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STATISTICAL CONTROL OF QUALITY IN JAPAN

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Introduction. The title of this paper was not a difficult decision for me because (1) SQC has pushed Japanese products into the marketplace the world over, and has brought to Japan a fantastic trend in prosperity; (2) the greatest satisfaction of my professional life is work in SQC in Japan. The purpose of this paper is to present, from my own point of view, why SQC has been so effective in Japan.

I shall concentrate later on a certain aspect of SQC, which appears to be especially important–namely, the distinction between special causes and common causes. We shall see that statistical techniques enable us not only to detect the existence of conditions that need correction; they also determine which administrative level is responsible to identify and correct the cause of trouble.

What is SQC? The following definition of SQC, given in 1950 and translated into ACTION, put Japanese industry into orbit:

> 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.

SQC embraces all formal quantitative aspects of production and marketing. No further adjective is either necessary or helpful. SQC covers planning, specification, and purchase of materials. It covers production, marketing, and re-design of product, as displayed in Fig. 1. It provides an audit of the management function. This is what Shewhart meant by SQC.* To him, SQC was everything, and so it has been in Japan since 1950.

Statistical theory helps substantive experts in industry and in research (engineer, production expert, manager, doctor of medicine, expert in consumer research, psychologist, or other) to solve their problems and to help them to plan more effective systems. Statistical theory provides a plan, a road-map, that leads to better competitive position in industry. Forward or backward movement in competitive position can have meaning only in terms of statistical measures of advancement toward a goal.

Incidentally, industry in this paper means the design production and marketing of any product that may have a customer. It includes services, such as a hotel, a laundry, or even a university, where the product is research and education of students.

Some responsibilities of management. Use of SQC places certain responsibilities on management, and on the scientists, engineers, foremen, operators, and hand-workers in a company. No amount of knowledge in the heads of engineers and statisticians is a substitute for management. The job of management is (a) to decide on goals for the future, (b) to make use of knowledge and skills to achieve these aims, (c) to keep the plan flexible so that changes in direction are possible. It is management's responsibility to find problems that have some chance of solution. Statistical techniques help to achieve these goals.
Examples:

1. How might we expand the market and profitability of our product?
2. How might we alter the design of our product to make it more acceptable in the market?
3. What new products that we could make will be in demand three years from now, and how would we go about it to find the market for them?
4. What are some of the reasons why our profits are slipping?
5. How might we increase profits? At which stages of production and distribution are we losing profit?
6. How could we increase output from our present equipment?
7. How could we increase output without increasing our work-force?
8. How could we reduce the variability of our product?

Statistical methods detect causes of variability and they indicate the level of responsibility for improvement.

9. What do our customers think of our product? How does our product compare with competitive product, in the opinion of our customers?

Management must decide what statistical information would help in planning ahead for expansion of a market. Management must allow expenditure for the cost of the studies that will provide basic information about the consumer's views. Management must provide feed-back of results into re-design of product: otherwise the expenditure for information will be largely wasted.

Some companies carry out consumer research, but get little good out of it either because the results of consumer research never reach the group of men responsible for re-design of product, or because the group of men responsible for design assume that they know what to do without the help of consumer-research. Only top management can correct such failures of organization.

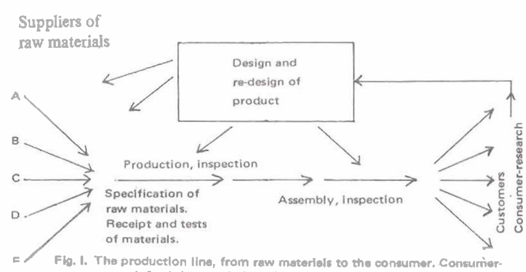

Fig. I. The production line, from raw materials to the consumer. Consumer-research feeds into re-design of the product, which in turn brings changes in the requirements for raw materials and in production.

A goal, if it is not to demoralize the personnel of a company, must lie within the capability of the process. A great mistake in management and administration is to set a goal that is unattainable or too costly to attain. Statistical methods provide the only safe measure of the capability of a process.

Translated into action, SQC means use of statistical methods:

1. To construct meaningful specifications of raw materials, piece-parts, assemblies, and performance of finished product, by appropriate statistical design.
2. To measure the capability of a process. (Calculable once a state of control is reached.)
3. To assist suppliers. Any raw material or piece-part is someone's finished product. Dependable quality of incoming materials from vendors or from a previous operation is one of the most important requirements in a program of quality. Statistical methods are essential for designing specifications and for testing materials.
4. To control the process and to separate the responsibility for finding and removing:
   a. Special causes of variability (local).
   b. Common or general causes of variability (upper management).
5. For acceptance sampling, where appropriate, to ensure an AOQL

* W.A. Shewhart, THE ECONOMIC CONTROL OF QUALITY OF MANUFACTURED PRODUCT (Van Nostrand, 1963); 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.

(guaranteed level of quality).

6. To test the product in service and in the laboratory. Consumer research.

7. To re-design the product on the basis of tests, including consumer research.

8. To hasten development of a process or product.

9. To calculate optimum levels of inventory and to formulate policy for re-order.

10. To guide policy of maintenance and replacement of equipment.

11. To discover the proportionate time that workers spend drawing parts out of stock; to discover the proportion of time that machines are down for repairs. (Use of Tippett's ratio-delay methods; also called work-sampling.)

12. For optimum allocation of capital and personnel for service (commonly called queueing theory).

13. To define reliability, and to measure approaches toward a specified degree of reliability. (Note that the term reliability has no meaning except as it is defined operationally in statistical terms, nor can it be measured except in statistical terms.)

14. For solution of complicated mathematical equations, integrals, and differential equations by Monte Carlo methods (methods of sampling).

The reader may little suspect that these diverse applications are covered by one body of statistical theory. The material and the aims vary from one problem to another, but not the basic theory. Theory is transferable.

Statistical theory goes also by several other names—theory of probability, theory of sampling, stochastic processes.

Statistical control is dynamic. Use of statistical methods 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.

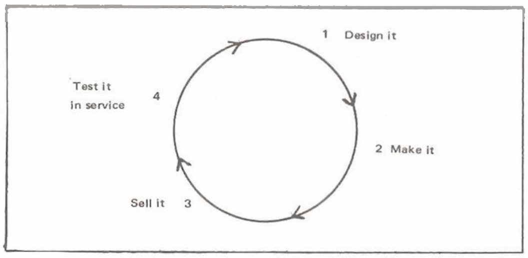

Fig. 2. Cycle of applied statistical methods

A few notes about SQC in Japan. History is easy to forget, and in any case is only what someone recorded for posterity to read.* And so I record here a few notes about Japan in 1950. SQC was, of course, already known in Japan. Some of the world's finest statisticians were Japanese, contributing papers to the world's store of knowledge in statistical theory and practice.

Applications to production had been mainly in the form of design of experiment and analysis of variance. Courses in simple statistical techniques for the masses and for management were undertaken in 1950 by the Union of Japanese Scientists and Engineers, under the untiring efforts of Kenichi Koyanagi, Managing Director until his death in 1964. This education was conducted in courses at many levels for engineers and for management. I myself during the years 1950 to 1952 conducted 8-day courses for 1100 engineers in Tokyo, Osaka, Nagoya, and Fukuoka, and lectured a number of times to top management (next section). It was through the influence and efforts of Mr. Ichiro Ishikawa, President of the Federated Economic Societies, respected leader in many other civic and scientific endeavors, that executives in management were assembled, first at the Industry Club in Tokyo on the 25th July 1950, next at Hakone on the 19th August, same year. By 1951, Mr. Keizo Nishimura (deceased, then President of the great Furukawa Electric Company) had within a year achieved so much success in his wire and cable factories that he assembled at an inn in the mountains above Nikko 20 leaders in industry for further lectures and to exchange points of view. From then onward, SQC was a snowball.

Results were spectacular, even after only one year, especially in productivity per man-hour, with little new machinery. One steel company saved 28 percent on consumption of coal per ton of steel. A huge pharmaceutical company put out three times as much finished product per unit of input of raw material. A big cable company reduced greatly the amount of paper and re-work on insulated wire and cable. Many companies reduced accidents to a permanent low level. Improvement in quality and dependability came in due course, and in five years, as predicted, many Japanese products had earned respect to the point of fear in markets the world over.

Courses for engineers, foremen, middle management, and top management, to fit all requirements short of the functions of statistical education in a university, were announced almost weeekly by the Union of Japanese Scientists and Engineers. Committees were formed for special studies. The committee on sampling ore and other bulk materials, under the leadership of Dr. Kaoru Ishikawa, developed procedures and standards that are now known, admired, and copied in all parts of the world. The K-Committee for the study of higher mathematical statistics and applications, under Dr. T. Kawata, now Professor of Statistics at the Catholic University of America, was another.

Lectures to management. The lectures to top management beginning in 1950 emphasized how essential it was for management to assume responsibility for their part in the improvement of quality. No matter how many of their engineers learned something about statistical techniques, and no matter how much further study they carried on, no great forward movement could take place in the quality of Japanese products, I told them, unless they laid the proper climate, mainly the goal of quality, with diligent application of statistical techniques in the broad sense, from vendor and raw materials to the consumer and re-design of product (Figs. 1 and 2).

I was 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.

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 to improve quality, I pointed out, with its vast pool of skilled and educated industrial manpower, and with so many highly proficient engineers, mathematicians, and statisticians. Statistical methods could help: in fact, realization of any goal to raise quality to a sufficiently high level would be impossible without statistical methods. Seeing their serious determination, I predicted at the first assembly of Japanese manufacturers in July 1950 that in five years, manufacturers in other industrial nations would be on the defensive, and that in ten years the reputation for top quality in Japanese products would be firmly established the world over.

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 redesign. Statistical techniques became a living, vital, and essential force in all stages of Japanese industry.

I may point out that Japanese manufacturers took on the job themselves. They did not look to their government nor to ours for help. When they arranged for consultation, they sent a ticket and a cheque. They gave financial and moral support to statistical education, mainly through the Union of Japanese Scientists and Engineers.

One ought also to mention the stimulus of a prize offered annually in the name of an American statistician to the Japanese manufacturer, who, in the opinion of the Committee on Awards, has made the greatest advance in quality of his product during the past calendar-year. Many companies compete for the prize, often laying plans years in advance. Although only one company, or at most two, can receive the prize, the continual competition of many companies has had an important leavening effect in quality.

Statistical education became a continuing process. 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. Perhaps the main accomplishment in the eight-day courses that began in 1950 was to impart inspiration to learn more about statistical methods.

Why distinguish between special causes and common causes of variation or of wrong level? One of the important uses of statistical techniques is to help

* Max Nordeau, THE INTERPRETATION OF HISTORY (Rebman, 1910), translated from the German by M.A. Hamilton; p.4.

an engineer or scientist to distinguish between special causes and common causes, and hence to fix (with adjustable risk of being wrong) the responsibility for correction of undesired variability or of undesired level. Common causes could also be called general causes, or faults of the system.

Confusion between common causes and special 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 is to blame a specific operator or machine. Anything bad that happens, it might seem, is somebody's fault, and it wouldn't have happened if he had done his job.

Actually, however, the cause of trouble may be common to all machines, 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, in a situation where the trouble is actually a common cause, affecting all operators and machines, and correctible only at a higher level of management.

The specific local operator is powerless to act on a common cause. He can not change specifications of raw materials. He can not alter the policy of purchase of materials. He can not change the lighting system. He might as well try to change the speed of rotation of the earth.

A mistake common amongst workers in the statistical control of quality, and amongst writers of textbooks on the subject, is to assume that they have solved all the problems of production, once they have weeded out most of the special causes. The fact is, instead, that they are at that point just ready to tackle the most important problems of variation and level, namely, the common causes, faults of the system.

Detection of a special cause of variation. Variation of any quality-characteristic is to be expected. The question is whether the variation arises from a special cause, or from common causes. A special cause is detected by a point outside limits on a control chart, or by a run or other pattern, or by a significant value of t or F. Special causes are what Shewhart called assignable causes (but without, I believe, the concept of the responsibility of management for the common causes).

Statistical techniques, based as they are on the theory of probability, enable us to govern the risk of being wrong in the interpretation of a test. Statistical techniques defend us, almost unerringly against the costly and demoralizing practice of blaming variability and rejections on to the wrong person or machine, when in fact the trouble is with the system.

Statistical tests do more than detect the existence of a special cause, or the absence of special causes: THEY INDICATE THE LEVEL OF RESPONSIBILITY for finding the cause and for removing it. 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 over-estimated.

This aspect of the statistical control of quality was not appreciated, I believe, in the earlier history of statistical methods in American industry, and is even now neglected.

Common causes of variation and of wrong spread, wrong level. Responsibility of management. If we succeed in removing all special causes, then henceforth (until another special cause appears), variations in quality behave as if the units of product were being drawn by random numbers from a common supply. The causes of variability are then common to all treatments, to all operators, to 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
Management's lack of interest in a program for quality
Poor food in the cafeteria
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

Common causes are usually much more difficult to identify than specific causes, and more difficult to correct. In the first place, carefully designed statistical 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 change the design of the product? to install new machinery? to change the lighting? to put in air-conditioning for certain operations? Only management can take action on these things. If the trouble lies in management itself, who is going to make the correction?

Illustration of a common cause and need for action by management. This will be an illustration of an administrative type. The vertical axis on Figure 3 shows for any point the number of successes achieved by an interviewer whose job it was to dial telephone numbers and make certain enquiries, according to a prescribed routine (questionnaire). The horizontal scale is the number of failures. A completed interview is a success. No answer or a refusal is a failure. Each interviewer had a valid sample of telephone numbers for an entire district. It will be observed that some interviewers had greater success than others, but that none of them fell outside the 3-sigma limits. That is, no special cause is evident. Yet the overall percentage of success, namely 7 percent, is so low that costs are high. No one interviewer is responsible for excessive departure either above or below the average. The causes of low success and high costs are common to all interviewers. The trouble is in the system. The only way to increase success, and to lower costs, is by some action of management that will affect all interviewers. Only management can change the system. Here are some of the changes that management could make:

1. Increase the number of audible rings from 5 to 8 or to 10. (There are 6 seconds between rings, wherefore this action would increase the cost of each trial from 18 to 30 seconds.)
2. Provide better supervision. For example, assemble the interviewers in one group under skilled supervision and controls.
3. Change the questionnaire and the approach.

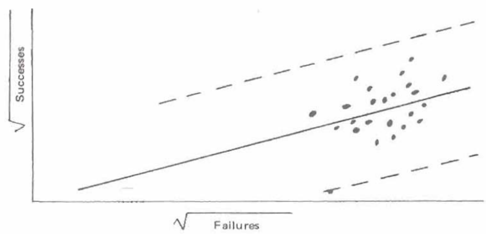

Fig. 3. Action by management is required to raise the slope of the line (i.e., to improve the process average).

Remarks on various statistical techniques. Acceptance sampling is a scheme of protection (provided one will really reject and screen a lot when the sample contains more than the allowable number of defects). 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 making a product unless he has in hand, in addition, the plan by which his lots will be sampled by the purchaser and accepted or rejected. How big is a lot? 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. The plan of acceptance sampling is a necessary specification of a contract for lots.

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

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

In a problem of estimation, one is not seeking to detect the existence of a special cause. He is not trying to discover whether there is a difference such as $P_1 - P_2$ or $X_1 - X_2$ between two processes, or between two machines, standard and propose. One knows in advance without making any test, that there is a difference; the only question is how big is the difference?

Statistical calculations using data from two samples (coming from two treatments, two operators, two machines, two processes) provide a basis on which to decide, with a prescribed risk of being wrong, (a) whether it would be economical to proceed as if the two samples came from a common source, or (b) whether it would be more economical to assume the converse, and to proceed as if the difference has its origin in a special cause, not common to the samples, which makes one of the treatments, operators, machines, or processes different from the other. Essential considerations in fixing the probability of being wrong lie in the economic losses to be expected (a) from the failure of being too cautious – failure to make a change that would turn out to be profitable, or (b) from making a change that turns out to be costly and unwarranted.

Capability of the process. This function of statistical techniques is so important to management that it deserves special mention. Capability of a process can be defined and measured only by statistical methods. It is determined by the variation of dimensions in a state of control. No greater uniformity or precision is possible unless there be a fundamental change in the process. In manufacturing, capability of the process means the ultimate precision of uniformity in dimensions, color, hardness, or of some other quality characteristics. In administrative work it means the ultimate reasonable degree of accuracy that one may hope to achieve in computing charges, in transcription, punching, and other operations. In other types of business it might mean the minimum feasible variation in performance of drivers, trucks, and operators of other equipment. Knowledge of the capability of a process has saved more than one company from entering into a contract to produce precision, uniformity, or quantity that they can not deliver.

Power and limitations of statistical theory. 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 contributions 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. Thus, the statistician need not be an expert in a production process in order to make a contribution to production. He works with people that know production; what the statistician needs to know and do is his own job, statistics, not someone else's job.

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 $\theta\varepsilon\alpha$ 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 statistics, another for engineering. Instead, there is statistical theory.

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. Other professions (e.g., management, administration) have the same goal, but the statistician is the one that has the skills and tools for accomplishment of the goal.

Of course, in a small plant, 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 from entering into a contract to produce precision, uniformity, or quantity that they can not 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.

However, 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, production, 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 comparison of two or more processes or machines. It might be a new idea in a chemical process.

Which quality-characteristic to test and to use in a Shewhart chart, or what questions to ask in a comparison of products in a study of consumer research, is fundamentally a problem in subject-matter (enginnering, chemistry, etc.). Statistical theory can not tell anyone which quality-characteristic to test.

A goal, whatever it be – more product per unit of cost, better design of product, more profit, more sales, greater dependability of product - must be desired and stated by management, and translated into statistical terms. Statistical methods are a necessary ingredient in the definition and in the attainment of a goal, first to indicate whether improvement is possible under the present system, then to measure advancement toward the goal. A goal without any way of measuring advancement toward it is no goal at all.

Note on automation. Smooth operation of machinery becomes more and more essential with the expansion of automated processes. It is a fatal error to assume that automation eliminates need of statistical methods. Automation presents new and more exacting problems for the statistical control of quality. The cost of breakage and of jamming increases exponentially with the complexity and speed of the system. Systems and compoenets must be made and tested under increasingly exacting conditions. Statistical aid in design, in testing, and in redesign of parts and assemblies becomes more than just a good idea: it is vital.