THEORETICAL LIMIT TO THE CONTROL OF INHERENT QUALITY

We customarily think of any physical thing, such, for example, as a pencil or a piece of telephone apparatus, as having a certain reality independent of ourselves. In this sense we conceive of it as having a finite set of physical properties or quality characteristics, X'_1, X'_2, ... X'_i, ... X'_m, which make it what it is independent of any human interest or volition. These m characteristics constitute the inherent quality of a thing. It should be noted, of course, that we are talking here about what we might term objective quality characteristics and not observations thereof. The object of the present discussion is to consider the question: How far can one go in the control of the inherent quality of a manufactured product in the light of the generally accepted concept of natural laws and of the nature of the ultimate causal relationships? It should be noted that the question here considered is as to how far one can go and not as to how far it is practicable or economical to go. The answer depends upon the conceived theoretical basis for quality control, or, in other words, upon the conceived state of causal relationship.

State of Exact and Certain Causal Relationship

It is taken for granted that the theory and practice of quality control must rest upon certain assumptions as to the existence of certain uniformities or causal relationships in nature. As far back as the beginnings of experimental science in the 13th century there was comparatively general acceptance among philosophers and scientists alike of the belief that any present state of the world is a necessary consequence of a previous state. The success of the dynamical theory of moving bodies did much to strengthen the belief of scientists in this concept of causal relationship. In fact, it was believed to be theoretically possible to know enough about any present state to predict any future state. The particular characteristic of this concept of immediate interest is that it permitted of exact and certain prediction. Applied science must go further in the way of assumption. It appears to rest upon the assumption that it is theoretically possible to discover certain natural laws and make use of them in a way that makes it possible to control at will, at least some characteristics of any future state. In other words, it is assumed not only that there is a causal relationship between a succession of observable states but also that one can find and use such causes to change at will some aspects of a future state.

Now let us consider the problem of quality control as it originated in making interchangeable parts. Although there is evidence that as far back as 3000 B.C. the Greeks succeeded in making interchangeable bows and arrows it was perhaps not until 1787 that we have the first attempt at mass production of interchangeable parts, that of LeBlanc in the production of muskets. For our present purpose let us consider the question as to how far we can go in making parts alike. In other words, having once made a given part, how far is it conceivably possible to go in duplicating this part at will? There is some evidence for believing that it was early conceived to be possible (though perhaps admittedly not practical) through an acquired knowledge of natural laws, to attain a state of control wherein it would be possible to duplicate the inherent quality characteristics of a given part or thing at will, with certainty, and in an exact manner[1]. Thus let X'_{i1} represent the ith inherent quality characteristic of a thing to be duplicated at will. Presumably the condition or requirement of control in this exact and certain sense is that we know a sufficient number of natural laws to enable us to make another thing with the ith quality characteristic of magnitude X'_{i2} such that we will know with certainty beforehand that the difference

$$X'_{i1} - X'_{i2} = 0 \qquad (1)$$

for each and every one of the m inherent quality characteristics. Such a requirement specifies what we shall term an exact and certain state of control.

State of Statistical Causal Relationship

With the rise and rapid development of the kinetic theory of gases within the past century, there has come about the introduction of the concept of an objective state of statistical causal relationship. For example, an ideal gas is assumed to have the inherent quality characteristics of pressure, viscosity, entropy, and temperature. It is conceivably possible, of course, to invest the ultimate atoms with all four of these qualities. Instead the procedure has been followed of explaining these properties in terms of a very large number of like particles possessing inherent quality characteristics of position, velocity, and mass, and sometimes moment of inertia. In doing this the four quality characteristics -

1. The first attempt to specify quality in a way that it could be gauged, somewhere about 1840, was in terms of a single aimed-at value for each observed quality characteristic. This smacks of the exactness of the then current concept of the attainable state of exact control.

pressure, viscosity, and the like, are assumed to be predictable only in the statistical sense.

Closely patterned after such a conception there follows the conception that even though we might not know a sufficient number of natural laws to make it possible for us to produce two pieces of product of identical inherent quality characteristics, it is still possible that we may know sufficient to produce pieces alike in what is termed the statistical sense. In other words, it is assumed that there may exist systems of unknown or chance causes (so-called constant systems of chance causes) in the production process such that, if they are the sole source of variability, we may say that the probability p' that the production process will, if followed, produce a thing of any inherent quality characteristic X_i' within the range $X_i' \pm 1/2\, dX_i'$ is given by the expression

$$p' = f(X', \theta_1', \theta_2', \ldots \theta_s')dX', \qquad (2)$$

where f is a mathematical functional relationship involving s parameters. Such a conception of state of statistical control underlies most of the developments of modern physics.[1]

Some Critical Comments

1. What does it mean to say that a production process is in, let us say, the state of statistical control? In general, such a statement cannot be experimentally verified in the present state of our knowledge and, from this viewpoint, may be said to be meaningless. Hence from the viewpoint of specifying the state of control to be aimed at in practice, we must keep in mind that it is meaningless from an experimental viewpoint to specify that the process shall be in a state of statistical control. In a later memorandum, we shall contrast the meaninglessness of such a statement implying the attainment of a state of control in the sense

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1. The belief in the existence of such states does not imply an abandonment of the belief in the existence of exact causal relationship but instead represents as it were a belief in the existence of a midway station that appears to be a useful concept in the theory of physical causation. Again it should be noted that here as before we are talking about inherent quality characteristics and not about observations or measurements, the statistical character of which has been recognized since the time of Laplace and perhaps before.

Today we are living in the midst of a discussion of what is usually considered to be a radical change in the concept of controllability. In 1927 Heisenberg announced his principle of indeterminism which, if accepted, leads to a denial of the existence of exact causal relationship. Although of great importance from the viewpoint of the fundamental character of the conceived nature of objective uniformity which exists between events, the degree of indeterminacy is of such order of magnitude as not to be of consequence from the viewpoint of practical quality control. In other words, it remains true that the generally accepted theoretical basis today of feasible control is statistical.

here used with the meaningfulness of a similar statement about a state of control expressed in terms of verifiable pointer readings supposed to accompany specific operations. However, an operational technique can easily be imagined whereby such a state of control could be verified. Moreover the concept of state of statistical control constitutes the basis of our picture of the objective physical framework or reality behind our experimental pointer readings. It is the picture which, to a very large extent at least, if not entirely, patterns the scientist's techniques in handling observations.

For our present viewpoint, it is sufficient to note that whereas the concept of exact control leads to the development of a theory of mathematical physics primarily involving differential equations as a basis for prediction, the concept of statistical control leads to the development of a theory involving so-called statistical distribution functions. In other words, whereas differential equations were perhaps the principal foundation of mathematical physics up to less than a century ago, today the mathematical theory of distribution functions has assumed a prominent place in the theory of controllability. In fact, distribution theory occupies the center of the stage in the theory of quality control from a mathematical viewpoint when considered in the light of modern physics.

2. It is of interest to note that the concept of the state of statistical control was introduced into theory in order to free theory of a mass of details which, even though they are conceivably knowable, could not be comprehended in the lifetime of any one individual. In fact even though they be known in certain cases, they could not be used. Hence it is not attainability that theoretically forces us to the adoption of the concept of a statistically controlled state but rather usability of the results. For example any future state of a cubic centimeter of gas in respect to certain inherent quality characteristics is conceivably describable in an exact manner in terms of something like 10^{20} differential equations involving the inherent quality characteristics of the molecules of gas at some previous state. No person has lived long enough to copy down, even if they were known, such a set of differential equations.

Conclusion

From the viewpoint of usability, the theoretical limit to which we can feasibly go in controlling inherent quality must be based upon the concept of a statistical state of control.