Quality Assurance—A System in Practice

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The trend toward rapid highway construction and maintenance operations has resulted in certain deficiencies in the classical specifications and procedures of past years. This has resulted in a decision to begin an ordered restructuring of the system then in existence. The objective was eventual establishment of a quality-assurance system that would be adequate for the department's needs and use the resources that would be made available. Major areas that have been substantially affected by the decision are briefly discussed. These areas include training, specifications, sampling and testing, information handling, and the owner-contractor relations. Changes noted that have been implemented in these areas include: (a) technician certification, (b) routine application of the concepts of probability, (c) clear definitions of the contractor's responsibility for quality control and the department's responsibility for acceptance, (d) use of contractor-developed data by the department, (e) development and application of rapid test and evaluation methods, and (f) the routine use of electronic data processing in daily operating procedures. Based on the favorable results obtained, performance specifications are workable, and the continued use of systems engineering techniques is the most practical way to maintain an overall course of action that is directed toward the achievement of our goal—a quality-assurance system that works in practice.

When we speak of a quality-assurance system we are actually speaking of a system that involves quality control, design, maintenance, planning, and environmental, social, and many other incidental factors that relate to human and natural resources (1-4). The total quality-assurance system can be illustrated as shown in Figure 1.

The role of quality assurance within this context is to verify, audit, and evaluate the quality factors that affect the design, specifications, production, construction, maintenance, and use of a product or service. Quality assurance used in this manner represents management's concern for quality as well as management's efforts to ensure quality.

Concern has been expressed during the past decade about the need for more homogeneous, rational, and significantly applicable decisions with regard to quality of highway construction and maintenance materials. Together with this concern has come considerable information and development of concepts. This concern and the attendant outgrowth of conceptual development resulted from the realization that the classical pre-1960 specifications and acceptance procedures were not sufficient for current highway construction and maintenance operations.

The state of the art of quality assurance and acceptance procedures for highway construction materials, current and predicted, has been addressed on a national level (5). Attention has been focused on a multitude of different, although related, approaches to improved quality and acceptance decisions. A few of those many different approaches involve such often heard terms as "rapid test method", "end-result specification", "statistical specification", and "automatic data processing systems approach". However, it has been the experience of the West Virginia Department of Highways that a combination of many of these various approaches is necessary in order to provide an efficient quality-assurance program. Our needs for the future require the development of systems that involved all of the factors shown in Figure 2.

It was recognized that a comprehensive quality-assurance system would have to be composed of two separate and distinct subsystems--that of process control and that of acceptance sampling, inspection, and testing. Process control is, of course, the responsibility of the producer of the product, that is, the contractor (see Figure 3). Acceptance inspection sampling and testing are the responsibility of the user, that is, the transportation agency (see Figure 3). Further, an optimized quality-assurance system must balance the need of the producer and user for a decision at the earliest practical time against the need for delaying a decision to the latest practical time.

PERFORMANCE SPECIFICATIONS

Accordingly, a quality-assurance system ceases to be strictly a project activity, because acceptance decisions must be made throughout the full range of the elements that comprise the system. Conversion to performance specifications seemed the best method to accomplish this. Also, the department thought that this conversion (from the classical pre-1960 specifications to performance specifications) should be an evolutionary process, rather than a revolutionary process. This approach, along with a permanent cooperative training program and regularly scheduled industry-department communication sessions have allowed the contracting industry to be prepared to accept its responsibility for the quality control of the production process.

Quality-assurance systems, as used by the West Virginia Department of Highways and as used in this paper, denote in general terms the following: a total procedure for the acceptance of highway construction or maintenance materials based on specification limits, statistical criteria for evaluation of central tendency and variability, input of process control and acceptance testing, and decision criteria--all evaluated by using automatic data processing equipment. The end-result decision produced by the system is one that culminates in required quality-control adjustments by the contractor and either increased or decreased levels of acceptance sampling and testing that are necessary to maintain an acceptable risk level for the department.

The development of these systems could not have been successful without access to electronic data processing (EDP) equipment. Systems logic has been available to highway engineers and planners for several years. However, it was not until the relatively recent past that the hardware and software necessary to process and evaluate larger quantities of data on a near-real-time basis became available to an appreciable segment of the highway engineers who were principally concerned with quality assurance. Although the computer has been with us as a tool in highway departments since the mid-1950s, only in recent years has it been routinely used for the application of engineered systems (6).

Implementation of the conversion to performance specifications has been carefully programmed and practically paced. The pilot program for our quality-assurance system was initiated in late 1964 with the implementation of Highway Planning and Research (HPR) Project 18 (7-10). This project was designed to evaluate and define what was considered to be satisfactory materials construction and to provide practical performance specifications for consideration. This project has been completed and the above goals achieved.

We decided early that only through the concepts of probability could we hope to develop a

Figure 1. Elements of the quality-assurance system.

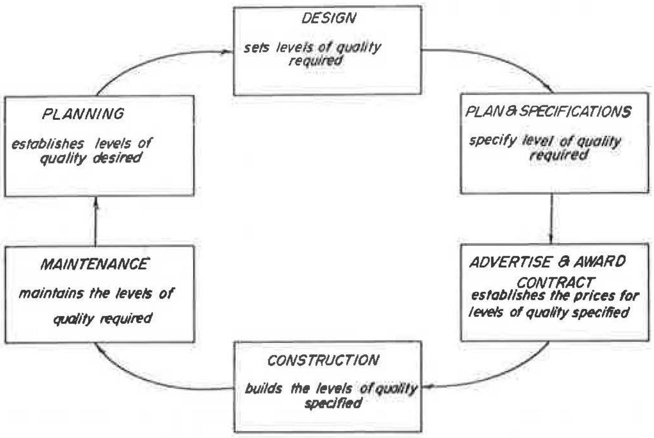


Figure 2. Quality assurance.

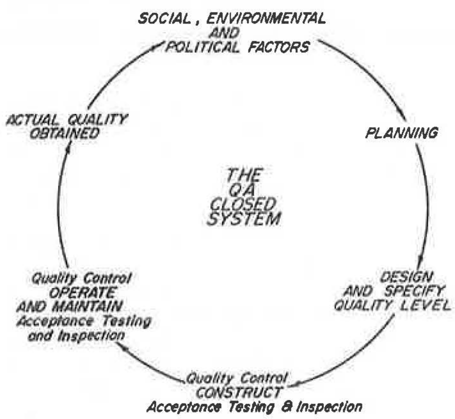
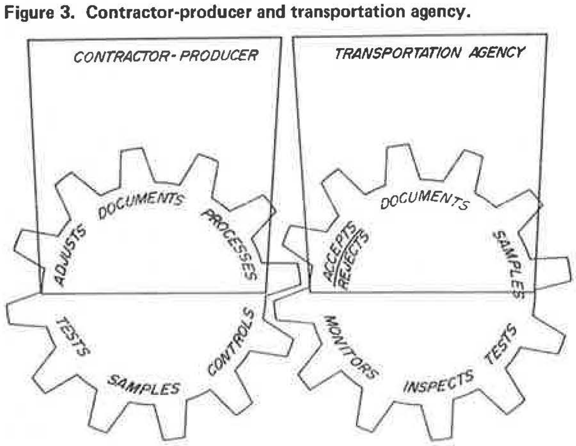


Figure 3. Contractor-producer and transportation agency.



satisfactory program. In developing these concepts, we recognized three basic considerations. These have been defined in various ways, but the following are perhaps the best known and most widely quoted (11):

1. What do we want?
2. How do we order it? and
3. How do we determine that we got what we ordered?

Some facts quickly became evident. The first was that we could not realistically define what we wanted in quantifiable terms. Although we had plenty of construction projects that could be judged fully acceptable from an engineering standpoint, we knew they had been accepted as substantially rather than as fully complying with the specifications under which they were constructed. Further, inspection and testing had been conducted under the traditional judgment procedures so that the resulting test data probably contained appreciable bias. Therefore, if a quantifiable system was to be adopted, we needed to know the true construction parameters of acceptable work under such a system.

The first priority, therefore, was to initiate a research program that had designed experiments to be conducted independently and on ongoing projects. Through these experiments, a realistic measure of the typical level and variability of the characteristics of our major construction and materials items was obtained. This information was then used to establish realistic, practical, and enforceable specification limits and acceptance procedures. These specifications focused on four major construction items--portland cement concrete, bituminous concrete, aggregate base course, and embankment construction.

All prototype specifications were field tested under the research program through experimental projects. Therefore, when finally adopted for general use, we knew we had a workable specification. The department's standard specifications since 1965 have been in a gradual state of evolution and change due to our research findings and the systems approach to our overall quality-assurance program. Current specifications give the responsibility for quality control to the contractor (3). He or she must have a qualified technician and develop a quality-control plan that details the type and frequency of sampling and testing that are deemed necessary to measure and control the various phases of the work. Current specifications also specifically state that acceptance inspection and testing is the department's responsibility. Our specifications are somewhat unique because the contractor's data may be used by department inspectors as part of their acceptance tests. This approach is fully consistent with the philosophy that the owner should perform only that inspection that is necessary to ensure that the consumer's risk is within acceptable limits (1). It should also be noted that most of the tolerances that currently appear in our specifications have been adjusted to more realistic levels as a direct result of our research findings.

From the beginning, we divided our quality-assurance system into two distinct functions:

1. Process control by the contractor and
2. Acceptance inspection and testing by the department (see Figure 3).

Competent industry and agency personnel are required to accept responsibility for their individual functions and produce complementary results. Training and recognition of such personnel are essential.

A cooperative program for the certification of technicians was initiated in 1965 (12,13). This was a joint industry-department effort, directed by a committee composed of representatives from both areas. In addition, the department has a program for the certification of several categories of inspectors. Also, in 1979 the department adopted a new classification based on the transportation engineering technician series administered by the Institute for Certification of Engineering Technicians.

A continuing annual training and certification process keeps the program up to date. The program has been well received and the use of a qualified technician by industry is now a specification requirement on all department projects.

Some contractor-producer organizations may feel that the costs associated with a contractor quality program are a disadvantage to their organizations. However, the greater majority of contractor-producer organizations that have contractual relations with us believe that the advantages far outweigh any disadvantages. They report that some of the more significant advantages are as follows:

1. Conflicts between the department and the contractor-producer are greatly reduced because there is no longer a question of test value validity and test results are available to the contractor-producer sooner,
2. The contractor-producer can control the number and quality of testing personnel necessary for control of the product and does not have to wait for the department technician to start production,
3. The contractor-producer is able to make better use of good but borderline materials by having control of the process, and
4. Faster test results and knowledge of trends allow more positive response by the contractor-producer; this results in less loss of production and a significant reduction in production or use of nonspecification material.

To further our communication with industry, periodic meetings are held with representatives of various producer organizations to discuss common problems and future developments. These meetings have provided a means for the review of proposed changes as the state of the art advances. The meetings encourage industry input in the development of specifications and quality-assurance systems. In addition, monthly meetings that include the department and the West Virginia Contractor's Association provide a vehicle for the discussion of problems, review of contractor- and department-proposed changes in procedures and specifications, and service as a springboard to allow for general discussion of quality-assurance associated problems.

TESTING ERRORS

In dealing with probability specifications it is necessary to analyze the inherent and assignable causes of error in testing and to eliminate as many of these assignable causes as possible. Our efforts in this regard have included development of standard sampling and testing procedures and extension of the Aggregate Materials Reference Laboratory (AMRL) and Cement and Concrete Reference Laboratory (CCRL) standard sample concepts to our field laboratory installations on a regular basis. Industry needs the same confidence in test data and is invited to participate in the testing. Also, any supplier, contractor, or manufacturer may send his or her quality-control personnel to our laboratory for consultation and comparative testing. This policy has proved very beneficial because it gives mutual confidence to all involved parties.

Improvements that reduce testing time are always helpful and our research in this area included designed experiments for the purpose of developing rapid methods of testing. Several methods have been developed and are now operational in the system. These include the early determination of potential strength of concrete cylinders by means of the maturity concept and an alternate capping procedure for concrete cylinders (14-16).

It was obvious from the beginning that the processing, evaluation, storage, and retrieval of data would become a major consideration. Under the relatively light work loads that had developed the conventional specifications, it was not uncommon for engineers at central headquarters to be intimately familiar with detailed data from every major project site. Under these conditions the human mind could make sound engineering judgments on a real-time basis. As the work load increased, it became necessary to make maximum use of EPD. Many factors were involved as we progressed toward optimization of this activity. Standardization of forms, documentation storage, retrieval, and distribution methods had to be approached so the end result would be workable. One innovation we use is the combining of a source document and the EDP input into a single item without the need for intermediate clerical processing. As data are developed in the field, they are recorded on 40-column punch cards by using a small portable punch board, or markscan forms, or directly on magnetic tape. All mediums are directly readable by the computer. We have become operationally dependent on EDP in our quality-assurance system.

SUMMARY

The steps that lead to where we are today started with the careful determination of the construction and materials characteristics associated with satisfactory work. This gives the answer to the first question, What do we want? The next step is the development of prototype specifications to be used experimentally on selected projects. Concurrently, close communication with and training of department and industry personnel are necessary so that they know what is expected. This provides the information necessary for development of specifications to answer the second question, How do we order it? and the third question, How do we determine that we got what we ordered?

Any summary would be incomplete, however, without restating the concept and underlying philosophy that governed our steps toward the current quality-assurance system. The final stage of creating a transportation facility from engineering concept to accomplished work usually involves the successful completion of a legal contract between the owner and the contractor. The owner is motivated by a desire to obtain a completed facility that complies fully with the contract documents or that exceeds the requirements in these documents and to achieve this end at minimum cost. The contractor is motivated by a desire to provide a completed facility that will satisfy the owner by means that will yield a suitable profit margin. These motivating factors, although they are fully compatible when viewed on an overall basis, can cause the adversarial factors of this relationship to be magnified to the detriment of both parties in the long run. Conversely, a cooperative approach between the two parties can lead to a greater probability of each realizing their individual goals (i.e., minimization of cost to the consumer and maximization of profit to the contractor). These basic motivators have, however, resulted in differing approaches by differing agencies in an attempt to obtain better contractual methods for achieving these desirable goals. In the usual case, monetary rewards, labeled by some a negative approach (i.e., the price adjustment downward for failure to achieve a specified quality in the product), have been placed in the contract documents. Such methods are workable and have been used widely at various times in the construction industry.

The debates over the positiveness or negativeness of such approaches have generally served only to obscure the real issues. One persuasive argument is that a bonus for good work is psychologically an excellent motivator; a good case can also be made that a cost reduction for deficient work is an equally persuasive motivator. In either case, the consumer must eventually pay the full cost of the product since it is elementary that a contractor cannot subsidize the contracting agency.

The intent of all such approaches, whether they result in increases or decreases in payment, is to provide legal mechanisms that will, by contract, reward the contractor whose quality equals or exceeds the specification requirements and to likewise place at a disadvantage in the construction market the contractor who provides a product quality level that is less than that specified. When this fact is recognized by all parties concerned, discussions of the various means by which this intent can be achieved are inevitably fruitful. We have moved consistently toward performance specifications. Our aim is to allow the contractor as much latitude in using optional materials and methods as possible so he or she can select the most economical ones. Performance specifications contain sampling plans and acceptance criteria so that all parties concerned know at the time of bidding the quality level required and how it is to be determined. Our specifications encourage the contractor to develop strong quality-control programs. Such programs provide timely information useful in controlling the project, especially in correcting deficiencies before they get out of control and in maintaining the optimum scheduling of the project.

Communication is an essential ingredient to mutual satisfaction with any legal contract. This should include those regular sessions for general discussion between user agencies and contracting industry as well as prebid and preconstruction meetings for specific projects. It is encouraging to note that contractors who have good quality-control organizations have indicated that an adequate quality-control program, properly administered, yields a net gain rather than a net loss (i.e., such a program improves potential profits).

CONCLUSIONS

Conclusions from our experience are as follows:

1. Performance specifications are workable, practical, and economical when properly implemented through systems-engineering techniques;
2. An agency that uses appropriate performance specifications can cause a decrease in the consumer's risk and generally can provide the opportunity for a decrease in producer's risk; in any event, the risk becomes manageable;
3. The contracting industry is fully capable and competent to provide the quality-control system necessary for production of a finished project that will meet the requirements of the plans and specifications; and
4. An agency that uses performance specifications can, by using an appropriate quality-assurance system, shift its activity emphasis to verifying the adequacy of the contractor's control systems as the principal means of ensuring that the specified facility is received.

In closing, we believe that we have demonstrated that the application of systems-engineering techniques has provided the way to achievement of our goal--a quality-assurance system that works in practice.

ACKNOWLEDGMENT

The contents of this paper reflect our views and we are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policy of the West Virginia Department of Highways or of the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

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Process Control in Practice

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Our approach to process control is discussed for portland cement as this is the only phase of construction that we encounter. Our process-control system has been in existence since we first started to produce transit mix concrete in the late 1930s. Management took the position from the start that it would provide a quality product—to the point of overdesigning mixes to allow for some error in placement, handling, and testing. This was done and still is being done, to a lesser degree now, at the expense of the company. Changes in the concept of quality assurance introduced by the West Virginia Department of Highways in the mid-1960s, which were accepted by us in the early 1970s, have helped us to achieve and document goals of consistency in our manufactured product. Consistency was achieved by training technicians, setting up our own certified laboratory, maintaining complete control of our aggregates, testing cement from our suppliers, and, probably most important, switching from transit mix to an automated central mix plant. The sharing and use of test data collected by electronic data processing have been invaluable to us in our daily operating procedures. The raising of the iron curtain of communications from the owner to the contractor to us, the supplier, also contributed greatly.

Pfaff and Smith Builders Supply Company has been in business at the same location in Charleston, West Virginia, since 1902. It was founded to produce sand and gravel from the Kanawha and Elk Rivers for construction projects in the local area. Until the late 1930s it continued to produce sand and gravel and to sell wholesale products such as cement, plaster, and lath. Then, Pfaff and Smith entered the transit-mixed concrete market. The business remained basically the same until the early 1960s, when transit-mixed concrete gradually became the predominant product sold.

The first significant change in our operations came about in the early 1960s, when our dredge was modernized in order to produce higher-quality aggregates. We stayed current with the changing times by purchasing new transit mix trucks that allowed us to take on additional and larger jobs. During this period we encountered more stringent concrete specifications. This was also our initial introduction to process control.

QUALITY CONCRETE

During the mid-1960s we believed that we were producing good-quality concrete. Our aggregates were of good quality, cement appeared to be consistent, and the causes of problems in the field could usually be isolated as either the result of inconsistent testing procedures or the result of transit-mixer driver error. We were proud that we were often asked to furnish concrete after competitors had failed to meet specification requirements. We earned a good reputation and were thus able to sell quality concrete and service at a higher price. The reputation for quality and service at a higher price, although successfully sold to many local contractors, proved to be hard to sell to new contractors in our area. At this time we also realized that our gravity-fed transit mix plant was obsolete. It had been in continuous service for more than 30 years. We investigated conversion of the then-existing plant to a semiautomated plant, but this idea was quickly ruled out as too expensive and also this system would only meet the existing needs for plant capacity.

Next, we investigated the installation of a central mix plant. Although we believed that central mix was the way to go, the decision was delayed because it was very expensive, and we were uncertain that we could sell central mix concrete at the higher price needed to justify our investment. However, perhaps the main reason we delayed our decision was that preliminary plans for the Interstate system indicated that our property was in the path of one of the proposed routes.

Quality-Assurance Specifications

The West Virginia Department of Highways introduced their comprehensively rewritten standard specification in 1965. Area producers, already unhappy with the amount of concrete rejected on department of highway projects, viewed the new specifications with much apprehension. Meetings between producers and the department of highways usually ended with the attitude of near antagonism, at least from the producers' side.

During this period of transition, we declined to enter into substantial relations with contractors who were doing jobs under the specification of the West Virginia Department of Highways. For those jobs we did quote, we added up to one additional bag of cement to our cost of materials. In addition, a rule-of-thumb price of up to $4.00/yd^3 was added to the bottom line above the amount quoted to a commercial contractor for a like mix design.

As we neared the end of the 1960s, changing business conditions caused us to take a closer look at department of highways jobs. The Interstate system of roads to be built was coming closer to our area, which could mean more than 200 000 yd^3 of concrete for us. By this time our experience on department of highways jobs had improved and much less concrete was rejected. Test reports indicated good strength; however, we lacked consistency with wide ranges in strength, air, and slump.

Process Control

Good commercial laboratory facilities had not been available in our area, thus concrete test results were unreliable and costly. Therefore, we decided to set up our own laboratory and requested Cement