Highway Department Needs

In a discussion of obtaining the level of quality of highway construction necessary to perform its intended functions, quality assurance in its simplest terms is defined (1) as a 3-step process:

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

Most quality assurance programs have stressed answering question number 3.

These three questions are interrelated. In essence, what is needed may be termed a "closed system" in that design should specify what is needed and the end result obtained should dictate future design. A system is needed where "what we got" is recycled back to "what we want," and "what we want" is revised in accordance with performance and the "what we got" data. This is the basic need of a highway department in the area of quality assurance.

Inasmuch as the concepts presented within this report depend on a mutual understanding of certain terms used, the following definitions are provided:

Product Quality—The characteristics of the product that are required for its intended use, including desired levels of these characteristics and allowable tolerance.

Quality Control—All activities and considerations during the manufacture of the product which are necessary to ensure that the product has the desired quality characteristics, both levels and tolerances.

Acceptance Sampling and Testing—The collection and testing of samples of the product and/or the inspection of the manufacturing process as required to determine if the quality characteristics of the delivered product conform to the required levels and tolerances.

Quality Assurance—The actions and considerations included in both "Quality Control" and "Acceptance Sampling and Testing."

Quality assurance and acceptance procedures currently used by the highway industry need to be critically reviewed and assessed for adequacy. Much of the basic technology, concepts, and some data required are presently available. The need is to assimilate the contributing factors and devise a suitable systems approach.

In appraising the entire system, differing viewpoints will undoubtedly be encountered, particularly in the beginning of such an undertaking. It is possible to predict that at least 3 general classifications of opinion will be encountered, namely, (a) those who feel that the entire system must be excised and replaced with new concepts, (b) those who hold that an orderly evolution toward more effective methods must occur, and (c) those who feel that little or no change is necessary in the existing system. It is predicted that the most prevalent opinion would fall in the second category. If this is the case, how can the evolutionary process be hastened?

It should be apparent that the envisioned system of quality assurance affects all areas of a highway department and not just materials inspection to which it is often limited in current thinking.

The entire cycle of quality assurance affects design, construction, and maintenance. Improved design depends on feedback from construction and from maintenance. Information provided by maintenance can keep the designer informed on the effectiveness of his design and the correctness of his assumptions. Information from construction can aid the designer in establishing specifications that are workable in a realistic sense.

The utopian goals and needs have been defined in the most general terms. What has been so simply stated is, in reality, more complex than might appear. To reach these goals, changes are necessary in the quality assurance process as it interacts between the parties engaged in the engineering endeavor. These changes will affect three major areas, namely, specifications, standardization, and information-handling systems.

SPECIFICATIONS

Specifications must be written in such a manner that there will be reasonable assurance that materials or construction items of acceptable quality are not rejected—otherwise, the result would be eventual increased bid prices—and that material of inferior quality is not often accepted with consequent future excessive maintenance costs. To be practical, specifications must contain realistic and workable for each characteristic measured. To set realistic tolerances, it is necessary to have intimate knowledge of the factors contributing to variation in the observations. The engineering consequences of exceeding such tolerances must also be evaluated. The mathematician who is adept at classifying the variances may inadvertently do a great service by goading the engineer into reassessing the consequences of apparent infractions of the specifications. These consequences may not always be as serious as supposed.

Specifications must be worded in a manner that the required properties are clearly outlined so that, ideally, only one interpretation can be made concerning the intent. Furthermore, action to be taken when specified tolerances are exceeded must be set forth; it is highly probable that there always will be necessity to deal with "gray areas" or borderline cases, necessitating possible acceptance of pay items with equitable reductions in price based on reduced performance potential.

It is probable that the criticality of defects should be classified; one such system is as follows:

1. Critical—This defect will make the product dangerous to use;
2. Major—This defect will seriously impair performance of the item;
3. Minor—This defect may impair performance but not seriously; and
4. Contractual—This defect is likely to have insignificant effect on performance.

In the typical case of manufactured products, specifications should exhibit clear recognition as to which parties are responsible for the formulation and quality of ingredients throughout the chain of events from initial processing of the raw materials to final acceptance in the finished work. Best consumer-producer relations will usually be engendered by postponing entry of the purchaser into the inspection process until as close as possible to completion of the work at which time he should make final "quality assurance" determinations. Earlier control measures are best undertaken by the producer and are designated "quality control." Inspection techniques employed by the two parties may be quite different; for example, a manufacturer of galvanized metal sheet may find it advantageous to use dynamic inspection methods during high-speed progress of the sheet through the mill, whereas the purchaser will use static methods of inspecting finished metal culvert pipe.

Attainment of such ideal inspection schemes as outlined above is often hampered by economic or technological considerations, or a combination of both. For example, postponing all final "quality assurance" inspection of concrete until it is hardened in place is not feasible because of the often tedious tests now available for such inspection and the inordinate economic consequences if serious deficiencies are discovered.

The contractor or materials supplier needs a strong quality control group responsible for the control of the process on a day-to-day basis and with sufficient management support to make the entire organization quality conscious. Acceptance testing undertaken by a highway agency, on the other hand, might be described as a final check on the efficiency of the contractor's quality control program.

Finally, it might be well to consider a positive incentive in the form of bonuses for superior quality if the latter could be demonstrated to yield better performance, longer service, or have other advantages.

LABORATORY (TESTS AND TEST METHOD) STANDARDIZATION

Realizing that the future will bring an ever-increasing expansion of contractor and supplier quality control facilities, it becomes evident that a between-laboratory standardization program will be required. Currently, highway departments rely on the Cement and Concrete Reference Laboratory and the AASHO Materials Reference laboratory of the National Bureau of Standards for checks in this area. However, as contractors and producers tend to do more of their own testing, more conflict can be anticipated when test results of control samples do not agree with those obtained for acceptance sampling. A standardization procedure consists of 2 parts. First, a laboratory must be able to demonstrate that it is in control within itself, that it is reproducing tests with a specified accuracy. The second part of the standardization program is to provide a service that will extend the standardization between laboratories, including the supplier, producer, and consumer. The first part of the standardization program can be carried on within a laboratory on a monthly, weekly, or daily basis depending on the need. The second part of the program, while necessary, is not a substitute for the first. Standardization between laboratories is a slow process and can only take place on an annual, or at best, semiannual basis. Nevertheless, it serves a function of pointing up operational differences and nonstandard equipment. A means must be found that will extend standardization services to all laboratories involved, including supplier, producer, and consumer. As contractors assume more of their rightful responsibility for quality control testing, it becomes imperative that test methods contain definite statements of repeatability and reproducibility that are achievable under practical field conditions. The tests should be rapid and reliable and be capable of evaluating both the individual components and the end product. In every case, all parties must use a common yardstick for measurement.

INFORMATION-HANDLING SYSTEMS

Someone has recently noted that each civilization turns its excess energy to the development of large edifices with which to enshrine itself for posterity. As examples, the Egyptians built pyramids, the Greeks large statues, and medieval Europe large churches and cathedrals. In this line of thought, it has been noted that perhaps the Western Civilization of the twentieth century is destined to build for itself a mountain of paper. Perhaps this is more truth than jest. With this sobering thought in mind, it might be well to look at the highway industry and determine where it stands on this so-called mountain of paper. Further, this should provide motivation to look at the highway industry's future direction on this mountain. Will the mountain be allowed to rule the highway program? Or will industry become its master and landscape it to be the servant without enlarging its size?

To evaluate the future in this area, the past, current, and future status in the field of information storage, retrieval, analysis, and transmission must be examined.

The term "information storage and retrieval" can encompass many facilities. At the mention of this term the mind might envision any number of different things—from a stack of correspondence placed on a shelf in a random manner to the most sophisticated of electronic systems capable of transcribing, electronically, entire texts on an area the size of a pinhead. Analogous statements concerning information transmission or information analysis can readily be imagined. The truth is that most of the industry is operating with systems that are somewhere between the extremes.

It is generally recognized that the orderly and efficient function of the typical highway department, which is aimed toward providing a modern highway transportation system, requires the interplay and interdependence of all the department's separate sections. This interplay is provided by the transmission, storage, retrieval, and analysis of information. Notwithstanding the criticality of this dependence, systems of information storage, transmission, retrieval, and analysis developed in the typical highway department over the past years have, with few exceptions, been only those of immediate daily necessity. To put it another way, it might be said that developments have progressed only a small portion of the way necessary for a completely adequate, integrated system.

It is probably safe to assume that the typical highway department's quality assurance program generates a large amount of data or information. The current and future usefulness of this information involves its analysis and dissemination to the user and its storage as a retrievable record throughout the required retention period.

Although the systems currently in use may be satisfactory for the immediate present, it can logically be predicted that more efficient methods will be required in the near future if available technology is to be used effectively. Then it may well be asked, "On what grounds is such a prediction made? Why the desire to change from the present system? Has it not been stated that current systems are meeting the necessary day-to-day demands? Then why speak of going to a new or different system?" The answer is progress—progress in the area of improving planning, designs, specifications, construction, maintenance, operation of the highway system, and thereby service to the traveling public.

More specifically, the need for rapid analysis and dissemination of information necessary for the evaluation of quality during a construction sequence is certainly self-evident. The need for long-term storage, retrievability, and analysis of information for subsequent performance and cost-effectiveness evaluations, material selections, and other studies should be equally evident.

To accomplish such objectives within reasonable economic boundaries will require development of a totally integrated system for the storage, retrieval, analysis, and transmission of information. Such a system could be capable of maintaining in a small amount of space all needed information for many projects and items over a long period of time. Thus, it may be feasible to enter perhaps 10 or 20 years of operating characteristics under the same file reference as the original design and construction data. Such information should be accessible at any time. From this could stem the development of truly comprehensive criteria based on the mathematical correlation of all phases of highway transportation technology with the performance data. To maximize the use of the data acquired in such a system, it is probable that in the terms of equipment and hardware a more than modest automatic data processing, storage, and retrieval system, coupled with maintenance and performance feedback systems, must be used.

This procedure, while the most desirable, has not been feasible in the past inasmuch as neither the equipment nor the technology were available. Today they are.

The use of mechanized-electronic information storage, retrieval, analysis, and transmission systems has come of age in many industries. It has been noted (2) in other industries that "The cost premium on useful knowledge means that investment in mechanizing our information today is mandatory, because traditional methods have proved inadequate."

To make use of the expanding technology in highway construction it is necessary to apply the same farsighted planning in this field. The future thinking involving information use must therefore be directed toward a system that uses the advanced methods of electronic data processing. There must, then, be envisioned a system that would eventually provide for totally integrated information storage, retrieval, analysis, and transmission that could be controlled, evaluated, and processed by electronic computer. The establishment of a totally integrated system would create a "systems dependent" industry. However, such an approach may very well be necessary if the required efficiency is to be maintained in the future.

It is, of course, possible to continue at great length with additional detail concerning the foregoing, such as desirable goals, feasible alternates, necessary subsystems, etc. However, there are probably as many different variations and workable modifications to a master system as there are interested parties in the use of same. One, therefore, arrives full circle back to our original question. Recognizing that a multitude of differing opinions may exist, many of them based on extensive research in the areas of quality assurance, how can any needed evolution of quality assurance and acceptance procedures in the highway industry be best promoted and supported? Although the risk of oversimplification must be recognized, the answer can be stated very briefly. Any such evolution will, of necessity, require the support of top management in the highway departments and the industry. This segment of management will inevitably base decisions on the cost-effectiveness of quality assurance programs. It would, therefore, appear that "what we need" is a proverbial magic box that could tell what the cost-effectiveness would be in any of the many quality assurance programs that might be proposed when said programs were applied to any of the wide varieties of highway construction projects.

Because access to such a magic box or other means of instant solution is unlikely, it is felt that the key to the entire array of problems could be obtained by development of a model for optimization of the cost-effectiveness of quality assurance programs for highway projects by the use of statistical decision theory.

A very simplified overview of the problem can be stated as follows:

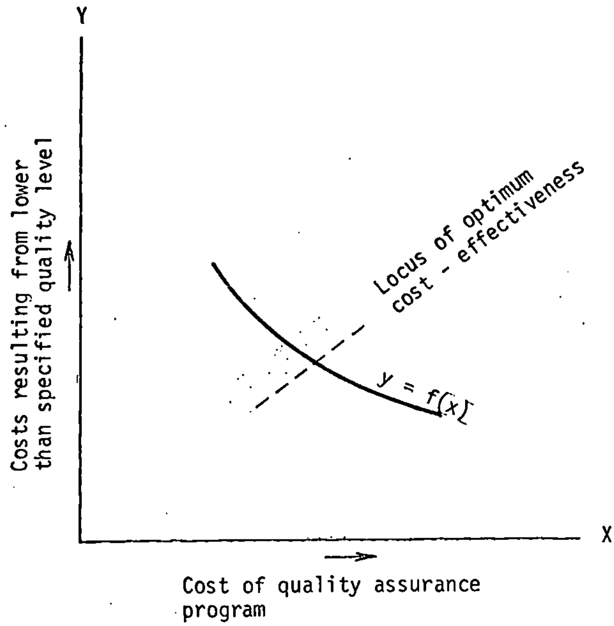

Figure 1.

1. There are typical highway projects of many sizes and types with many complex conditions involved. These should, however, be amenable to mathematical modeling.

2. There are many specifications that could be used. Whatever specification is to be used can be mathematically modeled.

3. There are quality assurance programs with many variations and modifications: some practical, some theoretical, some previously used, others untried. All can be mathematically modeled.

Once this is done, a grossly simplified picture of cost-effectiveness might be envisioned by plotting the cost of increasingly poorer quality versus the cost of increasingly larger and more complex quality assurance programs. One might assume that such a function for a given circumstance might resemble that shown in Figure 1. It can, therefore, be easily seen that if the scales were equal on both axes, the optimum cost-effectiveness would be achieved by a quality assurance program that yielded the level of quality indicated in the intersection of the 2 lines. The actual development of such a model is, of course, of considerable complexity and would require a substantial research effort to accomplish. Such a model suitable for computer utilization should (a) enable simulation of a typical highway construction project of any size and type; (b) generate on demand, by use of statistical decision theory, the cost-effectiveness of a given quality assurance plan for the type of project specified; and (c) generate on demand, by the same methods, the optimum quality assurance plan for a given type of project.

The final report from such a research project should include a complete computer software package for use of the model. Development of such a package would be a major undertaking and would necessitate coordination by a national organization such as the Highway Research Board. This package could then be made available through HRB to all interested parties.

SUMMARY

Quality assurance must be a common effort, requiring cooperation of the supplier-contractor industry and all sections in a highway department, from advanced planning to operations, to provide a system that most economically produces acceptable highways.

Specifications must be realistic, economically controllable, and must clearly define the responsibility of the contractor and the owner in the area of quality assurance and acceptance.

Maximum usefulness of data derived by different testing facilities can only be achieved if standardization services are available to and used by all facilities involved.

Data derived during the course of a project must be quickly and accurately analyzed. Data from completed projects must be immediately fed back to the interested parties for consideration and utilization on future projects.

Management subjects must be considered. Cost benefits, availability, and training of manpower, communications, and other factors must be recognized and suitably provided for.

Realization of these goals will require coordination of major research and development efforts to evaluate present systems and to devise systems that optimize the cost-effectiveness of quality assurance programs.

REFERENCES

1. McMahon, Thurmul F., and Halstead, Woodrow J. Quality Assurance in Highway Construction: Part 1—Introduction and Concepts. Public Roads, Vol. 35, No. 6, Feb. 1969, pp. 129-134.
2. Frank, Richard D. Datamation, Feb. 1968.