluation scheme that is already in operation in the state.

Comparison of Ranges of Utilities

The confidence limits (mean $\pm$ 2 σ) for the mean values of these utilities are shown in Figure 3. If the utility values are normally distributed, these limits represent approximately 95 percent probability that the mean values lie in that range. In state classifications A and B, the confidence limits of Schemes I, III, and IV overlap, which indicates that these schemes are close to each other. Schemes I and IV are also similarly close to each other in state classifications C and D. Scheme II had the lowest range of utilities in all states. It may be concluded from this that the utilities of evaluation Schemes I and IV are not much different, but that Schemes III and II definitely rank lower than Schemes I and IV.

Sensitivity to Weights of Attributes

An analysis of the effects of changes in attribute weights on the utilities and relative rankings of

TABLE 6 State Classifications

Class	Support for Highway Materials Evaluation	No. of Sources	Typical States
A	High (total highway budget more than $500 million[a])	Large[b] (600-1,000)	California, Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, New York, Ohio, Pennsylvania, Tennessee, Virginia, Washington, Wisconsin
B	High	Average to small[b] (300-500)	Florida, Georgia, Louisiana, Maryland, Massachusetts, Missouri, New Jersey, North Carolina, Texas, West Virginia
C	Medium-low (total highway budget less than $500 million[a])	Large	Colorado, Kansas, Nebraska, New Mexico, Oklahoma
D	Medium-low	Average-small	Alabama, Alaska, Arizona, Arkansas, Connecticut, Delaware, Hawaii, Idaho, Maine, Mississippi, Montana, Nevada, New Hampshire, North Dakota, Oregon, Rhode Island, South Carolina, South Dakota, Utah, Vermont, Wyoming

[a]From 1975 FHWA highway statistics.
[b]Assumed very roughly on the basis of Figures 3 and 5 by Witczak et al. (*1*).

TABLE 7 Utilities and Relative Rankings of Schemes in Different State Classifications

State Class	Utilities of Schemes I	II	III	IV	Relative Rankings of Schemes in State Class
A	0.78	0.70	0.75	0.75	I, IV, III, II
B	0.81	0.76	0.79	0.81	I, IV, III, II
C	0.77	0.65	0.72	0.73	I, IV, III, II
D	0.81	0.71	0.76	0.71	I, IV, III, II

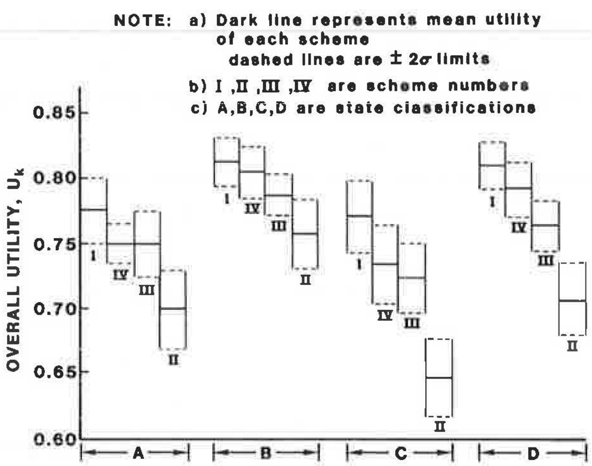

FIGURE 3 Utilities of different schemes in various state classifications.

different schemes was made for state classification B. Four different sets of weights for attributes were used, but the weights of decision and subdecision criteria were not changed in this analysis because they belong to a lower order of hierarchy. The first group of weights (original) placed a high emphasis on significance of procedures; in the second group all attributes were weighted nearly equally, with a little higher emphasis on cost, which is typical of a low budget state; the third group put equal emphasis to all attributes; and the fourth group kept least emphasis on cost and highest emphasis on implementation, which may be typical of a high budget state. A comparison of utilities with these weights indicated only minor differences in utilities, but no changes occurred in relative rankings of the schemes. It is thus concluded that changing of attribute weights will not significantly effect the rankings of the aggregate evaluation schemes.

Sensitivity to Change in Estimates of Decision Criteria

There is always a possibility of personal bias, especially when the estimates are subjective. A person may be more optimistic or pessimistic about a scheme, which will have an influence on the subjective ratings. With this in mind, Scheme III for state classification B was chosen to study the effect of a change of input decision criteria values by 10 percent on the optimistic side, while leaving all other schemes as they were before. With this input, the utility of Scheme III increased considerably, and it ranked first followed by Schemes I, II, and IV. This indicates the necessity of exercising care in estimating decision criterion values.

Effect of Status of Development of a Particular Scheme in the State

The utility values given in Table 7 are based on the assumption that the state does not have a scheme similar to the one being considered, and that the scheme must be implemented from the beginning. However, in some states, especially those that have large highway budgets, and aggregate evaluation scheme close to one of these four schemes under consideration may already be in operation. In such a case it will be easier to implement that scheme in the state with little additional personnel and equipment, and the input values for the decision criteria under the implementation attribute will be considerably higher. Making this adjustment in the input, utilities were again computed. It was found that in states where the current practice is similar to proposed Schemes III or IV, these schemes move up to the top rank, whereas Scheme II moves up only to second rank. Thus it appears that current practice in a state may have considerable effect on the utilities of the schemes.

Summary

The main purpose of having an aggregate evaluation scheme is to determine the quality and performance of an aggregate from a given source. However, in the selection of aggregate sources for highway construction, other factors such as aggregate reserves, production costs, hauling distances, environmental factors, and energy use also need consideration in addition to quality and performance. These factors are outlined in Figure 4.

A utility decision analysis program similar to the one used to rank aggregate evaluation schemes may also be applied for selecting an aggregate source while taking all of the factors in Figure 4 into account. It can be seen that the evaluation of quality and performance, using a given scheme, forms only one element of the decision-making process. It is quite possible that even a marginal quality aggregate or suitably modified aggregate may have a higher utility than normal aggregates when all the pertinent factors are taken into consideration. Such a source selection program represents a rational approach in making the decision whether or not to use marginal quality aggregates in a given situation, and thus can become an important tool in extending the aggregate supply in the United States for construction of flexible pavements.

Thus aggregate selection is a two-stage process. The first stage involves selection of a rational aggregate evaluation scheme most suitable for conditions in the state, and the second stage involves the evaluation of an aggregate source using this scheme and considering other factors previously mentioned. The computer program developed in this research can handle this two-stage aggregate selection process. Another important question is which aggregate, and which asphaltic mix tests and petrographic evaluations, are best predictors of aggregate performance. This aspect was also studied in the second phase of this research; the results are reported in another paper (10).

SUMMARY AND CONCLUSIONS

A survey of state practices resulted in the identification of four aggregate evaluation schemes. Utility decision analysis showed highest utility for Scheme I, which emphasizes aggregate tests but also

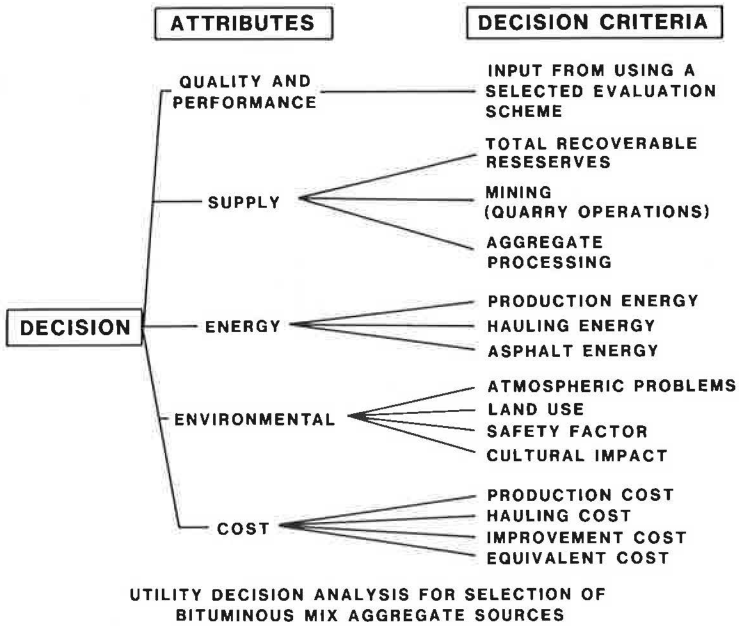

FIGURE 4 Utility decision analysis for selection of bituminous mix aggregate sources.

includes asphalt mixture tests for mechanical stability and moisture damage. Scheme IV, which includes prequalification evaluations for durability, polish resistance, and moisture stability, came in a close second. Thus either of these schemes, or a judicious combination of procedures included in these schemes, would probably be most suitable for aggregate evaluation in many states.

It is suggested that aggregate selection is a two-stage decision-making process. The first stage involves selection of an aggregate evaluation scheme to determine the quality of an aggregate, and the second stage involves selection of an aggregate source considering other factors such as aggregate reserves, production costs, haul distances, environmental impact, and energy use in addition to quality of an aggregate. The utility decision analysis program developed in this study can be helpful in the aggregate selection process.

An aggregate may be considered marginal if it is a borderline material with respect to some aggregate qualification tests such as abrasion value or soundness. However, if it has a satisfactory service record or receives a satisfactory petrographic evaluation or it can be improved with a combination of other coarse or fine aggregates, it may be accepted. Such a flexible approach would certainly enhance the use of marginal aggregates and help in the aggregate supply situation.

Although the evaluation of individual testing procedures formed the subject of another paper, some of the conclusions reached are given here for completeness of this paper.

The following tests were related to performance as determined from regression models: among aggregate tests--sulfate soundness, water absorption, crushed particles, Los Angeles abrasion, and and equivalent values; among asphalt mixture tests--Marshall stability, tensile strength, and tensile strength ratios (Lottman test); and among petrographic evaluations--general quality of rock, powder and film coatings, and chemical character of rock. Attempts were made to establish acceptance limits for these tests, but the results were inconclusive because of the limited number of aggregate samples tested in the study.

ACKNOWLEDGMENTS

The work reported here was sponsored by AASHTO in cooperation with FHWA; the work was conducted in the National Cooperative Highway Research Program, which is administered by the Transportation Research Board of the National Research Council. The research was conducted at the Texas Transportation Institute of the Texas A&M University. Other participants in the study were H.R. Blank, F.S. White, and the late S.C. Britton.

REFERENCES

1. M.W. Witczak, C.W. Lovell, Jr., and E.J. Yoder. A Generalized Investigation of the Potential Availability of Aggregates by Regional Geomorphic Units Within the Conterminous 48 States. In Highway Research Record 353, HRB, National Research Council, Washington, D.C., 1971, pp. 31-42.
2. R.L. Lytton and P.M. Gandhi. Acceptance of Aggregates Used in Bituminous Paving Mixes, Final Report. NCHRP Project 10-12. TRB, National Research Council, Washington, D.C., Sept. 1980.
3. S.C. Britton and R.L. Lytton. Acceptance of Aggregates Used in Bituminous Paving Mixes, Interim Report. NCHRP Project 10-12. TRB, National Research Council, Washington, D.C., Nov. 1978.
4. M.W. Lifson. Decision and Risk Analysis for Practicing Engineers. Cohners Books, Boston, 1972.
5. R.C. Fishburn. Decision and Value Theory. Wiley, New York, 1964.
6. W. Edwards and A. Tverslay. Decision Making. Penguin Books, Baltimore, 1967.

7. A.P. Sage. Methodology for Large Scale Systems. McGraw Hill, New York, 1977.
8. W. Ledbetter et al. Techniques for Rehabiliting Pavements Without Overlays: A Systems Analysis. Report FHWA-RD-77-132. FHWA, U.S. Department of Transportation, Sept. 1977.
9. F.N. Rhodes and A.D. Ader. Techniques for Rehabilitating Pavements Without Overlays: A Systems Analysis--UDAREM Computer Program Documentation. Texas Transportation Institute, Texas A&M University, College Station, Nov. 1977.
10. P.M. Gandhi and R.L. Lytton. Evaluation of Aggregates for Acceptance in Asphalt Paving Mixtures. Presented at Annual Meeting of the Association of Asphalt Paving Technologists, Scottsdale, Ariz., April 1984.

Deterioration of Bituminous Pavement Surfaces by Growth of Alum Crystals

JAMES R. DUNN

ABSTRACT

Some 1.5-in. bituminous pavements in Stafford County, Virginia, have developed numerous small domes from 2 to 4 in. in diameter and about 1 in. high. Each dome has a core of white, astringent-tasting crystals that are under the bituminous pavement and at the top of the subbase. The crystals appear to be closest in composition to pickeringite, a magnesium alum, which commonly results from the weathering of pyritic schists. The domes were observed primarily between vehicle wheel tracks and in areas of poorest drainage. The aggregate in the bituminous pavement is quartz sand and gravel and does not appear to be casually involved in the deterioration. The subbase aggregate is largely crushed biotite schist and granite and is from a quarry near Culpeper. Analyses of water in the quarry and of salts leached from stone piles indicate that the quarry is the probable source of the alum, and that the salts are in the subbase stone. It appears that salts concentrate under the bituminous pavement because water without the contained salts moves through the bituminous pavement, which appears to act as a semipermeable membrane. A particle count of subbase aggregate under the bituminous pavement indicates that the darker particles of biotite schist have produced local zones of capillarity in the subbase. This allows for water to be transmitted upward at certain spots, thus causing the salts to concentrate in mushroom-like masses under the bituminous pavement.

Work for the project described in this paper was done during August, September, and October 1982, and was financed by the General Crushed Stone Company. The objectives of this research were to (a) determine the cause of small mounds occurring in bituminous pavements in the area of River Ridge Estates, which is at the end of State Route 655 in Stafford County, Virginia, and (b) suggest remedies for minimizing the deterioration problem. The discussion in this paper concentrates on the causes.

The deterioration was first observed in 1981 and was brought to the attention of General Crushed Stone, which furnished the subbase aggregate. The Virginia Highway and Transportation Research Council (VHTRC) reported on the chemical composition of the substance associated with the deterioration in a memorandum dated October 1, 1981. Froehling and Robertson, Inc. (engineers and chemists), in a report dated December 31, 1981 (1), described the problem and made chemical analyses of salts that concentrated under the pavements. The Virginia Department of Highways and Transportation (VDHT) looked into the problem and took samples for investigation. In the fall of 1982 General Crushed Stone had samples of waters from the area analyzed by Environmental Systems Service, Ltd. of Culpeper, Virginia.

ROAD AND MATERIAL SPECIFICATIONS

The roads in which the deterioration occurs were constructed according to the following specifications.

1. Subbase, 6 in., type I, size no. 21A: "Type I aggregate base material shall consist of crushed stone, crushed slag, or crushed gravel; with or