tract and the limited number of contracts suitable for this study it appears that

1. The variation in material properties in a section constructed during a particular day is not statistically significant, and for pavement design purposes the section may be regarded as homogeneous;
2. The statistical variation in material properties in sections constructed on different occasions or days is significant, and these sections may not be considered the same, even when the same materials, contractor, and specification apply to all the sections;
3. The material properties are not constant throughout the depth of the layer, and the upper half seems to have higher values than the lower half; and
4. The properties of materials constructed on a road by a contractor are significantly poorer than the values obtained on similar materials prepared in a laboratory. From this study it is not possible to indicate the degree of this difference.

Predicting the future behavior of a cement- or lime-treated layer in a pavement from laboratory-prepared samples would appear to be misleading. The extent of the difference between the design properties and the properties of the on-site material is unknown and seems to vary from contract to contract. Nor is the difference constant during the construction period; it varies from day to day. Until these differences have been studied and quantified accurately, for example by controlling the relevant properties or by tightening up the specification on the standard deviation of materials quality, it seems a very difficult task to accurately predict the long-term behavior of a pavement containing cement- and lime-treated materials.

RECOMMENDATIONS

From practical observations and until more specific recommendations become available, it is recommended that the values of the properties of field-prepared cement- and lime-treated materials be taken as 70 percent of those of laboratory-prepared materials. A 30 percent reduction in the laboratory values is thus recommended. Research along the lines indicated in the paper should be continued.

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Demonstration Project 42: Highway Quality Assurance

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The purpose of the Federal Highway Administration's demonstration project on highway quality assurance was to develop a short course for government and private administrative personnel in the highway industry to demonstrate the benefits of using statistical methods in quality assurance programs. The two-and-a-half-day course was divided into two essential parts: the first devoted to the development of basic statistical methods, the second to the application of these methods in acceptance plans. This paper discusses briefly the statistical methods covered and several of the areas in which they are applied. A limited discussion of the response to the 31 courses presented and comments on possible future programs of this type are included.

Federal Highway Administration (FHWA) Demonstration Project 42—Highway Quality Assurance, sponsored and funded by FHWA region 15, developed a short course for presentation to federal, state, and local highway and transportation administrative personnel and administrative personnel from the construction and materials production industry. The course presented statistical quality control and acceptance techniques designed to instruct course participants in judging the benefits of using statistical quality assurance programs.

The course lasted two and a half days. The first day was devoted to the development of basic methods used in statistical quality assurance and the second day to the application of these methods in acceptance plans. Control procedures such as control charts were covered only briefly, but the implications of statistical acceptance plans for the contractor or producer were discussed. For instance, the required average strength of concrete with a given variability was indicated for various acceptance plans. An additional half day was alloted for contractor and producer comments on statistical quality assurance, for a description of computer simulations of acceptance plans, and for discussions of rapid testing procedures and testing methodology.

COURSE CONTENT

The two-day portion of the course covering statistical concepts and applications was developed by C. S. Hughes, M. C. Anday, K. H. McGhee, and me, all from the Virginia Highway and Transportation Research Council and acting as consultants for FHWA region 15. The course outline was as shown below, and the course manual followed the same outline.

Session No.	Topic
1	Need for statistical methods
2	Introduction to distribution of measurements
3	Characteristics of normal curve
4	Calculation of standard deviation
5	Variability of highway products
6	Relationship of means and individuals
7	Relationship of statistics to specifications
8	Development of several statistical specifications
9	Implications of several statistical specifications
10	Summary

In the outline, sessions 1-7 covered the basic concepts of statistical quality assurance as developed in the project, and sessions 8 and 9 illustrated the applications developed by several states and the FHWA.

Basic Concepts

In the initial session the instructor indicated that statistics is simply the science that deals with the treatment and analysis of numerical data; it is no more than a tool that can be used to put acceptance and control plans on a quantifiable, rational basis. He stressed that the use of statistics does not eliminate the need for proper and often difficult engineering decisions such as which product characteristics should be tested and what the acceptable levels of the chosen characteristics are. In fact, statistical quality assurance was defined as a two-component process of making sure the quality of a product is what it should be. The two components are "making sure the quality of a product is," which involves control and acceptance and can benefit from statistical procedures, and "what it should be," which involves making proper engineering decisions.

It was also indicated in session 1 that highway materials and processes are not perfect, but that variability does exist, and that statistical methods can be useful in defining the amount of this variability. In this regard, the importance to private enterprise of its involvement in the whole statistical quality assurance issue was discussed. Appropriate acceptance plans, including specification limits, can be accomplished only after the reasonable production variabilities have been identified.

In session 2 the concepts of population and samples were discussed. In a chip-sampling class exercise from a known population, about 40 samples were drawn and used to illustrate that sampling tends to miss extreme values in the population. Plotting the sample also results in a histogram that tends to form a bell-shaped distribution similar to the known population distribution. By averaging each four consecutive sample results and plotting the averages it was shown that sample averages vary less than individual sample results and form a similar but narrower distribution.

The concepts discussed in session 2 were reemphasized in session 3, first by showing histograms of several types of highway-related sampling data and then by discussing the characteristics of the normal curve. The concepts of average (μ), standard deviation (σ), and areas under the normal curve represented by $\mu \pm z\sigma$ were presented, and several class problems were used to illustrate them. It should be mentioned that throughout the remainder of the course all concepts were presented on the basis of the normal distribution, essentially because of time limitations in presenting concepts; that is, sampling distributions and, in particular, the t distribution were not introduced in the course. But it was and is believed that, for presenting general concepts, the use of the normal distribution only is sufficient.

Session 4 dealt with the method of calculating the standard deviation and the relationship of the standard deviation and the range for various sample sizes. Most of session 5 was devoted to presenting typical variabilities found in highway products and processes from various data sources. One new concept was presented in session 5: the components of variance. It was explained that in statistical control or acceptance plans the square root of the total variance (σ^2) is the value of interest but that this value is the square root of the sum of both testing variance (σ_t^2) and materials variance (σ_μ^2). Thus, changes in either sampling and testing practices or in production practices could influence σ.

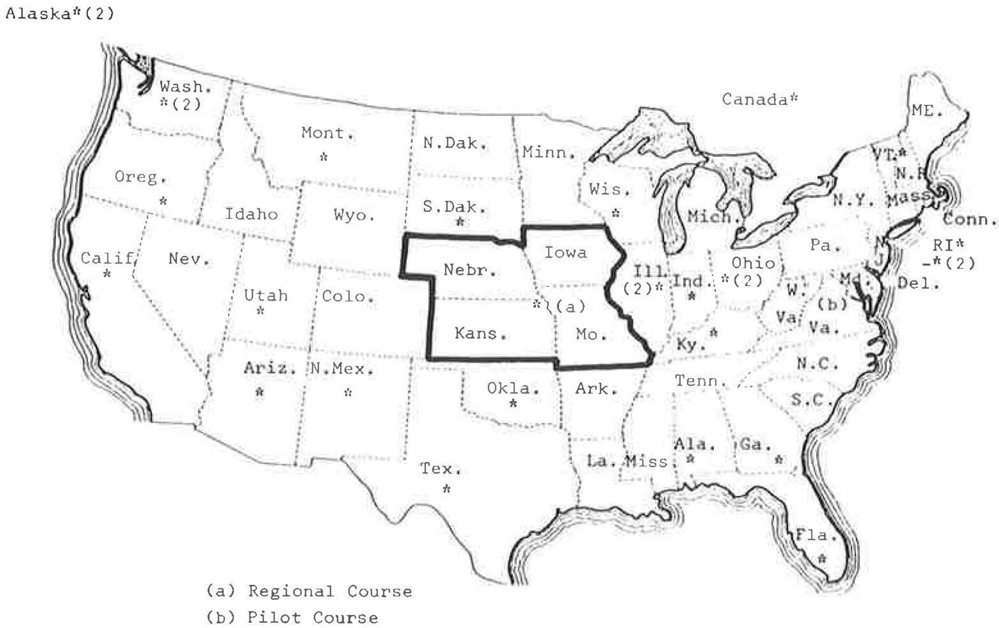
The use of sample averages initially discussed in session 2 was discussed in detail in session 6. The concept of the standard error of the mean ($\sigma_{\bar{X}}$) was introduced and its relationship to the standard deviation (σ) was discussed ($\sigma_{\bar{X}} = \sigma/\sqrt{N}$, where N is the number of samples averaged). It was indicated that areas under the curve are determined in the same way with $\sigma_{\bar{X}}$ as with σ and that clearly the ability to estimate the true population mean value (μ) improves as N increases. The importance of considering sample size when setting specification limits was stressed through the use of illustrations and class problems.

For session 7 the concepts presented in the previous six sessions were used to illustrate how statistical methods relate to the development of acceptance or control plans. The concepts of producer and consumer risks and how they influence sample size and acceptance limits were discussed, as were lot size and random sampling. Again, it was stressed that in developing acceptance or control plans extremely important engineering decisions must be made on what is acceptable and what is unacceptable in a product and that statistical methods allow specification limits to be set so that the probability of rejecting an acceptable product or accepting an unacceptable product is known. Both variability-known and variability-unknown approaches to specification development, as well as some limited discussion of control charts, were included in session 7.

Applications

As already indicated, the second day of the course (sessions 8 and 9) was devoted to the application of statistical methods in acceptance plans. The thought process used in developing some statistical specifications was covered in session 8, and the implications of several additional

Figure 1. States where Project 42 classes were held.



specifications for the producer and for the accepting agency were covered in session 9. The specifications covered in the two sessions included

1. A strip method for controlling and accepting compaction,
2. A specification for the acceptance of the cement content of pug-mill-mixed aggregates,
3. Specifications for the acceptance of gradation and asphalt content of bituminous concrete,
4. Specifications for the acceptance of gradation and liquid limit of pug-mill-mixed base and subbase materials,
5. The American Concrete Institute (ACI) building code, part 3 (portland cement concrete),
6. The FHWA Demonstration Project Guide Specification for portland cement concrete, and
7. The Georgia and West Virginia specifications for the thickness of concrete pavement.

This list includes both variability-known and variability-unknown types of specifications.

COURSE PRESENTATIONS AND RESPONSE

The pilot course was held in August 1976 in Washington, D.C. Participants included members of the Technical Advisory Committee and several FHWA region 15 personnel. Several constructive criticisms voiced at the initial course were incorporated, particularly those on session 7 about risk and variability-unknown specifications.

Originally, 10 regional courses were planned to follow the pilot course. However, because of the very good response, the courses shown as asterisks in Figure 1 were given. One course (a), that at Kansas City, Missouri, was a regional course covering FHWA region 7. All other courses were conducted essentially for the requesting state, and two courses were held for several states (Alaska, Washington, Illinois, Ohio, and New Jersey).

Generally, attendance at each of the courses was between 35 and 45 representatives from state and other local agencies, the FHWA, and, to a lesser extent, contractors and producers. Usually the statistical quality assurance concepts and methods covered were well accepted. In fact, in several courses the contractor and producer personnel, who had exhibited a negative attitude at the beginning of the course, became particularly enthusiastic about the potential of this approach.

There were three areas in which problems recurred. The concept of risk always confused several people. The idea of determining what an unacceptable product is and deciding what a reasonable chance of accepting this product is can seem somewhat unusual. Second, the course participants frequently confused testing methods and technology with statistical procedures. A final problem was that in several of the courses participants held positions too low in the administrative structures of their agencies to be among those who decide if statistical methods are desirable and should be used. Thus, although the response was good, the course may not have been as effective in promoting the implementation of statistical procedures as had been hoped, because top management people were not involved in the courses.

DESIRABLE FUTURE ACTIVITIES

While I feel that Demonstration Project 42 was very successful, I also feel that additional educational activities are desirable. Already some courses for presenting statistical methods and procedures to technical personnel and technicians are under way. In addition to this effort, other possible activities could include

1. A very concise, one-day course for top-level management that would cover the essential concepts of statistical quality assurance, including the concept of risk and the definitions of an acceptable product and an unacceptable product from an engineering standpoint;
2. A workshop course of two or three days designed to develop greater expertise in the states for developing statistical acceptance procedures (some actual specifications based on the needs and characteristics of particular states) would be developed in a general form; and
3. The development of some model specifications in an attempt to standardize to some extent the efforts of various states.

It is not necessarily intended that all or several states adopt the same specification for any given production items. Conditions, requirements, and values vary from state to state. However, some consistency in approach is desirable, and a flexible guideline specification could help develop consistency.

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