Some Statistical Logic in the Management of Quality

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The industry is in continuous development, and so are the
tempers of consumers. Both demand more and better
quality....—Egyptian Cotton Exporting Companies,
in the New York Times, 15 January 1971, page 63.

Introduction

Purpose and preamble. Quality may be everybody's job in a company, but nobody can take part effectively in a program for quality without rules for action that are based on application of statistical techniques. People in all ranks need to know when action would be effective, and they need to know what kind of action to take.

The primary aim of this paper will be to fill in some of the missing links in the use of statistical methods, with special reference to responsibilities at the management level for effective mobilization of statistical knowledge and skills. Management needs to know what the statistical control of quality is. Perhaps if they knew, they could perceive what type of organization might be suitable, and might perceive what is wrong with what they are doing at present about quality. The statistical control of quality is

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* This paper follows the theme of numerous lectures delivered to top management and to engineers in Japan, beginning in 1950; and in Taiwan 1970. Keynote speech at the All India Conference on Quality Control, New Delhi, 17 March 1971.

a system, not a bag of techniques. Too often, myriads of figures, so easy to produce nowadays, convey no information or even misinformation.

Statistical methods, properly used in the design of an information system, will indicate not only when action will be effective toward reduction of trouble from defective or sub-standard product, low productivity, and high cost, but also the level of responsibility for action.

Thus, it is well known that simple statistical techniques (run chart, $\bar{x}$- and R-charts) will indicate to the individual production-worker when he needs to take action on his operations to reduce variation and trouble, and when he should leave them alone. This is important, but it is only part of the problem. It seems not to be so well known that statistical techniques will also measure management's share of the causes of low productivity and low quality (vide Fig. 2 infra). The magnitude of management's share is not generally appreciated. This is natural in the absence of objective measures, but there is no longer any excuse of this chasm of darkness.

This paper will attempt toward the end to outline some logic in organization for effective use of the **statistical control of quality**. We may note here, however, that statistical techniques do not grow up without seed and cultivation. They are not installed like a new carpet or a new Dean. Sending a man to take an 8-day course in rudimentary statistical techniques does not initiate a quality-control program : it is too often the end, not the beginning. Statistical theory and applications thereof are scholarly and productive. Statistical ability is rare : it is not on the market, and is not produced nor bought on specification. A program of the statisical control of quality requires nurture and soil in the form of appropriate organization and tenure.

Be it noted that I write not as a consultant in management, but as a statistician working with management, and with engineers, statisticians, and experts in various fields of subject-matter, who have goals to meet.

It is not the aim of the statistician to recommend these goals or any others. The statistician's job is to help management to meet management's goals. Formulation of goals belongs to management; though a goal, to have meaning, must be stated in statistical terms.

It is of course generally understood and need not be elaborated on here that improvement in quality does not necessarily mean higher grade : it means greater uniformity of output and greater dependability, at a level of quality geared to demand. It is worthy of note, however, that advancement toward greater uniformity by statistical methods is inevitably accompanied by economies in manufacture, higher productivity, and greater profit.

What is the statistical control of quality ? The following definition of the statistical control of quality, given in 1950 and translated into ACTION, by management, engineers, and production-workers, put Japanese industry into orbit :

> THE STATISTICAL CONTROL OF QUALITY IS APPLICATION OF STATISTICAL PRINCIPLES AND TECHNIQUES IN ALL STAGES OF PRODUCTION, MAINTENANCE, AND SERVICE, DIRECTED TOWARD THE ECONOMIC SATISFACTION OF DEMAND.

The statistical control of quality is a system of application that embraces all formal quantitative aspects of planning, purchase, production, service, marketing, and re-design of product. The statistical control of quality, for best results, should be viewed as a system. It is a subsystem in the over all problems of management. As a system, it provides management with meaningful measures of quality and performance. It helps to state problems in meaningful terms, and to solve them. It provides a plan, a road-map, that leads to better competitive position. As a system, it has seldom been tried. It started right in Japan in 1950, and has done well.

Statistical methods are used in the design of product, in tests of new product, and in other problems of consumer research (*vide infra*). They are essential in the testing of drugs, materials, machines. Industry here includes services, such as libraries, hospitals, government agencies, hostels, laundries, newspapers, railways, carriers of motor freight, airlines (compliance with time-tables, service at airports, reduction in amount of lost luggage, over-selling), banks, credit-organizations (what characteristics constitute a bad risk ?) The statistical control of quality is essential in the design and interpretation of records of service on automobiles, computers, aeroplanes, railway cars, and in the interpretation of reports on sales. A partial list of applications appears in a later section.

Simplified flow diagram of production. Raw materials come in. Some raw materials may actually be raw; others may be semi-finished goods or parts; some may be assemblies. Some of them may come from an outside vendor, some from another department or plant of the same company or from a subsidiary. Whatever be the source, material used at any stage is someone else's finished product. Finished product eventually goes off the production-line and into service, where the consumer will decide what is right and what is wrong with it.
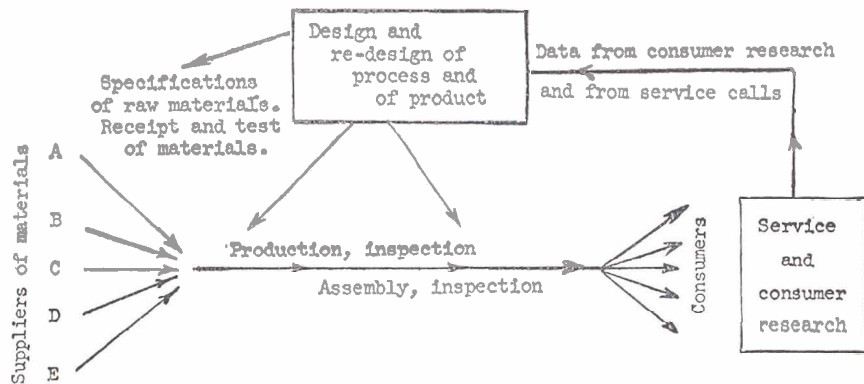

Fig. 1. The production-line, from design, raw material to the consumer. Data from consumer-research and from service-requirements provide a basis for re-design of the product and for changes in the requirements for raw materials and in production.

Statistical methods in improvement of operations

Special causes and common (environmental) causes of trouble. Variation of any quality-characteristic is to be expected. Variation may lead to loss of profit, even if it does not lead to rejections. Variation should be studied, not left to chance. The question is whether the variation arises **from a special cause, or from common causes.** One of the great contributions of statistical methods to the management of the production-line is the distinction between what I call special causes and common (or environmental) causes of variation :

1. Special cause : detected by simple statistical tests (example, x- and R-charts); a failure of the specific production-worker, and to be corrected BY HIM. **Special causes afflict a specific worker or machine. They often** come and go.

2. Common or environmental causes, faults of the system, common to all production workers, affecting them equally. There are usually a number

of common causes in any production-line. Common causes stay on the job until corrected or reduced. Simple statistical tests detect their existence and measure the magnitude of their combined effect on rejections. Elimination or reduction of common causes can be effected ONLY BY ACTION OF MANAGEMENT.

Statistical methods do more than detect the existence of either cause, or both, when they exist : THEY INDICATE THE LEVEL OF RESPONSIBILITY for identification of the cause, and for ACTION thereon.

Examples of common causes of variation and of wrong spread, wrong level. Responsibility of management. Examples of some common causes appear in the following list. The reader may supply others, appropriate to his own plant and conditions.

Management's lack of interest in a program for quality

Failure to measure the effects of common causes, and to reduce them

Failure to provide the production-workers with information in statistical form that shows them where they could improve their performance and the uniformity of the product

Raw materials not suited to the requirements.

Procedures not suited to the requirements

Machines not suited to the requirements

Settings of the machines chronically inaccurate. (Fault of the crew responsible for settings.)

Poor instruction and poor supervision (almost synonymous with unfortunate working relationships between foremen and production-workers)

Poor light

Vibration

Humidity not suited to the process

Mixing product from streams of production, each having small variability, but different levels

Uncomfortable working-conditions : noise, confusion, unnecessary dirt, awkward handling of materials, unnecessary extremes of heat or cold, poor ventilation poor food in the cafeteria, etc.

Shift of management's emphasis from quantity to quality is one common environmental cause of trouble. The production-workers continue to work with emphasis on quantity, not quality. Methods by which management may direct the shift from quantity to quality, however important, is beyond the scope of this paper.

Another common cause is management's failure to face the problem of inherited defective material. Defective items or sub-assemblies fed into one operation from a previous operation in the same company, or from the outside, are demoralizing. **No matter how well the operator** performs his own work, the product will in the end still be defective. The multiplicative effect of intermediate defectives is astounding.

Quality-assurance in intermediate operations is therefore vital for econo-**mic production and for assurance of quality in the final product.** Failure of management on this point (step-by-step quality-assurance) is a good example of a common cause of trouble, which only management can correct : the individual worker is helpless : he has to take what comes.

A possible way out, in certain circumstances, is to pay an operator to throw out defective material delivered to him. Another solution, again advised with caution, is to pay him for correcting a defect that he inherits, with a charge against the previous operator that was responsible for it. Administration of such a system is beyond the scope of this author, even if space were not a problem.

A problem closely allied, is to put an operator to work on a machine that was not set properly. He can only wonder if anyone cares about the product.

Still another common cause is failure of management to make it clear to the production-workers and foreman that they are developing a system that will distinguish between special causes and common causes—a system that will ascribe to the production-worker only the faults (special causes) that are rightfully his to correct, and which will at the same time tell management how much of the trouble can be ascribed to common (environmental) causes, for management to work on; that the whole idea is production and quality, not merely keeping score. A certain amount of experimentation and recommendations for action on common causes may be decentralized, as in the QC-Circle Movement in Japan.

We shall see in Fig. 2 a simple chart that will tell management what proportion of defectives is attributable to common causes. To identify

the common causes may, however, be difficult. Carefully designed tests may be required. Once a cause is identified, come questions about whether and what to do about reduction or elimination. Would it be economically feasible to change the specifications for some incoming material that is causing the trouble ? to change certain operations that cause trouble ? to alter the machinery ? to change the lighting ? to set the machines oftener ? to put in air-conditioning in some sections of the plant ? It is management's responsibility to try to predict the cost and benefit of such problems, and to take action. Sometimes the optimum solution is to leave conditions as they are, and to accept the capability of the process as it exists today.

Two ways for statistical methods to go wrong in the production-line. There are many ways to fail to achieve optimum success in a program for improvement in the production-line. Two main faults, in my experience, are these :

1st fault. Failure to provide the production-worker with information in a form that indicates where action on his part would be effective in improving his performance, and when he should leave the process as it is.

2nd fault. Failure to provide management with incontrovertible demonstration of the existence of common causes and the magnitude of their combined effects on rejection.

Management's failure to face up to their responsibilities and to strive for a quality-control program that will minimize loss from both these faults is, in my observation, a big gap in the alleged use of statistical methods.

Costly confusion. 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 the operators. Anything bad that happens, it might seem, is somebody's fault, and it wouldn't have happened if he had done his job correctly. The worker knows what his job is, yet he turned out defectives. Sounds as if he doesn't care.

This statement is very often absolutely true, but the truth of this observation will not solve the problem. It may be that the workers are putting into the job all that they will ever put in, under the circumstances. The cause of the 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 common (environmental), 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 the specifications of raw materials. He can not alter the policy of purchase of materials. He can not change the lighting system. He is not responsible for the design of the product.

Fortunately, confusion between the two sources of trouble can be **eliminated with almost unerring accuracy**. It is possible in nearly all circumstances to collect figures and to put them in the form of statistical charts or tests that detect almost unerringly the existence of trouble, and indicate the level of responsibility for correction.

The contribution that statistical methods make in placing responsibility almost unerringly squarely where it belongs (on the local operator, on the foreman, or at the door of higher management) can hardly be overestimated. Statistical techniques defend management against the costly and demoralizing practice of blaming variation and rejections on to the production-workers when the cause of the trouble is one on which only management can take action.

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

A common mistake, even now, in quality-control programs, and amongst nearly all writers of text-books on the subject, is to assume that they have solved all the problems of the production-line, once they have weeded out most of the special causes. The fact is, instead, that they are at that point just ready to tackle what are usually the most important problems, namely, the common or environmental causes, faults of the system. No fundamental improvement of the production-line will take place until management has a quality control program that works on common causes as well as on special causes.

One sees similar mis-use of other decision-theory. At best, decision-theory can only indicate what would be optimum under the conditions

prescribed for the calculations. Instead of acting on the results of the calculations, and assuming in bliss that this would be the best possible solution, we may be smart to use some dynamite and alter the conditions. Perhaps if we would listen, this is just what the calculations are trying to tell us.

For example, in a recent problem, calculations made with actual data indicated that the optimum work-load per inspector, to achieve a specified reliability at least cost, would be 60 items per day. It would be difficult to find enough inspectors, or room for them, or enough supervisors, at such a low work-load. Instead of acting blindly on the calculations, the statistician, in possession of broader theory, suggested improved controls for supervision, and alteration of certain basic physical conditions. After a period of trial, new calculations showed that the optimum work-load had trebled. The original calculations told us what was best under existing circumstances. They did not tell us that we had to accept those circumstances.

Simple measurement of common causes. It is sometimes easy to demonstrate the existence of common causes, and to measure their importance. One way, for example, is to study statistically the records from all the production-workers or from all the production-lines that perform a certain operation. If the production-workers are all having the same kind of trouble, then common causes are the root of the trouble. There may of course be several common causes or combinations of causes. No improvement is possible until these causes are found and, so far as feasible, corrected.

The first step in a quality control program is to try to procure meaningful figures. A quality control program is woefully one-sided if it fails to produce figures for appropriate statistical information that tells management how they are doing. In Fig. 2 is a p-chart showing the fraction defective made by 20 production-workers that performed essentially the same operation last week. It shows clearly that :

1. The output of the 20 production-workers constitutes a stable, definable process, with a process-capability.

2. The process-capability is 2% defective.

The production-workers have put into their jobs all that they have to offer. Improvement can come only from management, whose duty is now clear : find and remove (or reduce so far as practicable) some of the
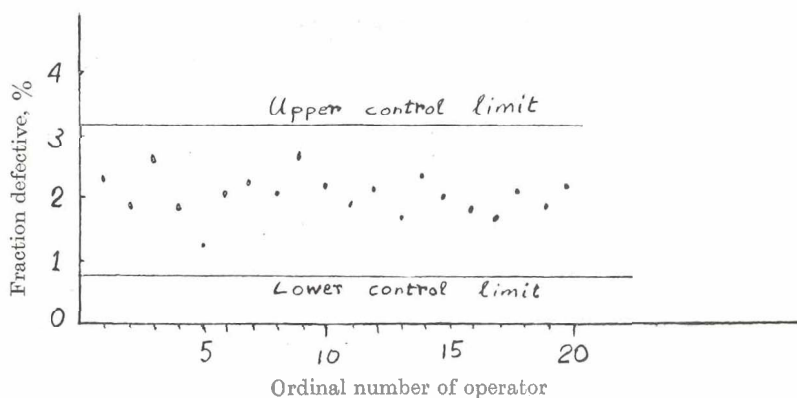
Fig. 2. Fraction defective produced by each of 20 operators. The points are in order of position. (All produced about the same number of items.)

common or environmental causes of trouble, or accept the inevitable continuation of 2% defective.

In how many quality-control programs are there records by which Fig. 2 or some equivalent may be plotted ? In one plant in my experience there was a record of the number of defective items that each operator had produced last month, but no record of his total number of items. In other words, there was a numerator but no denominator for the fraction defective. (An average number would hardly serve the purpose here, because some of the men were in and out of this operation.) Yet the management of this plant boasted that they were fully computerized ! They had a highly paid quality control department, whose chief contribution so far was a wealth of information on every aspect of production except what was important.

We include now an example of a common cause that presented management with a difficult decision. This was the case of a single skilled worker whose job it was to place a stencil in position for imprint of figures on a dial. She did all the imprinting for the output of 100 workers. A single defective imprint was expensive, because the imprinting took place after calibration of the instrument. The plant manager was absolutely correct in his assertion that the girl knew her job and was skilful at it; that every defective dial that she produced could have been a good one instead.

I asked for data : her defectives per week turned out to be in control, which meant that she was helpless to change her level of defectives without

a complete brain-wash and a new start. How to accomplish this was not a statistical problem. The possibility of replacement was, to the manager, not a thought to entertain. Besides, the only replacements would be under-studies. The manager could only accept the girl's level of defectives as the capability of this process. He could also start at once, by trial and error, to develop a completely new operation or combination of operations that would give the girl a new chance. Prior to the statistical tests, no thought had been given to the possibility that the operator was powerless to improve her work.

Curiously, if her defectives had shown evidence of special causes (lack of control), there would have been a good possibility that, by study of her control chart, she could develop a stable process at a lower level of defectives. Unfortunately, she was in a rut.

All variation should be studied. A moderate amount of variation may not lead to defective product. However, if a special cause of variation can be found, it should be removed, as it may otherwise return in intensity or in the opposite direction and cause trouble. Moreover, controlled variation well inside specifications may indicate that cheaper materials could safely be used, or that greater speed and more output could be achieved without risk of more defectives.

Statistical aid to job-description. One contribution of statistical methods in industry is to put operational meaning into job-descriptions. It is customary in industry to give the production-worker a course of training when he comes onto a new job. This training may be merely to watch a seasoned worker for a time. Then comes practice and criticism. The new man may be handed a written description of what motions to perform, and how to use certain tools and materials, plus a statement of the end-product desired. Written instructions, if any, are often difficult to understand, if not incomprehensible, especially by someone literate. The new man relies heavily on help from his fellow-workers. A typical example of an instruction is, "drill the hole in the exact centre."

Unfortunately, the exact centre can not be defined nor found. "Exact centre" requires translation into meaningful (operational) terms. Marks or lights to indicate the centre do not eliminate the problem.

His job-description, to make the best use of modern techniques, should require him to keep his work in statistical control. This is about all that

he can do. He is responsible for his own work, not for the environment. To take action on his own work, he needs to know when his work was out of line, statistically. Given his help, he can usually find the (special) cause and eliminate it for the visible future. Without statistical help (in the form of, for example, an $\bar{x}$-chart) his actions will almost certainly be erratic and chaotic causing more trouble, not less. Judgment is no substitute for a statistical signal.

When the production-worker has eliminated all the special causes in his operation (as by use of $\bar{x}$- and R-charts or otherwise), he has reached a stable process, with a process-capability. If the level of his process is satisfactory, then no further effort on his part can reduce the number of defectives.

Equally, until he has eliminated his special causes and reached a stable system, he has not made his full contribution to quality and to reduction in cost.

Whether the production-worker makes his own chart, and whether he inspects his own work, are irrelevant : the above principles hold with the same force for the same reason.

The above principles hold whether the work is done by hand, with or without mechanical guides, or done wholly by machine. A machine has troubles in production, and the same kinds of troubles that people have. A machine is under human supervision.

Merely to tell the production-worker that his work has been causing trouble later on in production, or even that (*e.g.*) 3% of the holes that he drilled last week are so far off centre that they caused scrap later on, is not much help to the man. If he is smart, he will wonder how much of the 3% he himself is responsible for. If he is conscientious, he will make frantic and chaotic adjustments, hoping for improvement, without the direction that statistical methods could provide. The inevitable result is more trouble than before, along with demoralization from frustration.

Special causes are what Shewhart called assignable causes. The remaining variation, once the assignable causes are removed, is from chance causes, as he put it, because its behaviour satisfies the statistician's conditions of randomness. Actually, as we know now, it is uneconomical to leave the remaining variation to chance. The remaining variation is management's contribution to trouble, and management's responsibility to reduce,

Figures with little or no meaning are especially to be feared where there is feed-back from computers. This need not be so, but in my experience it is. Expert programming without statistical guidance will dependably, in my experience, turn out figures that do not distinguish between what is chargeable to the production-worker and what is chargeable to environmental causes. An information-system is not to be measured in the volume of figures turned out, but in effectiveness, utility. An information-system, to be effective, must produce figures that will fit into a formula or chart that will help to guide a course of action.

Brief mention of uses of statistical methods in various stages of production

We have reviewed to date some important uses of the statistical control of quality in the production-line. We now take a brief look at some additional problems of management in which statistical methods play a part, sometimes minor, sometimes major. The following partial list of items, some offered with comment, some with none, will perhaps indicate that statistical control of quality is a system of assistance to management. It will also serve as background on which to reach some logical conclusions about training, education, and staffing for the statistical control of quality. Some items are repeated from previous sections, as reminders. The order is of no significance.

1. *Feed-back to the production-worker.* A system of speedy feed-back from inspection to the individual production-worker of information in appropriate statistical form (distribution, run chart, Shewhart chart) to indicate when he should take action on his own operation.

2. *Feed-back to management : how is management doing ?* Continual measurement of the effects of common or environmental causes of variation and of defectives. Another aspect of the feed-back to production-workers is a regular summary to present to management to show how all the production-workers in a certain operation are performing (Fig. 2). Such summaries and other regular presentations of measures of the effects of common or environmental causes of variation, and of action taken by management to reduce or eliminate them, is a vital part of the statistical control of quality.

3. *Specifications and tests of materials.* A specification, to have meaning, must be stated in statistical terms. This is so whether the specification be for raw material like coal or ore, or for piece-parts, assemblies, or

finished product, incoming or outgoing. The appropriate raw material, its minimum tolerance and maximum tolerance in respect to content of an impurity (*e.g.*, of sulphur) or of a desirable ingredient like chemical iron, depend on the process that the raw material will be fed into. What a manufacturer should specify is the cheapest material, hence the lowest grade that will serve the purpose. How may he know and express in meaningful terms the lowest grade of purity that he can tolerate ? He requires tests of the process, with ores of different grades, to observe the costs and difficulties encountered. Not only what is the minimum grade, but what degree of uniformity is required ? Then, upon receipt of a lot of material, there is the question of whether it meets the tolerances. How is the load of ore to be sampled ? Must every sample meet the tolerances ? Or is it the average of all samples or of 4 successive samples that must meet the tolerances ? How much variability is allowable from sample to sample ? Obviously, a specification would be meaningless unless it would answer these questions. The only language that can answer them with meaning is statistical.

One may sense the dependence of specifications and tests on statistical methods by noting that he can not without statistical methods define such seemingly simple adjectives as uniform, reliable, quality of a single lot, quality of a succession of lots, effectiveness of a drug, quality of service, unemployed. One can not define, for example, on-time performance of delivery, or on-time arrival of a train or aeroplane, except in terms of a distribution of arrivals.

4. *Rules for acceptance for a succession of lots.* There will be tests and criteria that determine whether a single unit of product conforms to specifications. It is equally important to have rules for the sampling and acceptance, on a lot-by-lot basis, of a stream of lots, to guarantee a desired level of quality in lots accepted (supplemented by lots re-worked according to the rules of the plan), commonly called the average out-going quality limit and abbreviated AOQL, after Dodge and Romig.

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 ? How big a sample will be drawn from each lot ? How will the sample be drawn ? What will be the allowable number of defective items in a

sample ?   What is to be done with pieces found to be defective in a sample ? The acceptance plan by which lots will be accepted, or a ship-load of ore or of coal, is as necessary for economic production as the specification that tells whether a unit conforms to a specification.

5. *Assistance to vendors or suppliers.*   Any raw material or piece-part is someone's finished product.   Dependable quality of incoming materials from vendors is one of the most important requirements in a program of quality.   Statistical methods are essential for showing suppliers where they need improvement.   Shewhart charts and other tests serve as an effective link in communication.   Some of the best gains from statistical methods have come from assistance to vendors.   If a chart for fraction defective in samples of product from a particular vendor shows statistical control, this vendor, to improve, must make some fundamental changes in his shop, as his main trouble is common causes (vide infra). This condition presents a chance for the purchaser to render assistance with the help of his own experts.

If, on the other hand, the chart shows lack of statistical control, then the vendor is tolerating erratic conditions in his shop, which he can clean up.   **He will of course be plagued in addition with common causes.**   Help to a vendor to develop him to his own quality-program may be a vital part of the quality-program of the purchaser, as it was in Japan in 1950, and since.

A plant-manager meets the same problem in the requirements for quality as a product moves from one stage to another in the production-line.   One operator's raw material is finished product from a previous operation.

6. *Capability of the process.*   This statistical measure is so important that an understanding thereof could well be said to embrace the major part of the theory and application of the statistical control of quality, or even of the whole theory of management in production.

A goal of uniformity, or of level, or of productivity, if it is not to pull down destruction of pride and profit, and not to demoralize the personnel **of a company, must lie within the capability** of the production-line.   A great mistake in management and administration the world over is to set goals that are economically unattainable : to presume that any desirable level of precision and quality could be achieved if the production-workers would only do their jobs.   Knowledge of the capability of a process has

saved more than one company from entering into a contract to produce precision, uniformity, or quality that they could not deliver, and which could only have brought down heavy loss.

In the first place, a process exists and has a measurable capability only in a state of statistical control. A Shewhart chart, for example, for a process in control, shows the level of quality and the degree of uniformity that CAN BE MET ECONOMICALLY. No greater uniformity or precision is possible until management corrects some of the common causes of variability. This correction may require a fundamental change in the process. In manufacturing, capability of a process is a measure of the precision or uniformity in dimensions, color, hardness, process average, average number of flaws per test specimen, or of some other quality characteristic that a controlled process is delivering. In administrative work it may measure the economical degree of accuracy in some operation such as computation of charges, billing, transcription, punching. In administration of the out-patient department of a hospital or clinic, it might be reduction of waiting-time and the variation thereof, day by day. In administration of a department store, it might be reduction of the waiting-times of customers day after day in the various departments. In some types of business it might measure the feasible performance of drivers, maintenance of trucks or of other equipment.

7. *Statistical aids to supervision.* The working-relationship between production-worker and his foreman and management should, for economic production, be one of mutual aid with a common goal. Unsupported criticism does more harm than good. A control-chart or equivalent statistical tool, when understood, provides incontrovertible evidence of how the production-worker is doing. **It is there for everyone to see.** It indicates to anyone whether the production-worker could improve his work, or whether the rest is up to management. Need of re-training or of transfer to other work may be management's solution.

The work of the foreman is made effective when the advantages of statistical aids to supervision are recognized and applied. Statistical supervision calls for a shift in emphasis. It should be to help the production-worker to understand the signals for action on a special cause, and to discover common causes, with a recommendation for action at a higher level.

The U.S. Census, especially in its numerous recurring sample-surveys, has by use of statistical aids to supervision cut costs to a third of the usual

cost of surveys in consumer research carried out by private industry, and has achieved quality incomparably superior.

8. *Control and improvement of inspection.* This means experimental design for re-inspection of small samples, or by interpenetrating samples in destructive testing, to improve the reliability of inspection and to learn how inspection can produce more useful results. Unreliable inspection can create havoc and demoralization of production-workers by classifying good product as defective, and the converse. Unreliable inspection can lose future business : no one can calculate the cost of a defective item once it goes out on the market.

9. *Maintenance of standards.* This means statistical tests of instruments and guages; training and supervision of use of instruments. Maintenance of quality of product, and quality-assurance, are highly intricate statistical problems; also highly intricate substantive problems.

10. *Interlaboratory testing* (closely allied with the quality control of **instruments and guages**). This activity is important for both buyer and seller, else the buyer may pay too much for his material purchased, or the **seller may receive too little. Both are entitled to a square deal. This** activity is important in a company that has several plants that make the same or nearly the same products.

11. *Consumer research. Design and re-design of product.* This is one of the most important steps in the production-line. Without the consumer, there would be no production. Recognition of the need of consumer research, and the type needed, is one of the problems of management. It is a responsibility of management to provide funds for studies that will provide information about the consumer's views. Management must provide feed-back, into the re-design of product, results from tests, whether conducted in the laboratory or in service : otherwise expenditure for such information will be wasted.

The content of consumer-research is largely substantive, but the design of tests of prototypes, tests of product in the laboratory and in service, tests of questionnaires, the sampling of product and of people, and the interpretation of results, are essentially statistical for reliability and economy. So is the design and interpretation of service-records.

Consumer research tells the company how the product is being evaluated by the customers. It also tells the company how customers size up their

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product and how in their opinion it compares with the product of some other company. It attempts to evaluate the results of advertising, the effect of a change in quality or in price, and the effects of other schemes aimed at selling and increasing profits. Consumer research may lead to re-design of a product, or new alignment for service to the product. Re-design (as depicted in Fig. 1) may call for different raw materials, may be less expensive, may be more expensive. Re-design may call for changes in the method of production.

Make it right has no meaning except for a product that was designed to satisfy a market. No matter how well the production-workers perform their jobs, a product of inferior design will lose out to competition and will drag the company toward lower earnings. Anyone can cite instances of a product that was made accurately, uniformly, and economically, while it was made, but which was pulled off the market, at considerable loss to the manufacturer, for the simple reason that it would not sell.

Some companies that carry out consumer research fail to get much 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 claim that they know what to do without the help of consumer-research. Only management can correct such failures of organization.

Another important application of consumer research is to help management to look ahead to plan production economically. There is no profit in a warehouse full of product that has lost its appeal to the consumer, or that moves too slow and has to be downgraded to get rid of it. The manufacturer that underestimates the demand for his product and is caught short while his competitors fill the vacuum also suffers. Use of statistical methods in consumer research is no guarantee of correct vision into the crystal ball for the future, but they can help by providing information of known precision on reasons for acceptance or rejection of product on the market, and under appropriate conditions, about product on trial but not yet in production.

12. Meaningful monthly reports on quality and production, or on sales, sent out from headquarters to plant managers and supervisors, written or depicted so that the recipient can understand where action would be effective. (The usual globs of figures sent out from headquarters are worse than useless.)

13. Optimum policy for inventories of materials and spare parts, to meet at lowest net loss certain risks (probabilities) prescribed by management of (a) being caught short, and of (b) over-investment.

14. Design of equipment and manning of service-organization, to meet at minimum net loss certain risks (probabilities) prescribed by management of (a) being caught short—too many customers wait too long, and of (b) customers satisfied, but equipment and man-power idle too often. The statistical theory used here is commonly called queueing theory (originated by A. K. Erlang in the Copenhagen Telephone Company, 1909, and onward, and by E. C. Molina in the American Telephone and Telegraph Company).

15. Development of optimum operating conditions; scheduling; sequencing. Reduction of interference. Optimum number of operators and optimum number of machines at each operation.

16. Estimation of the proportion of time that workers wait in line to draw parts out of stock; estimation of the proportion of time that machines are down for repairs (as by use of Tippett's ratio-delay methods; also called work-sampling). Estimation of the costs of various operations.

17. Experimentation and calculation of rules for economic blending of product of different grades or different concentrations to meet a prescribed standard—cotton, wool, ore, coal, fertilizer, grain, oils, and other bulk products.

18. Experiments on packaging and shipping to find the minimum net loss from damage in transit and the cost of better protection.

19. Evaluation of approach toward a desired degree of reliability of performance of product. Theory of reliability and theory of complex equipment are important. (Note that the term reliability has no meaning except in statistical terms, nor can it be measured otherwise.)

20. Prediction (from records) of extreme values of gust, thrust, tension, compression, torsion, temperatures, voltages, lightning, etc., likely to be met by mechanical or electrical structures and devices.

21. Optimum policy for maintenance and replacement of parts and equipment, highly dependent on statistical theory to achieve at lowest cost a specified degree of reliability of performance. Statistical design of studies to estimate the physical condition of machines, as a basis for allocation of funds for repairs over the next five years.

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22. Tests of drugs and of treatments.

23. Design of meaningful information systems.

24. Inventories by sampling, for greater accuracy and speed.

Most of the content of today's censuses are collected and tabulated by sampling. Monthly and quarterly economic indicators on employment, unemployment, prices (consumer and wholesale), number of new dwellings, home-repairs, are in most countries outstanding examples of application of modern statistical methods.

The non-statistical reader may little suspect that these divers 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 by several names, theory of probability, statistical theory, theory of sampling. Some people would call the statistical **control of quality operations research or systems analysis.** New names for a discipline or for a profession neither discover problems that need solution, nor solve them. **The name is not important.** What is important is action by whatever name.

Some remarks on organization and education for the statistical control of quality

It may be obvious now that statistical work in any company large or small has diverse applications and requires extraordinary talent. The material benefits from skilled statistical work are huge. Competent statisticians are scarce. What can management do ? It is obviously necessary to stretch competent statistical knowledge as far as it will go, to make the best possible use of it. The problem is so acute that the reader may forgive an attempt to offer here some principles of organization.

Training and education for the statistical control of quality falls into **two broad categories.** Easiest to explain (because it is so well known) is the training of the production-worker so that he may understand simple charts, to help him to remove special causes (for which he alone is responsible). Concentrated courses in rudimentary principles and techniques given in the span of a few days have been highly successful in teaching thousands of production-workers and foremen to think statistically and to learn simple statistical techniques that help them and their foremen to do their jobs better.

The educational requirements for statistical work as assistance to middle and upper management for the measurement and reduction of common (environmental) causes, and for working on a host of problems like those mentioned in the last section, are a completely different matter.

Men to head up a program in the statistical control of quality, as I said at the beginning, are not on the market, nor are they produced or **bought on specification. They are not made in 8 days. They are theore-**tical statisticians—that is, statisticians that guide their practice with the aid of theory, in contrast with the practical man who was described by Julian Henry Huxley as the man that practices the errors of his forefathers. Continual acquisition of new theory is necessary, along with a lively interest in helping management to see what are the important problems ahead, together with ability to educate other statisticians in the organization and to teach rudimentary statistical methods to production-workers and foremen.

It is obvious that effective organization for statistical methods must be modeled on principles of conservation of rare, valuable resources—in this instance, knowledge and ability in statistical methods. No company can afford to waste statistical talent. In this connexion, I may call attention to the contribution to statistical organization that my colleague Dr. Morris H. Hansen developed years ago in the Bureau of the Census in Washington. All statistical work is under the technical direction of a statistician (as it happens, having the title of Assistant Director for Statistical Standards, ADSS hereafter). A statistician in a subject-matter division (population, housing, agriculture, business, etc.) is responsible to the ADSS for his statistical work, though responsible administratively to the head of the subject-matter division.

Thus, the statistical work throughout the Bureau is under constant **review by a competent statistician.** Promotion of a statistician anywhere in the Census depends on the merits of his performance as a statistician. He does not advance by mis-using his talents to justify questionable statistical procedures that happen to be the pet whims of the chief of a subject-matter division. This system provides nurture and incentive for advancement of knowledge of statistical theory, and for skill in application. **Statisticians grow in stature. The decision of the ADSS is final on** statistical matters. At the same time, the system gives to the chief of a

subject-matter division complete responsibility in substantive matters and complete latitude in the acceptance or rejection of the statisticians in his division. Small wonder that statisticians come to the Census in Washington from various parts of the world to study statistical theory and application.

Some companies, as everyone knows, provide under certain arrangements scholarships to send some of their promising statisticians to great statistical teaching centres for doctorates. Any size of company can have the benefit of statistical consultants of the highest competence, provided management exhibits interest and determination to act on statistical advice.

Impediments in the road to better quality in most parts of the world are (1) the scarcity of theoretical statisticians; (2) failure of management to acquire appreciation for the statistical control of quality as a system; (3) failure of management to provide organization for effective use of the statistical knowledge that will attract and hold competent statisticians, and draw forth their best efforts.

It is a common fallacy of management to assume that a statistician, before he can be useful to a company, must be thoroughly familiar with the company's policies of procurement, production, and marketing. Management even sometimes looks for a chemist or an engineer that is also statistician.

This is a costly fallacy. Abundant experience shows the benefit of bringing into an organization a new kind of knowledge. The statistician with an interest in problems will learn rapidly what he needs to know about the subject-matter and about the production-line, the procurement of materials, the instruments used for tests, the distribution and marketing of the product. His knowledge of theory will tell him what he needs to know and what new data are relevant to a problem, and what are irrelevant.

Statistical work is not a side-line and is not a part-time job. One does not dabble in statistics. One is not engineer and statistician; nor economist and statistician; etc. He is one or the other, or neither. There may be exceptions, but it is poor management to hope to engage the exception. Expression of such hope from the head of a company would itself deflect a competent statistician.