# ON THE USE OF THEORY

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Being an address delivered upon receipt of the Shewhart Medal, at the 10th annual meeting of the American Society for Quality Control, Montreal, 7 June 1956

(Reprinted from *Industrial Quality Control*, Vol. XIII, No. 1, July 1956)

# On The Use of Theory

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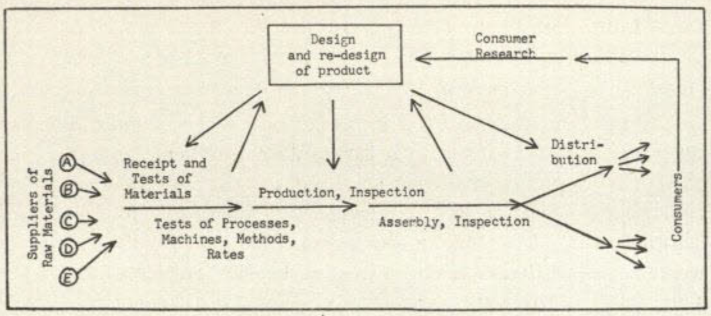
MY THEME tonight is the source of power of statistical theory, how to use it in industry and in research, and more especially, how not to misuse it. In this day, when so many decisions of business and management, technical and legal, depend on the results of samples and experiments, it is important to be sure of what the results mean, and what they do not mean. To this end, I propose to study tonight the power and the limitations of statistical theory; also the power and the limitations of substantive knowledge, in order to try to understand the different kinds and degrees of knowledge.

The use of statistical theory, because it offers economy, speed, and security not attainable otherwise, has become an indispensable aid to procurement, to production, to processes and methods, and in marketing and consumer research. Without a theory, any prediction, and any decision based thereon, is risky. The day has past when "theoretical" means impractical. There was a time, not so long ago, when jobs open for men with knowledge of statistical theory placed emphasis on experience in a particular business or industry. The question today is only whether the man knows enough theory, and whether he understands what he knows.

I once defined the statistical control of quality as THE APPLICATION OF STATISTICAL PRINCIPLES AND TECHNIQUES IN ALL STAGES OF PRODUCTION DIRECTED TOWARD THE ECONOMIC MANUFACTURE OF A PRODUCT THAT IS USEFUL AND HAS A MARKET. This definition stretches from the procurement of raw materials on one end of the line, to the consumer at the other end, as the accompanying diagram indicates. I need not elaborate here on the importance of the consumer and of consumer research, nor why it is important that the management of a manufacturing concern be so organized that the results of consumer research have a clear channel to feed back into the design of the product, which is of course, incidentally, the design of future product. Price without a measure of quality has no meaning, and quality has no meaning except in terms of the consumer's demands.

**The 1955 Shewhart Medalist W. Edwards Deming**




**The production line, from raw material to the consumer. Statistical techniques are indispensable in one form or another at every point in the entire production line. At every stage in the production line, and in the consumer research as well, statistical information should feed back in a continual stream for re-design of the product to relieve problems of production and to meet changing demands in respect to quality, uniformity, and quantity.**

Between the procurement of raw materials on one end of the production line, and the consumer on the other end, lie the problems of design, of production, of specifications and of standards, both for product made and for product purchased; problems of the selection and training of people, problems of accounting and auditing, of distribution, of inventory. There are the basic value-judgments in the management of a business enterprise, and the perception of the social, political, and economic problems that a business encounters in the achievement of these aims.

The first selection of problems is the responsibility of management, delegated perhaps to expert knowledge of specific subject-matter such as chemistry, engineering, economics, marketing, medicine. The screening of problems, to decide which ones have any possible solution, and their formalization for the use of decision-theory, is largely statistical. Once formulated, the statistical portion of a problem is dependent purely on statistical theory. Statistical problems are not solved by chemistry, administration, engineering, medicine, nor by anything but statistical theory.

Two features about theory are impressive: first, the multivaried form of application of statistical techniques in the solution of the host of problems that stretch from raw material to consumer; second, the universal form of the basic statistical theory and principles for all these problems.

Statistical theory is based on probability. Decision-theory is based on the concept of achieving, in the long run—i. e., on a probability model—the minimum economic loss from the possible errors in decision. The manifestations of statistical theory take the form of theorems on variance, tests of significance, tests of hypotheses, the Shewhart charts, nonparametric methods, order statistics, and other specific techniques. The symbols in statistical theory care not whether they will be used to design and interpret a sample of human populations or a sample of physical material. They care not whether they will be used to design a test of consumers' reactions to products, or to test concentrations of materials, different levels of heat, and different levels of pressure, in the manufacture of a pharmaceutical product. In fact, the symbols don't care whether we use them at all. Like any real theory, statistical theory is knowledge a priori, independent of experience. Like a theorem in plane geometry, which would remain true even though we were two-dimensional beings on a sphere, and had never thought of a plane, statistical theory remains smugly true whether we learn how to use it or not, or even whether we try.

It is interesting to take a look at the impact of statistical theory during the past 20 years. The fact is that statistical theory has changed practice in almost everything that man does. We need only turn back the clock and look at what has happened to:

Production; quality, uniformity, output

Testing of materials

The science of inventory levels

Appraisal of inventory

Consumer research

Marketing

The science of maintenance and replacement

Government statistics

Accounting and auditing

Management and administration

Current information for management

Studies in sociology and in population

Studies in opinions and attitudes.

I have omitted agricultural science and medical research because use of statistical methods commenced many years earlier in those sciences.

It is noteworthy that the new practices were generated, NOT from expert knowledge of engineering, chemistry, production, accounting, population, census methods, agriculture, marketing, but from statistical theory. Much of the impact has been brought about by very simple statistical theory. Surely, any theory that possesses the power to change practice in so many activities of man calls forth extreme respect.

Every year, while all these drastic changes have been taking place, plant managers and experts in production would certainly have declared that they have squeezed the last ounce of efficiency from their methods; that everything possible is being done to improve quality and uniformity and to satisfy the consumer, that there remained no possible further savings of materials, manpower, or machines. Yet look what has happened to uniformity, to output, to quality.

You will get the same answer today. Improvements are nevertheless visible month by month. For example, traditional procedures in auditing, operation, and management, used by nearly all industries today will gradually be displaced during the next few years by the speedier and more reliable results of sampling.

One may under the proper conditions place absolute faith in a statistical calculation, but it is important to know what these conditions are and what the calculations mean. If the requirement of randomness is met in an experiment or in a survey, then a calculated producer's risk, a test of significance, or a standard error, has the standing and dignity of a mathematical theorem. The interpretation of a statistical calculation, under conditions or randomness, is not a matter of opinion nor of judgment, but is incontrovertible and is standard the world over.

For example, concerning the results of a test, carried out on a sample of pieces drawn by random numbers from a shipment of pieces, one may calculate (e. g.) that the percentage of impurity in the shipment is estimated by the sample to be 24 percent, and that on the average only one sample in hundreds drawn and tested by this same method will depart more than three percent from a complete test of all the pieces in the shipment, were the complete test carried out with the same care, with the same instruments, and with the same definitions as were expended on the samples. This is a pretty important statement, of far-reaching consequences.

A statistical calculation of this kind, however valid and useful it be for the material that had a non-zero probability of selection for the sample, does not apply objectively to other material that had no chance to be in the sample. This other material may nevertheless be of importance.

A physician who carries out an experiment on a treatment with different concentrations of a drug may select by random numbers patients in a hospital and give to each one at random a concentration of 0, 25, 50, or 100. Statistical calculations such as the t-test refer only to the patients that had a chance to be in this experiment. The generalization from these patients to other people that suffer from the same disease, or to all people, is not statistical theory at all, but is subject-matter—in this case, medicine. Someone must make the generalization, or refuse to make it, on the basis of judgment. This is not a job for statistical theory.

Statistical theory can, however, furnish methods by which to test samples of other lists of patients, from different hospitals, or from different forms of the disease, or at different times of the year, and can furnish tests by which one may judge whether the different lists of patients are significantly different from one another. These statistical calculations are of extreme importance as aids to the substantive expert when he must decide whether to generalize to other material, or to the process or to the cause-system.

Statistical theory can not generate a hypothesis to test; yet statistical theory is essential in the design and in the interpretation of the test of a hypothesis that the substantive expert formulates for his work. Statistical theory can not decide which quality-characteristic to measure, nor whether any quality-characteristic at all should be measured. Statistical theory can not decide which material to test, nor whether any material should be tested. Statistical theory can not think of a new product. Statistical theory can not decide which products to compare in a test of consumer reactions. Statistical theory can not decide whether temperature, concentration, or rate of flow are important variables to study in an experiment to discover the optimum operating conditions for the production of a chemical compound. Statistical theory can not put questions into questionnaires in a study of consumer attitudes and demands.

It is the expert in the subject-matter who must choose which quality-characteristic to measure, which material to test, what new products are needed, which products to compare, which components of the process to test, which conditions of environment to test, and to declare IN ADVANCE how he will generalize from the material subject to test, to material not subject to test.

It is a fact, though, that one can not design a new product, nor test it, nor compare two or more products, without the aid of statistical theory. Without theory, the development and tests are unreliable and too costly.

Statistical techniques show us how to discover reliably and economically the difference between a selected quality-characteristic for one material, and the same quality-characteristic for another material, or the difference between two methods of manufacture or of treatment. In fact, without the statistical theory of design, there is no reliable or economic approach to the problem of significant differences nor to the discovery of optimum operating conditions.

Statistical techniques, in their ability to aid the discovery of causes, are creating a science of management and a science of administration. Statistical techniques have the ability to separate out the responsibilities for action into different levels of administration. A point out of bounds, a significant difference in rates of production, or a significant difference between the proportions defective from two suppliers, or between the accident-rates in two areas, a significant trend or a run, all point to the existence of a SPECIAL CAUSE of variation NOT COMMON to all the lots or to all the areas involved.

The discovery of a special cause of variation, and its removal, are usually the responsibility of someone who is connected directly with some operation. It is his job to find the cause, and to remove it. In the case of accident rates, a significant difference indicates the existence of causes specific to a certain area.

In contrast, there are COMMON CAUSES of defectives, of errors, of low rates of production, of low sales, of accidents. The discovery and the correction of common causes is usually the responsibility of someone higher up. The common causes may be poor light, poor or variable raw material, obsolete equipment, humidity, inadequate instruction, poor supervision, or plain lack of a quality-program. Poor sales may stem from a faulty product. The worker at a machine can do nothing about causes common to all machines. He is responsible only for the special causes chargeable to him. He can not do anything about the light; he does not purchase raw materials; the training, supervision, and the company's policies are not his.

The common causes are the most difficult to discover. The removal of a common cause is not always feasible: the gain in production or in uniformity may not be worthwhile. The decision belongs to management.

A usual mistake in administration is to attribute any difference to a special cause (to a machine, to a worker, to a specific area) when no special cause exists, and when the real causes of the defectives, errors, low sales, and accidents, are common to all the product, or to all the areas. This mistake is an easy way out, as it points the finger at some person or at some special condition or circumstance and gives the appearance of action. It is costly action, however, as it is misdirected and its effect is exactly opposite to what is desired. It actually raises the frequency of defectives, and creates more errors and accidents, and will eventually demoralize a force of workers.

Success in administration depends heavily on a judicious choice of problems and clever separation of the responsibilities for solving them. Statistical techniques provide an indispensable aid to administration, as they perform this separation with reliability that is impossible otherwise. We are at the dawn of a real science of administration and management.