computerized quality control

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This paper discusses the application of a computerized quality control package to a construction project in Utah. The package, comprising seven computer programs, was based on the premise that quality of bituminous pavements can be controlled by regulating bitumen content, aggregate gradation, relative compaction, and surface variation. The seven computer programs are described. As a result of this pilot project, Utah has begun statewide implementation of this quality control system.

•The quality of materials and workmanship used in construction has long been of significance to the highway engineer. For this reason, much effort has been directed toward development of specifications that control the quality of construction without forcing the costs of this construction to exceed reasonable limits. No specification, however, can be more effective than the material test on which it is based, and the results of this test are of no value until they reach the project engineer and the contractor. If the results of a test that show nonconformance to specifications were not made known to the project engineer and the contractor in time, a whole section of roadway might have to be either accepted at a low level of quality or removed at great expense. Problems of this type, as well as others, inherent in present quality control methods can be minimized by using revised specifications and testing procedures in conjunction with a computerized quality control system. A pilot project using such a system has recently been completed in Utah. The results of that project as well as some of the characteristics of the quality control system itself are discussed. In addition, the new quality control system being instituted in Utah, which was a direct result of this pilot project, will be covered briefly.

The feasibility of establishing a computerized quality control system with its associated specifications and test methods in Utah was tested by setting up a pilot project for construction of a 5.3-mile section of Interstate 80N near Tremonton in the northern part of the state.

THE SYSTEM AND ITS USE

The specifications and computer programs used at Tremonton were modified versions of a quality assurance computer program package obtained from the Federal Highway Administration. The package, which will be discussed in detail, contained several programs using punched cards as input-output media. The input cards were to be punched in the field and were to contain records of daily test results. They were then to be delivered to a computer terminal for processing and the results of the computer analysis were to be delivered back to the project engineer. Because the project was relatively remote from an available computer system and because of the problems as-

sociated with using punched cards for data records in a project of this type, an alternative solution was devised. The computer programs were converted to operate on a commercial time-sharing computer system, and a teleprinting computer terminal was placed in the project engineer's office near the construction site. This allowed the engineer or members of his staff to build daily data files, call the program wanted, and receive almost instantaneous results on the conformance to specifications on the project.

The project presented some new experiences for the engineering staff and the contractor. The project engineer who had graciously consented to take on this pilot program spent many extra hours in the first few weeks learning to communicate to the computer and learning how to get the computer to respond in meaningful terms. Because the computer programs were hurriedly converted and were not specifically designed to operate on a time-sharing system, the data input requirements were somewhat more cumbersome than normal. However, it was not long before the engineering staff had mastered the new system and was making meaningful comments about future refinements to the program package. The contractor too had his problems initially. He set up operations and began placing material only to receive a 60 percent reduction in payment for the first 2 days' operation. Upon learning of the reduction, he promptly shut down operations on the project; and, when they were resumed several days later, the specifications were being met. After the initial shock of the new system was overcome, the project ran rather smoothly except for a few minor problems, which were to be expected in an experimental project of this nature.

As was mentioned previously, the original quality control package was modified before the beginning of the pilot project to operate on a time-sharing system, and later it was again modified to more effectively serve the project engineering staff. These modifications were almost entirely in the input-output functions of the computer programs. The basic analytic and deterministic processes of the package were not altered. A brief discussion of the programs in the package and how they combine to provide a total quality control system for bituminous concrete follows.

QUALITY CONTROL PACKAGE

The package is based on the premise that the quality of bituminous pavements can be controlled by regulating four characteristics: bitumen content, aggregate gradation, relative compaction, and surface variation. This is done by using the first three programs of the seven in the package.

The vacuum extraction program computes the results of each vacuum extraction test made on the bituminous pavement. The averages of these results are compared to target values for each sieve previously agreed on by the project engineer and contractor. The deviation of the results from these target values determines the adjustment that is made to the unit bid price. This deviation depends on the particular sieve and on the number of tests taken from the test lot. The program produces a lot summary of the tests taken on each production day. The program prints out the lot averages for percentage of bitumen, percentage passing each sieve, unit bid price adjustment, and amount of the reduction for the day. Input for the program is placed into an input file from the remote terminal located in the project office. Output is provided on the same device.

The nuclear density program computes the relative compaction of material by using as input the raw measured data from a portable nuclear gauge and its gauge constants. A control strip of pavement is constructed, and 10 nuclear readings are taken. The average density of the readings is used as a target value for the remaining material in the test lot until another control strip is constructed. Core and Marshall density tests can also be taken to ensure that the target density is the required percentage of laboratory density. The measured densities on the pavement are compared to the target values to obtain the relative compaction of the material and the subsequent penalty to be assessed

if any. The program produces a summary of the control strip data including core and Marshall data. It also produces a table of density tests with their associated percentages of compaction and a lot summary containing the average density, target density, percentage of compaction, and pay factor. Input methods are similar to those of the vacuum extraction program.

The smoothness program computes the percentage of nonconforming tolerances in pavement surface measurements by using a profilograph. The percentage of nonconformance for each day is compared with an adjustment schedule for percentage of nonconformance to determine the unit bid price adjustment. The program produces a unit bid price adjustment schedule and a summary of each production day including lengths and sublots measured, lengths of sublots exceeding $^3/_{10}$ inch of surface variation in 25 feet, and the percentage of nonconformance and its associated pay factor.

The vacuum extraction, nuclear density, and smoothness programs also provide information that goes directly into storage files located in the computer system. These files can be used to provide summary data for a project, but their main function is to provide input data that are used by the other programs in the package.

The fourth program in the package is the total program. This program summarizes the data from the storage files of the first three programs and computes a single pay factor and a cumulative tonnage for each production day. The program produces a summary table for the period of time desired. The summary table contains the production day, the daily tonnage, pay factors for each program, and the total pay factor for each day.

The final three programs are statistical analysis programs that use storage file contents from the vacuum extraction program. The programs are analysis of variance, standard deviation, and a graphical program called histogram. The analysis of variance program analyzes the duplicate samples and gives the overall variance and the components of that variance. Other statistical parameters are given for both the production process and testing errors. The standard deviation program summarizes and computes the average, standard deviation, sum, and sum of square values for the differences between the test values and the target values. The histogram shows a graphical summary of the distribution of deviations from the target values for the vacuum extraction test.

FURTHER COMMENTS

Thus, the programs that make up the quality control package act as a unit to provide the project engineer with information to help him regulate those characteristics that are essential to production of quality bituminous pavements and to provide this information soon enough to eliminate the possibility that large amounts of substandard work are completed.

As a result of the pilot project at Tremonton, Utah has begun statewide implementation of this quality control system. The specifications used in the new system have been modified based on the findings of the pilot project and have received endorsement from the Association of General Contractors. The most significant change perhaps is that Utah has purchased a new computer system, an IBM 370/155, and along with this system there are plans to place a remote-access terminal in each project office throughout the state. Not only will this provide the benefits associated with this quality control package, but also it will allow an engineer to use the capabilities of a large computer system in other areas such as design and earthwork calculations.

The computer has, to one degree or another, established itself in virtually every phase of highway engineering. It ranges from small one-time analysis programs to unbelievably

large data storage systems. In Utah one of the last thresholds to be crossed by the computer was in construction. Now that the first step has been taken, it is inevitable that computers will become more and more valuable to those engineers and technicians involved in the construction area. With respect to quality control, as test methods are developed that permit more rapid detection of nonconformance in concrete pavements and bridge decks, the computer can provide the same advantages it does for bituminous pavements. The computer can take over all routine or redundant correspondence or paperwork associated with construction. It can provide information for various levels of management or for designers and those engaged in research. Thus, the only limitation to this engineering tool is the failure of the engineer to use it.