SOME ASPECTS OF QUALITY CONTROL

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The object of this paper is to make clear what is meant by quality in a practical objective way that is subject to experimental verification and to consider some aspects of the problem of control. As a basis for judging the quality of current product it is necessary to obtain first of all adequate information, in the most efficient manner, on which to render a judgment. This can be accomplished by providing an inspection specification which is distinct from the design specification. One specifies the quantity and kind of evidence that is required as a basis for judging whether or not the quality of the product will attain its goal, the other specifies the goal. Certain elements of uncertainty must be allowed for in setting the goal. The discussion closes by pointing out the necessity of keeping a running report or record of the evidence used in judging the quality of current product as a part of any scientific plan of making use of hindsight as well as foresight in controlling quality.

NEEDLESS to say, the problem of controlling quality is not the same for all kinds of product or for all kinds of conditions. For example, it may be one thing for a large producer and quite another for a small one; one thing for a product of short life and another for a product of long life; one thing for a product that has been produced in much the same way for ages and quite another for a new kind of product. What I have to say is directly applicable to a large producer who assumes the responsibility of providing his consumers with a product of a standard of quality which is satisfactory, adequate, dependable, and economic from a long-range viewpoint and of changing this standard whenever the developments in the field of applied science make such changes

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desirable. It is felt, however, that most of the points to be made have significance in any control program.

Before we can talk intelligently about control of quality, we must make clear what we mean by quality in a practical, objective way that is subject to experimental verification. The object of this paper is to provide such a meaning and to consider some aspects of the problem of control. It will be shown that quality has objective meaning only in an operational, statistical sense, and that the statement that the quality of a given thing is such and such is a probable inference which has definite meaning only when (1) the such and such is specified in an operationally verifiable way, and (2) when we know the evidence upon which the inference is based. It will be shown that to specify quality in this experimentally objective way involves three steps: (*a*) Specification of qualia to be experienced, (*b*) specification of an experimental operation, and (*c*) specification of a technique of verification. Such a set of specifications for a quality characteristic constitutes a quality mark, as it were. However, as will be shown, the problem of control does not become definite from an experimental viewpoint until the degree of assurance of hitting this mark is also specified. The specification of the quality mark and of the desired degree of assurance consitutes a definite quality goal and is a legislative function. In the same sense the production of things designed to attain the quality goal and the judging of the things thus made as to whether or not available evidence gives adequate assurance that they will attain the goal are coordinate functions. As a basis for judging quality of current product it is necessary to obtain first of all adequate information upon which to render a judgment. Furthermore, it is desirable to get this information in the most efficient manner. These objectives can be met by providing an inspection specification which is distinct from the design specification. One specifies the quantity and kind of evidence that is required as a basis for judging whether or not the quality of current product will attain its goal, and the other specifies the goal. The judgment of quality upon the basis of such evidence is a step which must allow for certain elements of uncertainty in the setting of the goal.

Our discussion closes by pointing out the necessity of keeping a running report or record of the evidence used in judging the quality of current product as a part of any scientific plan of making use of hindsight as well as foresight in controlling quality.

MEANING OF QUALITY

We want a practical, verifiable meaning of quality. Why not look in the dictionary, you say; but it will do no good for we shall not find one there. Let me give one such illustration: Viz., quality comes from "qualis" meaning how constituted and signifies what a thing really is. This dictionary definition like all others that I have seen certainly does not fill the bill. For example, today as never before we realize that we do not know what makes a thing what it really is. How then could one verify such a concept of quality? How could one control that which he does not know? If one talked in this meaningless way, he would not be likely to make much progress in developing a rational theory of control.

But we do not need to talk this way. At least since the turn of the century students of science have begun to wake up to the truth in the old adage that "Actions speak louder than words." That is, we are now in a place to realize that practical, verifiable meaning lies in the experience associated with a specific operation. Let us consider in sufficient detail for our present purpose the meaning of quality from this viewpoint.

Our consciousness of the external world at any instant consists of a more or less confused awareness. We soon recognize, however, certain repetitive elements in the stream of consciousness expressible in the form "that looks brown," "looks elliptical," "looks far away." Such "looks" are termed "qualia" and constitute the given in experience. One early recognizes in his stream of consciousness the uniformity of simultaneous appearances of sets of qualia. The next discovery of importance is that such uniformities are usually, if not always, followed by other recognizable sets of qualia, provided we act in a specified manner. Thus one comes to interpret the consciousness of such a set of associated qualia as a signal of the possibility of experiencing a definite previously conceived succession of associated qualia. The objectivity of experience consists in the verifiability of this succession as predicted. Such an objective succession of associated qualia constitutes the quality of a thing or object. *It follows that the concept of quality of a thing has the meaning of a succession of perceivable qualia associated with a previously conceived or specified set of operations.* Conclusions of far-reaching importance follow from this concept of quality, as we shall now see.

First, it is significant that there is not a universal meaning to the quality of a thing because objective thinghood lies in the possibility of experiencing a previously defined set of qualia associated with a previously conceived set of operations, the number of possible such sets of operations being indefinitely large. We have no rational basis for talking about *the* quality of a thing except in reference to a specified set of operations. For example, my concept of the quality of an automobile is fixed by the qualia which I expect to experience when operating a car as I do. Both in that we may not have interest in the same sets of qualia and in that we do not operate cars alike, there are grounds for marked differences among our individual concepts, although they may be expected to have definite similarities. Moreover, the concept of the consumer or user of anything, such as an automobile, usually begins with the finished product, whereas the concept of the producer begins with raw material and includes all operational steps in development, design, and fabrication, as well as a specified operation of the finished product.

Second, it is significant to note the nature of the verifiability of an external object or thing, such as any piece of manufactured product, in terms of a concept of quality. As noted, such a concept held by any individual involves a succession of qualia experienceable as the result of previously specified sets of acts or operations. If the sets of specified operations involve a finite sequence of sets of qualia, the individual may be said to have verified the object or thing thus conceived when, upon carrying out the operations, he has observed the sequence of qualia within the limits of error of his perception.

Third, it is significant to note that up to the time the producer delivers the finished product to the consumer, he can have verified any specified concept of quality only up to the time of delivery. In delivering the product to the consumer, he can only *judge*, with a probability less than certainty, that the consumer's concept of quality will be verified. In other words, it is not humanly possible for the producer to render other than a probable judgment as a basis for which he must rely on the following generally accepted postulate of probable inference: ***The objective degree of rational belief p'_b in an inference or judgment P is not an intrinsic property like truth but inheres in the inference or judgment through some relation to evidence Q.*** There follows from this postulate the important fact that the degree of rational belief in the judgment that the concept of quality of a given piece of product, involving operations after it leaves the producer, will be found to be verifiable, depends upon the set of previously observed sequences of qualia taken as evidence.

Perhaps a schematic diagram will help to fix the essential elements in the meaning of the quality of a thing. The judgment that the quality of a thing is such and such is essentially a prediction of the future. For such a prediction to have definite and verifiable meaning at any time taken as the present, it must be in terms of one or more sets of qualia to be experienceable respectively as the result of one or more definitely specified operations. The degree of rational belief p'_b in the prediction depends upon the information Q which we have about the

Information Q	|	$P =$ { (*a*) One or more specified sets of qualia to be experienced; (*b*) One or more specified sets of operations
Past	Present	Future

FIG. 1

thing up to the present. Since, as just stated, the degree of rational belief p'_b in a judgment P inheres in this judgment through some relation to evidence Q, it is evident that the judgment that the quality of a thing will meet the conditions P is meaningless as a probable inference unless we know the evidence Q. Likewise the judgment is meaningless in any sense that can be verified experimentally unless the sets of qualia and associated operations are definitely specified.

We are now in a position to consider in turn the meaning of three types of quality of interest from the viewpoint of control.

QUALITY OF TYPE 1

Definition: Quality of Type 1 is that which characterizes a thing itself independent of all other things and of human volition and interest.

Non-critical common sense attributes to every thing or object about us certain quality characteristics independent of human interest. Fundamentally, such quality characteristics are supposed to represent the objectivity of the external world, or the given in experience, or that part of experience which comes to us whether we wish it or not when we act in certain ways; they are supposed to represent what is knowable about the real external world; for the most part at least they are the type of characteristics in which the engineer conceives of the quality of a piece of apparatus as being that which makes it what it is and which he tries to include in his specification of the physical aspect of that piece of apparatus; they are the characteristics that the hard-boiled, cold-blooded natural scientist attributes to the external world in which we live, as usually contrasted with the wish-colored and interest-tinged quality characteristics of experience in which we try to interpret the whole of experience or, more particularly, our likes and dislikes and our method of valuing external objects.

In so far as these common-sense quality characteristics may be observed either in the form of the pointer readings of the physicist and chemist such, for example, as those interpreted as mass, density, resistance, capacity, and velocity, or in the form of direct sensations, such as color, they become experimentally verifiable and have objective meaning.

Strictly speaking, the quality of any object is relative, although as engineers we are perhaps justified in considering some quality characteristics, as, for example, mass, as being independent of other things, as well as of human interest and volition. There are, however, many quality characteristics such as linear dimensions, volume, density, resistance, and the like, which are fixed in terms of operations so long as such operations are carried out under the same essential conditions. Fundamentally, there is always implicitly involved in the concept of the objectivity of the quality of an object the assumption that the conditions under which this quality is to be measured or experienced are to remain *essentially the same*. That is to say, scientific method never gets away from depending upon the human element involved in judging conditions to be the same except in so far as the type of observer can be specified as a part of the operational technique. The meaning of quality of Type 1 is partially fixed by the operations involved in the measurement of such quality, including those taken to insure that the same essential conditions are maintained.

As a result of a series of n repetitive operations or measurements of some property such as mass, we get n observed values $m_1, m_2, \ldots, m_n$ which, in general, will not be the same even though conceptually the mass of the real object under the same essential conditions is assumed to be a constant m'. That is to say, even though there be a *real* mass which is constant when the real essential conditions are kept constant, such mass is not experienceable except in the form of measurements involving definite operations, and the results of such successive operations are not constant but constitute an observed frequency distribution.

Now, let us consider what it means to verify a quality characteristic of Type 1 that can be observed again and again under presumably the same essential conditions, because, as we have noted, the objectivity of quality must lie in the experienceability of a certain predetermined set of qualia associated with a given set of operations. As an example, I am thinking of the thickness of a particular type of feeler gage. According to the design specification, this gage is to have a uniform thickness of 0.008 in. ± 0.0003 in. The specification goes on to define the procedure or operation of measurement and to describe the same essential conditions so as to be intelligible to an experienced operator. Can such a quality characteristic be verified? To make the problem more specific let us assume that you are a consumer in the market for a gage as thus specified, and that I am a producer of such gages. Assume that I have one of my gages here in my hand and that I tell you that it has the quality specified. What would constitute a verification of my statement?

The answer to this question is that there is not a definite process set forth in the specification by which to make a verification. For example, you might measure the gage according to the procedure specified and get an observed thickness of 0.0083 in. If you take four more readings you may, however, get values such as 0.0084, 0.0082, 0.0084, and 0.0083 in. According to the first, third, and fifth readings, the gage is within the specified range. Two readings are outside and the average of the five is outside the limits. Obviously, for the quality characteristics to be verifiable it is not sufficient to state the method of measurement and to maintain the same essential conditions in so far as possible. It is also necessary to specify the number of measurements to be made the basis of the verification as well as the method of using these measurements or, in other words, a statement as to whether the limits 0.008 in. ± 0.0003 in. apply to each of some specified number n of observations or to some function of these such as an average. Only then does the quality of thickness become objective and experimentally verifiable.

In general, to make a quality specification objectively verifiable it is necessary that it specify: (*a*) The qualia to be experienced, (*b*) the accompanying operation, and (*c*) the detailed technique of verification. Thus in the case of the gage, the quale is the scale number, the operation is the method of manipulating the gage and the measuring mechanism, and the verification is defined in terms of an operation on a specified finite

	Past		Future
Q_X =	(*a*) Measurements of X on given thing (*b*) Measurements of X on things of the same kind made in the past under presumably the same conditions (*c*) Evidence that measurements made under presumably the same essential conditions give no indication of the presence of assignable causes (*d*) Other relevant information such as measurements of other quality characteristics on the given thing; past experience with similar things; and consistency of measurements on a given thing with all prior accepted facts that are pertinent	P_X =	(*a*) Specified qualia to be experienced (*b*) Specified operation (*c*) Specified technique of verification

Past Present Future

FIG. 2

number of scale readings. Likewise in shooting at a standard target with a rifle, the quale might be the scale reading representing the distance from the edge of the hole made in the target to the center of the target, the operation would include specifications as to the manner of shooting at the target and of measuring the quale, and the method of verification would, as before, define an operation involving a finite number of scale readings.

Thus far we have considered a quality characteristic that can be measured again and again under presumably the same essential conditions. Of course there are many characteristics for which the operation of measurement is destructive so that verification must be in terms of a single observation.

We are now in a position to consider some important aspects of the problem of judging quality of Type 1, illustrated schematically in Fig. 2, for any quality characteristic X of a given thing.

A set-up such as sketched in Fig. 2 holds for each quality characteristic used to determine or specify the quality of a given thing. As already noted, the judgment that the quality of a thing will meet the specification Px is a probable inference derivable in a rational way from evidence of the type Qx. It is of interest at this point to note that in the case of a probable inference about a quality characteristic of Type 1, such as thickness, where repetitive measurements on the same thing can be made at will, all of Qx can be made the grounds of the inference, whereas in the case of a quality characteristic in which the measuring operation is destructive, only parts *b*, *c*, and *d* can be used as grounds for such inference.

From the viewpoint of control of the quality characteristic X of a given kind of thing, the set of specifications Px constitutes the target usually set up before commercial production starts. Of course, the specifications Px cannot be set out of thin air. Instead they must represent a practical mark which means that they must take into account manufacturing limitations. As a result, the specifications for the quality of a new kind of product are ordinarily taken as tentative and may be changed after a study of the results of early production. The important point for the present discussion is simply that before any one particular piece of product is produced there is some set of specifications Px serving as a mark for that piece. The production organization aims at this target in producing things of the given kind. However, before any piece of product is actually fired at the target, it is necessary, in accord with the policy we are here considering, that sufficient grounds of the type Qx be available and that those give adequate assurance that the piece of product will hit its quality mark. It is the function of what I shall term the inspection specification to fix the operation of choosing the necessary amount of information of type Qx in the most economical way.

In general, it should be noted that the specifications Px serving as a mark for a given piece of product must take place before production of that piece and constitute the quality mark of production, whereas the inspection specification, in so far as it uses (as it is almost sure to do) evidence of Types *a* and/or *b* and *c* of Qx in defining a definite inspection operation must be in terms of data accumulated after the goal is set and production started. Furthermore, we need to keep in mind that the inspection specification is definitely different from the specified technique of verification under P_X, a fact that is generally overlooked. For example, P_X defines something wanted or, in other words, an end to be attained, whereas the inspection specification defines an operational step constituting one of the means to this end. The means may change though the end remains fixed, as I shall now illustrate.

Let us assume that n measurements of X are required on this thing to give the necessary assurance that it will hit its quality goal. Now, suppose that, after having made, let us say, 1000 things of this kind, on each of which we have made n measurements, we make the observation that the one thousand appear to have come from a statistically controlled product. The assurance given by the n measurements, let us say on the one thousandth one, taken with the fact that there is no evidence of lack of statistical control, is greater in general than the corresponding assurance given by the n measurements on the first one. If only n were required on the first, less than n are required on the one thousandth one to give the same assurance. In other words, the number of measurements per piece required to give the necessary assurance depends upon the history of the degree of control of the production process and cannot be specified once and for all in the same way that the aimed-at quality can be specified.

In fact, it turns out in general that the minimum amount of sampling required to give adequate assurance of quality of product is attained when the quality gives evidence of being controlled in the statistical sense. Hence in order to reduce to a minimum the cost of inspection effort required to give adequate assurance, it is desirable to take into account evidence of the existence of control, which can be done, of course, only as the production process gets under way.

Thus far we have considered the quality of a thing itself in so far as it is possible to free it from the influence of all other things in a practical engineering sense. We must next consider the quality of a thing in relation to the quality of other things.

QUALITY OF TYPE 2

Definition: Quality of Type 2 is that which characterizes a thing A in its relation to another thing B as a part of a whole and independent of human volition and interest.

This is the sense in which one speaks of a piece part in its relation to the whole of which it is a part or in the sense that parts of a telephone circuit, for example, contribute to the transmission characteristics of the circuit. Other typical examples are the quality of one condenser as a part of the overall quality of two condensers in series or parallel; the qualities of resistances, inductances, and capacities as parts of the overall impedance of a circuit; the quality of a conduit to resist corrosion; the quality of a chemical compound as a plant fertilizer; and the quality of a drug as a medicine. The quality of a thing in this relational or use sense may be extended indefinitely at will.

For our present purpose, let us consider the meaning of quality of Type 2 that has significance from the viewpoint of the control of quality. To begin with, let us consider any piece of equipment or apparatus built up of a number N of different kinds of parts as, for example, an automobile, electric fan, telephone instrument, or the like. Let us assume that the quality of the whole W in which we are interested is expressible in terms of m_2 quality characteristics $Y_1, Y_2, \ldots, Y_i, \ldots, Y_{m_2}$, each having operational meaning. From the viewpoint of controlling the quality of any piece part A, we, of course, try to determine the set of m_1 quality characteristics $X_1, X_2, \ldots, X_i, \ldots, X_{m_1}$ of the part A itself, the control of which is a necessary and sufficient condition for controlling the contribution of the part A to the quality of the whole W, expressed in terms of the m_2 quality characteristics of the whole. Let us assume, moreover, that the desired quality of the whole can be given objective, verifiable, operational meaning by m_2 sets of operations of the form P_{Y_i}, where P_{Y_i} has for the quality characteristic Y_i of the whole the same significance as P_X (Fig. 2) for the quality characteristic X of the part. Ideally we try to set up for any part A the m_1 sets of operations of the form P_{X_i} which are to be met if the part A is to contribute as desired to the quality of the whole when the same conditions are satisfied for each of the N piece parts constituting the whole.

There are at least three distinct ways in which a quality of a part may contribute to the quality of the whole. First, there is the case where the quality characteristic of the whole in which we are interested has the same operational meaning as the quality characteristic of a part A, and where these are mathematically related through past experience. An example is the quality characteristic of capacity of a condenser considered in its relation to the capacity of two or more condensers in series or parallel. Second, there is the case where the quality characteristic of the whole in which we are interested does not have the same operational meaning as the quality characteristics of its parts, although these are mathematically related through past experience. An example is the impedance of a circuit in terms of the resistances, capacities, and inductances of elements of the circuit. Third, there is the case where the quality of the whole does not have the same operational meaning as the qualities of the parts and where they are not mathematically related through past experience. Examples of this case are the qualities of a chemical compound as a fertilizer, the quality of a drug as a medicine, the quality of sheet metal to resist corrosion, and the contribution of piece parts in an automobile to such a quality characteristic of the whole as its smoothness of operation.

The problem of controlling the quality P_{Y_i} $(i = 1, 2, \ldots, m_2)$

of the whole through the control of the quality P_{X_i} ($i = 1, 2, \ldots, m_1$) of a part is fraught with many more difficulties and more uncertainties in the third case cited in the previous paragraph than in either of the other two. In particular, it is extremely difficult to determine a set of necessary and sufficient conditions P_{X_i} ($i = 1, 2, \ldots, m_1$) for a part in terms of conditions P_{Y_i} ($i = 1, 2, \ldots, m_2$) in the case of a chemical, drug, or sheet metal, as a fertilizer, medicine, or resistance to corrosion, respectively, because it is difficult to attain precision in carrying on experiments under the same essential conditions.

Now, the important point to which I wish to call attention is that in going from the specifications of the form P_{X_i} for a quality characteristic X_i of a part to its contribution to the quality of a whole, there is an element of uncertainty. In other words, we can never be sure that $X_1, X_2, \ldots, X_{m_1}$ constitute the necessary and sufficient set of quality characteristics that should be controlled so as to control the quality contribution of the part to the whole. Hence the judgment of quality of product involves two elements, viz., (*a*) judging the quality of current product as to whether or not the available evidence of the form Q_X is such as to give adequate assurance that the quality will hit its mark, and (*b*) judging when the failure of the quality to hit its mark is attributable to lack of control of the proper quality characteristics of the parts. The attempt to hit a quality mark of the form P_{Y_i} ($i = 1, 2, \ldots, m_2$) for the whole through the control of the quality characteristics of the parts reminds one of the gunner shooting at an object he cannot see by aiming at the specifications set for him as to elevation, correction of wind velocity, and the like. In both cases, as elsewhere in life, it is not only how we aim but how we hit that counts, so that the specification defining the aim must be changed when a sufficient number of hits are not made. The gunner must rely upon some one to analyze the placement of shots and tell him whether or not there is evidence of assignable and uncontrolled causes or variation, much as the one who draws up the specifications of the form P_{X_i} must rely upon the judge of quality to tell him when the deviations in the m_2 quality characteristics of the whole from their specified values P_{Y_i} are greater than must be left to chance and hence indicate that the specifications of the form P_{X_i} ($i = 1, 2, \ldots, m_1$) for the part are not sufficient.

QUALITY OF TYPE 3

Definition: Quality of Type 3 is that which makes a thing wantable by some one or more persons.

Thus far we have considered the meaning of the quality of a thing as independent of human interest or volition. Fundamentally, however, the ultimate goal of the producer under conditions which we are here considering is to produce a product the quality of which will be adequate, satisfactory, and dependable to the consuming group. This makes it necessary to consider the wantableness of a thing as the ultimate goal at which the producer is aiming in the control of quality of a product.

From the viewpoint of control, one of the first steps to be taken is to determine in what sense quality of Type 3 has an operationally verifiable meaning, realizing that the consumer is primarily interested in the operational characteristics of the finished thing in the sense, for example, that I as the user of an automobile am primarily interested in the operation of that automobile and not so much in the quality of Types 1 and 2 of the piece parts. For our present purpose let us assume that there is some set of m_3 quality characteristics Z'_1, Z'_2, . . . , Z'_1, . . . , Z'_{m_3} of the finished thing such that when these take on any set of fixed values, the degree of wantableness of the thing is fixed. Stated in another way, let us assume that two things which are alike within specified limits in respect to these m_3 characteristics are equally wantable, and in turn that the degree of wantableness is fixed by variations in this set of characteristics for this particular kind of thing. The goal of the producer is, of course, to produce a thing of the given kind having the particular set of values of these m_3 characteristics which will harmonize and maximize the satisfaction of this kind of thing for the consuming group.

Now, let us assume that there is some set of specifications of the form $P'_{z'_i}$ $(i = 1, 2, \ldots, m_3)$ such that they define in a definite, operationally verifiable way the desired quality characteristics of a thing from the viewpoint of the consumer. From a producer's viewpoint in respect to a given kind of thing, such a set of specifications characterizes the ideal of quality that will give maximum satisfaction. If we were in a position to specify the operational characteristics of a thing in this ideal way, there would be no difference between what I have called the specifications $P_{Y_i}(i = 1, 2, \ldots, m_2)$ and the specifications $P'_{z'_i}(i = 1, 2, \ldots, m_3)$. In much this same manner we are in a position to view what may be considered the ideal goal in quality control, namely, the setting up of a set of specifications of the type $P_{X_i}(i = 1, 2, \ldots, m_1)$ for each piece part such that if they are met for each part and the parts assembled at random, the finished article will be the ideal desired. In actual production, of course, we have to deal with the judgment that a given piece part will meet its specification and hence it would be necessary in the ideal situation for us to be in a position to note with certainty for each part that it would later prove to have the desired quality.

Perhaps the most important point to note about this ideal quality goal is that there are two distinct elements in it: (*a*) The specifications $P'_{z'_i}$ $(i = 1, 2, \ldots, m_3)$ which would make the meaning of quality definite and experimentally verifiable, and (*b*) the ideal requirement that we be able to judge with certainty whether or not a piece of product at a given time is such as will meet the specified ideal requirements. In other words, it is not sufficient to be able to specify the mark that we are supposed to hit in this ideal situation; in addition we must also know when the thing is such that it will hit that mark.

Now, let us look at the practical situation. Sometimes wants are well enough defined in terms of verifiable operational quality characteristics to enable us to set up what is pretty close to the ideal quality mark, as in the case of the establishment of the desired operational characteristics of some circuit. In turn it may be feasible through accumulated experience to provide a circuit which we believe with a high degree of rational belief will meet the requirements in respect to the operational characteristics. In general, however, it is not possible to set down in operationally verifiable form the requirements $P'z'_i (i = 1, 2, \ldots, m_3)$. For example, such a specification for milk written a few years ago would not have included any requirements as to operations to insure against tubercle bacilli or to give assurance that the milk would contain the necessary vitamins by requiring that the cows be bathed with the proper amount of sunshine or fed the proper amount of spinach. Who knows what such an attempted specification will look like at some future date? Much the same situation is true when we try to provide a set of specifications of the form $P'z'$ for any one of the hundreds of different articles which we use every day.

In other words, there is always an element of uncertainty that any set of operationally verifiable specifications P_{Y_i} $(i = 1, 2, \ldots, m_2)$ constitute the ideal set. Hence in considering the problem of control of quality from a practical viewpoint, we must take into consideration the degree of uncertainty involved in assuming that the set P_{Y_i} $(i = 1, 2, \ldots, m_2)$ is the ideal set $P'z'_i$ $(i = 1, 2, \ldots, m_3)$. Furthermore, we must take into account the fact that we cannot with certainty establish a set of operationally verifiable requirements of the form P_{X_i} $(i = 1, 2, \ldots, m_1)$ for a part that are necessary and sufficient to control its contribution to the quality of the whole. In turn, there is always the element of uncertainty in any prediction about the experienceable quality of a part based upon information of the form Q_{X_i} $(i = 1, 2, \ldots m_1)$ about that part.

In the practical problem of control, there may be more steps than those which I have indicated in the sense that partial assemblies of piece parts are often thought of as wholes which in turn become piece parts for larger wholes. Thus, in the telephone plant there are something like 110,000 different piece parts, groups of which are assembled to constitute different kinds of parts which in turn are assembled into still larger parts and these ultimately into the completed telephone system. Likewise in an automobile, there are the piece parts which go together to make up the carbureter; other piece parts which go to make up the engine; other piece parts to make up the body, etc. Fundamentally, however, there are only the two kinds of quality characteristics of a thing, whether it be a piece part or something made up of several piece parts, in that there is the quality of a thing by itself and the quality of the thing taken in relation to something else. Hence for our present purpose, it is not necessary for us to complicate the picture by introducing more steps than we have. We should, however, point out the obvious fact that in the control of quality of anything considered as a whole, it is customary to apply, in those cases where possible, certain measuring operations to the whole which are to be taken together with the information of the type Q_X of each piece part as a basis for judging the quality of the whole, and, in turn, similar operations may be performed on partial assemblies.

There are, of course, three more or less fundamental aspects to the problem of control. One is that of setting up the specifications of the form P_{X_i} $(i = 1, 2, \ldots, m_1)$ on the part and of the form P_{Y_i} $(i = 1, 2, \ldots, m_2)$ on the whole in the specific sense in which we have defined them in this discussion. To make this goal objectively complete, however, it is also necessary to specify the degree of belief or assurance that a piece part, partial assembly, or assembled whole will meet its respective set of specifications. To do this economically, it is desirable, of course, to take account of the fact that we can never be certain of any step and hence that the requirement as to the degree of assurance that a piece part should meet its specification is somewhat dependent upon the degree of assurance that the whole will meet its specified quality when the piece parts meet theirs.

In other words, we have the steps of going from Q_X to P_X, from P_X to P_Y, and from P_Y to $P'_{Z'}$. If it were possible to express our degree of belief as a commensurable probability, we could say that the probability of taking the first step is p'_{b1}, the second step p'_{b2}, the third step p'_{b3}. It would follow that upon the evidence Q_X the probability of hitting the final mark would be the product of these, namely, $p'_{b1}p'_{b2}p'_{b3}$. Hence in trying to determine the economic advantage of increasing one of these probabilities by a certain fixed amount, we must note that the final increase will be less than this fixed amount. For example, if we increase the first probability by an increment $\Delta p'_{b1}$, the overall increase in assurance will be only $p'_{b2}p'_{b3}\Delta p'_{b1}$.

JUDGMENT OF QUALITY

While this first step is legislative in character, the second step is that of producing or manufacturing physical things designed to meet these specifications. The first step is largely one of specification or legislation; the second is one of execution.

The final step is that of judging whether or not an actual piece part or whole when produced is likely to meet its specifications and whether or not there is any evidence that the specification should be changed. I have discussed elsewhere some of the aspects of the theory of control in economic production. I wish now in closing to emphasize some aspects of the problem of judging the quality of product.

As we have already seen, the judgment of quality has objective, operationally verifiable meaning only on condition that we have, for the part or for the whole, specifications of the form P_{X_i} $(i = 1, 2, \ldots, m_1)$ or P_{Y_i} $(i = 1, 2, \ldots, m_2)$, respectively, and also that we have some definite indication of the degree of assurance that we are to have in rendering the judgment that the quality of a particular piece part or whole will meet its associated specification. To a large extent, the fixing of these specifications and the desired degrees of belief is a legislative function which is tempered in practise by a knowledge of the economic attainableness of any specified goal. We have seen, moreover, that there must be an element of uncertainty in the fixing of such specifications. It follows, therefore, that the problem of judging quality of product is not alone to see for each accepted piece of product that there is available evidence to give adequate assurance that it will hit its quality mark, but also to see that any failures to hit this mark are analyzed in such a way as to indicate whether or not it is desirable to modify the specifications.

If the quality goal is specified in a definite manner, the first problem in judging the quality of product is to determine in a given case *how much* information of the type Q_X should be collected and *how* this information should be selected from the classes *a*, *b*, *c*, *d*, under Q_X of Fig. 2 in order to be most economical. For example, such questions are involved as: How many observations shall be made on an object when tested? How are we to depend upon evidence of statistical control in the quality of product of a like kind? How much shall we depend upon other pertinent information?

In practise, however, it is very often the case that the specifications are incomplete in one way or another. In particular, they often fail to specify in an objective operational manner the verifiability of the quality desired and likewise often fail to indicate explicitly the degree of assurance that one should have in judging that a piece of product will meet its quality mark. In such a case, the first step in the judgment of quality involves the interpretation of specifications in a way to make them complete.

Another fundamental step in judging the quality of product is the interpretation of the evidence thus accumulated to determine whether or not it gives adequate assurance that the piece of product will meet its quality mark. In making such interpretation, due allowance must be given for the fact that practical quality specifications of the form P_{X_i} ($i = 1, 2, \ldots, m_1$) or P_{Y_i} ($i = 1, 2, \ldots, m_2$) have in them an element of uncertainty, so that cases may arise where the resultant effect of non-conformance of a piece of product in respect to one quality characteristic may be in a given case counterbalanced by the effect of the non-conformance of another in the opposite direction.

In the judgment of the quality of the final product, it is desirable to keep a running record of the evidence made the basis of the decision that the current product going to the consumer will meet its quality mark P_{Y_i} ($i = 1, 2, \ldots m_2$). Such a record, in so far as it reveals evidence of statistical control of quality characteristics up to a certain time, constitutes a basis for reducing to a minimum the amount of inspection that is required to give adequate assurance that current product will be found to have the quality specified. Such a record also constitutes a scientific basis for the adjudication of complaints and helps to make it possible to determine in a given case whether or not a complaint condition is attributable to an assignable variation from the specified quality, P_{Y_i} ($i = 1, 2, \ldots, m_2$), and to trace evidence of the presence of assignable causes of deviation from such specified quality back either to the lack of control of specified qualities of the piece parts or to the insufficiency of the specified quality characteristics of the parts.