

CONCLUSION

This paper has presented many methods in which the computer can be used in the development of a statistically based acceptance plan. These methods include the following:

1. Preliminary data analysis to determine parameters necessary for the development of the plan;
2. The determination of areas under probability distributions by mathematical algorithms, thereby eliminating the need for tedious hand calculations and interpolations from tables;
3. A means for obtaining a good estimate of the expected payment curves for acceptance plans that incorporate continuous rather than discrete price adjustment schedules;
4. Computer simulation to develop OC curves in terms of means and standard deviations that can easily be related to the contractor's process capabilities; and
5. Computer simulation to develop OC curves for acceptance properties requiring both upper and lower specification limits that would not be practical if theoretical methods were used.

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REFERENCES

1. T. A. Ryan, B. L. Joiner, and B. F. Ryan.

- Minitab Student Handbook. Duxbury Press, North Scituate, MA, 1976.
2. SAS User's Guide, 1979 Edition. SAS Institute, Inc., Raleigh, NC, 1979.
3. Commentary to the Eastern Region P-401 Specification. Federal Aviation Administration, Engineering Bulletin No. 11, AEA-620, 1977.
4. J. H. Willenbrock and P. A. Kopac. Development of Price Adjustment Systems for Statistically Based Highway Construction Specifications. TRB, Transportation Research Record 652, 1977, pp. 52-58.
5. J. H. Willenbrock and P. A. Kopac. The Development of Tables for Estimating Percentage of Material Within Specification Limits. Pennsylvania Transportation Institute, Pennsylvania State Univ., University Park, Rept. FHWA-PA-74-27(2), Oct. 1976.
6. G. J. Resnikoff and G. J. Lieberman. Tables of the Noncentral t-Distribution. Stanford Univ. Press, Stanford, CA, 1957.
7. G. J. Lieberman and G. J. Resnikoff. Sampling Plans for Inspection by Variables. Journal of the American Statistical Association, Vol. 50, 1955, pp. 457-516.
8. J. H. Willenbrock and P. A. Kopac. The Development of Operating Characteristic Curves for PennDOT's Restricted Performance Bituminous Concrete Specifications. Pennsylvania Transportation Institute, Pennsylvania State Univ., University Park, Rept. FHWA-PA-74-27(3), Oct. 1976.
9. IMSL Library 1 Reference Manual, 6th ed. International Mathematical and Statistical Libraries, Inc., Houston, TX, Vol. 2, 1977.
10. R. H. Weed. Basic Techniques and Examples of Computer Simulation. TRB, Transportation Research Record 613, 1976, pp. 44-50.
11. J. L. Burati and J. H. Willenbrock. Acceptance Criteria for Bituminous Surface Course on Civil Airport Pavement. Federal Aviation Administration, Rept. FAA-RD-78-89, Oct. 1979.

Conversational Programming: Making Computer Technology More Accessible

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Although the most practical way to handle many of today's sophisticated engineering and statistical analyses is with high-speed electronic computers, engineers often lack the programming skills necessary to take full advantage of this approach. Conversational programming, which provides explicit instructions to the user at an interactive terminal, enables even less-skilled subordinates to perform complex tasks on the computer. Almost any quantitative analysis can be computerized, and the potential applications are virtually endless and are limited only by the imagination and inventiveness of the program writer. Benefits of conversational programming are discussed, and a reference is cited to aid in the development of programs of this type. An example is presented that deals with the testing of statistical acceptance procedures by computer simulation, an extremely powerful technique of great potential value to quality assurance engineers. By using another conversational program, a theoretical analysis is made and compared with the simulation results.

In a time that historians are beginning to call the com-

puter age, many engineers still have little or no programming ability. Although computer terminals are readily accessible to engineers in most organizations and computer programming is now strongly emphasized in engineering colleges, many practicing engineers have never acquired the ability to take full advantage of these facilities. In some cases, this means that considerable time will be wasted in making complex calculations that could be performed much more efficiently by computer. In other cases, potentially useful analyses may never be attempted because of the impracticality of doing them by any means other than a large computer. Although many engineering functions have been computerized by software specialists in recent years, much still remains to be done.

As more and more engineering graduates enter the profession, this shortcoming will gradually disappear.

Eventually, programming ability will be as commonplace as the ability to use a slide rule was to earlier generations of engineers. Until that time, however, engineers will not realize the full potential of the computer unless a means can be found to make its capabilities more readily accessible to them. One way to accomplish this is by using conversational programming.

CONVERSATIONAL PROGRAMMING

Conversational programming refers to a technique in which a computer appears to converse with a user operating an interactive terminal. In actuality, the program writer has anticipated virtually every bit of dialogue that might reasonably occur and has included the necessary checks to cause the proper messages to be typed out (or appear on a video screen) at the appropriate times. Sophisticated programs of this type are quite involved and seem to endow the computer with almost human intelligence.

For engineering and statistical applications, somewhat less sophistication is required. Basic instructions must be provided to guide the user, and various checks and diagnostic messages must be included to guard against misuse. About all that is required of the user is an awareness of the purpose of the program and the ability to follow simple instructions. There is no need to be familiar with programming techniques nor is an intimate knowledge of the analytical procedure required.

The examples that follow illustrate the more common features of typical conversational programs. The first program is one that might be written to enable quality assurance engineers to test statistical acceptance procedures by computer simulation. The second example illustrates how a particular type of acceptance procedure can be evaluated analytically and is used to check the results of the first program. The messages printed out by the computer are in capital letters and the user's replies are in lower case, just as they would appear with most interactive terminals. Brief commentaries in parentheses have been added at appropriate points.

ACCEPTANCE PROCEDURE SIMULATION (EXAMPLE 1)

ENTER NAME OF ANALYSIS TO BE PERFORMED
acceptance procedure simulation

(The program "acceptance procedure simulation" is one of several contained in this particular package. Very probably, the computer is required to read only the first few letters of the user's reply to identify this program.)

DO YOU WISH AN EXPLANATION OF THIS PROGRAM?
yes

THIS PROGRAM PERMITS THE TESTING OF VARIOUS ACCEPTANCE PROCEDURES BY COMPUTER SIMULATION. THE USER SPECIFIES THE ACCEPTANCE CRITERIA, THE SAMPLE SIZE, THE TYPE OF DISTRIBUTION, THE DISTRIBUTION PARAMETERS, AND THE NUMBER OF LOTS TO BE SIMULATED. THE USER SELECTS THE DESIRED OUTPUT FORMAT WHICH MAY INCLUDE HISTOGRAMS AND ELEMENTARY STATISTICS FOR THE RANDOMLY GENERATED DATA, THE PERCENTAGE OF LOTS FAILING EACH ACCEPTANCE REQUIREMENT, THE ESTIMATED PROBABILITY OF ACCEPTANCE, AND CONFIDENCE LIMITS FOR THIS ESTIMATE.

ENTER NUMBER OF ACCEPTANCE CRITERIA TO BE USED
2

(Many specifications use multiple acceptance criteria. This program provides the capability of testing various combinations of these criteria.)

ENTER CODE NUMBERS FOR ACCEPTANCE CRITERIA TO BE USED
explain

(Conversational programs usually provide a means for the user to request additional assistance. In this example, the word "explain" is entered in place of the expected numerical quantities. This cues the computer to type out an explanation of the various acceptance criteria that may be selected.)

THE FOLLOWING ACCEPTANCE CRITERIA MAY BE SELECTED

1. LOWER LIMIT ON SAMPLE MEAN
2. UPPER LIMIT ON SAMPLE MEAN
3. LOWER LIMIT ON INDIVIDUAL VALUES
4. UPPER LIMIT ON INDIVIDUAL VALUES
5. MAXIMUM PERCENT DEFECTIVE BELOW LOWER LIMIT
6. MAXIMUM PERCENT DEFECTIVE ABOVE UPPER LIMIT
7. MAXIMUM TOTAL PERCENT DEFECTIVE OUTSIDE LOWER AND UPPER LIMITS
8. MAXIMUM VALUE FOR SAMPLE STANDARD DEVIATION
9. MAXIMUM VALUE FOR SAMPLE RANGE

ENTER CODE NUMBERS FOR ACCEPTANCE CRITERIA TO BE USED
1 3

[Following the explanation, the input instruction is repeated. The user has selected codes 1 and 3, which specify dual acceptance criteria to be applied to the mean and lowest value of each sample—a type of specification frequently recommended by both the American Society for Testing and Materials (1) and the American Concrete Institute (2).]

ENTER LOWER LIMIT FOR SAMPLE MEAN
3000

ENTER LOWER LIMIT FOR INDIVIDUAL VALUES
2500

(The user is testing an acceptance procedure for some quality characteristic with limits of 3000 and 2500 for the mean and individual values, respectively. The specific units are not identified in this example and may be regarded as either metric or customary quantities.)

ENTER SAMPLE SIZE (MAXIMUM 30)
3

ENTER CODE NUMBER FOR DISTRIBUTION TYPE
explain

THE FOLLOWING DISTRIBUTIONS MAY BE SELECTED

1. UNIFORM
2. NORMAL
3. SKEWED NORMAL
4. EXPONENTIAL
5. POISSON

ENTER CODE NUMBER FOR DISTRIBUTION TYPE
2

(Although most construction quality characteristics are normally distributed, the program provides the capability to test the acceptance procedure on other types of distributions.)

ENTER CODE NUMBER FOR MEASURE OF VARIABILITY TO BE USED
explain

THE FOLLOWING MEASURES OF VARIABILITY MAY BE SELECTED

1. STANDARD DEVIATION
2. COEFFICIENT OF VARIATION
3. VARIANCE

ENTER CODE NUMBER FOR MEASURE OF VARIABILITY TO BE USED

2

ENTER COEFFICIENT OF VARIATION (PERCENT)

15

ENTER MINIMUM, MAXIMUM, AND STEP SIZE FOR POPULATION MEANS

2500 4400 100

(The user has decided to test the acceptance procedure over a series of possible mean production values ranging from 2500 to 4400 in increments of 100.)

ENTER NUMBER OF LOTS TO BE SIMULATED FOR EACH RUN (MAXIMUM 5000)

2000

ENTER RANDOM GENERATOR SEED NUMBER (7-DIGIT ODD NUMBER)

1234560

ERROR IN INPUT

SEED NUMBER MUST BE ODD

ENTER RANDOM GENERATOR SEED NUMBER (7-DIGIT ODD NUMBER)

1234567

(To guard against their misuse, conversational programs must have an elaborate system of checks to detect improper input data. The random generators in this program require that a single odd number be entered to initiate their operation. The computer checked the input, found it to be an even number, typed out an error message, and repeated the input instruction. The user then entered an appropriate seed number.)

ENTER CODE NUMBERS FOR OUTPUT INFORMATION DESIRED explain

THE FOLLOWING OUTPUT INFORMATION MAY BE SELECTED

1. SUMMARY OF INPUT INFORMATION
2. HISTOGRAMS FOR RANDOMLY GENERATED DATA
3. ELEMENTARY STATISTICS FOR RANDOMLY GENERATED DATA
4. PERCENTAGE OF SIMULATED LOTS FAILING EACH REQUIREMENT
5. ESTIMATED PROBABILITY OF ACCEPTANCE
6. CONFIDENCE LIMITS FOR PROBABILITY OF ACCEPTANCE

ENTER CODE NUMBERS FOR OUTPUT INFORMATION DESIRED

1 5 6

ENTER CONFIDENCE LEVEL FOR PROBABILITY OF ACCEPTANCE (PERCENT)

95

A novice just becoming acquainted with this program might wish to print out all the available output information in order to become familiar with the simulation process. The user in this example has selected a more abbreviated printout (Figure 1). For the particular input values chosen, the output provides the data necessary to plot an operating characteristics curve that gives the probability of acceptance for any mean production value. This would enable a specification writer to decide if any modifications of the acceptance procedure should be made.

Because the development of acceptance criteria is often a trial-and-error process, it is likely that the user of this program will wish to make several repeat runs. Although not shown in this example, a convenient means would be provided for the user to return to various points in the input sequence. (The order in which the input information was entered in this example was chosen to simplify the presentation. A somewhat different order

Figure 1. Sample of printout for example 1 shows results of computer simulation.

ACCEPTANCE CRITERIA		
LOWER LIMIT ON SAMPLE MEAN = 3000.000		
LOWER LIMIT ON INDIVIDUAL VALUES = 2500.000		
SAMPLE SIZE = 3		
NORMAL DISTRIBUTION PARAMETERS		
MEAN = 2500.000 TO 4400.000 BY 100.000		
COEFFICIENT OF VARIATION = 15.0		
NUMBER OF SIMULATED LOTS PER RUN = 2000		
SEED NUMBER = 1234567		
CONFIDENCE LEVEL = 95.0		
POPULATION MEAN	ESTIMATED PROBABILITY OF ACCEPTANCE	95.0 PERCENT CONFIDENCE INTERVAL
2500.000	0.01	0.00 - 0.01
2600.000	0.03	0.03 - 0.04
2700.000	0.09	0.08 - 0.10
2800.000	0.19	0.17 - 0.21
2900.000	0.30	0.28 - 0.32
3000.000	0.45	0.43 - 0.47
3100.000	0.57	0.55 - 0.59
3200.000	0.72	0.70 - 0.74
3300.000	0.79	0.77 - 0.81
3400.000	0.84	0.83 - 0.86
3500.000	0.90	0.89 - 0.92
3600.000	0.91	0.90 - 0.92
3700.000	0.95	0.94 - 0.96
3800.000	0.96	0.96 - 0.97
3900.000	0.97	0.97 - 0.98
4000.000	0.98	0.97 - 0.98
4100.000	0.99	0.98 - 0.99
4200.000	0.99	0.98 - 0.99
4300.000	0.99	0.99 - 1.00
4400.000	0.99	0.99 - 1.00

would be more efficient for an actual program.)

ANALYTICAL EVALUATION OF ACCEPTANCE PROCEDURE (EXAMPLE 2)

Depending on the type of acceptance procedure, it is not always possible to determine the probability of acceptance analytically. In these cases, computer simulation is the only practical method of analysis. For a dual acceptance procedure, such as the mean and lower limit specification in the first example, an analytical solution for the exact probability of acceptance is not known. However, lower and upper bounds for this value can be calculated from an expression I developed in another paper that appears in this Record on multiple acceptance criteria—i.e., $P_1 P_2 \leq P[\text{ACCEPT}] \leq \text{MINIMUM}[P_1, P_2]$ in which P_1 and P_2 are the (somewhat correlated) probabilities of passing the individual requirements separately. An analysis of this type is less involved than a simulation, but it does require extensive use of normal distribution theory and is sufficiently tedious to warrant computer assistance. The following conversational program would greatly simplify this task:

```

ENTER NAME OF ANALYSIS TO BE PERFORMED
dual criteria evaluation

DO YOU WISH AN EXPLANATION OF THIS PROGRAM?
yes

THIS PROGRAM COMPUTES LOWER AND UPPER BOUNDS FOR
THE PROBABILITY OF ACCEPTANCE RESULTING FROM DUAL
ACCEPTANCE CRITERIA APPLIED TO SAMPLES FROM A NORMAL
POPULATION. THE USER SPECIFIES THE NORMAL DISTRIBUTION
PARAMETERS, THE SAMPLE SIZE, AND LIMITS FOR BOTH
THE SAMPLE MEAN AND INDIVIDUAL VALUES.

ENTER CODE NUMBER FOR MEASURE OF VARIABILITY TO BE
USED
2
    
```

```

ENTER COEFFICIENT OF VARIATION (PERCENT)
15

ENTER MINIMUM, MAXIMUM, AND STEP SIZE FOR POPULATION
MEANS
2500 4400 100

ENTER SAMPLE SIZE
3

ENTER CODE NUMBER FOR DUAL CRITERIA COMBINATION
explain

THE FOLLOWING COMBINATIONS MAY BE SELECTED
1. LOWER LIMITS ON MEAN AND INDIVIDUAL VALUES
2. UPPER LIMITS ON MEAN AND INDIVIDUAL VALUES
3. LOWER AND UPPER LIMITS ON MEAN AND INDIVIDUAL
VALUES

ENTER CODE NUMBER FOR DUAL CRITERIA COMBINATION
1

ENTER LOWER LIMIT FOR SAMPLE MEAN
3000

ENTER LOWER LIMIT FOR INDIVIDUAL VALUES
2500
    
```

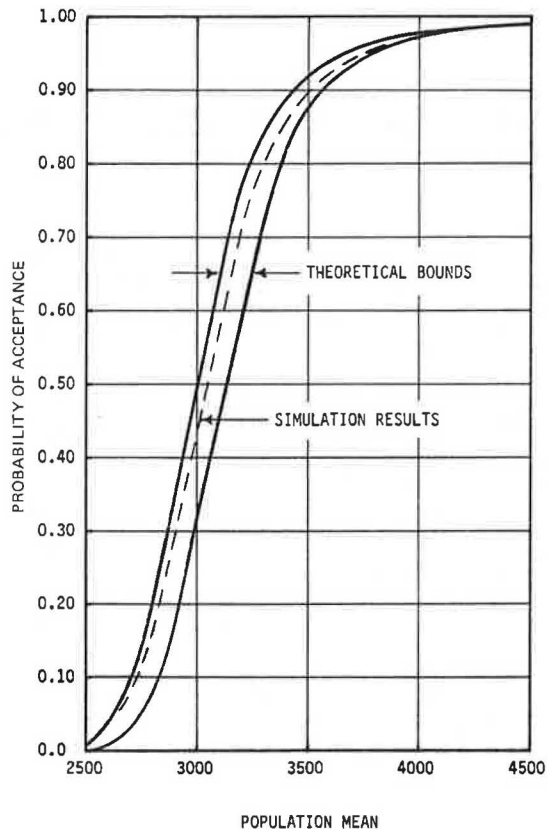
The printout for this example is shown in Figure 2. Like the output for the first example, this provides the information necessary for a specification writer to evaluate the effectiveness of the acceptance procedure.

The output presented for both of these examples was obtained from actual computer runs. It is interesting to observe that the results obtained by simulation fall within the theoretically predicted bounds in every case. For ease of comparison, these results are plotted in Figure 3.

Figure 2. Sample of printout for example 2 shows results for analytical evaluation.

ACCEPTANCE CRITERIA	
LOWER LIMIT ON SAMPLE MEAN = 3000.000	
LOWER LIMIT ON INDIVIDUAL VALUES = 2500.000	
SAMPLE SIZE = 3	
NORMAL DISTRIBUTION PARAMETERS	
MEAN = 2500.000 TO 4400.000 BY 100.000	
COEFFICIENT OF VARIATION = 15.0	
POPULATION MEAN	ANALYTICAL BOUNDS FOR PROBABILITY OF ACCEPTANCE
2500.000	0.00 - 0.01
2600.000	0.01 - 0.04
2700.000	0.03 - 0.10
2800.000	0.09 - 0.20
2900.000	0.19 - 0.35
3000.000	0.33 - 0.50
3100.000	0.47 - 0.65
3200.000	0.61 - 0.76
3300.000	0.72 - 0.85
3400.000	0.81 - 0.89
3500.000	0.87 - 0.92
3600.000	0.91 - 0.94
3700.000	0.94 - 0.95
3800.000	0.96 - 0.97
3900.000	0.97 - 0.98
4000.000	0.98 - 0.98
4100.000	0.99 - 0.99
4200.000	0.99 - 0.99
4300.000	0.99 - 0.99
4400.000	0.99 - 0.99

Figure 3. Comparison of simulation results with theoretical bounds.



BENEFITS OF CONVERSATIONAL PROGRAMMING

The major benefit to be derived from conversational programming is the tremendous computational power it provides to anyone with access to a computer terminal. The examples presented in this paper illustrate how a broad range of acceptance procedures can be tested by following a few simple instructions. Ordinarily, analyses of this type would require a working knowledge of quality-control theory, statistical analysis, computer programming, and simulation techniques. When developed as conversational programs, these analyses can be delegated to individuals with very little specialized training.

Like these examples, many of today's engineering problems require expertise in a variety of disciplines. Frequently, when individuals capable of applying the multidisciplinary approach are not readily available, these problems are referred to outside consultants. Depending on the nature of the analyses required, it may often be possible to develop general conversational programs that would permit the in-house solution of similar problems in the future. In many cases, a well-planned conversational program might obviate the need for the repeated use of outside consulting services.

Other obvious benefits are speed and accuracy. Once the program has been tested and validated, it can be depended on to produce reliable results. Because of the tremendous speed of the computer, many runs can be made in a short period of time in order to thoroughly analyze the problem at hand. In most cases, this capability would translate directly into economic savings.

Finally, conversational programming can result in the more efficient use of engineering specialists. If it appears that there will be repeated requests for a par-

ticular type of analysis, it will often be advantageous to develop a general solution and put it in the form of a conversational program. Future applications will then require minimal involvement on the part of the specialist.

CONCLUSION

Although engineers can benefit greatly from the use of computers, many do not have sufficient programming ability to take full advantage of this approach. Conversational programming provides a means to make the benefits of computer technology available to a much broader segment of the engineering profession. The examples illustrate how complex analyses can be performed by anyone capable of following simple instructions. The use of programs of this type can enable engineers to do better work, do it with less effort, and save both time and money. The reader interested in further examples of conversational programming along with the appropriate FORTRAN IV coding is referred to a publication on computer simulation by the Federal Highway Administration (3).

REFERENCES

1. Standard Specification for Precast Concrete Barrier, Annual ASTM Standards, Part 16. American Society for Testing and Materials, Philadelphia, C825-76, 1976.
2. Building Code Requirements for Reinforced Concrete. American Concrete Institute, Detroit, ACI 318-71, 1971.
3. R. M. Weed. An Introduction to Computer Simulation. Federal Highway Administration, 1976.

Quality Assurance Through Computers

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A sound quality assurance program is one that must be capable of providing information to users and not just data. It is information prepared from analysis of data that is important. Such information should be provided rapidly, economically, and efficiently. Such information flow can only be accomplished through the use of computers. However, a necessary prerequisite to this flow or feedback of information is its availability at a centralized location, namely, computer files. This residence requirement further mandates a fast data-entry system on on-going operations. Louisiana's Material Test (MATT) data-reporting system comes close to satisfying the requirements of a user-oriented quality assurance feedback system. The system is an on-line computer-based system through which data generated on construction projects can be entered, corrected, updated, deleted, and retrieved through the department's terminal network system. The system, which has been in operation since the early part of 1978, is capable of providing information not only to those responsible for monitoring the construction projects but also to those involved in the planning, design, evaluation, research, and maintenance of pavement systems. Specific examples of the application of the computerized system related to quality assurance are presented in the paper. An overview of the system, with respect to design, development, hardware, and software, is also discussed. The paper emphasizes the need for a computerized quality assurance system as a subsystem of the overall pavement management system.

In recent years the task of recovering information from

construction and material testing has increased enormously. This has largely been due to the accelerated quality assurance program within the Louisiana State Department of Transportation and Development (LDOT) and an increased awareness of the constant improvement in the acceptance sampling plans and specifications. Literally thousands of pieces of inspection and test-related data are generated from various sources in a year. The sheer volume of data has created two separate but related problems:

1. The continuing increase in effort required by various personnel in collecting, recording, and processing the data on a variety of test documents, and
2. The difficult and, at times, frustrating task of retrieving these data manually for use in on-going operations, research, problem solving, and planning for the future.

To resolve these problems, LDOT initiated a project that would provide an integrated computer-based system by which the various districts of LDOT can transmit the construction and material test data through the terminals