Quality Control at ALL Levels of Road Construction

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LEVELS

First, what are the various "levels" in our industry? At the top is Mr. John Q. Public. He is in the driver's seat, in more ways than one. As taxpayer and voter he is our boss, as well as the user of our product. Under him our industry may be split into two main categories—Public Domain, or the various governmental agencies, and Private Enterprise, which includes the contractor, the material suppliers, equipment manufacturers, and the consultants.

Under Public Domain the three principal levels are the customary national, state and local, i.e., county and municipal. Actually, there should be four levels since there is a world of difference between our big, relatively rich units such as the County of Baltimore, or the New York Port Authority, and the more numerous smaller organizations throughout our country which are responsible for many miles of rural roads, residential and city streets. We must not lose sight of the fact that our villages, boroughs and the majority of our counties have some real problems in road construction and maintenance, which must normally be handled with inadequate facilities and finances.

At all levels of Public Domain, however, we have both the legislative and the executive branches. At the national level Congress establishes the broad policies and appropriates the funds, delegating execution of the program to the Department of Commerce which, in turn, delegates administration to the Federal Bureau of Public Roads. As you know, the Bureau is departmentalized into various functions at Washington level, with administration in the field conducted through Regional and District Offices.

In turn, road construction at state level involves a legislative function for broad policy and appropriation purposes and an executive function through a State Highway Department charged with getting the job done. Other political subdivisions—the county, the parish, the municipality, etc.—also have their counterpart of a legislative and an executive function. Each element of Public Domain thus has its political seg-

ment and its operating or "doing" segment, and both have an influence on quality control considerations at all levels.

As engineers we are inclined to begrudge the political segment its place in the sun—to take a bit of a "holier-than-thou" attitude. We realize that someone has to raise the money, that someone must sell the program, that someone must meet and deal with the public, but the politician is too often looked upon as a necessary evil rather than as a fellow public servant. Let's face it, roads are in politics and there are varying degrees of politics in most road building. There are good and bad politicians as there are good and bad contractors, material suppliers, consultants, technicians *and* engineers. While function, motivation and responsibility may differ, we are all part of the same industry having a common goal—to build roads. And build them we will, in good political atmospheres and in those not so favorable. Political reform is made at the polls, however, not on the job. Lamenting the other fellow's weakness or adopting a defeatist attitude doesn't help anyone, and surely not the road. In fact, the poorer the situation, the greater is the need for quality control and the greater is the administrative and engineering challenge.

I am not going to condone or condemn the patronage system, nor will I, at this time, discuss the pros and cons of civil service. It should be realized by all, however, that the quality of highway construction depends a great deal on *morale,* particularly the morale of people at field level—the resident engineer and inspectors. Any action, or lack of action, at policy making level, that influences morale has an indirect but very real effect on quality.

Within the operating segment of most departments there are three principal functions directly involved with quality. These are the Design Division, the Construction Division, and the Materials or Testing Division, or their counterparts. In some states the testing and inspection of materials comes under the Construction Division. I feel that this is an organizational weakness—that the Chief Materials Engineer, Construction Engineer and Design Engineer should report to the same Management level.

For purposes of this discussion I think we need to recognize only three levels within the highway organization, whether it be a state or local department. These are top, middle, and bottom. At the top is Management, and at the bottom is the field—the men who work on the grade. In between is that large group of dedicated people in the central office, in the laboratory and in the district offices who constitute the backbone or "hard core" of the department. They are the administra-

tors and staff personnel who stand in back of and support the resident engineer on the one hand, and who interpret and implement the policies and desires of management on the other. As important as this hard core, this real heart of the Department, may be, full advantage of their invaluable experience and know-how can be realized only insofar as their influence can actually be felt and reflected at field level. Roads are built on the grade, not behind someone's desk. By the same token, it is a management's responsibility to see to it that this hard core does not become ingrown and complacent that both the "tried and true" *and* modern tools and techniques are used to best advantage for the overall good of the department.

Before leaving Public Domain, we should recognize another group in the overall quality control picture. These are the "watch dogs"—the General Accounting Office, the City or State Comptroller, and others whose job it is to protect public funds. The Blatnik Committee might also be included in this general category. Whereas we may not always agree with their methods, we must recognize that these people too have a job to do, a responsibility to discharge. They are very much a part of our form of government and over the long pull help to protect our free enterprise system by inhibiting excesses that could ultimately destroy it. Right or wrong, the Blatnik Committee is having its influence on quality control and I would commend for your attention a reply to "Restore Inspection Sanity—We'll Clean Our Own House," given last month by W. O. Wright of the Nevada Highway Department before the National Bituminous Concrete Association meeting in Las Vegas. Also right or wrong I anticipate more, rather than less, "investigation" type activity spreading into all levels of road construction—municipal, county, state and federal. Intelligent moderation and an appreciation of relative perspective—maintaining proper balance by avoiding excesses of exaggeration in any direction—is needed. Each of us can do our part within our own back yard or sphere of influence to help protect the overall best interest of our industry.

On the other side of the ledger we have the Private Enterprise groups who also have a real interest in quality—the contractors, materials suppliers, equipment manufacturers and consultants. While readily admitting that there are mavericks on both sides, I would like to take just a moment to pinpoint some facts which I feel are pertinent in this correlation of "quality" versus "level" in our industry.

I believe that the contractors generally want to do a good job; that they want to upgrade the quality standards of road construction. The good ones will wholeheartedly back and support sound and realis-

tically applied quality controls. The ten-point Quality Improvement Program of NBCA is a reflection of this desire. Here the bituminous contractors are putting up their own cash to sponsor research under the able guidance of Charlie Foster. May I also remind the skeptics that there is no practical way in which the contractors can really police themselves. Sure, they can kick the fly-by-night out of their Associations, but they have neither the means nor the authority for controlling the quality of the other fellow's work. This is the responsibility of the engineers in Public Domain, and if we do not do a proper, uniform job of quality control, we are letting down the legitimate contractor who is trying to build a better road. He wants and should have *uniform* interpretation and enforcement of the specifications to protect his competitive position as well as the quality of our roads. Forcing him to compete—and compete he must—with shoddy workmanship or substandard materials is obviously unfair and detrimental to everyone and to all levels of our industry. The contractors have a responsibility and must do their part, but the engineers set both the ground rules and the level of attainment.

The material suppliers and the equipment manufacturers are spending an estimated $100 million a year in research, much of which is aimed at quality improvement. They have contributed greatly in recent years to such things as automatic controls, leveling devices, improved machines, testing instruments, etc. Again, the engineers have a responsibility for evaluating technical advances and implementing early adoption in their specifications and special provisions. For instance, much good research has recently been accomplished on mixing time for both bituminous and portland cement concrete. If specifications are not changed, your department not only loses the advantage for your road, but the contractor no longer has an incentive to buy a modern, more efficient mixer. Why should he, if you are arbitrarily going to make him mix longer than is necessary or desirable anyway? We must go forward together—Private Enterprise and Public Domain.

I won't say too much about the consultants at this time because I am one. Nevertheless, we are an integral part of this industry and contribute to its well being. We also have our mavericks and our shortcomings, but, particularly those of us who have specialized, can bring something worthwhile to both Public Domain and Private Enterprise. We offer an independent and objective opinion or analysis, backed by broad experience and a generally wider scope of study, which is available in a relatively short time. Consultants should not supplant but they should supplement existing organizations or functions wherein specialized

skills, available manpower, or timing factors can profitably justify their use. Quality Control Engineering currently qualifies on all three counts.

Lastly, in our discussion of "levels" there are some quasi-official groups, between Public Domain and Private Enterprise, who render an extremely valuable service to our industry. We should recognize and honor such men and organizations as Fred Burggraf of the Highway Research Board, Alf Johnson of AASHO, Bob Swain of IRF, General Prentiss of ARBA, and Tom Marshall of ASTM.

Those of you who were not privileged to hear Gen. L. W. Prentiss speak in San Francisco in March, 1962, would be well advised to read his address in the ARBA publications.[2] He made one recommendation, however, which I feel should be further discussed. I cannot concur that it is practical under our present political set-up for the Bureau of Public Roads to approve or disapprove the capabilities of any one of our State Highway Departments to properly administer quality control. The implications of any Federal Bureau judging the adequacy of a State Highway Department and making it stick is untenable, in my opinion. It is just too big a club to be used effectively and therefore, in spite of its shortcomings, I am afraid that Bureau check of quality control on a project basis is the more workable approach.

THE NEED

The quality of highway construction probably warrants more consideration today than it has at any time in the past. Quite apart from the current limelight focused by the Blatnik Committee, responsible management has long been cognizant of the basic soundness and need for uniform high quality construction. While the federal government participates in new construction, the cost of maintaining these roads is to be borne solely by the states. Every mile of new construction, regardless of type, automatically commits a certain number of maintenance dollars from then on. This is a fundamental concept of growing concern at all levels of both Public Domain and Private Enterprise. Some budgets are already hurting for maintenance dollars, and matching funds are becoming increasingly difficult for both state and local agencies. The best way to hold future maintenance costs to a minimum is to "build 'em right" in the first place.

Service requirements have imposed a greater burden on both new and existing roads. On purely technical grounds, pavements of higher strength and more nearly uniform high quality are a "must" to meet the challenge of today's wheel loads, tire pressures, and traffic counts; to say nothing of tomorrow's demands. At the same time we have

unprecedented construction programs at all levels to be administered by organizations disrupted first with a major war, then with a major industrial boom. As a result, we have need for new tools, new systems, new know-how in the broad management concepts, as well as in the more specific operations of road building. It is important that the quality control of highway construction be maintained at a high level of efficiency and that management *at all levels* know without doubt that these controls are being effectively and uniformly applied.

Quality control is, unfortunately, a bit like Mark Twain's weather. We have been inclined to do more talking about it than we have to take positive and realistic steps to *do* something about it. Our industry has made some rather remarkable advances in both engineering and construction productivity. Photogrammetry, electronic computers, bigger pans, bigger dozers, bigger plants have greatly increased our capacity to engineer and build roads. The AASHO Ottawa test results should be another milestone in improved design criteria. Technical and production advances are, of course, important but they have little to do with maintaining uniformity or controlling the quality levels with which construction materials are put together in the field to make a road. We are producing at 1962 rates but supervising the construction largely with pre-war methods and attitudes.

Possibly I am a bit more cognizant of the degree to which quality control has lagged behind production rate because of our particular consulting specialty. We have more or less concentrated on quality control engineering in heavy construction since 1952. Unlike the weather, we have attempted to do something about quality control by objective analysis and by studying the experience of others faced with related production control problems. Over the years we have "cut and tried"—fitting here, discarding there—various of the techniques and tools and principles used in industry to maintain high quality production. Some we experimented with were found to be totally unsuitable for highway construction, others have proven their value on various toll facilities, such as the Garden State Parkway, and the Illinois Toll Road; and airports such as the Dover Air Force Base; and in various State Highway Departments and County Public Works agencies.

Quality control engineering, as such, is a relatively new professional classification in highway circles even though it is a branch of engineering upon which industrial management has leaned heavily and with growing confidence for a number of years. It involves the study and development of improved systems and techniques for handling *all* known factors or functions which are related to quality. It combines under

one discipline the technology, planning, and coordination of functions which are normally the split responsibility of a number of different people or groups in a traditional highway department. This is why our staff consultants are highway engineers first, preferably with materials, construction, and administrative experience in more than one state, who are then backed by a group of specialists versed in quality control engineering principles and practices.

Quality control engineering is not the exercise of quality control. It is, rather, the application of broad engineering principles to the upgrading of an organization from one which is not too effective at "quality control," to one of greatly improved capabilities. Quality control engineering involves the analysis and improvement of people functions, operating facilities, systems, testing techniques, methods for evaluation and proper use of materials, communications, training programs and all of the other factors which directly or indirectly influence the quality of the finished road.

In another paper I recently commented in effect that the systems and techniques which make up quality control engineering deal with "Men, Materials, Machines, and Methods, but never with individuals." A friend observed that he would top my four "M's" with "Money" and "Management," which I concur are powerful influences in the attainment of quality control.

SOME OF THE PROBLEMS

I would like to cite a few of the problems facing various levels in our industry from the viewpoint of quality:

1. Highway management inherits an existing organization and normally has certain restrictions on both hiring and firing. Even without patronage influences and/or Civil Service, the availability at permissible salaries of qualified replacements or additional personnel is limited at best. Both freedom and the means to either build from within by training and reorganization, or to strengthen from without with new blood, is thus inhibited. While four years may seem adequate at the start of an administration, it soon becomes apparent that both "timing" and time itself, also impose important limitations from the management viewpoint.
2. Reliance on the "old timers" can be a mixed blessing. On the one hand a certain complacency often accompanies those waiting for retirement. They are reluctant to delegate and it is difficult for many to accept and use new and unfamiliar tools. The old shoe wears best and maintaining the status quo is the easy answer. On

the other hand, we vitally need the know-how of these experienced men at all levels. We must, in fact, constantly be on the lookout for new and better means of spreading their knowledge over more miles of road. Unfortunately, too many of these invaluable administrators and staff personnel are kept so busy "putting out fires" that their know-how is not used to best advantage. They are given inadequate time to think, to evaluate new tools, or to indoctrinate and train younger men so that their experience can be safely delegated over a wider scope.

3. Communications is a traditional problem in most highway departments. Management must be able to "reach" its people at all levels and, for quality control purposes, especially at *field* level.

   Every effort should be made to expedite means of conveying an accurate mental picture of what is to be communicated—both *upward* and *downward*—within the department. EXPRESSION must equal IMPRESSION or something is out of whack with the transmitter or the receiver; *both* must be tuned to the same open channel for the message to get through. Just issuing a bulletin or a memorandum doesn't get the job done. Policy as well as technical information is too often delayed, garbled and valueless by the time it reaches the actual construction. We must reach and motivate field people WHILE THE ROAD CAN STILL TELL THE DIFFERENCE and, in turn, field people must be able to reach and get answers WHILE THE ROAD CAN STILL TELL THE DIFFERENCE. Correspondence, test data, and records accumulated for the sake of history have little effect on quality control. In my opinion this is one of today's most critical management problems, influencing department morale, public relations and contractor relations, as well as today's construction and tomorrow's maintenance.

4. Maintaining morale, particularly at field level, has already been mentioned. The highway jobs closest to the field (again, WHERE THE ROAD CAN TELL THE DIFFERENCE) are not well paid relative to industry, nor are they as secure in some areas. Temptation looms larger under these conditions—conditions which make it more difficult to build the esprit de corps and sense of responsibility needed to resist temptation. An adequate system of cross-checks and balances is therefore more important in highway work than it is in industry. Means of *rapidly* detecting and picking out the "bad apple" are vital and preferably these means should

be self evident and as far removed from the stigma of discrimination as possible.

Motivation for our field people needs to be considered. They can no longer be motivated by the dollar alone. They not only need support and moral backing, but they need to feel that they are personally important; that management thinks enough of them to recognize and check up on them now and then. They need a sense of belonging; a feeling that they are an integral part of a team that is efficient, well-run and doing a worthwhile job.

5. Training is a crying need of our industry from a quality control viewpoint. The need to be versed in the technical skills and requirements of the job at all levels is obvious, but there is more. It has been said that "a man will do what he knows how to do, but he will not do what he does not know how to do." Proper training is one of the best ways of building morale and a sense of responsibility. An inspector or resident engineer can not be expected to stand up to a contractor's foreman who is better informed than he. Not knowing breeds doubt, fear, or lack of willingness to ask, and ultimately weakens the spirit of the best of us.

   Training is needed at all levels. Just because a man has been a good project engineer or a good materials engineer does not make him an administrator without some administrative training. Much of the problem in spreading our experienced men over more miles of road is that they have never learned how to delegate, how to use staff functions to best advantage, how to expedite communications, how and why the organization works. Above all, just because a man has been a good engineer or even a good administrator does not qualify him as a teacher. In fact, most highway engineers are poor teachers and heartily dislike the customary winter training programs. The need for professional help has been recognized for management training and the sessions sponsored by the National Highway Users Conference and AASHO have been rewarding. Why not outside help for the training of other levels within the department It is needed and, where used, has also proven to be well worthwhile.

6. Another important problem is a general lack of standards or basis for comparison of jobs, contractors operations, pieces of equipment, people functions or the other facets of quality either within the department, or for materials and services purchased outside. This is particularly true *within* a given organization, whether at local,

state or national level. What is an acceptable quality?—of operation?—of material supply?—of construction uniformity?—of lab and field control?—of personnel productivity and reliability? How can we measure and compare? What are the yardsticks?

A corollary problem is our inability to agree on even simple quality level, to say nothing of quality in the sense of uniformity. State specifications vary widely and some municipal specifications are sadly outdated. Equally disturbing is that interpretation and enforcement of the same specification will frequently vary from area to area within a given state.

Of more importance than quality level, however, is the fact that we have no yardstick for measuring and controlling quality from the viewpoint of variability. The fallacy of average alone is well recognized.

7. Next is the matter of tolerances. How do we judge and attain specifications with realistic and enforceable tolerance limits? Wide open tolerances invite high safety factors and costly over design, whereas unrealistic tolerances invite cheating in one form or another by both the contractor and the inspection forces.

   Unfortunately, practice prevalent throughout our industry of not reporting negative results has not only warped judgment as to what constitutes a realistic tolerance, but has resulted in the loss of the data needed to establish technically sound specification limits. It has become common practice for inspectors and technicians to assume automatically that they made a mistake in sampling or testing, if the result falls outside of the specification limits. They, therefore, retest, sometimes repeatedly, until they get a result that passes. The negative results are never reported. Administrators at all levels —local, state and federal—have directly or indirectly encouraged the practice by either condoning it or ignoring its existence. The result is a distorted impression of construction uniformity and to some degree, a false sense of complacency.

8. Finally, there is the matter of significant points versus lint-picking in quality control. Our rules and regulations have become so bogged down with details and so complicated with fringe factors that picking out the "meat" has become a real burden. As materials or construction engineers we have learned to look for and control the significant points, but the "watch dog" level—the accountants and lawyers—cannot be expected to know the difference. We need some better way of first pinpointing and then rapidly and effectively

implementing action as needed to control the really important and significant construction variables, relegating secondary issues to their proper place both in our operations and in the minds of the layman.

Some Answers

These are not all the problems, but enough for today. Defining them helps, but I would like to cite some specific answers that have been used to advantage by various departments at both the state and local level. All of them come under the general classification of Quality Control Engineering and while practice varies somewhat, a typical pattern or scope might include the following:

1. An independent and objective appraisal of construction operations in the field. This includes all materials, their use, handling, testing, proportioning, and also, the techniques for control of construction.

2. Evaluation of inspection procedures. The methods, tools, frequency, uniformity and, equally important, the reporting and use of both materials tests and field inspection data.

3. Assistance in the planning and conducting of some worthwhile training programs. Pertinent subject matter to meet primary needs is ascertained by observations made under No. 1 and 2. The training needs of different organizations vary widely—some are strong in some skills, but weak in others. It is important to tailor-fit the training program to the needs and level to be reached; then to use the best of visual aids and proven training techniques to maintain proper interest and participation.

   Most important, however, is the follow-up during the next construction season to see which portions have "taken" and, to help guide application, to encourage proper and uniform interpretation of both training and other QCE recommendations.

4. Review and updating of specifications.

5. Study of communications. These are both upward and downward communications within the department, and also between the department and the contractors, material suppliers, etc. A special case is the rewriting of construction manuals to make them understandable and more usable at field level.

6. Lastly, is the adaptation from industry of those quality control techniques and methods which have been found to be suitable for highway construction. One of these tools has been selected for an abbreviated illustration.

Incidentally, another special answer in the broad communications category is the IS&R, which stands for Information, Storage, and Retrieval system for putting our technical literature onto IBM cards using key words so that pertinent information can be more easily and readily recovered as needed. NBCA, who sponsored this work, recently made it available to all and wish to encourage its use.

An Illustration of One QCE Tool

Fig. 1 is a normal frequency distribution curve. This is the pattern

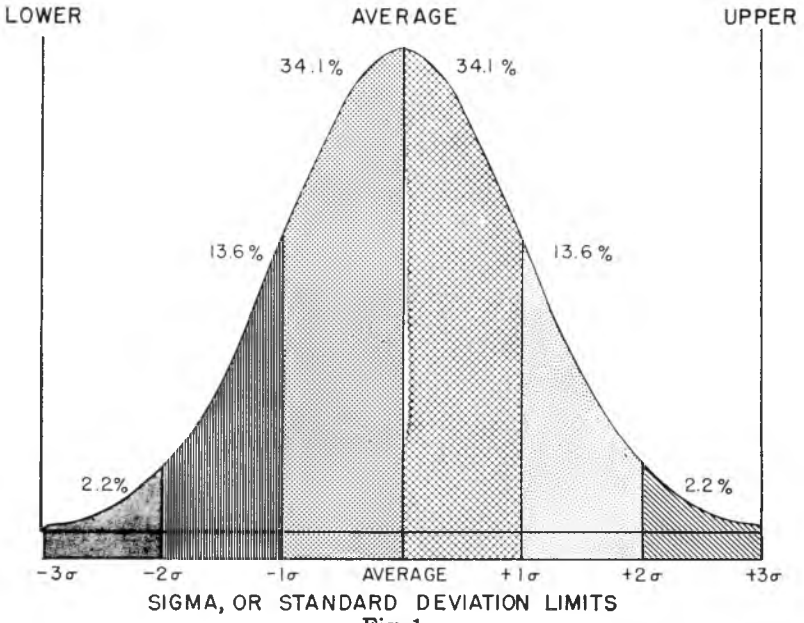

Fig. 1.

that is obtained when the variations within any given material, plus the sampling and testing errors, are random; i.e., they have just as much chance of lining up on one side of the average as they do on the other. For those of you who are not acquainted with the frequency distribution curve, I invite your attention to a description presented before the AASHO Committee on Productivity in March 1962 in San Francisco. Reprints are available from the Bureau of Public Roads.[3]

Briefly, this curve represents the distribution of the individual test results about the average. It has a characteristic shape which is *independent of the particular material or function under test.* To provide a yardstick for measuring the degree of uniformity of different materials, or operations, or people, or procedures, we divide this characteristic curve into three areas. The distance covering the first one-third on

either side of the average in Fig. 1, is called the standard deviation, and is represented by the Greek letter sigma, σ. A minus one sigma, -1σ, spans the dotted area to the left of the average and a plus one sigma, $+1\sigma$, spans the cross-watched areas, to the right. A little over two-thirds (⅔), or 34.1 + 34.1 = 68.2%, of the test results will fall within plus or minus one standard deviation, $\pm 1\sigma$, of the average in a normal distribution. Some 95 per cent of the test results will fall between plus or minus two (2) standard deviations, 2σ, and about 99.6 per cent between plus or minus 3σ. THESE RELATIONSHIPS WILL HOLD REGARDLESS OF THE MATERIAL OR FUNCTION UNDER TEST OR REPRESENTED BY THIS NORMAL CURVE.

The numerical value of the standard deviation sigma depends on the horizontal scale selected. When thus applied it becomes a valuable tool for numerically measuring variability and provides a basis or yardstick for comparing contractors, plants, materials, operators, methods of construction, inspection, test procedures, district or division offices, etc. Knowing sigma we can not only measure and compare, but we can estimate the degree of confidence or assurance we have that a valid comparison has actually been made and that it has been made without bias or influence or discrimination. Incidentally, our company is in the course of setting up a sigma "bank" in which we will accumulate information on the variability of *the different* operations or functions associated with road building as it becomes available in the literature or in State Highway Departments where we are working. Armed with this background a highway department will be better able to determine how its operations, contractors, test procedures, etc. stack up with those from other areas.

Charting Quality Control

One means of applying these principles to actual field control is to turn the frequency distribution curve on its side and to plot test data as they become available along the horizontal scale. The basic chart is shown in Fig. 2. This time we have selected bitumen content as the test property. A number of recent publications have shown that the standard deviation, sigma, for control of percent asphalt in the mix at normal hot-mix plant operation is about 0.2 per cent. In this case let us assume that the job mix formula calls for a bitumen content of 6.0 per cent, which means that *one* standard deviation will be 5.8 on the low side and 6.2 on the high side. Most state specifications require that the bitumen content be controlled within ± 0.3 per cent of the job mix formula; i.e., 5.7 on the low side to 6.3 on the high side.

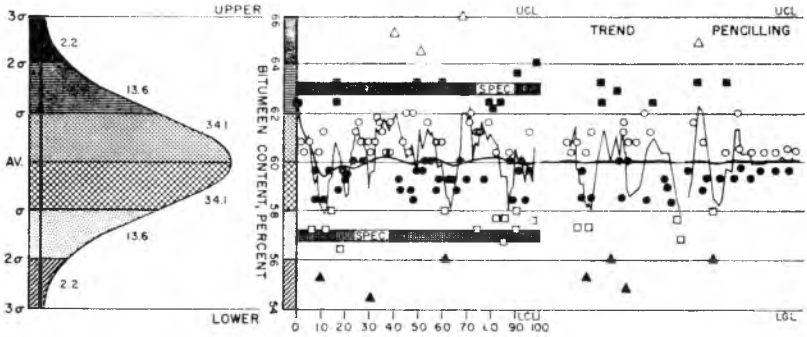

Fig. 2.

Under these conditions *all* of the test results cannot and should not conform to these tolerance limits. Some 14 per cent of the individual test results will fall outside the specifications limits due to normal variations in plant control, sampling and testing techniques.

In practice the chart as shown, but with no points, is prepared before the job starts and as the test results are obtained they are plotted consecutively. The left half of the plotted data in Fig. 2 shows the individual points of the first 100 extraction tests on a typical project. It will be noted that the number of points in each band designated by the various cross-hatchings correspond to that anticipated by the normal frequency distribution curve, Fig. 1. Thus the facts confirm that, under these conditions, all of the individual test results cannot possibly fall within the ± 0.3 per cent specification. In fact, if they do, somebody is cheating.

The heavy black wavy line represents the cumulative average and it will be noted that it approaches the value of 6.0 as time goes on. The thin zig-zag line is the "moving" average of four consecutive points. Each time a new test result is added, the fifth oldest is dropped so that this line represents the average of the last four results. The "moving" average of groups of four points is a conventional means of highlighting trends, if any, as they may occur.

The plotting may be done at any convenient place such as in the district office or in the laboratory. Clerks, usually girls, can be trained easily to plot the points and draw in the cumulative and moving average. Periodically, they run the chart through a duplicating machine (Thermofax, Verifax, or similar) and copies are sent to the project engineer, to the plant under control, to the district office or central laboratory, and to management, usually the office of the State Construction Engineer.

As the job progresses, successive points are plotted and periodically

reported. The time interval can be selected to reflect the degree of control or communications needed. Two things are immediately apparent from a glance at the chart: 1) any change in level or operation of this plant in bitumen content is immediately reflected, and 2) the distribution of the points about the average tells whether control of uniformity is being properly maintained.

The right hand half of the plotted data in Fig. 2 is an extension of this control chart to illustrate two happenings. Beneath the portion labelled "Trend" it is apparent that the bitumen content on successive tests has dropped; the individual results are no longer randomly distributed. The occurrence of five successive tests results on one side of the average establishes that this is in fact a real trend; it is not due to chance variation. Something has happened in this plant that requires administrative attention.

In the last portion of the figure under "Pencilling" is an admittedly exaggerated illustration of what could and has happened when the tester, for some reason or other, gets tired of reporting actual or honest results and starts "pencilling" data. When the distribution of the points about the average is no longer normal, something has happened. Both administrative and operating people up and down the line are quickly and easily made aware of the discrepancy.

Charts Do More Than Control

These charts are prepared for the important tests or controls only. Rather than thumbing through a stack of test reports, administrative people can tell from a glance at this type of chart what is happening to the *significant* controls—the important tests—governing operations. In practice, our clerks soon learn to recognize and call attention of their supervisor to trends or other irregularities which should receive administrative attention. In this manner the activities and judgment of experienced people are increasingly spread more effectively over more miles of road.

The psychological effect of these charts on the average highway inspector and contractor's superintendent is marked. They know their work is being followed closely and that management is able somehow or other to pick up deviations and transgressions that formerly they could get away with. Operators and inspectors both soon take pride in maintaining a more uniform operation, and start thinking ahead of their job as a team.

Lastly, these charts provide a means for establishing realistic and practical specification limits with tolerances which have meaning to

both the contractor and the engineer. They provide a graphic illustration to the layman, whether he be an accountant or a legislative investigator, with regard to what is meant by engineering control, the significance of "substantial compliance." They show that due diligence is being exercised in protecting the taxpayer. Check samples taken by the Bureau of Public Roads or by a central laboratory should follow the same distribution pattern, with typical occasional results outside of the specifications. Lack of 100 per cent compliance need no longer require the embarrassment and annoyance of a letter of explanation. On the other hand, lack of conformance with the established normal distribution is bona fide evidence of real and significant differences. Further, the degree of confidence, that both the bureau and the state can place upon a limited number of test results, can be calculated thus holding bias, discrimination, or the stigma of personal opinion to a minimum.

The importance of these concepts is being recognized in highway circles. The Pennsylvania Highway Department, for instance, is in its second year of the study and application of statistical methods in its laboratory control. They have successfully evaluated corollary techniques such as random sampling in field control. Contractors too have recognized the importance and potential of these methods and some are applying the techniques to their own operations. In addition, the National Bituminous Concrete Association as part of its Quality Improvement Program is sponsoring a research project at Ohio State University under the direction of Dr. Robert F. Baker to evaluate statistical methods in control of hot-mix plants.

I would like to emphasize again that the use of the statistical tool is only *one* of the techniques of quality control engineering. It is but one of the improved methods proved by some ten years of specialized study to be of value for assuring better and more uniform control of construction quality in the highway industry.

In closing I would like to come back to correlation of "quality" with "level" by highlighting a few of the more important areas wherein I believe the various levels can exert the greatest influence on quality improvement.

At the federal level I would suggest in behalf of quality that the Bureau of Public Roads:

1. Take the lead in encouraging the reporting at all levels of *all* test results, whether or not they conform to the specifications; and then lead in the adoption of modern statistical techniques to provide a better understanding of variability in construction control, and,

especially, to provide the basis for establishing specification tolerances that will have real meaning for design purposes and be enforceable on the grade for control purposes.

2. Take the lead in evaluating improved methods of training for all levels of the highway team.
3. Implement improved means for the coordination, communication, and wider use of the mass of pertinent research findings and technical data still buried in our literature.

At the state level I would suggest in behalf of quality that:

1. Objective appraisals be made of the reasons underlying the "special" features of state specifications which make them differ from AASHO recommended standard practice to assure that each area of nonuniformity is really a bona fide reflection of experience found to best fit local conditions or materials, and that the "special" need still exists.

At the municipal and county level I would suggest in behalf of quality that:

1. The requirements for pavements in new housing developments be strengthened, and that you insist that the work be done at a time that will minimize the number of utility cuts, and in a manner which will give the greatest chance for long-lived service at minimum maintenance expense.
2. You get outside help, if you do not have your own facilities for conducting the necessary soils surveys, to properly provide for drainage and adequate bases on both secondary roads and in housing developments. Such help might come from the state or from consultants, and might be financed by two or more counties getting together.

At management level for all departments I would suggest in behalf of quality that:

1. You back up your organization and particularly that you back up your men at field level—that you recognize their needs and motivation as *people* as well as *employees* of the department.
2. You provide training in both technical *and* administrative skills at all levels.
3. You not only encourage but actively help to sell an open minded and receptive attitude within your department toward new methods, new tools, and new techniques.

To the engineering family at all levels I would encourage in behalf of quality that:

1. You take advantage of new technological equipment and procedural developments by *early* evaluation and reflection of the worthwhile advances in your specifications and special provisions.
2. You strive for uniform interpretation and enforcement of your specifications.
3. You strengthen the pre-construction conference as a means for spelling out the job requirements from the quality viewpoint.

To contractors I would suggest in behalf of quality that:

1. You avoid working close to the specification limits—aim for the middle one-third of the band whenever possible.
2. You pay more attention to the day by day maintenance of equipment to assure all proper adjustments needed for *uniform* operation.
3. You take a close look at the profit, as well as the quality improvement, potentials of such modern tools as the critical path method, statistical techniques, and other means for avoiding costly delays and disputes.

To the politician at all levels I would beseech of you in behalf of quality that:

1. You disrupt our highway organizations as little as possible.
2. You leave the selection of pavement type and other engineering decisions to the engineers.
3. You take a longer look at *overall* cost, considering maintenance as well as initial cost, in keeping your constituents happy; don't force sacrifice of adequate bases and proper attention to drainage by attempting to stretch this year's budget over too many miles of road.

Finally, to the *most* important level of all, from the quality viewpoint, I would suggest that the resident engineer and the contractor's superintendent in the field, with full respect for the other fellow's function and responsibilities, think *together ahead of the job* to help each other foresee trouble *before* it happens and work as a team to maintain steady production of uniform high quality of which both can be proud.

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