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This issue of *The Bell System Technical Journal* is devoted to a selection of articles dealing with various phases of mathematical statistics and quality control. The Editorial Board and Editorial Staff of the *Journal* present this "all statistics" issue in the belief that the growing importance of statistics to communication technology warrants the simultaneous publication of these articles.

The Editors are pleased to include in this series of papers on statistical subjects one by Dr. Walter A. Shewhart whose pioneering work in statistical quality control has served as an impetus to wider use of statistical methods in the Bell System. This paper, which dates back to 1935, was one of a series of internal technical memoranda of the Quality Assurance Department of the Bell Telephone Laboratories, Inc. It was prepared by Dr. Shewhart in the course of a series of departmental group discussions having to do with the development of the fundamental philosophies of quality control and quality assurance.

Nature and Origin of Standards of Quality

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This paper discusses the importance, from the viewpoint of judging quality, of: the end to be served by a standard of quality; the nature of the accepted binding force of the standard upon the acts of those interested in the standard; and the role of the judge of quality in shaping the standard in terms of natural law, authority, specification, custom, and precedent.

I. OBJECT

The control of quality of manufactured product involves three coordinate functional steps: the specification of the aimed-at standard of quality; the production of pieces of product that will be of standard quality; and the determination of whether or not product thus made is of standard quality. These three steps are respectively legislative, executive, and judicial in character. The object of this paper is to consider the nature and origin of standards of quality from the viewpoint of judging the quality of product.

Such a judgment as herein considered is made the basis of one or the other of two kinds of action: (1) the acceptance or rejection of a piece of a given kind of product for service; and (2) the adjudication of a complaint about the quality of a piece of product in service. The two judgments are of the type: J_A — this piece of product (or this lot of N pieces of product) is (or is not) of standard quality, and J_B — this piece of product (or this lot of N pieces of product) was (or was not) of standard quality. In either case, it should be noted that the judgment is rendered in respect to the quality of a piece of product that is already in existence at the time the judgment is rendered — it is a judgment after the act of specifying and after the act of making the piece of product in question. This problem of judging the quality of a piece of product after it is made is definitely different from the legislative problem of specifying prior to the making of a piece of product what its quality should be in the light of information then available; and different from the coordinate executive problem of making a piece of product that will have the standard quality.

Judgment, in the sense here used, implies a comparison of the quality of a piece of the given kind of product at some particular time with the standard for the piece at that time in the light of the evidence then available. If it were possible to specify completely and in an operationally definite and verifiable sense the standard of quality for things of a given kind, and if it were possible to specify the operational technique that would determine with certainty whether or not the quality of a given thing was that specified, the problem of judging would be routine in nature. But neither of these operations is possible. Hence in judging the quality of product, we must take account of the fact that a standard cannot be specified in this rigorous sense and that the practical standard of quality is determined not alone by written specifications of the quality characteristics prior to the making of a particular piece of

product but also by natural law, authority, custom, and precedent, existing at the time the particular piece of product is being judged. In other words, the quality judge is not, as it were, handed a standard of quality already made with which to compare the quality of a given piece of product. Instead he is only handed the stones with which to build such a standard. Through his interpretation of specifications, custom, precedent, natural law, and authority, the quality judge in a sense gives operational meaning to the standard of quality in much the same way that a judge gives operational meaning to the law of the land, whether it be statutes, custom, precedent, or constitution.

Obviously, therefore, before a quality judge may render a judgment of either type J_A or J_B , he must "determine" the standard that is to be used. But what is there to guide such determination? It goes without saying that he is not free to act as he pleases. In what follows we shall see how the acts of the quality judge in determining the standard depend upon: (a) the intent of the standard; (b) the nature of the binding force that the standard is presumed to have upon those concerned; and (c) the available source or sources from which a standard must be derived.

To begin with, we shall consider the nature of a standard of quality as a means to an end, as this will give us a background for considering in turn the binding or constraining force of a standard upon the acts of those making use of it and then the origin of a standard in natural law, authority, specifications, custom, and precedent.

II. STANDARD AS MEANS TO AN END

Dr. Gaillard of the American Standards Association defined a standard as: "A formulation established verbally, in writing or by any other graphical method, or by means of a model, sample or other physical means of representation, to serve during a certain period of time for defining, designating, or specifying certain features of a unit or basis of measurement, a physical object, an action, a process, a method, a practice, a capacity, a function, a performance, a measure, an arrangement, a condition, a duty, a right, a responsibility, a behavior, an attitude, a concept, or a conception."

This definition stresses one important characteristic which is commonly attributed to a standard, namely, that it is something fixed. The definition of standard here is very broad indeed; it would seem to include the rules of mathematics and formal logic, the rules of syntax of a language, and even legal statutes. In fact, it also includes social mores

assumed policy objective of production, any evidence which may have come to hand, particularly in the processes of production, inspection, and analysis of complaints, indicating the present specifications to be incomplete in that they do not include requirements on certain variables which it seems desirable to control. Quite naturally such requirements will sooner or later find their way into specifications, but the quality judge must, insofar as possible, act in accord with what he considers to be potential changes if the policy of accepting only quality that may reasonably be expected to be satisfactory, adequate, dependable, and economic is to be met. In other words, the quality judge must fill in the gaps in existing specifications in so far as new evidence obtained since such specifications were written would indicate to be reasonably desirable.

(b) If the quality judge is to accept the theory that a specification is but a means to an end and is to take account of the fact that the justification of a specification rests upon an ever-changing body of evidence, it is necessary for him to use discretion in judging quality of product to be either acceptable or rejectable upon the basis of specifications alone. In other words, certain non-conformance cases may arise in respect to specified quality characteristics which may have under certain conditions little effect upon the experienceable quality of such equipment in use. In such a case it may likely be uneconomical on the part of all concerned to reject such product. Such action on the part of the quality judge is not, as it were, ignoring a specification but rather making a judgment upon evidence which was not available at the time the specification was written.

(c) If any one of the four items in S_x , and S_y , are omitted in the written specification, it is necessary that such be supplied by the quality judge. For example, specifications sometimes simply state that some

ment should lie if it is to be that which he believes will prove to be wanted. True enough, he is likely to give weight to the data constituting his previous experience of production methods which indicates limits within which variability may be expected under production. Obviously, however, such evidence is likely to be very meagre indeed as compared with the cumulative evidence obtained after production starts. Experience shows that there is an economic limit to the allowable variation in the quality of product turned out in a given process. In other words, it is often found that it is more economical to discover and eliminate assignable causes of variation of quality than it is to leave these in the production process and reject that portion of the product that does not meet the required limits. The quality judge has an important rôle to play in devising techniques which will indicate the presence of assignable causes and of using these in helping the production department to establish economic control limits which serve as standards for future production.

(e) We now come to what is perhaps the most important rôle of the judge of quality in giving operational meaning to a specification. Even though an operationally definite and verifiable meaning of quality is given in the specification, there are two reasons why it is often necessary to resort to sampling in order to determine whether or not quality meets the specification: (a) it is often uneconomical to give 100 per cent inspection, particularly where defective parts would be weeded out in final assembly or at the time of installation, and (b) it is often not feasible to give 100 per cent inspection because of the destructive nature of the method of verification of the quality, as, for example, in testing the tensile strength of materials and the blowing current for fuses. In such a case the quality judge must supply an inspection specification which will insure the following two things: (1) that a satisfactory amount of data or evidence will be accumulated upon which to render judgment as to the nature of the quality of the unsampled portion of the lot, and (2) that an operation will be indicated to determine whether or not it should be rejected whenever the degree of belief in the satisfactoriness of the unsampled portion of the lot upon the basis of evidence thus accumulated is insufficient to justify the acceptance of the lot. The question, How much data?, depends in general upon the degree of economic control of quality previously obtained and hence the inspection operation specified must be such that it keeps abreast of the continual supply of information obtained in the process of inspecting product if such an operation is to give adequate assurance of quality at a minimum of cost.

We are now in a position to turn our attention to a consideration of the nature of the binding force of specification. In the first place, a specifica-

tion may be made the basis of a contractual agreement between two parties, in which case it takes on certain legal as well as moral binding force characteristic of a contract. One of the conditions usually assumed for the validity of a contract is that the two parties to the contract be cognizant of the contents thereof. Of course, in many instances specifications of quality are extremely involved from a scientific and engineering viewpoint and hence it is to be expected that parties to a contractual agreement involving highly technical specifications of quality must be capable of arriving at a common meaning of such specifications. This limits the field in which technical specifications may be made the basis of valid contracts. The second source of binding is, of course, the requirement that the quality accepted as meeting the specifications be judged in the end as satisfactory by those making use of the product. In this case, however, we should note that the binding force is not so much that requiring that the quality of product meet the specifications as it is that requiring that the quality be found in the end to be satisfactory by those making use of the product. In this case, however, it must not be overlooked that there is a growing tendency on the part of the majority of users of most kinds of goods to place reliance upon the judgment of men or groups of men whom they accept as being technical authorities, such, for example, as national or international standardizing committees.

In the third place, as previously noted, a producer is sometimes bound because of his own future interests to adhere to a specification even when such adherence would not be demanded at the time by those whose wants the quality is supposed to satisfy. For example, the appreciation of high quality often comes through experiencing high quality. One who has never heard what a technician would consider to be good music, good quality of radio transmission, good quality of telephone transmission, or good quality of some musical instrument, might never have the desire to experience such. Progress, therefore, often comes by living up to a specification of quality even beyond the limits wanted by the majority of those concerned at a given time. In other words, the producer's personal interest is often more binding than either or both the bindingness of a specification made a part of a contractual relation and the immediate interests of the consuming group, if he is to lead the way in evolving standards that will later be wanted by the majority.

4.4 *Custom*

All of us are more or less creatures of habit; all of us are more or less influenced throughout life by the habits and the common methods of

acting of those around us. We early learn that society always takes a revenge of one form or another for a breach of any of its common ways of acting and hence as members of any group we feel more or less bound to follow the conventions of that group. For example, in our methods and means of communicating one with another, we are bound to a large extent to the customary use of symbols, either written or spoken. Even the meaning of a written specification of quality so far as the majority of a group or society is concerned inherently depends to a large extent upon the customary interpretation of words and other symbols used therein. It is to be expected that custom should play a part in the production of standards. Thus a long while before the development of written specifications of standards of quality there existed unwritten standards, as it were, fixed by the customs of certain groups. At least the meaning of certain words was sufficiently common to members of a group to enable the interchange of goods.

With the development of mass production practices first introduced in the eighteenth century, there has grown up an ever-increasing appreciation of the economic advantages to be attained by securing a high degree of uniformity in the quality characteristics of a given kind of thing. It is significant for what follows that there exist at least three ways in which customary quality may differ from specified quality in such a way as to constitute a part of the standard which is inherently binding upon the group.

In the first place, a given kind of product produced over an extended period of time in considerable quantities may exhibit a uniformity in quality characteristics not specifically expressed in the specifications of the form S_{x_i} and S_{r_i} . In the second place, one or more quality characteristics may be specified to have magnitudes lying within a definite range although experience has shown that over a certain period in the past in which many pieces of this kind have been produced the magnitudes of the particular quality characteristics thus specified have differed from their specified values but in a way which has been acceptable from the viewpoint of use. For example, take the case where the production of a new kind of product is started in which the specification of one of the important quality characteristics, such as length of life, is that it shall not be less than some specified value. Let us assume that N pieces of this kind of product have been made and put into service and that the experience thus obtained shows that the lengths of life of these N pieces of product have been distributed uniformly about an average length \bar{L} considerably above the specified length S . Particularly if the number N of pieces of this kind of product that have gone into service is large and

if those making use of this kind of thing come to expect an average life of approximately \bar{L} , even though the specification simply calls for a life not less than S , most producers would feel bound in certain ways to maintain a quality not assignably less than \bar{L} . It is quite likely, to say the least, that some consumers of this kind of thing might feel justified in registering a complaint if they should find in the future that the length of life of this kind of thing was significantly lower than \bar{L} even though it did not fall below S . In the third place, even though no specific mention is made of the fact that in the specification, users of a given kind of product may reasonably expect that observed variability in the quality characteristics specified should be no larger than that which for economic reasons should be left to chance. For example, consider the class of users of a given kind of thing such as an automobile. If we find upon comparing notes with our neighbors or others using the same make of car that ours differs from theirs in a way which we consider undesirable, we are likely to feel like registering a complaint.

In rendering quality judgments the quality judge must take into account at least these three ways in which custom may effectively constitute a part of the standard of quality binding in a given case. In fact, he not only must take into account custom in certain instances but in fact, as we have seen in the previous section, he must also in certain ways help in establishing custom, as, for example, in the analysis of results of inspection and the determination of economic limits of variability.

The ultimate source of binding force in maintaining uniformity is quite naturally the consumer's desire for uniformity. Such a common want, however, is in a certain sense potentially of legal binding in the sense that many statutes as well as common law have their origin in custom. In any case, the degree of binding depends among other things upon: the available evidence of the existence of a custom; how long and how continuously it has existed; whether or not the custom has been peaceably enjoyed; to what extent those affected have regarded it a duty to follow the custom; and whether or not the custom in question is consistent with all other accepted customs.

4.5 *Precedent*

To begin with, it is desirable to clarify the distinction here made between custom and precedent. Custom, as we have seen, is of the nature of an established practice that has more or less gradually come into existence. Precedent, on the other hand, arises in the judgment in re-

spect to the quality of product that has already been produced as to whether or not it is or was of standard quality. Precedent arises, in other words, in the finding of the quality judge. If it were feasible to write specifications of quality that were ideally necessary and sufficient for satisfaction, adequacy, and dependability at an economic cost, and if it were feasible to determine with certainty whether or not the quality of a given article met such specifications, there would be little, if any, occasion to consider the rôle of precedent. Since, however, this is not feasible, there are three types of judicial findings which are important in quality control.

Cases of non-conformance with specified requirements are bound to arise where the information available at the time justifies the judge of quality in concluding that, under the specific conditions existing in the case, the quality, even though non-conforming, is acceptable. Likewise, conditions are bound to arise where, even though the quality of a given thing does conform to specifications, it may not be acceptable. This follows at once from the fact that we are not able to state the necessary and sufficient quality requirements. This class of precedent arises as a natural consequence of looking at a standard as a means to an end, rather than as an end in itself.

Just as common law arises for the most part in the judicial recognition, interpretation, and formulation of custom, so also does the effective control of custom in standardization come about through the recognition, interrelation, and formulation of custom on the part of the judge of quality. Thus judicial declarations or recognitions of the existence of a custom constitute another source of precedent. In quality control one of the very important examples is the judicial decision as to whether or not a custom has been established with regard to the degree of variability which should be left to chance.

A third source of precedent is interpretation: first, interpretation of the operational meaning of a standard even in so far as it is specified; second, interpretation of the sampling technique required in order to give adequate information upon which to render a judgment; and third, interpretation of the rules of judging and interpreting evidence as to the quality of product.

V. CONCLUSION

The practical meaning and significance of a standard of quality is largely determined by the end which it is supposed to serve in use and by

the nature and degree of the binding force or sanction accorded it by the group interested in or affected by the standard. The standard itself may originate in one or more of the five sources: natural law, authority, specification, custom and precedent. In any case the judge of quality is not handed a standard ready made with which to compare the quality of any given kind of manufactured goods — instead he of necessity plays an important rôle in shaping and determining the standard as derived from these sources.