JOINT EFFORT TO IMPLEMENT RESTRICTED PERFORMANCE SPECIFICATIONS IN PENNSYLVANIA

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One of the key elements in the Pennsylvania Department of Transportation program for the implementation of statistically based restricted performance specifications for highway construction material is concerned with the necessary education of department and industry personnel. This paper discusses the experiences of Pennsylvania Department of Transportation and Pennsylvania State University in the past 2 years in their joint effort to provide the first phase of the training required. The background information for the series of training courses and for the development of a quality-control manual, the guidelines that were set up for the courses, and the objectives of each course session are discussed. The experiences and insight gained as a result of the first 5 courses in the series are discussed by relating some of the observations that participants made about the course itself and also about the proposed program of implementation that Pennsylvania Department of Transportation will follow. The objective of the paper is to share these experiences with other state departments of transportation that are at similar stages in the implementation of these types of specifications.

•IT is generally acknowledged that statistical quality control (SQC) had its origins in the work of Shewart, Dodge, and Romig at the Bell Telephone Laboratories in the 1920s. The concepts and tools resulting from their work have been applied in industry since that time. It appears, however, that people within the highway construction industry did not begin to seriously consider SQC until the problems arising from construction control during the AASHO Road Test indicated the need for a reevaluation of existing control procedures.

In May 1966, a National Conference on Statistical Quality Control Methodology in Highway and Airfield Construction was held at the University of Virginia in an attempt to summarize existing knowledge and provide a forum for examining and discussing the techniques and implications of statistical procedures within the industry. The proceedings of the conference indicate that many excellent papers were presented.

The last section of the proceedings presented 7 papers under the general title, "Implications of Statistical Methods". It is significant to note that little mention was made in these papers (or throughout the conference, for that matter) of an area that the writer feels is one of the keys to the successful implementation of SQC in the highway construction industry. Wescott perhaps came closest to this key when he stated:

> It has often been said that quality control is people, and this is, indeed, a fundamental truth. Certain it is that quality control is not just statistics.... The strategies are there—control charts, frequency distribution analysis... but these strategies, however potentially effective they may be, become sterile—and indeed damaging—in the hands of amateurs or in an environment of suspicion, misunderstanding, or outright opposition. If the quality control function is to be

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> sharpened and modernized by the advent of modern statistical science as an integral part of it, there must be a well-planned incubation period during which the infiltration of SQC training of personnel and the gradual development of experience with these methods is given time to take root.

The objective of this paper is to discuss the experiences of the Pennsylvania Department of Transportation and the Pennsylvania State University in the last 2 years in their joint effort to provide for the important key of education that is required if restricted performance specifications are to be successfully implemented. It is hoped that the experiences presented here will serve as models for those in other states faced with the same situation.

COURSE BACKGROUND

The Pennsylvania Department of Transportation began the program of implementing "restricted performance specifications" (also referred to as "statistically oriented end-result specifications") in 1961 when a random sampling system was instituted. In 1967 the department required contractor technicians to control the quality of portland cement concrete and bituminous concrete, and in 1970 the department started gathering data for the development of a bituminous concrete specification. The first "bituminous" projects were constructed under this specification in 1974.

The implementation work plan (1, p. 1.22) indicates a projected completion date of 1980 for full implementation. It was recognized during the early stages in the development of this work plan that the total concept of switching from the present acceptance system to the statistical approach required extensive training and reeducation of both department material inspection and construction forces and contractor and material supplier personnel. The task was recognized as being extensive, and it was decided that it should be approached in an orderly manner so there would be a complete understanding by all concerned and a smooth transition into the new system.

In the spring of 1973, the writer was requested by PennDOT to prepare a program that would provide the training needed for Phase 1 of PennDOT's "Implementation Work Plan". This "basic statistical training" phase was viewed as the required first step to ensure that a proper foundation of understanding would be provided for all PennDOT personnel who were to be involved in the use of restricted performance specifications.

PennDOT expressed an interest in presenting the training in an environment conducive to learning, one that would take the personnel away from the day-to-day problems they would encounter if the training occurred at the local district level. The writer therefore proposed that the ideal location for the training would be at the continuing education facilities available at the Pennsylvania State University main campus. The writer proposed that Phase 1 training could best be handled by presenting a series of 8 "short courses", each of 5 days' duration, for 240 PennDOT personnel in 1974.

Work was begun on the project in July 1973, and the first course was presented during the week of February 18-22, 1974. It was the writer's opinion that one of the most important characteristics of such a series of courses is that the material be presented in a uniform fashion. It was felt that this could best be achieved by using the same instructional manual for all of the courses. Although many textbooks in the general area of statistical quality control have been written, none were available that were specifically designed for the highway construction industry. Although a considerable amount of research had been completed that defined SQC in highway construction, it appeared that no one has attempted to distill this information into a concise package that could be used for instructional purposes. In light of this situation it was proposed that a manual on SQC, geared toward the specific needs of PennDOT highway construction, be prepared for use in the series of short courses. This suggestion was approved by PennDOT.

The various parts of the paper that follow (a) explain the guidelines used in the development of the course, (b) present an outline of the course sessions (which is also an outline of the course manual), (c) discuss the observations of the course made by the students who attended, and (d) highlight some of the observations about the implementation of restricted performance specifications that were made on the last day of each session.

GUIDELINES FOR COURSE DEVELOPMENT

A number of guidelines were developed during the early stages of planning as well as during the period when the first 5 courses were given that greatly influenced the mode of operation and the success of the course. This section of the paper highlights some of these to provide some background and understanding of the course outline.

General Guidelines

A number of guidelines were general in nature and are therefore mentioned first:

1. As noted previously, PennDOT already had a restricted performance specification for bituminous concrete (as a special provision to their Form 408 Specification) at the time the course was being planned. This was considered to be the model for the future material specifications to be implemented. The overall guiding principle in the selection of session topics was therefore to provide the student with (a) an understanding of the theory that formed the basis for the various parts of this specification and (b) a working knowledge of the techniques needed in order to implement the specifications.
2. It was recognized by PennDOT that considerable benefits could be obtained by having a student mix in each course that included not only members of PennDOT's Bureaus of Construction, Design, and Materials, Testing and Research but also members of the contracting and material supplier groups. PennDOT therefore underwrote the cost of course development but agreed to allow 10 industry people from the Associated Pennsylvania Constructors, the Pennsylvania Ready Mix Concrete Association, the Pennsylvania Sand and Gravel Association, and the Pennsylvania Asphalt Paving Association to attend each course. It is felt that this common training and interaction opportunity for all parties will make future implementation of these specifications much easier.
3. Once tentative agreement on the session topics had been accomplished, it was recognized that certain of these were theoretical in nature whereas others involved opportunities for PennDOT philosophy and policy to be presented. It was therefore decided that a neutral party (university faculty) should present the former topics while PennDOT personnel should present the latter ones. The "faculty" selected consisted of the writer, a graduate student, and 3 members of PennDOT's Bureau of Materials, Testing and Research staff. Each party served as a "devil's advocate" for the others throughout the week in order to emphasize key points.
4. It was considered extremely important to obtain feedback from the students after they had taken the course. The first reason for this was to determine if the material had been presented in a fashion that most people understood. The second and perhaps more important reason was that this feedback would provide the personnel who were responsible for specification development with 240 "educated" responses from field people about the system, its shortcomings, loopholes, and potential problem areas from an implementation standpoint. Accordingly, all of Friday morning was essentially designed to be a forum feedback session. Some of the valuable points raised during these sessions have resulted in PennDOT's reassessment of parts of the specification.
5. The final general guideline was that the courses should be split, with half of them being presented in the spring of 1974 and the other half in the fall. It was recognized that the lecture notes would have to be revised at least once, based on the experiences gained in the early courses. It was decided that the rewriting would be done during the summer. The final course manual that resulted was issued in 2 volumes (1, 2).

Guidelines for Course Operation

There were some guidelines concerning details of course operation that had a great influence on the course. Some of these are discussed in the following.

1. It was decided that each student should be given a complete set of typed notes at the beginning of each session. It was recognized that most of the students would have been away from academic life for a long time, and hence the requirement for taking lecture notes should be kept to a minimum. Each instructor attempted to follow the notes as closely as possible, and extensive use was made of overhead transparencies of the notes to give the student a chance to read along as the lecture proceeded.

2. An attempt was made to keep the material as practical as possible with a reduction of mathematical complexity, because it was recognized that the mix of students would consist of those who had recently completed master's degree work to those who had been out of high school for 20 years. At the same time, however, it was recognized that if the objective of the course was to merely present "rules of thumb" related to the bituminous specification the course could have been given in 1 or 2 days. This was, however, not the objective, so the sessions were designed to provide an understanding of the underlying theory as well as training in the statistical techniques required. It should be noted that the latter material was reinforced by workshops interspersed throughout the week.

3. It was decided that a certain amount of homework would be given throughout the week. Aside from the occasional grumbling observed, all of the instructors were impressed by the attitude of the students regarding the homework assignments. It was felt that, unless the students were required to review the session notes each night because of a homework requirement, they would not gain the understanding required. The problem with all compressed-time courses is that there is not enough "recovery time" for the student to assimilate knowledge before another topic is covered. It was felt that the homework assignments partially compensated for this problem.

4. It was recognized that once the student understood the basic calculations he should also be provided with a system in the field that would reduce the required paperwork. Accordingly, in parallel with the development of the course, PennDOT's staff developed a statistical package of computer programs that could be utilized by people in all districts of PennDOT to aid them in their application of the techniques that had been discussed.

5. One of the major points in the course was the responsibility for process control that the contractor and/or material supplier had under the provisions of the specification. To provide some guidelines for the industry people in the last few courses of the 8-course sequence, the graduate student working with the writer was assigned the task of working with a bituminous producer during the summer between courses to develop a workable process-control system that would supplement the "Suggested Guidelines for Process Control" available in the specifications.

COURSE OUTLINE

The previous section of this paper presented the guidelines used to develop the course. The first 5 courses resulted in several changes in the original topics selected and the order in which they were presented. This part of the paper presents the outline that resulted from the evolutionary process and lists the objectives and topics covered in each session. The course sessions, as presently designed, extend from 12:15 p.m. on Monday until 12:00 noon on Friday. A typical day starts at 8:00 a.m. and ends at 5:00 p.m. The order of the sessions follows.

Session 1: PennDOT Overview (Monday 12:15-1:15 p.m.), J. Moulthrop, PennDOT

The objective of this session is to inform the student of how the material to be covered during the course relates to the current and future plans of PennDOT with regard to restricted performance specifications. The speaker is from the PennDOT Bureau of Materials, Testing and Research and is at an organizational level that provides him with an overall perspective of the topic. In the first part of the session the appropriate definitions for statistical quality control are presented. The student is made aware of the fact that 3 distinct levels of testing will be required if the quality-control system envisioned by PennDOT is to be workable.

The student is informed of the changes that will occur as these new specifications are implemented through a brief review of the current practices and problems connected with (a) the different levels of control a PennDOT inspector presently possesses (depending on the type of material) and how this often results in a conflict between process control and inspection; (b) the different types of specifications that are currently used (100 percent compliance, satisfaction of engineer, substantial compliance) and the problems involved with each type; and (c) the current concept of sampling, which is based on the single-representative-sample philosophy.

The student is then briefly introduced to some aspects of the new approach that he will learn in the next few days. The concepts of specifications recognizing variability, the relationship of specification limits to sample size, etc., are introduced. The 3 types of sampling and testing that are the framework for the specification and the responsibilities connected with each type are then discussed in greater depth.

The final part of the session covers the plans for implementation that PennDOT has developed. The concept of a deliberate approach to implementation, the development of specifications for each area in an orderly fashion, and an explanation of the plans for training at each step in the process give the student the proper overview of the subject before he begins to get involved with the various technical topics that will be covered.

Session 2: Collection and Organization of Data (Monday 1:15-2:30 p.m.), J. Willenbrock

The objective of this session is to outline briefly the 4 basic phases of statistical analysis (i.e., collection, organization, analysis, and interpretation of data) and then to discuss the first 2 in more detail. The different types of data collection included in the new specification are discussed. The main thrust of this session, however, involves the presentation of a series of tabular and graphical techniques (i.e., frequency tables, histograms, and polygons) that the student can use in the "organization of data" phase to obtain the maximum amount of significant information from a set of data.

Session 3: Sampling Experiment 1 (Monday 2:30-3:00 p.m.), J. Willenbrock

The objective of this session is to illustrate the results obtained when each student randomly draws a sample of size n = 1 from a bowl containing a population of concrete strengths that is slightly skewed to the right. The ungrouped data and a frequency table and histogram for the parent population are first presented. As each student draws a value from the bowl (and replaces it) the result is recorded on the population histogram and in a frequency table that is divided in a fashion similar to the one presented for the population. The point stressed is that 1 sample of size n = 1 does not give a very satisfactory indication of the characteristics of the population from which it is drawn. The point is also made that the histogram of a sample of size 40 (40 samples of size n = 1) has a shape that is similar to the shape of the histogram for the population.

Session 4: Analysis of Data (Monday 3:15-4:15 p.m.), J. Willenbrock

The objective of this session is to present the formulas required in order to determine the 2 most important characteristics of a set of data, i.e., the central tendency and the dispersion. The student is made aware of the fact at this point that the mathematical complexity of the presentation will be at a level he can understand. It is pointed out that the course is not intended for mathematical statisticians.

The student is introduced to the basic algebraic symbolism that will be used, and then the formulas used to calculate the arithmetic mean and the standard deviation are presented. It is pointed out that these are the 2 indicators of central tendency and dispersion he will most often use to describe the characteristics of data, although the range is sometimes substituted for the latter because of its ease of calculation. In each case, the formulas for both population data and sample data are presented (for both ungrouped and grouped data). The student is also introduced to the coefficient of variation at this point, and the situations where it is applicable are discussed.

Session 5: Workshop 1 (Monday 4:15-5:00 p.m.), J. Willenbrock

The objective of this session is to give the students some experience with the organization and analysis of data. Each student is required to use the results of Sampling Experiment 1 to (a) construct a relative frequency histogram for the data and compare it to the relative frequency histogram of the population; (b) construct a frequency polygon and a cumulative frequency polygon for the grouped data; and (c) calculate the mean and standard deviation of the grouped data.

Session 6: Additional Aspects of Statistical Analysis (Tuesday 8:00-9:45 a.m.), J. Willenbrock

The objective of this session is to (a) develop the relationship between a frequency histogram of a set of data and an idealized smooth curve approximation and (b) indicate the suitability of a normal distribution in light of the PennDOT data presented. A description of the shape of the normal curves, skewed curves, and other less frequently occurring shapes is also presented. A more detailed explanation of the mean, median, and mode is given and their relationship with respect to the type of skewness is explained.

The significance of a bimodal or multimodal distribution, as it relates to statistical quality control of construction materials, is also explained. Some of the points are illustrated by means of the histograms and polygons of sand cone, nuclear, and Proctor test results from the PSU-PennDOT Test Track. A brief explanation of the properties of a normal curve is also given by presenting the "empirical rule" that relates areas under the curve to sigma limits.

Session 7: Sampling Experiment 2 (Tuesday 10:00-10:45 a.m.), J. Willenbrock

The objective of this session is to indicate to the student that the procedure of multiple sampling ($n > 1$) has advantages for both PennDOT and the contractor of material supplier. This objective is achieved by first reviewing the results of Sampling Experiment 1 and indicating that a single sample (of size $n = 1$) may be quite far from the population average and that an individual high result does not indicate any more about the "true average" than an individual low result.

The discussion of Sampling Experiment 1 leads into the idea of multiple sampling. At this point, therefore, Sampling Experiment 2 (where each student draws 4 samples from a bowl and determines an average value to represent all 4) is performed. The student is informed that there is some sound theoretical basis for multiple sampling by mentioning the concept of the sampling distribution of the means and the central limit theorem.

Session 8: Workshop 2 (Tuesday 10:45-11:00 a.m.), J. Willenbrock

The objective of this workshop is to give the student an appreciation for the results of a multiple-sampling ($n > 1$) experiment as well as to provide an additional opportunity for practice with the organization and analysis of data. The student is required to determine the frequency histogram, the mean, and the standard deviation for the data and discuss the implications indicated by the "grouped data" presentation. The objective is to compare the "distribution of the sample means" with the distribution of the population.

Session 9: Additional Aspects of Dispersion (Tuesday 11:00 a.m.-12:00 noon), J. Willenbrock

The objective of this session is to give the student a further appreciation for uses and implications of the term standard deviation. The first item discussed is that standard deviation may be used as a new measuring scale to indicate the difference between 2 numbers. This concept, particularly when the difference is between a given number and the arithmetic mean, is important when the calculation of the percent within limits for the normal distribution is discussed.

The next item covered is the relationship between the standard deviation of a sample and the standard deviation of the population. It is noted that the standard deviation of a sample of size n does not give the exact value of the population standard deviation and that quite often the population standard deviation is an idealized concept that must be estimated as closely as possible from the information from sample data.

The final item discussed in this session is a method, called the "average range method", for estimating a population standard deviation from sample data. It is the method that is used later in the course to establish the control limits for control charts.

Session 10: Normal Distribution (Tuesday 1:00-2:00 p.m.), J. Willenbrock

The objectives of this session are to (a) provide the student with an understanding of the normal distribution and its usefulness as a theoretical distribution that "models" actual construction material data and (b) illustrate the use of this theoretical model for the purpose of calculating the area under a distribution. This leads to the determination of the "percent within limits", a concept that is an extremely important part of the PennDOT acceptance plan procedure.

Session 11: Workshop 3 (Tuesday 2:00-3:45 p.m.), J. Willenbrock

The first part of the session is devoted to a series of progressively more difficult example problems related to the normal distribution. The validity of the "empirical rule" is explained as these example problems are discussed. After the student understands these calculations, the concrete compressive strength data previously presented in session 2 are reexamined to determine the areas under the distribution and whether the "normal" approximation was a valid assumption for this set of data.

Session 12: Normality Test (Tuesday 3:45-4:15 p.m.), J. Willenbrock

This session is devoted to an explanation of the graphical technique (using normal probability paper) for determining if the assumption of "normality" for a set of data is valid. The various "goodness of fit" tests available are discussed, but the one that is emphasized for practical field application is the graphical method. An example problem using grouped data is presented to illustrate how the procedure is used and how it compares with the cumulative frequency plot on conventional graph paper.

Session 13: Distribution of Sample Means (Wednesday 8:00-8:45 a.m.), J. Willenbrock

At this point in the course the student will have been exposed to 2 sampling experiments, and he should understand the difference between a histogram (or distribution) of a population and that of a sample. He should realize that there is probably a relationship between the parent population distribution and the various "distributions of sample means" that are developed from it as the sample size n is changed. Since the acceptance criteria in the PennDOT specifications are written on the basis of $n > 1$, it is important at this point to establish the theoretical basis for the sampling distribution of the means and to discuss the central limit theorem and the standard error of the mean as the underlying principles for the concept of multiple sampling ($n > 1$).

Session 14: Uses of Sample Mean Theory (Wednesday 8:45-10:00 a.m.), J. Willenbrock

The objective of this session is to indicate the applications of the sampling distribution of the means to the statistical quality control of construction materials. The first application is made to hypothesis testing in order to indicate how the calculation of percent within limits, area in the tails, etc., is changed if a decision must be made on the basis of a sample of size $n > 1$.

The second application is in the area of material specification development. Several examples are presented to illustrate how the desired properties and specification limits of the population are transformed into equivalent specification limits based on a specified sample of size $n > 1$. The correlation between specification limits and the size n of the sample is stressed in this session. The relationship is further emphasized by briefly discussing the statistical significance of retesting.

Session 15: Student-t Distribution (Wednesday 10:15-11:00 a.m.), J. Willenbrock

The objective of this session is to indicate what procedure is followed when information about the population must be inferred (statistical inference) from information obtained from a small sample. The standard central Student's t-distribution is presented and its shape is compared to that of the normal distribution as size n of the sample increases. The student is acquainted with the fact that quite often the target value of the population mean is specified and he must perform a percent-within-limits calculation for the population based on the value of the sample mean and standard deviation he obtains from a sample of size $n = 4$ or 5. In this case, since his best estimate of the population standard deviation σ is the sample standard deviation s, it is suggested that Student's t-distribution be used.

Session 16: Sampling for Quality Control (Wednesday 11:00 a.m.-12:00 noon, 1:00-1:30 p.m.), R. Cominsky, PennDOT

The objective of this session is to explain some of the practical factors involved in sampling techniques under the restricted performance type of specification. The first part of the session is devoted to the levels of sampling responsibility that exist under this type of specification. The 3 types of sampling, for process control, acceptance control, and assurance control, and the relationship between the 3 respective parties involved, the contractor and/or material supplier, PennDOT Bureau of Construction, and PennDOT Bureau of Materials, are discussed in detail. The point is made that PennDOT will use a method of stratified random sampling in the acceptance phase of quality control. The use of random sampling tables and PTM-1 (which deals with this type of sampling) is explained, and several examples of random sampling are presented to illustrate the method of locating points on a random basis.

The last part of the session covers the various aspects of the measuring process that must be considered when a sample is obtained. First, the terms precision, reproducibility, and accuracy are discussed. This leads into a discussion of the round-off rules that will be followed under the PennDOT specification.

Session 17: Development of Statistically Based Restricted Performance Specifications (Wednesday 1:30-3:00 p.m.), R. Nicotera, PennDOT

The objective of this session is to provide the student with a background in the various principles underlying restricted performance specifications. The first part of this session introduces the student to the fact that the specifications for construction materials are the framework for the quality-control system. The 2 more common types of specifications, i.e., end-result and material and methods, are compared to PennDOT's restricted performance type. A discussion of the essential elements that are found in all restricted performance specifications covers items such as (a) the levels of quality-control responsibility, (b) the materials characteristics that will be tested, (c) the location of a sample, (d) the definition of the size of the lot and sublot, (e) the definition of a sample, (f) the definition of the method of test, (g) the establishment of limits of acceptance, (h) the development of the ground rules for acceptance determination, and (i) the existence of a reduced-payment provision for noncompliance.

The final part of this session is devoted to an explanation of how the various components of variance for a material characteristic are established so that realistic limits of acceptance for the material can be established. The various components of the overall variation of the material characteristic are first identified, and the role they play in variation is established. The need for a planned experiment that allows for an analysis of variance (ANOVA) is discussed.

Session 18: Development of Acceptance Plans (Wednesday 3:15-5:00 p.m.), R. Cominsky, PennDOT

One of the primary parts of PennDOT's restricted performance specification is the acceptance plan. This plan defines the procedure that will be used to determine the characteristics of the construction materials as they are estimated from the results of a small sample. The objective of this session is to give the student an understanding of the underlying principles used to develop such an acceptance plan.

The first part of the session is devoted to explaining the concept of acceptance testing. The different types of acceptance plans are discussed, and the student is informed that PennDOT will mainly use acceptance plans for variables based on controlling the percent within limits. The different types of risks (i.e., α, β) involved in statistical decision-making are explained, and the role played by operating characteristic curves in the development of acceptance plans is discussed.

The final part of this session is devoted to an explanation of the parts of Mil. Std. 414 that affect PennDOT's acceptance plans. The student is given a brief explanation of the important parts of Mil. Std. 414 and is further informed that the range approach to variables sampling based on percent within limits is the one that PennDOT has adopted. This method is discussed in detail. The various parameters (i.e., Q_U, Q_L, etc.) are defined and the associated tables for this method are presented. This final part of the session should bridge the gap between calculating percent within limits with a normal curve assumption and calculating the same factor by using the tables in Mil. Std. 414.

Session 19: Review of Sessions and Homework (Thursday 8:00-8:30 a.m.), R. Nicotera, PennDOT

The objective of this session is to tie together some of the concepts covered on Wednesday by reviewing the sessions and the assigned homework problems.

Session 20: PennDOT's Restricted Performance Bituminous Specifications (Thursday 8:30-10:00 a.m.), R. Nicotera, PennDOT

One of the objectives of this session is to present PennDOT's restricted performance bituminous specification (currently a special provision to the Form 408 Specification) as an example of the format that a statistically based specification will have. The second objective is to provide the student with a working understanding of all parts of the specification in light of the statistical background acquired during the week.

The first part of the session covers the changes that have been made in the specification. Some of the important changes stressed are as follows:

1. The PennDOT construction engineer is no longer required to use only his own opinion when judging the acceptability of material, since he now has a set of specification limits and an acceptance plan to aid him in decision-making.
2. The contractor must be operating with an approved quality-control system guiding his process-control activities.
3. The acceptance rules, tables, and formulas will be used to determine the percent within limits of a particular characteristic as well as the related adjusted payment.

It is pointed out that the concept of an approved job mix formula still applies in this specification. A set of tolerances for aggregate gradation and mix temperature are provided in the specification as process control criteria. It is noted that the acceptance criterion for the material at the plant will be the bitumen content based on the average of 5 tests taken on a random basis within a lot. An "adjustment of contract price" table is also presented in conjunction with the formula for determining the percentage of material within the tolerance limits. In addition, the material will be accepted in the field based on a density criterion, the target value of which will be determined on the basis of a control strip concept. An adjustment of contract price table based on the average and range of 5 density tests from each lot is also presented for this acceptance criterion.

The final part of the session involves a discussion of the problems connected with outliers and develops a procedure for dealing with them as well as presenting the suggested Guidelines for a Contractor's Quality Control System. The point is emphasized that the contractor must present a quality-control system for approval that is at least equal in scope to the one discussed.

Session 21: Workshop 4 (Thursday 10:15 a.m.-12:00 noon), R. Nicotera, PennDOT

The objective of this session is to provide the student with some exposure to the type of calculations that will be required by the specification for acceptance based on bitumen content, density, etc. This is accomplished with a practicum session covering (a) problems related to acceptance calculations for bitumen content; (b) problems related to acceptance calculations for density; (c) determination of reduced payment for a typical project; (d) problems related to outliers; and (e) problems involving the establishment of a process-control system for a contractor.

Session 22: Control Charts and Contractor-Supplier Quality-Control Systems (Thursday 1:00-2:45 p.m.), J. Willenbrock

The objective of this session is to introduce the concept of control charts as a process-control technique and to develop the equations necessary to implement the method. The first item discussed is the purpose of control charts and the need to differentiate between "chance causes and assignable causes" in the day-to-day control of a process. It is noted that the drawback to using samples of size $n = 1$ is that assignable causes cannot be easily identified.

The control chart equations for the target value and the upper and lower control limits of the $\overline{X}$ and $\overline{R}$ charts are developed for the cases where (a) the population mean and standard deviation are assumed known or given by the material specification and (b) the population mean and standard deviation are assumed unknown. The use of tabulated factors for the various constants is indicated in the development of the equations. After these equations are developed the student is given an understanding of the pattern of data points he might expect to find in a control chart as various external factors influence the process.

Session 23: Control Chart Applications (Thursday 3:00-3:45 p.m.), J. Marcin, Penn State

The objective of this session is to illustrate the use of the control chart technique in an actual situation that occurred on a PennDOT project. The data used are for Type 2A aggregate that was used for subbase material. The contractor had collected aggregate gradation data over a 3-month period and had randomly sampled twice during each 4-hour period.

Session 24: Workshop 5 (Thursday 3:45-4:00 p.m.), J. Marcin, Penn State

The objective of this session is to give students the opportunity to develop the equations for the control charts for the same data presented in Session 23 if the subgroup is changed. This problem is finished as a homework assignment.

Session 25: PennDOT Computer Programs (Thursday 4:00-5:00 p.m.), R. Nicotera, PennDOT

The objective of this session is to explain how the student can utilize the computer programs PennDOT has developed to simplify some of the statistical calculations required. The first program discussed is "Data Summary", which may be used to organize and analyze the variance, standard deviation, coefficient of variation, and skewness of the data set as well as to plot the histogram.

The second program discussed is "ANOVA", which may be used by someone from

PennDOT or a contractor or material supplier to perform an analysis of variance on a given material characteristic. It establishes each of the components of variance based on the data determined from a designed experiment that is explained in the synopsis for the program.

The third program discussed is "Control Chart". It may be used to plot the $\overline{X}$ and $\overline{R}$ control charts for a given set of process-control data. The program determines the estimate of the population central tendency and dispersion and then presents a control chart printout using these parameters to develop the target value and upper and lower control limits.

Session 26: Review of Sessions and Problems (Friday 8:00-8:30 a.m.), J. Marcin, Penn State

The objective of this session is to review the material covered on Thursday in relation to PennDOT's bituminous restricted performance specification and the control chart technique. Questions are answered and the results of the homework assignment in control charts are discussed.

Session 27: Participant Feedback Session (Friday 8:30-9:45 a.m.), J. Willenbrock

The objective of this session is to determine what the students felt was the most valuable information they obtained from the course. This objective is met by first allowing each student to verbalize the points he felt were most valuable, would be the hardest to implement, caused the most confusion, etc. These comments are written on the blackboard to provide everyone with a review of the course. After this phase is completed each student is asked to fill out a questionnaire that explains his observations about the course in more detail.

The information provided is extremely helpful in determining (a) improvements that must be made in the course in order to improve general understanding, (b) potential areas of confusion that may arise when field personnel attempt to implement some of the statistical concepts, and (c) revisions that should be made to the specifications in order to eliminate the confusion.

Session 28: PennDOT Plans for Implementation (Friday 10:00-10:15 a.m.), J. Moulthrop, PennDOT

In this session, PennDOT's plans for implementation of restricted performance specifications are again reviewed. The students now have a much better understanding of the items discussed than they had when the PennDOT overview was presented on Monday. This session also stimulates some questions that can be raised during Session 29.

Session 29: Panel and Open Discussion (Friday 10:15 a.m.-12:00 noon), J. Moulthrop, PennDOT

The objective of this session is to provide a forum where questions related to any material covered during the week will be answered. A panel is assembled and usually consists of representatives from (a) PennDOT's Bureau of Construction, (b) PennDOT's Bureau of Materials, Testing and Research, (c) a construction company, (d) a material supplier, and (e) a federal agency. The panel members are to be drawn from the class if possible and really serve only as a focusing point for questions from the floor.

OBSERVATIONS ABOUT THE COURSE

In general it may be stated that the course was well received by the people who attended. Almost all of the participants approached the educational experience in a businesslike fashion, attempted to do the homework and keep up with the session notes, and realized that it was necessary to understand the material in order to properly carry out their day-to-day activities. When the diversity of mathematical and statistical expertise of the participants is recognized it may be stated that all of them received a much better understanding of restricted performance specifications, although some expressed a need for more time and workshop experience in order to understand how to handle all of the calculations.

It is understandable, therefore, that quite a number of the participants felt that the course should have been longer than 5 days whereas only a few felt the period of time should be reduced. It is the writer's opinion, therefore, that if the objectives of a course like this one are to go somewhat beyond the rules-of-thumb approach a minimum duration for the course should be 5 days. Although several comments were expressed that the homework assignments were burdensome and reduced the amount of free time the people had, there were also comments suggesting that one of the best features of the course was the need to review the material because of the homework assignments.

One need that was mentioned a number of times and that subsequently was added to the course was a glossary of terms and a summary of equations and symbols. Many concepts, terms, and equations were presented at a fairly rapid pace with very little time for reflection. This is the perfect set of conditions for confusion. It is felt that the presentation of such a glossary is one method of alleviating this problem.

There was a recognition at the beginning of the planning session that not all of the statistical topics could be covered in sufficient detail in a first course such as this. Trade-offs were therefore made, and areas such as hypothesis testing, confidence limits, and statistical decision theory related to risks and acceptance plans were not covered in sufficient detail. Even when this was done, some comments were made that more time should have been spent on practical examples, applications to practice, and problem-solving in workshop sessions. Perhaps the answer to this dilemma involves the inclusion of some of the additional statistical material in a second-level course that concentrates more on one particular type of construction material.

In addition, it must be recognized that this was a course primarily intended to train PennDOT personnel. If a course were given strictly for industry personnel, greater emphasis would have been placed on techniques for process control, determination of the actual risk levels implied by the specifications, etc. There were a number of comments expressed by industry people about the shortcomings of the course in this regard.

OBSERVATIONS ABOUT THE IMPLEMENTATION OF RESTRICTED PERFORMANCE SPECIFICATIONS

Some of the items discussed in the first 5 courses during the panel discussion (Session 29) indicate the types of concerns that were expressed after the students (field personnel who would essentially be directly involved with the specification) had spent a week of intensive study related to statistically based specifications. A few of the major items are given here to indicate the areas that the writer feels merit further investigation if these types of specifications are going to be extensively implemented in Pennsylvania as well as in other states.

1. It was generally felt that the specifications outline in great detail the ground rules that will be followed for acceptance sampling but are not nearly as explicit with respect to process-control requirements and guidelines. Although this might be the result of a preference indicated by some people in the industry (perhaps prior to understanding the concepts of statistical quality control), it was a real concern of many of the PennDOT

and industry people who attended the course. Questions about how a PennDOT construction inspector was to evaluate the process control of a contractor, what the role of the PennDOT inspector was when the contractor claimed his process was being controlled but the inspector found obvious local deficiencies, and what the extent of the process-control system would have to be to ensure that the contractor and/or material supplier would not be penalized at the acceptance stage all indicate that additional information about process control is desirable. It is the writer's opinion that research into this phase of statistical quality control has not kept up with research into the acceptance phase of the system.

2. Many questions revolved around the concept of a penalty clause as it relates to statistical-type specifications. Questions were raised regarding the contractual agreement that must exist between a contractor and his material supplier in light of the penalty system. Was there a need for an acceptance-plan approach at this interface? What would happen if the contractor put very tight requirements on the material supplier and because of the demand for the supplier's product (in the present state of the economy) this caused a termination of their relationship? Other questions revolved around whether a contractor could optimize his profit at the expense of quality by accepting a penalty as part of doing business, whether a bonus was anticipated for satisfactory material if it was within the specification limits, and whether past performance related to a penalty history could be used as a basis for prequalifying contractors.

3. Questions were raised about the ramifications of the concept of multiple sampling in a project as it related to the number of additional inspectors and technicians that would be required, the time required to take each of the tests, etc.

4. Some people also expressed concern about the extent of the training that would be required for this new approach to be understood by the majority of the people in the industry, both those working for PennDOT and those working for contractors and materials suppliers. It was felt that the training that was accomplished in the 8 courses would have to be filtered down in the PennDOT districts to the organizational level that would be directly involved with implementation. It was felt that this need would be partially satisfied if all of those who had received training at Penn State would act as instructors during winter training sessions at the district or company level.

5. Concern was also expressed about how the information flow would be accomplished for all the data that would have to be processed and evaluated for the 3 levels of sampling (i.e., process control, acceptance testing, and assurance sampling) required by the specifications. The assimilation of this information into decision-making at the district level was also viewed as a problem.

6. Questions were also raised about how the new type of specification would affect contractors of various sizes. Concern was expressed that the smaller contractors would suffer and that the producer with an automatic batch plant, for instance, would have an advantage over the one with a conventional plant under this type of specification.

In summary, then, it could be stated that some people felt that not all the details and ramifications of this type of specification had been worked out. It was felt that the entire concept had to be examined and its impact on each facet of the industry had to be evaluated. It was recognized that in a state as large as Pennsylvania the people at the district levels had to be given a system that was fairly well defined to ensure uniformity of approval, particularly at the process-control interface between PennDOT and the contractor.

SUMMARY AND CONCLUSIONS

This paper has attempted to present guidelines of how the educational requirements connected with the implementation of statistically based specifications may be satisfied in those states that are at a stage of implementation comparable to Pennsylvania. The paper has covered the background and guidelines for the series of short courses presented for PennDOT and construction personnel in Pennsylvania by the Department of Civil Engineering of Pennsylvania State University. Included are a summary of the objectives and an outline of each session presented in a typical course. In addition, sections of the paper are devoted to the primary observations of the participants in these courses with respect to the course content as well as PennDOT's plans for implementation.

In conclusion, it is the writer's opinion that PennDOT approached the implementation of these specifications in the correct fashion by recognizing the need for an extensive educational program to ensure that these specifications will be accepted by the people who will use them. It is hoped that other states will also recognize this need.

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