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SOME REMARKS ON RECENT ADVANCES IN THE STATISTICAL CONTROL OF QUALITY IN JAPAN

By

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Introduction and purpose of this paper. To speak of recent advances in anything, one must first of all decide what is recent. Ten or 15 years are insignificant in the history of man, but they may be a very important period in modern industry.

One must also decide what it is that has advanced, and how. In speaking of recent advances in the statistical control of quality in Japan, does one mean an enumeration of new competitive products that are frightening American and British producers, and others too; or does one mean new methods, new points of view emanating from Japan? Enumeration of competitive products would require a definition of competitive that only the Federal Trade Commission would dare to attempt: certainly not I.

What is really important, in my opinion, about advances in the statistical control of quality in Japan since 1950, is their competitive position in techniques, and the lessons that we could learn from the contributions of the Japanese. The success of their efforts is well known. Reasons for the effectiveness and speed of their efforts are not so well known.

The purpose of this paper is to offer some observations on the reasons. Attention to the reasons could well have a healthy impact on American industry, and on the programs of the American Society for Quality Control.

Six features of the statistical control of quality in Japan. In my opinion, there are six main reasons for the success and speed of application of the statistical control of quality by Japanese manufacturers:

1. They are Japanese.

2. They learned the statistical control of quality at both ends, top and bottom: (a) engineers and plant managers in production learned techniques; (b) top management learned simultaneously something about the results that could possibly be achieved, and they learned something about their own responsibilities in any plan to put statistical methods to work.

3. They learned the statistical control of quality in the broad sense of Shewhart, as defined further on.

4. Statistical education must be a continuing process, and it became so through the efforts of Mr. Kenichi Koyanagi, Managing Director of the Union of Japanese Scientists and Engineers. The initial teaching of techniques was clearly indicated as only an introduction to statistical principles and methods, with admonition to continue the learning process. Statistical methods can not be installed once for all and left to run, like a new carpet or a new dean. They require constant adaptation, revision, extension, new theory, and new knowledge of the statistical properties of materials.

5. The Japanese learned the difference between a statistical problem and one in engineering, chemistry, management, or marketing. They learned to use statistical methods as an aid in the solution of statistical problems, not as a substitute for knowledge of engineering or of other subject-matter.

6. Japanese manufacturers took on the job themselves, through financial and moral support of the Union of Japanese Scientists and Engineers. They did not look to their government nor to ours for help. When they arranged for consultation, they sent a ticket and a cheque.

Lectures to top management. These lectures, beginning in 1950, concentrated on a few simple questions for management to think about. I am not an economist, nor a business-man, only a statistician, but some conclusions seemed inescapable. Why is it necessary to improve quality of Japanese products? Japanese products must now become competitive, because the market for cheap Japanese products in the rest of Asia is gone, if not to the western world also, and can not be regained sufficiently to pay for necessary imports of food. It is not necessary to raise all your own food. Chicago doesn't. Switzerland doesn't. It may be smarter for Japan to import food and pay for it with exports. These were questions put to Japanese executives in June 1950.

There is a market for quality. Why is there a market for British textiles in the U. S., even though their price is higher?

No country is so able as Japan, I thought, with its vast pool of skilled manpower, to develop a market for quality. Statistical methods could help: in fact, realization of any such goal would be impossible without statistical methods. It would require 5 years to develop a reputation for Japanese quality, and to unlive the reputation, earned in past years, for cheap trinkets. In 10 years, manufacturers in other industrial nations will be on the defensive, I predicted. Japanese manufacturers took these arguments seriously to the point of doing something about them.

The first lecture was held with leaders of industry assembled at the behest of Mr. Ichiro Ishikawa, President of the Union of Japanese Scientists and Engineers, at the Industry Club in Tokyo in June 1950. There was a further session next month at the Yama-no Hotel at Hakone, and meetings for study in subsequent visits, in various cities in Japan. The lectures charged management with the responsibility to optimize the use of statistical methods in all stages of manufacture, and to understand the statistical control of quality as a never-ending cycle of improved methods of manufacture, test, consumer research, and re-design of product. They described in simple terms management's responsibility to understand the capability of the process, and the economic loss from failure to take due regard of it.

The Japanese never knew the statistical control of quality in any way but in the broad scale introduced by Shewhart *. The statistical control of quality was defined in plain English in 1950 in big letters like this, and Japanese manufacturers took it seriously:

> THE STATISTICAL CONTROL OF QUALITY IS THE APPLICATION OF STATISTICAL PRINCIPLES AND TECHNIQUES IN ALL STAGES OF PRODUCTION, DIRECTED TOWARD THE ECONOMIC MANUFACTURE OF A PRODUCT THAT IS MAXIMALLY USEFUL AND HAS A MARKET.

Obviously, the Japanese never had need of adjectives to describe the statistical control of quality. It was never anything but total.

The lectures emphasized the economic loss of confusing a specific cause with a common cause, with illustrations. Confusion between common causes and specific causes is one of the serious mistakes of administration, in industry and in public administration as well. The natural reaction to any event, such as an accident of any kind, stoppage of production (of shoes, for example, because of breakage of thread), is to blame a specific operator or machine. The real cause may, however, be common to all operators and to all machines, namely, poor thread--a fault of management, whose policy may be to buy thread locally or from a subsidiary. Demoralization, frustration, and economic loss are inevitable results of attributing a common cause to some specific local operator or condition.

One of the main functions of statistical techniques is to distinguish between the two types of cause, and hence to fix (with adjustable risk of being wrong) the responsibility for variability and for undesired level.

This aspect of the statistical control of quality was not appreciated, I believe, in the earlier history of statistical methods in American industry. The Japanese had the benefit of advanced thinking on the matter.

Statistical education in Japan. The program of education in techniques commenced in June 1950 under the auspices of the Society of Japanese Scientists and Engineers. In all, 500 engineers attended the technical lecture courses of 8 days during 1950, and literally hundreds more attended every year thereafter. Additional courses in sampling for studies in consumer research were held in 1950 and 1951, and in later years.

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* W. A. Shewhart, THE ECONOMIC CONTROL OF QUALITY OF MANUFACTURED PRODUCT (Van Nostrand, 1931); STATISTICAL METHOD FROM THE VIEWPOINT OF QUALITY CONTROL (The Graduate School, Department of Agriculture, Washington, 1939). No attempt is made here to list his papers.

The effectiveness of such beginnings in mass education was more pronounced and more rapid than results observed from the 8-day courses that commenced in the U. S. nine years earlier. In the first place, Japan was in 1950 in desperate circumstances. Every minute must count. Second, management became aware of the possible results from use of statistical techniques, simultaneously with the commencement of education for engineers. Third, practically everyone in attendance at technical sessions in Japan knew calculus. One might argue that calculus is not necessary for productive applications of statistical theory. True enough, but it helps.

There were further reasons. Most important was a vigorous system of courses for continuation and advancement in theory, instituted by the Union of Japanese Scientists and Engineers. Courses in statistical theory at various levels were held, and are still held, the duration, days, and hours being varied from time to time to meet the requirements of engineers who must come from distant points, as well as for those that live in or near Tokyo. Some idea of the thoroughness of the courses for continuation and advancement may be gained by perusal of bulletins from the Union of Japanese Scientists and Engineers.*

An additional point of strength came from the formation of committees to work on new theory and to investigate various areas of application, such as the sampling of bulk materials (mainly ores), design of experiment, queuing theory, and other problems. The impact of the work of these committees has substantially changed much industrial practice in Japan.

Publication of a journal INDUSTRIAL QUALITY CONTROL was started by the Union of Japanese Scientists and Engineers, in Japanese: the journal is now in its 14th year. RESEARCH REPORTS, a journal now in its 13th year, has a high reputation amongst mathematical statisticians the world over.

Another reason for speedy results in Japan was that statistical methods had the benefit of nearly three decades of experience in the western world. There were naturally, at first, inevitable misunderstandings in America, and undue emphasis on certain aspects of techniques. For example, the control-chart was at first used only as a tool to help weed out specific (assignable) causes that remain (<u>vide infra</u>), and little attention was given to common causes. That statistical methods separate, almost unerringly, special causes from common causes is important, and that their removal rests with management, was by no means fully appreciated. Acceptance sampling was frequently at

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* Kenichi Koyanagi, "Statistical quality control in Japanese industry," a paper delivered at the national convention of the A. S. Q. C. in Rochester, 1952. (A limited number of copies are still available for distribution.) Also, his paper, "Some case histories of increased production and improved quality through simple techniques in Japanese industry," and another paper "Education activities for industrial statistics in Japan," both presented at the 29th Congress of the International Statistical Institute, Rio de Janeiro, 1955; "Quality emphasis in Japan's postwar trade," C. I. O. S., International Management Congress, New York, September 1963.

first confused with process-control. Some people looked upon it as furnishing estimates of the quality of lots. To others, it separated good lots from bad. Many people, here as elsewhere, in a burst of enthusiasm confused statistical methods with engineering or with other subject-matter. They would substitute statistical calculations for knowledge of engineering, and then try to solve statistical problems by consulting their own knowledge of engineering.

What is the statistical method? Some clarity of vision had pierced through the mist by 1950, and it was possible to make a fresh start in Japan. The statistical method means use of the theory of probability. The theory of probability, in industry, is not merely an expanding universe of books. Fundamentally, it is a tool, manifest in statistical techniques known by various names ($\bar{x}$- and R-charts, run charts, sampling, analysis of variance, theory of estimation, and many other techniques) which assist man to distinguish between:

1. Special causes of variation.
2. Common causes of variation and of wrong level.

In other words, one of the main uses of the theory of probability (the theory of random variation) is to DETECT THE EXISTENCE OF NONRANDOMNESS.

There are of course other and equally important uses of the theory of probability in production. Acceptance sampling is one; estimation is another.

The teaching of actual statistical techniques in Japan was concentrated in simplicity, mainly $\bar{x}$- and R-charts, run charts, acceptance sampling, sampling materials, sampling human populations and business establishments, rudiments of design of experiment. Charts were taught as statistical tools for the economic detection of specific causes of variation, not as tools that would actually find the cause. Emphasis was on ACTION, once a point goes outside limits.

Acceptance sampling was taught as a scheme of protection (provided one will really reject and screen a lot when the sample contains more than the allowable number of defects). It was taught as a necessary part of a contract. The specification of a unit of product is of course vital. However important it be, a vendor does not know how to predict the cost of a product unless he has in hand, in addition, the plan by which lots will be sampled and accepted or rejected. How big is a lot? What is to be done with rejected lots? What is to be done with pieces found to be defective? Answers to these questions are a necessary part of any plan of acceptance, if vendor and purchaser understand each other.

These techniques and variants thereof were mere examples of statistical methods. Statistical methods enhance the effectiveness of engineering and of other substantive knowledge. More knowledge of statistical methods would open up the possibility of greater contributions to production.

Specific causes of variation. Variation of any quality-characteristic is to be expected. The question is whether the variation arises from a specific cause, or from common causes. Specific causes are what Shewhart called assignable causes. The name is not important: the concept is. These are the causes that are indicated by a statistical test of some kind, such as a point beyond limits, or a trend or pattern, or $t > 3$ in a test of significance. They are associated with something special, such as a specific operator, a specific machine, a specific batch of (e.g.) thread or other incoming material. Variation due to a specific cause is correctible locally.

In applying a test of significance, for example, in the very simple problem of asking whether the proportions of black and white balls (process averages) in two production-lines are equal, we draw samples of size n from lots from each production-line, and calculate

$$t = |p_1 - p_2| \sqrt{\frac{n}{2pq}}$$

[p_1 and p_2 are the two proportions: $p = \frac{1}{2}(p_1 + p_2)$, $p + q = 1$]

We lay down in advance the rule that if $t > 3$, we shall proceed as if the proportions were unequal, and thereupon go into ACTION--try to find the cause of the inequality, and correct it--i.e., bring the two production-lines into agreement. The ACTION is engineering, not statistics.

Common causes. If we succeed in bringing the two production-lines into agreement, then drawings from then onward will behave AS IF THEY CAME FROM A COMMON SOURCE. That is, causes of variation would then be common to the two production-lines. Some common causes are in the following list. The reader may supply others, appropriate to his conditions.

- Poor light
- Humidity not suited to the process
- Vibration
- Poor instruction and poor supervision
- Raw materials unsuited to the requirements
- Poor food in the cafeteria
- Inept management
- Procedures not suited to the requirements
- Machines not suited to the requirements
- Mixing product from streams of production, each having small variability, but a different level

If we were able to eliminate all specific causes, there would still be common causes.

What statistical tests do ($\bar{x}$- and R-charts, run charts, and various other techniques) is to separate specific causes from common causes, and to INDICATE THE LEVEL OF RESPONSIBILITY FOR CORRECTION.

Common causes are usually much more difficult to identify than specific causes, and more difficult to correct. In the first place, carefully designed tests may be required to identify a common cause. Then problems really commence. Would it be economically feasible to change the specifications for incoming material? to install new machinery? to change the lighting? to put in air-conditioning? If the trouble lies in management itself, no experiment is needed, but who is going to make the correction?

Of course, it is sometimes very simple to correct a common cause of variation. If, for example, the final product is a mixture of product from several streams, each in control with small variability, but with settings at different levels, simple adjustments of the individual production-lines may be very effective in reducing the variability of the final product. It is worth noting that control-charts or other tests constructed on the basis of samples of the final product would never detect the existence of a special cause of variation: there isn't any.

It is a fact that some of the finest examples of improvement of quality have come from effort directed at common causes of variation, and at causes of wrong level. One example is the improvement of quality of statistical data put out by the Census. For many years, effort has been directed at basic causes of error, as well as elimination of special causes. The result today is quality, reliability, and speed of current statistical series that are the envy of organizations in the U. S. and abroad, and at costs that are about a third of what private industry pays out for the same thing.

The power and the limitations of statistical theory. Specialized knowledge of the theory of probability is the one thing that the statistician contributes to a job that is additional to the knowledge of the expert in engineering, business, chemistry, medicine, agriculture, law, or anything else. Statistical work is not a part-time job. The plain fact is that statistical work is difficult; at least it seems so to the statistician.

Statistical theory, like any other theory, is transferable. The symbols don't care what the problem is, nor what the material is. Therein lies the power of theory: the solution to one problem may aid in the solution of many other problems. Our words *theory* and *theatre* come from the Greek θέα, to see, to understand.

The statistician is interested in helping people to solve problems. The expert in subject-matter (engineering, chemistry, law, traffic, management, industry) generates the problem: the statistician helps him to solve it. Statistical work, in the hands of a statistician, means optimum allocation of human skills and of machines to provide and interpret with speed and reliability, as aid to administration, management, and research, the results of tests and of other observations.

There is not one distinct theory of probability for process-control, another theory for acceptance sampling, another for reliability, another for problems of estimation, another for design of experiment, another for testing materials, another for design of studies in consumer research, any more than there is one kind of calculus or theory of functions for economics, another kind for statistics, another for engineering.

To solve problems, one needs first of all, a problem. No amount of statistical theory will generate a problem. To find problems is the responsibility of management or of the expert in subject-matter. A problem in industry might be simply to enquire whether it would be possible to decrease the variability of some quality-characteristic, and if so, how? The problem might be more complex, such as to question the basic design of a product. It might be a new idea in a chemical process. Will it work?

Which quality-characteristic to test and to use in a Shewhart chart, or in a test of significance, or what questions to ask in a comparison of products in a study of consumer research, is fundamentally a problem in subject-matter, which might be engineering, consumer research, physics, law, chemistry, medicine, or agriculture. No amount of knowledge of statistical theory will tell one which quality-characteristic to test, although statistical theory is essential for reliability and economy in the design and interpretation of tests of a characteristic, or in tests to decide which of two quality-characteristics is a more reliable indicator of future performance of the product.

I may add, in case my own experience is worth anything, that an essential requirement of the statistician working in industry is to know statistical theory, and to continue to learn more. He must learn something about the subject-matter, of course, in order to work in it, but his contribution will be more successful if he will enhance day by day his knowledge of statistical theory instead of trying to become expert in the subject-matter. He works with people that know the subject-matter: what the statistician needs to know and do is his own job, not someone else's.

Of course, in a small place, the same man must sometimes work both as statistician and as engineer. He must nevertheless observe the same rules. He should, to be effective, use only the statistical theory that he understands, and should use it for statistical problems, not for engineering problems.

Such principles were woven into the teaching in Japan.

Relation of the foregoing principles to programs of the A. S. Q. C. There are two aspects to any quantitative problem: (a) subject-matter, (b) statistical theory. We have just learned that only knowledge of the subject-matter can generate a problem. Statistical knowledge provides a model by which to restate the problem in statistical terms so that measurements and calculations will provide meaningful information. Then, knowledge of engineering, production, economics, and marketing provide a basis for deciding whether anything should be done about the problem, once it is isolated and clarified.

Now certainly there are many different kinds of problems. No two are alike in appearance. However, the theory and techniques for understanding various problems are not distinct: theory is transferable. If the theory and techniques for understanding two problems are not distinct, then how can the two problems be? It is certainly important that the programs of the A. S. Q. C. be helpful to members that have problems. However, a paper is instructive only to the extent that it presents the appropriate theory. Once a problem is formulated and explained with aid of theory, it becomes a close relative of a host of other problems, whose solution will be to some extent similar.

Thus, to illustrate with an example, some recent theory that helps to evaluate the hazard of becoming schizophrenic as a function of age is immediately applicable, with only changes in symbols, to problems in the theory of failure, to problems in reliability, and to queuing theory.

It is possible that the A. S. Q. C. is dashing itself to pieces by splitting the programs of meetings into an ever-expanding list of names--inspection, management, administrative applications, specifications, vendor's problems, process control, acceptance sampling, reliability, value engineering, human engineering, and I know not what. There may also be, before we know it, sections on maintainability, dependability, qualitability. Invention of new words neither generates problems nor solves them. Splintering, without a unifying theory, represents loss of power, with motors pulling in random directions.

The A. S. Q. C. could recapture lost power in its meetings by pooling different problems into groups identified with various specialized branches of theory, rather than by subject-matter. In other words, it might be wise to subsume problems under the fundamental disciplines such as statistics, mathematics, economics, psychology, chemistry. In this kind of subdivision, we have a better chance to come away from a meeting with a real gain. If we understand a theory, even dimly, be it simple or complex, we have some idea about its limitations, and we are not likely to get into trouble by merely copying a solution.

With 20,000 members, from a cross-section of industry, the impact that the A. S. Q. C. could make on economic production is substantial. The unified approach might be successful here too, as it was in Japan.

It is easy to look upon past achievements and to imagine that everything possible has been accomplished toward economic production of one's product. Yet the next issue of INDUSTRIAL QUALITY CONTROL will feature some notable advances in quality and economy.

Restriction on the flow of dollars is a signal of disease, not a cure. Statistical methods, taken seriously and in sufficient quantity, might strengthen the competitive position of many U. S. products and help to reverse the flow. The A. S. Q. C. has a responsibility and faces a challenge. Few organizations have so great chance to help to raise the respect and marketability of American products.