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SOME REMARKS ON STATISTICAL CONTROL OF QUALITY IN JAPAN*

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INTRODUCTION AND PURPOSE OF THIS PAPER

The competitive position of many Japanese products is well known. This position, according to the testimony of Japanese manufacturers, has been achieved largely through full use of the statistical control of quality. Japanese manufacturers started in 1950 with a pool of skilled and willing labour, with the world's highest educational level, and with engineers, statisticians and other scientists eager to learn new methods. Reasons for the success of their efforts in the statistical control of quality are not as well known as the results.

The purpose of this paper is to offer some observations on the reasons for success. Attention to the reasons could well have a healthy impact on industry in other parts of the world, and on scientific programmes devoted to techniques of management, statistical methods, and demographic aspects of technological change.

EIGHT FEATURES OF THE STATISTICAL CONTROL OF QUALITY IN JAPAN

In my opinion, there are eight main reasons for the success and speed of application of the statistical control of quality by Japanese manufacturers :

(1) They were Japanese, with industrial experience, and with an inbred pride of workmanship.

(2) Knowledge of the statistical control of quality reached higher echelons of management, as well as engineers and statisticians. Engineers and plant managers in production learned techniques; top management learned at the same time something about possible results, and still more about what their own responsibilities would be. Proper arrangements for making contact with top management, at the outset, was one of the fortunate features of statistical education in Japan.

(3) Japanese top management, statisticians, and engineers, learned the statistical control of quality in the broad sense of Shewhart, as defined further on.

*Based on an Address delivered at a meeting of the American Society for Quality Control at Stanford University, California, 12 September 1964.

(4) Statistical education became a continuing process through the efforts of Mr. Kenichi Koyanagi (deceased), then Managing Director of the Union of Japanese Scientists and Engineers. Statistical methods cannot 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. It was made clear in the initial 8-day courses (in which I myself taught, in total, in 1950 and 1951 alone, over 1100 Japanese engineers), that these techniques were only an introduction to statistical principles and methods. Perhaps the main accomplishment in these courses was to impart faith in statistical theory, and inspiration to learn more of it.

(5) The Japanese learned the difference between a statistical problem and a problem in engineering, chemistry, management, or marketing. They learned to use statistical methods as an aid in the solution of substantive problems. Statistical knowledge is not a substitute for knowledge of engineering or of other subject-matter, nor can knowledge of engineering solve statistical problems.

(6) Japanese manufacturers took on the job themselves, by giving financial and moral support to 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.

(7) Suggestions and technical information have a fairly clear channel from lower to higher levels of supervision and management. A typical Japanese executive, it seemed to me, is never too successful to learn a better way.

(8) It was fortunate that management agreed on the importance of concerted effort throughout all Japan. A little fire here, and a little there, would be too slow. Concerted effort meant cooperation amongst competitors, assistance to vendors, and—probably for the first time in Japan—immediate attention to the demands of the consumer, and need for consumer research on a continuing basis, with feed-back for re-design.

Heavy impetus to quality came from formal contests, such as the annual Deming Prize, established by the Union of Japanese Scientists and Engineers. This is a double-barreled affair, (1) a considerable sum of money to a Japanese statistician for statistical work in theory, practice, or teaching, and (2) citation to a plant for effective use of statistical methods. The annual ceremonies for the Deming Prize are broadcast nationally by radio, and form an important item of news. Receipt of the prize, in the words of Dr. Juran, resembles the ceremonies for the launching of a great ship.

Lectures to Top Management

Lectures to management, beginning in 1950, brought up a few simple questions to think about. I am not an economist, nor a business-man, only a statistician, but some conclusions seemed inescapable. Why was it necessary to improve quality of Japanese products ? Because Japanese products must now become competitive : the market for cheap Japanese products is lost in Asia if not in the western world also.

It is not necessary to raise all your own food, it seemed to me. Chicago doesn't. Switzerland doesn't. It may be smarter for Japan to import food and pay for it with exports. There is a market for quality. How do you build quality, and a reputation for quality ?

No country is so able as Japan, I pointed out, with its vast pool of skilled industrial manpower, and with so many highly proficient engineers, mathematicians, and statisticians, to improve quality. Statistical methods could help : in fact, realization of any goal to raise quality to a sufficiently high level would be impossible without statistical methods on a broad scale. In 5 years, I predicted at an assembly in July 1950, manufacturers in other industrial nations would be on the defensive, and in 10 years the reputation for top quality in Japanese products would be firmly established. Japanese manufacturers took these arguments seriously to the point of doing something about them with concerted effort.

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, management's responsibility for common causes (*vide infra*), and the economic loss from failure of management to accept these responsibilities.

Definition of the Statistical Control of Quality

The Japanese never knew the statistical control of quality in any way but in the broad sense introduced by Shewhart.* The statistical control of quality was defined in plain English in 1950 and ever after in big letters like this :

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.

* 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). "Nature and origin of standards of quality," *Bell System Technical Journal*, **xxxvii**, 1958 : pp. 1-22. No attempt is made here to give a full list of Dr. Shewhart's papers.

Translated into action, this definition of the statistical control of quality means :

(1) Use of statistical methods to construct meaningful specifications of raw materials, piece-parts, assemblies, and performance of finished product.

(2) Assistance to suppliers. Any raw material or piece-part is someone's finished product. Improvement of quality of incoming materials from vendors or from a previous operation is one of the most important requirements in a programme of quality.

(3) Tests of raw materials, of semi-finished and finished products, by appropriate statistical design.

(4) Control of process. Detection of specific causes by statistical methods ($\bar{x}$- and R-charts, run-charts, design of experiment, and other techniques). Isolation of a common cause. Separation of responsibility for finding and removing causes of variability (*vide infra*).

(a) Specific causes (local).

(b) Common causes (upper management).

(5) Use of acceptance sampling where appropriate.

(6) Consumer research. Test of product in service.

(7) Re-design of product.

(8) Tests of new product, in the laboratory and in service.

(9) Use of proper theory for finding optimum levels of inventory, and for economy in distribution.

The main point was that the statistical method is a continuing process in a never-ending cycle :

(1) Design a product

(2) Make it

(3) Try to sell it

(4) Test it in service

(5) Repeat Step 1. Re-design the product on the basis of tests in service

(6) Repeat Step 2

(7) Repeat Step 3, etc.

As with Shewhart and with all the original workers in the statistical control of quality, it was never anything but a full-scale assault on procurement, manufacturing, and marketing with the aid of statistical techniques.

TWO TYPES OF CAUSE OF VARIATION: SPECIFIC (ASSIGNABLE) AND COMMON (GENERAL)

One of the important uses of statistical techniques is to help an engineer or scientist to distinguish between two types of cause, and hence to fix (with adjustable risk of being wrong) the responsibility for correction of undesired variability, or of undesired level.

Confusion between common causes and specific causes is one of the most serious mistakes of administration in industry, and in public administration as well. Unaided by statistical techniques, man's natural reaction to trouble of any kind, such as an accident, high rejection-rate, stoppage of production (of shoes, for example, because of breakage of thread), is to blame a specific operator or machine. The real cause, however, may be common to all operators and to all mahchines, e.g., poor thread, the 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 trouble to some specific operator, foreman, machine, or other local condition, when the trouble is actually a common cause, affecting all operators and machines, and correctable only at a higher level of management. The specific local operator is powerless to act on a common cause. He cannot change specifications of raw materials. He cannot alter the policy of purchase of materials. He cannot change the lighting system. He might as well try to change the speed of rotation of the earth.

What statistical tests do ($\bar{x}$- and R-charts, run-charts, tests of significance, and other techniques), is to *indicate the level of responsibility for correction.*

The contribution that statistical methods make in placing responsibility squarely where it belongs (at the local operator, at the foreman, or at the door of higher management) can hardly be overestimated.

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.

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 specific, such as a specific operator, a specific machine, a specific batch of (e.g.) thread or other incoming material.

A point outside limits on a control chart indicates the existence of a specific cause. A test of significance is a statistical enquiry to detect the existence of a specific cause of a difference (between treatments, between operators, between machines, between production lines), if there be any such causes worth searching for. For example, in the simple problem of testing the difference between two proportions, we are really enquiring whether it would be economical (a) to ignore the possible existence of a specific cause of the difference, and to proceed as if the two samples came from a common bowl, common causes only, or (b) to assume that a specific cause does exist that is worth the trouble to search for.

Variation due to specific cause is correctible locally. That is, the responsibility for correction of a specific cause lies with an operator, or with a foreman. It may be the fault of some machine. Something can be done locally about a specific cause to eliminate a source of variation.

Use of the theory of probability enables us to govern the risk of being wrong in our own interpretation of a test. We are able to defend ourselves, almost unerringly, against the costly and demoralizing practice of blaming variability and rejections on to the wrong person. At the same time, we are sure to detect, almost unerringly, the existence of a special cause when it is worth searching for.

Common causes of variation and of wrong spread, wrong level. If we succeed in removing all specific causes worth removing, then henceforth (until more trouble strikes), variations in quality behave *as if they came from common causes.* That is, they have the same random scatter as if the units of product were being drawn by random numbers from a common supply. The remaining causes of variability are then common to all treatments, to all operators, all machines, etc.

Some common causes are in the following list. The reader may supply others, appropriate to his own plant and conditions.

- Poor light
- Humidity not suited to the process
- Vibration
- Poor instruction and poor supervision
- Lack of interest of management in a programme for quality
- Poor food in the cafeteria
- Inept management
- Raw materials not suited to the requirements
- 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

A mistake common amongst workers in the statistical control of quality is to assume that they have solved all the problems once they have weeded out specific causes, and rarely see a point out of control. The fact is, instead, that they have only commenced. Specific causes are the easiest ones to identify and to remove.

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 ? Only management can take action. 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 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, interesting because it is outside the usual sphere of industrial production, is the improvement of quality of statistical data put out by the Census in Washington. For many years, effort has been directed at common causes of error and of high cost, as well as elimination of special causes. The result today is quality, reliability, and speed of current statistical series that are the envy of other statistical organizations in the U.S. and abroad, and at costs that are about a third of what private industry pays out for surveys in consumer research.

WHAT IS THE STATISTICAL METHOD ?

The statistical method means use of the theory of probability. The theory of probability, in industry, is not merely an expanding universe of books. One of the main uses is manifest in statistical techniques known by various names ($\bar{x}$- and R-charts, run-charts, theory of runs, sampling, analysis of variance, theory of estimation, and many other techniques) which assist man to distinguish between :

(1) specific (assignable) causes of variation,

(2) common (general) 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 statistical techniques in the 8-day courses in Japan was concentrated in simplicity. Charts were taught as statistical tools for the economic detection of the existence of specific causes of variation, not as tools that actually find the cause. However, emphasis was on *action, find the cause and remove it,* once a point goes outside limits. Then do something about common causes.

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

Estimation

Problems in statistical estimation are very important in industrial produ tion, as in decisions on whether one type of machine is sufficiently better than anoth to warrant the cost of replacement, or to warrant the higher cost of purchase of better machine. Consumer research presents hosts of problems in estimatio Determination of the iron-content of a shipload of ore is a common problem estimation.

In a problem of estimation, one is not seeking to detect the existence of specific cause. He is not testing the significance of a difference between two resul such as $p_1 - p_2$ or $x_1 - x_2$, which might represent the average percentage defecti produced by two processes, or two types of machines, or the speed or variability two types of machines. One knows in advance that there will be a difference; t only question is *how big is the difference ?* For the answer, one plans tests or surve by use of the theory of estimation.

In Japan, the teaching of statistical methods did not confuse statisti estimation with statistical tests of hypotheses, nor with statistical techniques detect the existence of a specific cause that is worth searching for.

Statistical education in Japan

The programme of education in techniques commenced in June 1950 un the auspices of the Society of Japanese Scientists and Engineers. In all, 500 engine attended the technical lecture courses of 8 days during 1950, and literally hundr more attended every year thereafter. Additional courses in sampling, with appli tion to physical materials (ores) and to consumer research, including field-work, w held in 1950 and 1951, and in later years.

The effectiveness of such beginnings in mass education in statistical meth in Japan was more pronounced and more rapid than results observed from the 8-d courses that commenced in the U.S. nine years earlier. In the first place, Jap was in 1950 in desperate circumstances. Every minute must count. Secon management was more responsive. Some top executives even became active in techniques. 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. A vigorous system of courses for continuation and advancement in theory was instituted by the Union of Japanese Scientists and Engineers, to follow the 8-day courses. The levels are varied. The duration, days, and hours 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* (in Japanese) was started by the Union of Japanese Scientists and Engineers: the journal is now in its 15th year. *Research Reports*, a journal now in its 14th year, has a high reputation amongst mathematical statisticians the world over.

Some idea of the importance of these publications in Japan may be had by noting that in the *International Journal of Abstracts*, a third of the citations refer to Japanese journals.

Another reason for speedy results in Japan was that statistical methods had had the benefit of prior 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 and other statistical techniques were at first used in America only as tools to help weed out specific (assignable) causes. Scant attention was given to common causes, and to consideration of proper level and allowable spread. That statistical methods separate, almost unerringly, special causes from common causes, and that the responsibility for the removal of a common

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*Kenichi Koyanagi, "Statistical quality control in Japanese industry," a paper delivered at the national convention of the American Society for Quality Control 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.

cause rests with management, was by no means fully appreciated everywhere, not even now. People forgot that consumer research and proper design with the help of statistical techniques were essential ingredients of the statistical control of quality.

Acceptance sampling was frequently at first confused in America with process-control. Some people looked upon it as a detector of specific causes. Other people supposed that acceptance sampling furnishes estimates of the quality of lots, and that it separates good lots from bad.

Many people, in America 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.

The Japanese were spared some of these miscalculations.

Other components of statistical education in Japan

Certain other features of statistical education in Japan have played an important role in the statistical control of quality. First, lectures by foreign experts. The Union of Japanese Scientists and Engineers never lost a chance to ask a visiting expert to give lectures while in Japan. They invite visiting experts to give lectures to engineers, statisticians, and top management, both in general assemblies and by invitation at specific plants. Amongst such visiting lecturers were Dr. Shewhart himself and Samuel S. Wilks (deceased). Top management, directors and supervisors, engineers, and foremen all turn out eagerly to sit or stand through a two-hour session in an indescribably hot auditorium in summer, or in an unheated auditorium in the winter.

The Union has arranged two lengthier formal courses under the great Dr. Joseph Juran, Management Consultant, New York. Anyone with the slightest acquaintance with Dr. Juran's work may well appreciate his contribution.

Another feature is the translation into Japanese of books in other languages, sales of which in Japan have in some cases almost equalled the sales in the original language.

Then there is Quality Control Month, with flags flying from every plant, with special meetings and papers for interchange of theory and experience. The Tokyo Chapter of the American Society for Quality Control is one of the biggest and most active chapters. In other words, quality is worth living for.

Power and limitations of statistical theory

The main emphasis in the teaching in Japan was on what statistical techniques can do, and what they can't do, and how statistical methods help the engineer or other expert in subject-matter (chemistry, consumer research, or other line) to make better use of his knowledge and creativity. Knowledge of statistical theory is no substitute for subject-matter, nor is knowledge of subject-matter a substitute for statistical techniques and statistical methods of inference.

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 θεα to see, to understand.

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.

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.

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 (engineering, consumer research, medicine). 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 selected characteristic, or in tests to decide which of two quality-characteristics is a more reliable indicator of future performance of the product.

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, statistics, not someone else's job.

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 he should use it for the statistical aspects of problems. He should not try to substitute statistical techniques for the basic input of engineering that must go into a problem.

Such principles were woven into the teaching in Japan.

Statistical methods, taken seriously and in sufficient quantity, as they were in Japan in 1950, could strengthen the competitive position of other countries as well. Statisticians and statistical organizations all over the world have in their grasp a chance to help to boost production in industry, as they have in agriculture.