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Special Memorial Issue

Journal of the American Society for Quality Control

In Memoriam

In recognition of his outstanding professional accomplishments, this issue of *Industrial Quality Control* is gratefully dedicated by the Board of Directors of ASQC to the memory of

Walter A. Shewhart

whose pioneering efforts in joining the forces of statistics, engineering and economics, opened the door to the science of statistical quality control.

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Industrial
QUALITY CONTROL

ASQC

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Vol. 24, No. 2 August 1967

DEPARTMENTS

MISCELLANY

ARTICLES

The First Shewhart Control Chart

Case 18013

WAS-724-5-16-24-FQ

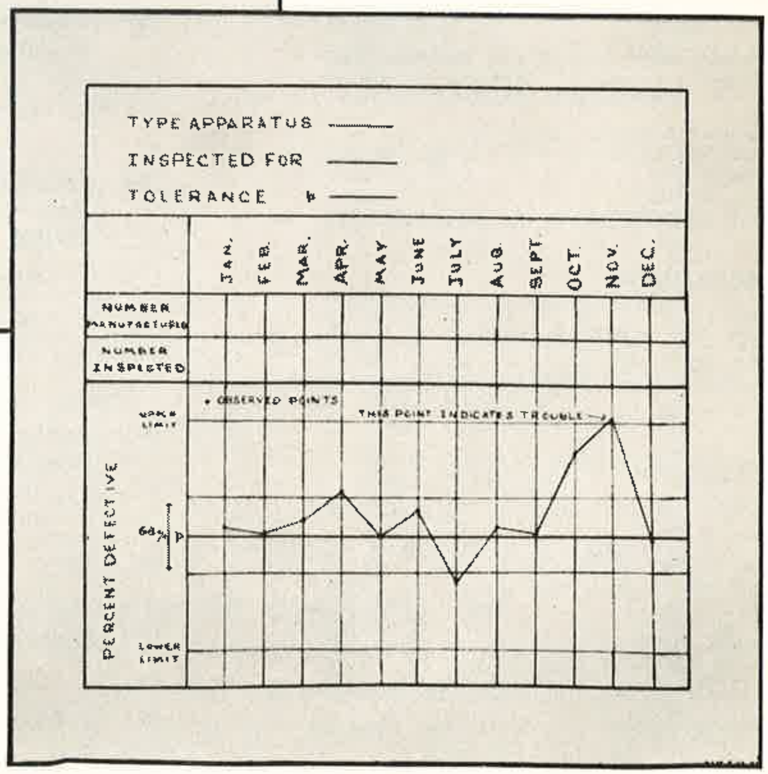
MR. R. L. JONES:-

A few days ago, you mentioned some of the problems connected with the development of an acceptable form of inspection report which might be modified from time to time, in order to give at a glance the greatest amount of accurate information.

The attached form of report is designed to indicate whether or not the observed variations in the percent of defective apparatus of a given type are significant; that is, to indicate whether or not the product is satisfactory. The theory underlying the method of determining the significance of the variations in the value of p is somewhat involved when considered in such a form as to cover practically all types of problems. I have already started the preparation of a series of memoranda covering these points in detail. Should it be found desirable, however, to make use of this form of chart in any of the studies now being conducted within the Inspection Department, it will be possible to indicate the method to be followed in the particular examples.

W. A. SHEWHART.

Enc.:
Form of Report.



Our Debt to Walter Shewhart

Each member of the American Society for Quality Control owes a debt to Walter Andrew Shewhart. In this Memorial Issue of *Industrial Quality Control*, some of us have tried to show by specific example the nature and extent of this debt. He was always interested in hearing about our problems, particularly those that we were finding hard to solve. He had worked out a compact theory that could be tested again and again. Each new problem provided new data for such a test. In a meeting of minds over such a problem, he would want to know what current theory suggested as an answer. With this in mind, the next step was to see whether the data were consistent with this hypothesis. In particular, would the data meet a criterion of control, such as might be exhibited by a simple control chart? Failure to meet such a criterion often led to discovery of an "assignable cause." As we use this basic procedure, we are continuing to test his theory.

The first control chart was attached to his first memorandum on Quality Control. A framed photograph of these two documents was presented to the American Society for Quality Control by Bell Telephone Laboratories in commemoration of the Twenty-Fifth Anniversary of their preparation. A copy of them appeared on the front cover of *Industrial Quality Control* in January 1950, and is reproduced on p. 72. The "series of memoranda" that he mentioned was the theoretical background for group discussions in the department where supporting examples were often supplied by his associates and others. These memoranda and discussions provided the essence of many of the chapters of his first book, *Economic Control of Quality of Manufactured Product*, published by D. Van Nostrand and Company in 1931.

The first chapter of this book provides an insight into the evolution of a physicist into someone quite different. As a physicist, he was exposed to the concept of "'exactness' of physical laws." After he turned to engineering work, it became increasingly clear that some other concept was needed. He refers to the "breakdown of the orthodox scientific theory" requiring "revision in our ideas of such things as a controlled product, an economic standard of quality, and the method of detecting lack of control." To assist others in following his line of reasoning, he included Appendix III in his book: "A Bibliographic Guide with Suggestions for Study in the Further Development of a Scientific Basis for the Economic Control of Quality of Manufactured Product." In introducing this appendix, he states: "the present book is but an 'initial' step toward the formulation of a scientific basis for securing economic control. Much remains to be done." This is a challenge to each of us. In this guide to his evolutionary thinking, he expresses the hope that "these references will be suggestive of work which may be profitably done in extending the theory of quality control, particularly in the direction of improved ways of securing good data through the more thorough application of the scientific method." A section of the appendix on "Detecting Lack of Control" is particularly interesting. Here, he urges the student to delve into the "fields of psychology, philosophy, and logic; into the field of psychology because we must get some sort of picture of the way the mind works; into the field of philosophy because we need some hypothesis as to the nature of reality and the function of laws, theories, and causal explanations; into the field of logic because it presents what we know about the formal methods available in the theory of deduction and induction." That his theory of Quality Control has a solid foundation is amply attested by the quality of his references, an example that all writers should be required to follow.

His second book, *Statistical Method from the Viewpoint of Quality Control*, edited by Dr. W. E. Deming and published by the Graduate School, Department of Agriculture, Washington, 1939, carried his thinking a long step forward. In the April 1967 issue of the *American Statistician* (and reprinted in this memorial issue), Dr. Deming pays tribute to Dr. Shewhart's contribution to scientific thought as expressed particularly in this book. The book helps us to think more clearly about what we mean by original data, about what we may lose in making a summary, and how the theory of statistical control may help in their interpretation. Particular attention is drawn to the limited usefulness of the "Student" or confidence range as compared to the tolerance range. The effect of this type of thinking on presenting the results of physical measurements is then considered along with a philosophical discussion of the meaning of accuracy and precision. Some of us may be surprised at his statement: "it is impossible to specify once and for all a satisfactory operationally definite meaning for either accuracy or precision." (p. 145)

Each recipient of the Shewhart Medal has indicated his indebtedness to Walter Shewhart in some way that made it possible to extend the Theory of Quality Control. Perhaps the American Society for Quality Control should consider republishing the Shewhart Medal Addresses in periodic bound volumes as a continuing memorial.

Dr. Shewhart was an inspiration to all who knew him. Sometimes, it took the form of suggesting a problem to be investigated by a mathematical statistician. He would promote meetings on standards. He even brought together people in the social sciences to sit down with others from the natural sciences. He encouraged everyone he met to get involved with committees and societies, no doubt hoping that this involvement would broaden their thinking and that Quality Control would benefit thereby. Truly, our debt is large.

Paul S. Olmstead

The Shewhart Medal

The concept of the Shewhart Medal originated early in 1947 and plans for it were consummated in 1949. The father of this Award, the man whose untiring efforts brought the plan to fruition, is Philip L. Alger of General Electric. The best statement of the plan and purpose of the Award was made by Mr. Alger at the Boston Convention in 1949. His speech, in part, is reproduced here as it appeared in the May 1949 issue of *Industrial Quality Control.*

"In June of 1947, the Directors of our Society voted to establish the Shewhart Medal for the recognition of individuals who have made 'suitably outstanding contributions to the cause of quality control.' In September, the Medal Committee was appointed, and in the following July its plans were announced.

. . . . .

"The real questions before us this evening, however, are: why should we have such a medal at all, and to whom should it be awarded?

"We *elect* persons to office, so that they may perform governmental or political services for us—thoughts of our own benefit being uppermost when we vote.

"We *appoint* other persons to positions in industry or government, so they may perform necessary tasks—here again with the thoughts of results beneficial to ourselves.

"The process of choosing a medalist is quite different.

"We *select* a medalist, to do him honor, with no thought whatever of any *quid pro quo* on his part. There is a real social benefit from this, however.

"This benefit accrues when the act of awarding the medal focuses the spotlight of public attention on the recipient, revealing in clear light the qualities that have won for him the esteem of his peers. In this way, the public obtains a glimpse of the values that make up a profession such as ours, and young men everywhere are inspired to emulate the ideals personified by the medalist.

"What are the qualities that lead us to so honor a man as to give him a medal? First of all, he must have intellectual ability, enabling him to clear away a little of the dark cloud of ignorance that always surrounds us. Second, he must have the generosity of spirit that leads him to so express and restate his pioneering ideas that other members of his profession may benefit from them. And finally, he must have that warmth of human feeling that marks the true educator, endearing him to his students or disciples, even those who learn from him only remotely.

"All of these qualities are eminently personified in Dr. Walter Shewhart. The members of your medal committee feel honored to have been the instruments of your appreciation of his generous and pioneering contributions to the new profession of quality control."

The first medal struck was presented to Dr. Shewhart as shown in the accompanying reproduction from the cover of the May 1949 issue of IQC. Except for one year the Medal has been awarded annually since then as a feature of the Society's Annual Technical Conference.

The roster of Medalists follows:

Leslie E. Simon	1948	Edwin G. Olds	1954	Ellis R. Ott	1960
Harold F. Dodge	1949	W. Edwards Deming	1955	Leonard H. C. Tippett	1961
Martin A. Brumbaugh	1950	Mason E. Wescott	1956	Lloyd A. Knowler	1962
George D. Edwards	1951	Cecil C. Craig	1957	Acheson J. Duncan	1964
Eugene L. Grant	1952	Irving W. Burr	1958	Paul C. Clifford	1965
Harry G. Romig	1953	Paul S. Olmstead	1959	Edward P. Coleman	1966

Spiraling Professional Vectors of the Quality Field: A Preliminary Study

EDWARD P. COLEMAN

University of California, Los Angeles, Calif.

Shewhart Medalist Address

by Edward P. Coleman

Introduction

On the 11th of March of this year of 1967, Dr. Walter A. Shewhart passed from the scene of his earthly activity. He was the acknowledged father of Quality Control in industry. Personally, I can remember very well the sound of Dr. Shewhart's voice, but I have wondered if this was recorded for the sake of posterity. I have also studied many times the products of Shewhart's pen[11,12], but I never did have more than very limited opportunity in the late 1940's and early 1950's to greet him at the end of a lecture at Princeton or elsewhere in the New York area. However this was quite sufficient for me to feel the warmth of the man, to observe his keen insight, and to witness the genuine respect held by his peers and friends, who surrounded him.

In considering the topic of "Spiraling Professional Vectors of the Quality Field" during the next few minutes may I invite you to give your full attention to this important subject. In these deliberations and in later considerations, let us be aware of the real world alternatives and consequences which uniquely face us in this particular field of quality.

It may very well be that in our future planning, we should consider the year 1967 of Walter A. Shewhart's passing as the beginning of the "second generation" of modern quantitative quality operations in industry. If we were to go so far as to designate 1967 as the beginning of the thrust of the true profession of quality, we hopefully would not be far in error. I can think of no other profession which had more creative and diligent pioneers to formulate its original concepts and to superintend its first applications. Likewise, there is no profession better equipped with knowledgeable and resourceful men to lead in future new discovery and in new practice than is our proverbial "quality profession."

May we mention here two outstanding and observable facts about the quality profession today. First, approximately ninety percent of the original pioneers of the field are alive today, and they are continuing to work actively in the highest tradition of a profession throughout their entire lifetimes, which now, in several cases, is considerably beyond age seventy. Second, a number of our younger professional quality men have accepted high level positions of company-wide administrative responsibility, others have moved to professorships at distinguished universities or visa versa, and still others continue to advise our government and foundations on national and international quality matters. In all of this activity, the batting averages of these men are very high indeed. They are making unique, unselfish contributions consistent with the balanced judgments required to truly professional men in any field.

Pertinent Characteristics of Vectors and Spirals

When we speak of the thrust of the "so-called" quality profession, we do not wish to imply that quality technology and practices have become such standard procedure that they now can be turned over to the "boys" to operate with carefree "8 to 5" freedom and indifference. Wade Weaver[18] said in his Edwards Medal Address in 1961 that he would like to give some "advice from an old fogy." Now, of course, we all enjoyed that grammatical construction of humor from a thinking and practical man like Wade Weaver. However, as my own years have begun to creep up a bit lately, I have come to realize that the problems of avoiding obsolescence is worthy of consideration of not only the average man like myself but also of the very best of men in any profession. I am sure that you have heard the continuing admonishments by many of our industrial leaders to the current crop of collegians and budding engineers—to the effect that one-half of their newly acquired education will be obsolete within five years or so. However, it is significant that we not become careless about our education, for we do not yet know which half of it will be obsolete in so short a period of time.

Mr. Coleman is Professor of Engineering at UCLA, and a Fellow of ASQC. Presented as the Shewhart Medalist Address at the 21st Annual Technical Conference, ASQC, in Chicago, Ill., June 1, 1967.

ASQC LCS Code 000:00:000

In preparing this article for your consideration, we have tried to relate the words *spiraling vectors* realistically to meaningful concepts of a *quality profession*. In this, we immediately think of the intrinsic vector concept as that of adding direction to what might otherwise be called a scalar concept only in the quality profession. However, we could easily ask ourselves, what is the azimuth of the direction for the quality profession?

We can also associate the *spiral* concept with the increasing complexity and diversity of the quality profession. A positively turning vector spiral can be thought of as covering more and more ground with each revolution. Likewise, a negatively turning vector spiral covers less ground each revolution, and it ultimately approaches naught. In an analogy with a fixed amount of education corresponding to a fixed radial point on a spiraling vector of the quality field, one would find, after a few cycles, that his professional horizon was very limited and that he was in fact an obsolete man.

The Intent of This Article

This article has been written to be a little longer than its oral presentation was. You will notice 21 references at the end of the article which are indicated by numbers in parentheses. This has been done so that the reader can study what other writers have said on related subjects, if desired.

After several years of some little study of the *professions* in relation to Engineering and Quality in industry,[1,2] I have been motivated to present this particular article rather than a more technical one for this occasion. However, I would appeal to your better judgment to realize that I should have no illusions of grandeur about proposing an all-inclusive solution to our many quality-professional problems. Moreover, we do not see final solutions to professional problems for engineering societies or even for our own American Society for Quality Control. We think that all of these organizations are doing excellent work and that they are making rapid professional progress. The remarks of this article are dedicated rather to the present-day individual listener or reader, who in the end must help solve his own problem of a quality profession.

The Learned Professions

The word profession (or professional) has different meanings to different people, depending upon its use and/or intended connotation. The professional diplomat certainly has a different connotation in statesmanship from that of the professional gambler in deceptive cunning. We all hear humorous references to the lady who dispenses her favors for a price as practicing the "oldest profession."

Let us ask what are the indispensable characteristics of a profession, which might be visioned as that of a "high calling, noble service, service to mankind, etc." We know from studies by eminent historians[21] that we must look deeply into our historical roots to understand our ecological niche and the enduring characteristics of a true profession.

According to a study conducted at the University of Arizona and reported on in February 1957, it is not always clear just what a modern professional calling really is. We have indicated earlier in[1] that there are approximately six basic characteristics of the learned professions. We try below to succinctly re-state these characteristics of a profession:

1) It must involve to a substantial extent for the prospective practitioner both a knowledge of fundamental science and a highly developed skill in a related art.
2) It should be reflected adequately in major and minor field curricula of the very best academic institutions, both for the pursuit of truth or scientific understanding and for career-making purposes.
3) It should require of the practitioner constant individual study and use of the corresponding science and art in daily practice throughout a working lifetime.
4) It must be a noble calling from a service-to-humanity viewpoint and be of tangible value to the public.
5) It should emphasize a strict code of ethics for all its practitioners in their relationships to each other, to their clients (employers) and to their employees.
6) It should constantly strive to increase the earned respect and public recognition of the calling as a whole through an ever-growing percentage of its practitioners who voluntarily in daily practice meet adopted professional, educational and ethical standards.

The professions of Theology, Medicine and Law are generally referred to as the *learned professions*. The origin, growth, and practices of these professions have an interesting history in human society. This history has been turbulent at times as well as inspiring. The learned professions compare very favorably with the criteria of the six above intrinsic characteristics of a profession, but the learned professions differ in many respects individually. These differences and similarities are very interesting studies in themselves, but they will not be elaborated upon in this article. Suffice it to say that these differences and similarities lie in the relationships and approaches of the professional practitioners to themselves, their clients (employers), and their employees. Sharp definitions and distinctions are found in the historical professional literature for the responsibilities, privileges, services, viewpoints and expectations of the *server* as well as of the *served*.

The Next Profession

Will there ever be another profession to equal or rival the earned respect of the learned professions in serving another human need? Is it possible that the professional high calling concept and practice in modern society is decaying? One can find many cases of professional breakdown in individuals and in these groups of our society. Professor Alexander Stoyanow of the University of Arizona says from his ecological and geological studies that man has made little progress in controlling his basic greed and selfishness. He contends that man's benevolent acts in an uncrowded environment of plenty would contrast markedly with his acts in an overpopulated world of deprivation and hunger.

There are other individuals who believe enthusiastically that *Engineering* will be the next profession, the fourth learned profession. Their enthusiasm is held even though the word *engineer* may refer to almost any vocation from train driver to research scientist. The Engineers' Council for Professional Development states that "Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind."

However, Dr. Marlene Dixon in well-planned sociology studies at the University of Chicago has stated recently, somewhat indefinitely, that a "profession is a job in which a man or a woman defines his own personal goals, and does his work in the way he knows is right and for which he is trained." She warns that engineers like to think they belong to a profession with strict standards, but that they are far down the road to the loss of independent status. She points out that there are three types of students in our engineering colleges: (1) students preparing for industrial management positions, (2) technicians for whom engineering is just a job, and (3) those committed to research and truth. She says that the latter group are the only ones that fit a professional classification, in which she emphasized the extreme importance of "independent judgment and freedom of action."

This points up the fact that a vocational or career group may not get to be a *profession* by merely calling down upon themselves a *professional* umbrella or by using the word *profession* in the definitions or titles they promulgate for themselves. It is significant to note in the literature of the learned professions that the word *profession* is seldom, if ever, used. A word like *physician* carries the full professional connotation for the medical field.

Joint Professional Activity in Quality and Engineering

We might ask the question—is there a truly professional area in the Quality field? If so, is the expression *Quality Profession* sufficient to identify it? Would there not be better words like *reliability, effectiveness* or some other word to carry the connotation of merit in product or systems performance? These questions should be given careful study in both professional areas of Quality and Engineering. (We will continue to use the word "quality" in this article for our professional field connotation.)

Should professional people in the quality field ally themselves professionally with engineers? Many think so. It is interesting to observe in[13] that Robert W. Shearman has attempted to make significant implicit comparisons in his recent article "ASQC—Lucky 13 Among the American Engineering Societies." He states that "ASQC as an organized technical society is in a unique position to meet . . . in the decades ahead . . . upgrading in quality . . . challenges. It (ASQC) has taken its place as both an *engineering society* and as a *management society.* Engineers will be called upon to design better products, and quality engineers will be in the forefront. . . ," etc.

We do not wish here to equate the American Society for Quality Control to the hypothesized quality profession, or to equate any engineering society directly to the profession of engineering. We would reiterate that professional respect and responsibility is not earned by mere self assertion. However, many of us, like Simon in 1949,[14] are concerned with the advance of the professional concept of quality. Simon provided sound argument that the fields of Quality Control and Engineering have many common techniques, procedures, and philosophies. Moreover, it is not surprising that Tippett[15] would state later that management and human aspects of quality work are most important.

It becomes clear from all such comparisons and deliberations that engineering and quality operations are highly related. An interesting comparison is that project engineers, design engineers and engineering technicians of the engineering field correspond favorably to Quality Managers, Quality Engineers, and inspectors of the quality field. We believe that the highly professional nature of both of these important fields has not been sufficiently understood and supported by many responsible leaders in the past and that this has tended to retard professional progress in the engineering and in quality fields.

Spiraling Vectors in the Quality Field

There are many dynamic forces acting in the quality field which we could describe as spiraling vectors. It should be noted that some of these forces are good and some are bad, some independent and some dependent, some external and some internal, some mutually exclusive and some overlapping, some supporting and some contradictory, etc. We should understand that each such force is centered on growth, recognition, and dominance in the quality field regardless of its merit.

1) *The System Vector.* As man moves toward the outer reaches of space, he must design and build systems with higher and higher levels of inherent reliability. He must understand that adding complexity to engineering systems composed of components at current performance levels will only decrease the reliability of the overall system. To add complexity and at the same time increase the reliability in future systems, new knowledge, new test procedures, and new components with significantly higher reliabilities must be discovered and perfected. Certain variable behavior in engineering, manufacturing, and human systems, once said to be stochastic in its fundamental nature, must now be explored and reduced as far as possible to deterministic laws or to acceptable states of technological control. To reach this new state-of-the-art and to achieve the industrial proficiency necessary to the competitive existence and excellence of our nation and the allied world, the engineer, the technical man, and the manager must improve their understanding of current real world systems with increased knowledge of mathematics, science, engineering, stochastic phenomena, statistical decision procedures, and human behavior.
2) *The Professional Vector.* Perhaps the most distinguishing and unique characteristic of the quality field is the use of the "so-called" scientific method and the discipline of statistical estimation and decision in the face of uncertainty.[10] It should be interesting to readers of *Industrial Quality Control* to realize that the new concepts of the producer's risk and consumer's risk were conceived and discussed by Dodge and others in the 1920's, several years before Neyman and Pearson advanced independently their concepts of the corresponding Type I and Type II errors in statistics. The basic risks of these errors correspond to certain human priority viewpoints of producers and consumers on quantity and quality in a design and/or production process as follows:
   - *Producer's viewpoint.* The producer is said to aim first for quantity and in addition to hope for the benefits of quality. In any approval or exchange transaction, or procedure, he demands

a given probability protection against the error of rejecting good product.

- *Consumer's viewpoint.* The consumer is said to aim first for quality and in addition to hope for the benefits of quantity. In any approval or exchange transaction or procedure, he demands the lowest feasible probability protection against the acceptance of poor product.
- *Professional viewpoint.* As you can see in the above, the priorities and demands of the producer and consumer are in first priorities in opposition to each other. However, these risks are both concerned totally about the same items. Juran in his new book, *Managerial Breakthrough,* has captured, perhaps more than any other person, the professional viewpoint in management that puts probability controls on these risks as well as recognizes creativity and competition in human existence.

3) *The Universals Vector.* Every professional field has its universals concerning applications of the appropriate science and art. The concept of the laws of science—say, Newton's laws of motion—stemming from the scientific revolution of the Sixteenth Century, is widely understood today. The concept of the laws of human behavior is not so widely understood or accepted today; however, there are many universal laws of human behavior. Following Juran[5] and specializing a bit to the quality field, let us state that a universal in quality operations is a rule which seems to be applicable to any appropriate quality problem, irrespective of the particular product, process, or function involved. Let us merely attempt here to mention three important universals in the field of quality:
   - *The Pareto Universal.* This is the principle that in almost any cause-effect system involving quality of product or process, a very high percentage of the effect is attributable to a very low percentage of the causes. For example, a company's quality control system may be rejected because of the high frequency of occurrence of only a few possible contributing causes. This principle has led Juran to identify the "vital few" and the "trival many."
   - *The Conflict of Interest Universal.* This is the principle that objective performance by a human being will be impaired when he has personal preferences which conflict with objectivity. For example, abnormally high percentages of discrepancies in measurement and in judgments have been observed when production men officially inspect their own work. This has led to the rule that production work and official inspection operations must be performed by different people.
   - *The Defect Prevention Universal.* This is the principle[4] that concentrating on defect prevention contributes more than anything else to quality and economy in production operations. For example, much more will be contributed to success by defect prevention in manufacture than by high efficiency in processing rejected product in "use-as-is", "rework", or "scrap" operations.

4) *The Empire Vector.* It would seem that there is a basic desire in most men to build bigger and bigger empires for themselves in industrial activity. Organization charts are one means of showing the extent of these assigned empires in authority, delegation, and company objectives. There is an essential truism, often quoted in industry, that a subordinate always works with the viewpoint and emphasis of his superior. Thus, quality men must report high enough in the organizational structure of the company not to be controlled by the short-range objectives of their fellow production men or designers. Yet, quality operations are not completely independent of schedule and engineering considerations.

5) *The Personal Vector.* The personal fulfillment and work satisfaction vector of any human being is a complicated force. Some years ago W. Julian King, a General Electric engineer, gave this subject considerable thought. In his "Unwritten Laws of Engineering,"[7] he recognized two extremes in the desires of engineers for a type of work—managerial and individualistic. It might be helpful for engineers to note that he used such words and phrases as cordial, practical, broad perspectives, fast, intuitive, competitive, opinionated, impatient and ability to get many things done through others to describe a managerial type of engineer. He also used reserved, idealistic, penetrating, methodical, peaceful, broad-minded, patient and ability to get intricate things done himself to describe an individual worker type of engineer. It may complicate this reasoning to add William F. Weaver's concepts relative to the characteristics of men best suited for work in the quality field. He used such words and phrases as intestinal fortitude, backbone, a firm stand, shoulders responsibility, sticks his neck out, a good communicator, keeps informed, scientific approach, knowledgeable, a salesman, a helping hand, takes the blame, goal-oriented, level-headed, nose for news and has a heart in his anatomy of an ideal quality man.[19] We see Weaver's anatomy as embracing perhaps an optimum combination of the characteristics assigned by King to managerial and to individualistic engineers. Thus, men in quality operations today need clearer thinking for tomorrow for the necessary professional breakthrough.

6) *The Problems Vector.* The quality field is never without pressing problems and conflicting views. Many of these are so universally present that they could be considered to belong to "Universals" vectors above. Some of these problems and conflicting views are:
   - Many people in industry classify quality work as nonproductive, indirect, etc. What should be done?
   - If the quality organization really succeeds in defect prevention, it will work itself out of a job and its personnel and budget should be cut. How do quality men stay in business and do an honorable job?
   - Quality personnel should work only in areas of engineering or production where there are recognized quality problems. What should quality men do when the current problem(s) is solved? Look for another problem!
   - Adverse comment on the non-engineering quality man by design engineers is often heard. The engineer who does not believe in sampling is a poorly informed man to the quality man. How do we bridge this gap?

7) *The Operator Vector.* In research, engineering, and production in industry, there is no class of men on test or under scrutiny more than reliabil-

ity engineers and/or quality professionals. There are many well-explained, respected, and frequently used words by these professional men, such as, risk, confidence, trade-off, optimum, life test, experiment, failure rate, quality level, etc. However, there is a group of nonstandard words from the common vernacular that tend to be adverse to sincerity of purpose, when used lightly. Some of these high density words and phrases, which have at times swept the country, are: expeditor, putting-out-fires, liaison, system, could-not-care-less, value-engineering, cotton-picking, interface, eye-balling, configuration - management, moonlighting, dialog, systems-engineering, square, cost-effectiveness, and presently, probably, mini-skirts and the reliability gap. Now, the use of these words is not totally bad; but, continually contrived uses, together with vague implications, tend to invalidate much hard-to-earn respect and confidence from men across the conference table. The quality man who does this, more often than not, is found to be a mediocre quality engineer and is often given the dubious title of "operator."

The Educational Process for the Quality Field

In comparing the professional characteristics of the quality field with those of the learned professions, it is somewhat regrettable to observe that the significant comparison is most unfavorable to the quality field in the area of professional education. This is not to say that generally too little in quantity is being done, but it is to say that specifically too little in the quality of professional quality education is being done.

In discussing engineering education a few months ago, Dean Everitt of the University of Illinois told of a committee in a small country church which was asked to recommend to the congregation the most beneficial investment the church could make with a few saved-up dollars. After deliberation, the committee unanimously recommended the purchase of a chandelier. Upon hearing the committees report, an old deacon immediately objected to the chandelier. He was asked why? He said of the chandelier that he could not spell it and he could not play it, and besides, what the church really needed most was more light. Following the thought of the old deacon, it might be useful to assume that what the quality field needs most today is more light in planning its professional education.

In Juran's nomenclature, we can very properly classify true professional education in quality to be among the "vital few", if not number one among the needs of our profession. It behooves quality men all over this nation to consider this to be the area where we can make our greatest professional progress. However, along with the professional education stem, we must consider carefully the entire education and training spectrums of the quality field. In professional quality education at the top, we, as a society and as individuals, should give strong leadership, wherever possible. At the lower levels, we should encourage and support many other bodies and institutions to accept leadership. In addition, we should improve the effectiveness of company training in industry.

For the present discussion, which must be limited, let us think of the work of the quality field as being performed, up the ladder, by persons classified as 1) clerical and operating, 2) inspectors and test technicians, 3) quality-professionals-in-training, and 4) quality professionals and mathematical scientists. This would parallel roughly the medical field with personnel classified as 1) clerical and operating, 2) nurses, dietitians, and laboratory technicians, 3) interns and residents, and 4) physicians and medical scientists. We shall not attempt at this time to discuss in detail the nature of the work in the above four categories of the quality field workers or of the medical field. This is probably pretty well understood already. However, in all future planning, we should think of developing from within each category of people the necessary supervision or administration, with policy and some regulation from the quality profession at the top.

It appears that planners of curricula and/or programs for quality education and/or training should recognize the following seven progressive or terminal stages of education:

1) *High School* without neglect of technical subjects.
2) *Junior or Community College* with solid lower division courses in Mathematics, Chemistry, Physics, and the Humanities and with appropriate terminal technical programs, including basic measurement and inspection technique and practice.
3) *Senior College* with solid upper division and professional courses and with creative specialties for the current professions, including the fields of engineering, business, and quality.
4) *University* with solid undergraduate and graduate curricula involving significant teaching and research for current and future scientific study and professional practice.
5) *Company Training* with highly motivated programs involving pertinent combinations of basic field principles and company practices, with emphasis on efficient applications of national and international standards of quality policy, administration, and customer controls, etc.
6) *Participation* with professional societies, institutes, and associations, and with universities in concentrated extension activities and professional educational programs.
7) *Lifelong Learning* for individuals in updating study of new science, new creation and new practice in appropriate fields.

Let us now mention briefly the four categories of persons in the quality field relative to the seven education or professional training categories available to them. It should be borne in mind that opportunity for education and training for the professions in the United States is perhaps the best in the world. But we need to be continuously vigilant as to purpose, content and setting for this education and training.[9,11,12] And, we might ask with Tukey "where do we go from here".[16]

It is our belief that the *clerical and operating* personnel of the quality field are doing as well or better for the quality field as their contemporaries are doing for any other field. Future organizational and educational planners might be advised to include these people in future company training programs to an increased extent. Basic studies for *inspectors and test engineering technicians* should begin in the Junior Colleges and should be extended directly from there to company training programs. *Quality-professionals-in-training* programs similar to the medical profession is an urgent must for the quality profession. We would recommend strong reliance on the colleges of engineering of the senior colleges and universities for truly *professional quality* education in the future. However, successful quality managers will continue to come from graduate schools of business, etc. There is much more that can be (and needs to be) said relative to education for a hoped-for *profession in quality*;[10,20] however, this will not be attempted at this time. It is rather to be hoped that this preliminary study can assist in intensifying the dialog on the structure of professional quality education and its implementation in the not-too-distant future.

A Message to the Individual

There is much to support placing truly *professional quality* education in the environment of professional engineering education on the campuses of the senior colleges and universities.[2,3] This could strongly support and even lead in the modern trends 1) of decreased engineering departmentalization within the senior colleges and universities and 2) of increased emphasis and flexibility for the engineering student in the choice of his major field of study, say, in quality engineering or reliability engineering. This could also put the field of quality engineering in the "engineering forefront", in Shearman's thinking again,[13] for trailblazing support of the professional engineering societies in their plans for the first professional engineering degree to be that of the Master's degree. The reader may wish to see the "Goals of Engineering Education" studies, performed under the direction of President Eric A. Walker of Pennsylvania State University and others.[17]

We would confidently state that the supply of new scientific, professional, and behavioral problems in the quality field will continue to come at a steady pace in the future. Quality activities and concepts of inspection engineering, productivity, objectivity, authority, responsibility, independence, reciprocity, control, costs, incentives, recognition, reports, coordination, representations, and education have many incomplete and unsolved problems. Not all quality people want to be professionals. However, the quality spectrum is sufficiently broad to include quality research scientists in the same manner as medical scientists are included in the medical field. All quality personnel will be helped by the rise of a true quality profession.

We can think of no more challenging field for professional operations and management than that of quality. In the view of the customer, quality of the product or a process is most important. We have been reminded for several years of the upgraded quality operations which are taking place in many companies, agencies and nations. Perhaps the most effective professional work in the quality profession since World War II has been that in Japan, led earlier by Mr. Ken-ichi Koyanagi[8] and at the present time by Mr. T. Takamatsu.

We would conclude by reminding the individual reader that the most unique and far-reaching characteristic of quality professional work is that of statistical decisions followed by dynamic actions. To emphasize this Dr. Shewhart warned in 1939[12] that "the long-range contribution of statistics depends not so much upon getting a lot of highly trained statisticians into industry as it does on creating a statistically-minded generation of physicists, chemists, engineers, and others who will in any way have a hand in developing and directing the production processes of tomorrow."

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Some Notes on W. A. Shewhart's Influence on the Application of Statistical Methods in Great Britain

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I cannot now recall how I first made contact with Walter Shewhart, but it is clear that during the 1920's he was familiar with British statistical literature and it is likely that he sent me some of his reprints of articles appearing in Bell Telephone Laboratory publications, thinking that I might be interested. I still possess several reprints of the period 1928-31 as well as a presentation copy of his book *Economic Control of Quality of Manufactured Product* given me in September 1931 as I was returning to London after five months in the United States. These reprints and my meetings with Walter that year, when passing westward and eastward through New York, undoubtedly made a deep impression on me. To a young statistician who had been primarily concerned hitherto with the more theoretical side of the subject, there were perhaps two aspects of this contact which particularly excited me.

In the first place, here was a man who described himself as a hard-boiled engineer, pointing out ways in which the theory of statistics was not only useful but necessary in large-scale industrial production. Here was a new field of application, it seemed, so far barely explored in England; for W. S. Gosset's ("Student's") problems in the Dublin brewery were rather different and B. P. Dudding's work was scarcely known outside the organisation of the General Electric Co. (England). Also, while the broad lines of Shewhart's attack could not be questioned, it seemed that there was scope for sharpening the statistical procedures which he was using and this may have been one of the matters on which I first wrote to him.

Secondly, I found that while his starting point was very different from mine, there was a good deal in his philosophy of approach—in his view of statistical techniques as tools which should aid but not control the process of decision—which was in tune with my own way of looking at things. His emphasis on the need to measure producer's and consumer's risks also provided an unexpected practical illustration of Neyman's and my conception of the "two kinds of error".

A paper of his, a well worn copy of which I must have read many times, had the title "When must a thing be left to chance?" It was issued in January 1929 as a Bulletin of the Inspection Engineering Department of the Bell Laboratories. In this Shewhart put forward his main thesis in clear terms and with much varied illustration: the inevitable existence of variation among nominally similar units of industrial production calls for methods of analysis of data which will help the engineer to decide whether part of this variation is likely to be assignable to causes which can be identified and then controlled or eliminated; or whether the differences must be attributed to uncontrollable chance causes, which cannot be eliminated without modifying the whole manufacturing process.

To help in the determination, the use of four "criteria" was suggested.

Criterion I involved the technique with which Shewhart's name has been so long associated, the division of the observations into 'rational subgroups' and the plotting of group means and standard deviations or variances in control charts on which were drawn the " $\pm$ 3-sigma" limits.

Criterion II involved the use of a more critical test for the significance of the differences between these group means. The criterion was a ratio $|d|/\sigma_d$, where d was the difference between the "within group" and "between group" estimates of variance and σ_d was the estimated standard error of this difference. If the ratio was greater than 3, "the test gives a positive indication of lack of constancy of cause system."

Criterion III was to be used when a considerable number, N, of observations were available ($N \geqq 500$), but it was not possible to divide them rationally into subgroups. Here, a curve represented by an Edgeworth series taken as far as the cubic term, involving the observed value of $\sqrt{\beta_1} = \mu_3/\sigma^3$ was to be fitted to the data, the χ^2-test of goodness-of-fit applied and if $P < 0.001$ this was to be taken as an indication that the cause system was not constant.

Finally, *Criterion IV* involved the determination of the coefficient of correlation, r, between N pairs of two variables, X and Y. If $N \geqq 25$ and $r \geqq 0.5$, this was to be taken as a positive indication that there was a common group of causes underlying the co-variation in X and Y.

It will be seen that there was a certain rugged simplicity at this date in Shewhart's method of attack which was characteristic of the engineer who was not prepared to take the statistician's probability measures at their face value. His approach was not perhaps altogether logical: the sampling distribution of a variance, for instance, was bound to be asymmetrical so that the "minus three sigma" limit in the control chart of variances might well have a negative value. Again since the estimate of σ_d used in Criterion II was based on the assumption of normal within-group variation, the ratio d/σ_d was in fact a function of R. A. Fisher's variance ratio, *F*, and the *F*-test might have been used*. The test of Criterion III did not take account of the possibility that observations which formed a symmetrical distribution with β_2-3 a

Dr. Pearson is Emeritus Professor of Statistics, and is the Business Manager and Tables Editor of *Biometrika*.

*I think it was likely that at this date Shewhart had not fully grasped the meaning of the analysis of variance.

good deal less than or greater than the normal distribution value of zero, need not be heterogeneous. The test applied to the correlation coefficient was also rather crude.

But Shewhart made his standpoint very clear. In another pamphlet of about this date (*Economic Quality Control of Manufactured Product*, Bell Telephone System Monograph B496, June 1930, p.13) he writes:

> "Furthermore we may say that mathematical statistics as such does not give us the desired criterion. What does this situation mean in plain every day engineering English? Simply this: such criteria, if they exist, cannot be shown to exist by any theorizing alone, no matter how well equipped the theorist is in respect to probability or statistical theory. We see in this situation the long recognized dividing line between the theory and practice. The available statistical machinery . . . . is, as we might expect, not an end in itself but merely a means to an end. In other words the fact that the criterion which we happen to use has a fine ancestry of highbrow statistical theorems does not justify its use. Such justification must come from empirical evidence that it works. As the practical man might say, the proof of the pudding is in the eating. Let us therefore look for the proof."

It followed, of course, that he placed much emphasis on the importance of establishing the robustness of statistical tests to departures from normality. This was an attitude which appealed to me since I had already been encouraged to investigate this subject by "Student". I find that in a paper of mine of 1931 I gave a diagram comparing the positions of the $\sqrt{\beta_1}, \beta_2$ points of nine frequency distributions of observations collected in the Bell Telephone Laboratories and those of seven distributions which I had used in experimental sampling, aimed at investigating test robustness.

It was indeed evident from our first contact that Walter and I had a great deal to discuss and argue about, so that when Henry Rietz asked me in the fall of 1930 to come next year and lecture in summer session at the University of Iowa, I jumped at the opportunity of getting to America and breaking a ten-year spell of teaching in London.

When I landed in New York in April 1931 after a stormy ten-day passage in the 8000 ton "American Merchant", I was given a very warm welcome. My hosts were partly the statisticians at Teachers College (I had known Henry Ruger at University College London) and partly Walter Shewhart and his colleagues. One memorable occasion was a dinner given me by some of the staff of the Bell Telephone Laboratories for which the menus were contained in miniature brown facsimiles (Fig. 1) of the *Biometrika* wrapper, of which journal I was then Assistant Editor with my father. I got to know H. F. Dodge, T. C. Fry, E. C. Molina and others of the more statistically minded in Bell and AT&T.

A rather hectic fortnight was followed by a weekend visit to Mountain Lakes, where I could at last be restful with Walter and Edna in their home among the trees and be shown something of spring in the New Jersey countryside.

After a grand tour across the States, which included a long stay in Iowa City where I first met Sam Wilks, and such diversions as a climb into the air (my first) with Harry Carver in Michigan and a descent to the bottom of the Grand Canyon on a mule, I returned to New York in September when Walter and I had some further useful discussions and I again stayed with him and Edna on Lake Drive.

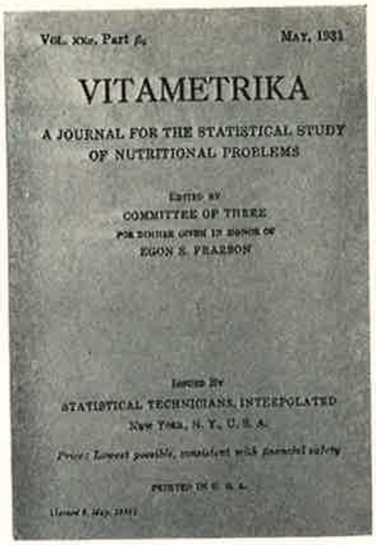

Figure 1—The cover of the menu for the dinner given for E. S. Pearson on May 8, 1931, under the General Chairmanship of Walter Shewhart. The menu was designed by a Committee of Three under the Chairmanship of Harold Dodge.

Neither of us could then tell what the future held, but an opportunity arose very soon after my return to London for Walter to come to England, the first of several lands, I think, where he was later to spread his message. He was invited in the spring of 1932 to give a series of three lectures in the University of London; he chose the title: "The role of statistical method in industrial standardisation." Considerable effort was made to bring to these lectures the representatives of a number of leading industrial firms. At the same time Percy Good, a man of vision who was then Deputy Director of the British Standards Institution, called a meeting of industrialists at which Shewhart gave a further talk. British industry was prepared to accept from an American engineer who had the backing of the Bell Telephone Company some ideas which it might have brushed aside if presented by an academic statistician.

A number of results followed from this visit. The British Standards Institution formed a small committee under the chairmanship of B. H. Wilsdon of the Building Research Station and including two representatives of Imperial Chemical Industries, two from the General Electric Research Laboratories, E. C. Snow (an Honorary Secretary of the Royal Statistical Society) and myself. Its main task was "to draw up a short report which would serve to awaken interest in the application of statistical methods on the part of manufacturers and others concerned with problems of standardisation and specification." The discussions in this committee lead in 1935 to the publication of the British Standard No. 600 on *The Application of Statistical Methods to Industrial Standardisation and Quality Control*, which the committee members generously agreed to have published under my name.

In December 1932 I was asked to broach the whole subject before the Royal Statistical Society and read a paper with the title "A survey of the uses of statistical method in the control and standardisation of quality of manufactured products." Following this, a year later, the Society formed its Industrial and Agricultural Research Section through which it was hoped to encourage the introduction into industrial experimentation of some of the methods which were already achieving such success in the agricultural field.

In all these developments warm tribute was paid to the stimulus provided by Walter Shewhart, partly in throwing out new ideas and partly in bringing together the few British industrial statisticians who had hitherto been tending to work in isolation. In his opening address to the new Industrial and Agricultural Research Section on 23 November 1933 Dr. R. H. Pickard, Director of the British Cotton Industry Research Association (and L. H. C. Tippett's chief), remarked:

> "It is perhaps not inappropriate that American statisticians, who have largely received their inspiration in theoretical matters from the English school . . . should now be influencing their English cousins in this field of applied statistics."

Looking back I am sure that we in Great Britain hoped for a more rapid approach to the millenium than was in fact to be achieved in the next few years. No doubt we suffered from not having among us the professional engineer who had convinced himself and his colleagues in one of the leading industrial concerns that the use of appropriate statistical techniques did lead to improvement in quality and to economic gain. We had not this backing of experience which could convince quickly the large industrial corporations who now, years later, have largely accepted the value of statistical analysis and operational research. However, the groundwork was layed in these early years and I think that Walter himself would have agreed that in the 1930's progress was very slow, even in his United States.

Others who knew a great deal more than I did of what industry has owed to him will be writing in this volume and I have felt that the best tribute I could pay to his memory would be to put on record this short account of our meeting over 35 years ago and its consequences. Among almost forgotten correspondence I have found in my files a long exchange of letters between Walter and myself, mostly in the years 1931-34. We discussed at much length and with considerable frequency both how best to push forward the use of statistics in industry and also philosophical questions in the field of statistical inference. If our most fruitful period of contact seems to have ended after these early exchanges, it was perhaps because other responsibilities, including the running of a statistical department and, after my father's death, the heavy burden of editing *Biometrika*, put an end to the years when I was relatively free to follow my own inclinations. But I shall always remember him gratefully as one among four or five persons who contributed most to my ways of thought and action in the formative period of my statistical career.

Walter A. Shewhart—Man of Quality—His Work, Our Challenge

WILLIAM A. GOLOMSKI

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All of you have heard about control charts and about some of the principles which underly them. You may use them and know that Dr. Walter A. Shewhart, who died on March 11th of this year, invented and developed them. The products that all of us buy are vastly better because of his work—important work in recognizing variability in processes and in product usage—insightful accomplishments in simplifying the presentation and analysis of data on quality. Some of his accomplishments will be reviewed here through quotes of Dr. Shewhart and his friends, and by trying to give those quotes a perspective important today.

In Chicago on June 5, 1947, George Edwards, the first president of ASQC said of his work and him,[1]

> On the 16 May, 1924, . . ., Dr. Shewhart prepared a little memorandum only about a page in length. About a third of that page was given over to a simple diagram which we would all recognize today as a schematic control chart. That diagram, and the short text which preceded and followed it, set forth all of the essential principles and considerations which are involved in what we know today as process quality control.
>
> While Dr. Shewhart is known to all of us as one who grasps the fundamentals, — the essentials, — in such matters, his modest and retiring disposition has tended to obscure, perhaps, the enormous contribution which that little memorandum has made to American industry and for which we all are so largely indebted to him.

Since George Edwards' good, concise, but complete statement, the contribution of Shewhart has become recognized in all countries of the world.

The founder of our field spent his most fruitful years as a member of the Technical Staff of Bell Telephone Laboratories. His broad interests in the field of control centered around his interest in using principles of control to enable the firm to do what it wants to do within economic limits. At that time, laboratories were the center around which basic product decisions were made. From his frame of reference we can understand the statement,[2]

> It is desirable that the departments of design, development, and production keep the laboratory research department informed as to evidence of the

Address presented at the Society's 21st Annual Dinner, June 1, 1967.

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existence of assignable causes where they arise up to the time that product goes to the customer.

But he goes beyond this to write about what is called reliability,[3]

> The theory is also of value in the study of the life history of product. Obviously, when equipment goes into the field it meets many and varied conditions, the influence of which on the quality of the product is not in general known. Such an example would be the varied conditions under which telephone poles are placed throughout the United States. *A priori*, it is reasonable to believe that the life of the pole depends in a large way upon the service conditions. Among the exceedingly large number of variables which may influence the life of the pole, little information is available to indicate the importance of any one. The value of laboratory research in improving the quality of a pole through life must take into account ways and means of preservation suited to each of the various conditions. Naturally, therefore, it is of interest to know when the variability in the quality of the material at any stage in life is such as to indicate the existence of an assignable cause so that further research may be instituted to find ways and means of effectively removing this cause.

Shewhart showed his interest in excellence—at a level beyond success. His associates who worked on the transatlantic cable were concerned with mean times to failure of the over 200 amplifying stages. The cost of messages not getting through was a great one, but so was lifting up the cable for maintenance.

Committee activity of a society is essential and the modest Dr. Shewhart worked as a member of our important Examining Committee and as a member of our Advisory Council of prominent scientists and businessmen. Topflight people were attracted to the field. Our early input from statisticians was enormous and continues today. Long and fruitful relationships with other professional societies were started. The excellent relations we have with the American Statistical Association and its current President, Professor Fred Mosteller of Harvard, started during those early days of ASQC. In fact, Professor Mosteller appears on the July, 1948 cover of *Industrial Quality Control*, which was my introduction to the journal.

Major General Leslie E. Simon was the first recipient of the Shewhart Medal. As part of his Acceptance Address he said,[4]

> The past two and one-half decades have seen "quality control" become progressively an important adjunct to four engineering or industrial fields; (1) Manufacturing process, (2) Acceptance inspection, (3) Study of systems or processes (largely industrial management), and (4) Research and Development. I put quality control in quotation marks because the scope of activities now associated with the term has now extended far beyond original concepts associated with it. Nevertheless, there are scarcely any of the many benefits that have come from quality control and its allied techniques that were not anticipated in Walter A. Shewhart's two books, one of which was published in 1931, and the other in 1939.

General Simon went on to say,

> During the late 1920's a number of important papers by Shewart and others appeared in the *Bell System Technical Journal*, but Shewhart's work did not attract serious attention until he was invited to give a series of lectures at University College (London) in 1932. Its cordial reception and utilization in England contributed much to its first real stimulus in the land of its origin.

This perceptive talk of General Simons's is excellent reading on the history of the field. I recommend it to you.

Dr. Shewhart's good friend and associate, Dr. Paul S. Olmstead, wrote expansively about him during the 10th year of ASQC.[5] We are told that he served as President of both the American Statistical Association and the Institute of Mathematical Statistics. The American Society of Mechanical Engineers awarded him its important Holley Medal. He served as an advisor to government and worked closely with General Simon. He was a member of the National Research Council and would you believe that he felt that attendance at Technical Conferences by wives was important to the growth of societies because of the implied endorsement of its activities. He would also have approved of the Ladies Auxiliary of the Southern Connecticut Section of our Society.

But Dr. W. Edwards Deming sums up his attitudes in a way that gives us an insight into the human professional side of the man,[6]

> Actually, he never thought of himself as helping anyone: he was simply glad to talk and absorb thoughts from anyone that was genuinely struggling to improve his understanding of the statistical method — interchanging ideas was his way of putting it.

Here was a way to have progress. Progress in which ideas were the currency of exchange. There was no thought of who got the credit—recognition was not contrived, but natural. Dr. Deming then goes on to say that,

> Quality control meant to him (Shewhart) use of statistical methods all the way from raw material to consumer and back again, through redesign of product, re-working of specifications of raw materials, in a continuous cycle as results come in from consumer research and other tests.

Dr. Shewhart is truly a hero to us. He was not content to dedicate his life to small purposes. He had the esteem of his fellowmen and the character to pursue those things that were expressions of the best that he had in him. He was a man of quality.

But what is the challenge to us? Who in industry, in government, in education will take his place in moving the field forward? What can each of us do to help? How is your capability and mine being translated into progress? Are you regretting what might have been? To witness carelessness in silence is to approve it. To neglect excellence is to disdain it.

Planning is a necessary function in any successful organization, but the implementer has an even greater role. Today professional societies have tended to fragment science and engineering to such a degree that, as a result, creativity has a smaller field in which to flex its muscles. I am not for unfocused talent, always missing its mark, a frustration to its members because of little growth and recognition, and puzzle to others who wonder why one particular fragment has such a limited scope. Rather I believe in the joining together of talent and other resources for resolving important issues. Will James the philosopher said, "The great use of a life is to spend it for something that outlasts it . . ." How can this happen? Paul Olmstead tells us,

> While developing the theory of statistical quality control, Shewhart realized the necessity of securing its acceptance by American industry, and not allowing it to remain an isolated fragment of science. To that end, he proposed and obtained sponsorship in

1929 for a joint committee for the development of statistical applications in engineering and manufacturing. The original sponsors were: American Society for Testing Materials; American Society of Mechanical Engineers; American Mathematical Society; and American Statistical Association. Later, it was also sponsored by the Institute of Mathematical Statistics. The quiet work of this committee provided the necessary support for successful introduction of statistical techniques prior to the formation of ASQC.

Quality control thus represented and became an attempt to interconnect and synthesize several engineering and management disciplines in the unified realization of a common objective—quality and reliability.

When have so many societies in recent years cooperated to introduce new technology into business and government? Are we too interested in who gets the credit? If we hope to reach a higher level of professionalism, we have to learn how to cooperate. As a start, I would suggest joint discussions on the staff and officer level of the various societies represented here to find ways and means of tackling the serious problems that exist today in technological development and quality improvement in both the commercial and government sectors. This will lead to the creation of jobs. It will lead to better and new products and services, and they will be available at lower cost. Joint meetings are a means of arriving at awareness and some solutions but other forms are needed to give leverage to the effectiveness of our efforts.

Sometimes splitting a problem into its parts helps to solve it; but there are other crucial times when it is necessary to step back to get a perspective in which we view the problem in a broader setting. In ignoring the need for taking the broader view, we actually lessen our creativity; but studying the overall picture we build on it. Sometimes in our training courses, we try to strip new employees of their knowledge and outlook by using destructive training principles, when we should rather build on what they already know and broaden their capabilities. So it is with the problems of quality and technology today. Increased creativity through *less* fragmentation should be our goal.

Science and technology are not moving forward so rapidly as to create a world of chaos with islands of order. Of course there are real problems in information retrieval and professional obsolescence, but they are surmountable. Human intelligence can comprehend these problems but this does not require atomization or fragmentation of effort. The effects of the unified approach will not be immediate. Shewhart and his professional society associates spent over ten years at it. But immediate success is never so interesting as a struggle—even to the winner.

One of the interesting phenomena of increased education and leisure is the number of people with imagination who have time on their hands. Hardly a week goes by when some individual or group decides to form a society. All it takes is imaginative men with fertile ideas who consider their goal worthwhile. While such devotion to a single specialized cause is commendable at times, it can, if carried too far, result in an epidemic of fission at a time when fusion and the inter-disciplinary sharing of knowledge are a crying need.

I am mindful of the aphorism of the British educator, Sir Richard Livingstone in which he said, that a great teacher, "is known by the number of valuable subjects that he declines to teach."

But, then, "Boss" Kettering, who had little time for complacency, observed, "It's amazing what ordinary people can do if they set out without preconceived notions."

We are not ordinary men, and with our tremendous scientific technological and executive abilities and know-how, we should be able to accomplish a lot.

During the past year your society decided that this was no time for little thoughts. It continued the work of Shewhart in education, through its Education and Training Institute; it re-evaluated its position in publications and will enlarge its scope of service; it recognized, through certification, not licensing, certain of its members as Quality Engineers; it got involved in an enlarged program of standards; it worked hard and long to assist in the establishment of the Commission on Product Quality suggested last year by ASQC past President Feigenbaum, and which is today a reality; it recognized and accepted Dr. Juran's observation that the hardest job any manager has is to make sure that the department or organization is in at least as good shape on Monday as it was at the end of the previous week; it developed an increased awareness of the field and utilized unusually competent professionals in public relations to assist in this important task; it participated in conferences with governments; it held seminars on important issues; it strengthened its staff support; and it aided in the development of over 21,000 people who are the quality consciences of their organizations.

But a lot was left to be done. This reminds me of the man who feels that a different combination of college courses would have been more valuable. In Mark van Doren's book, *A Liberal Education*, he offers a consolation, which could be paraphrased in terms of the activities of the society. In his book he says,

> It is impossible to discover a man who believes that the right things were done to his mind. He is forced to learn many things, or too few. It is all too general; or too special. The present is ignored, or the past. Something was left out entirely, or at its best skimmed over: mathematics, poetry, the method of science, the secret of religion, the history of this or that.

This year Dr. Shewhart congratulated our collective efforts and said that you have "extended the field beyond my early visions and saw areas of service that pleased and amazed me. I hope that you continue." We will!

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Stop, Look, Inspect

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> **Thinking of Walter Shewhart brings the realization that there is a compensation for reaching that reminiscing age which enables one to resavor the rewards of the past. One of life's greatest rewards is the friendship of fine people. Walter Shewhart was an old friend and a fine person. Like old soldiers, old friends never die—neither do they fade away.**

What might one be expected to discuss under the assigned, rather nebulous, title—*Stop, Look, Inspect?* It is reminiscent of its progenitor, the "Stop, Look, Listen" sign on unattended railroad crossings—an early and simple form of inspection instruction which cautioned the traveler to perform a sequential visual and auditory inspection in behalf of his own personal safety. To many of my age, the association of the words "inspection" and "railroad" recalls the overalled, and to the unsophisticated, seemingly aimless, man with the sounding hammer, who was practicing an early form of what is now known as nondestructive testing—though, from his standpoint, he was merely "looking for cracks". At any rate the title seems to permit a great deal of liberty in subject matter, and I have elected to take advantage of it by talking about the broad functional purpose of, and the ever-increasing critical need for, inspection as such, rather than about any one of its many interesting and important techniques.

Although I originally started my quality career in an Inspection Engineering Department, it has been a long time since I was an active inspector. What I have to say about inspection, therefore, arises from the viewpoint of an observer rather than a participant, but as one who has leaned heavily on the inspector and his contributions. In this guise I shall try to comment, as I see it, on the place and importance of the inspection activity in the over-all quality assurance process, and to give my opinion as to its future role in the continually expanding quality and reliability effort.

Since disagreements are so often prompted by misunderstandings, it is advisable at the outset for us to understand what is meant by inspection and the inspector, or at least to understand what I think they mean, and hence the connotations in which I shall use them. The word "inspection" derives, of course, from the Latin "inspicere", literally "to look into". We have broadened its application in technology to imply an act or procedure by which one ascertains the status of some quality attribute—its presence or absence, its magnitude, its persistence, and so on. The process of ascertainment may include formal measurement, test, analysis, or merely comparison; but since it involves one of our senses, and since it presupposes a conclusion—a mental process—it is, in part, subjective. When we broaden the term to include decision-making in respect to sorting, compliance, or acceptability (strictly speaking these are acts of discrimination subsequent to, and consequent upon, inspection), we likewise increase the subjective element involved. For its bearing on what I have to say, it is important to keep in mind that inspection, when it involves an action in which the mind of man plays a part, is partially subjective at best.

The Government (MIL-STD-109A) defines inspection as "The examination (including testing) of supplies and services (including, when applicable, raw materials, documents, data, components, and intermediate assemblies) to determine whether the supplies and services conform to technical requirements." This definition indicates a comprehensive procedure including testing and the examination of documents and data. Most of us, I think, would agree with it and regard the term "testing" as merely a particular form or type of inspection—even though we often characterize the individual who performs the task as a "tester".

Each one of us, at one time or another, performs inspection—especially when he buys, makes, or repairs something. In fact, there are occasions when we would permit no substitute for our own personal inspection. Highly specialized forms of inspection are carried on from time to time by specialists in other fields, e.g. scientists, research people, design and development engineers. What distinguishes a so-called inspector particularly, and gives him his title, is not only what he does but the extent to which and why he does it, i.e., his functional purpose. Thus proofreaders, assayers, fire-underwriting engineers, and bank examiners might be regarded as inspectors who are clothed in titles which indicate their particular specialties, and proficiencies. For the purposes of our discussion, however, it seems reasonable to confine the term inspector to one who, in the industrial complex, is functionally responsible for, and spends at least a substantial portion of his time in, examining or testing a product in order to determine the *status quo* of its technical attributes. The particular manner by which he does this may be, and frequently is, specified by others, as are quite customarily the product attributes of interest.

Most of the pertinent literature, past and current, implies that inspection—and its prosecutor, the inspector—represent a necessarily specialized and highly requisite activity. This conclusion proceeds from many authors whose status disavows any pretense of self-pleading. At least one article, however, one whose authoritative source commands both attention and respect, seems to indicate the contrary; that the independent inspection function, and perforce the inspector, may be and perhaps even should be, in the throes of slow death. Perhaps the article was intended only to be arrestingly provocative. Perhaps I have misunderstood some of its contents and import; for, frankly, I find parts not so ear-marked by the author fully as subtle as parts that are specifically so characterized.

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In any event, its conclusions and the, to me, highly questionable premises upon which they are built, are destructive to my own thesis; although I must, in fairness, add that the author is by no means alone with his premises. There are others, whose opinions I also respect highly, who feel that the inspector, as such should eventually be abolished. It is my own feeling, however, that such advocates are basking in unjustifiable euphoria; for if what appears to be the article's premises, council and prognostication were to be accepted, many of us would be genuinely apprehensive about the continuing effectiveness of the control and assurance of quality and reliability. Since to my knowledge such ideas have not been questioned, analyzed or rebutted, it may be well, in the interests of those with contrary ideas, to challenge even such an authoritative and highly respected proponent — and perhaps provide an arena receptive to long-held, opposing opinions.

The article is by Dr. Joseph M. Juran and appears in "Managements Corner" of the October, 1965, issue of *Industrial Quality Control* under the title "Inspectors—headed for Extinction?" The answer to the question appears to be: probably, but without jeopardy to quality. I will try to give an undistorted brief of its contents—full enough, I believe, to provide a fair presentation of its import. It goes thus:

> There are plants, in the small minority to be sure, but big plants representing some of the most respected industrial companies in our economy, in which life is being lived without inspectors. Historically, as small shops grew into large factories, inspectors were introduced to relieve the foremen of their overburdening checking function. Following this in due course, "the foremen were found wanting" in that "they were unable to strike a proper balance among their multiple responsibilities for cost, delivery, and quality." Centralized inspection departments (which thus resulted) "and indeed the inspectors are the result of unbalances in knowledge, training, and motivation among production operators and production foremen." Elimination of these unbalances should in theory make the inspectors redundant and, "it works out that way in practice." The solution is "to assign to the operators the responsibility for *all* the following actions and decisions:" process set-up, approval for its starting and continuation, product measurement, and approval for shipment or withholding. The prerequisites involved are: process debugging by engineering and supervision, mutual respect and confidence at a reasonable level among management and the men, and operators trained in interpretation of quality information, use of instruments, recording, charting, use of quality data.
>
> As an independent control "a new job is created—that of quality auditor." But he checks the *decisions* of the production operator by sampling operator approved lots "to see if the operator is making good decisions, not to see if the product is good." The auditor's data feedback "to the operator and production supervision are data on the goodness of the operator's *decisions*, not data on the goodness of the product." It is pointed out that "every one of the prerequisites is a formidable, long range project" collectively constituting "a program of forbidding proportions, several years as a minimum, a decade in really severe cases."

The Article concludes: "As yet, not many managements seem disposed to embark on such an adventure."

To a fervent hallelujah for Management's reaction as expressed in the author's closing, let me add a few observations in support of Management's reluctance to denigrate the importance and need for independent inspection—present and prospective.

By inspection, I have in mind the independent function directed primarily toward the ascertainment of the status of product quality in an area of reasonably advanced sophistication. I exclude those circumstances where a sorting operation can be mechanized or automated with sufficient, but infrequent, checking to insure its continuing effectiveness. (Nor have I reference to those special circumstances and techniques such as disclosed in an account in the *Washington Post*. In this particular case pigeons were trained successfully to inspect for defective pharmaceutic capsules; allegedly with 99 percent effectiveness. Even here, however, not only was the principle of independence maintained but the objectiveness of the function was actually enhanced.) I must admit my ignorance, and acknowledge the limitations which it imposes upon me, of not knowing any large inspectorless, industrial plant in which demonstrated, good quality, reasonably sophisticated product is being produced.

Perhaps the intent of the article was to limit the inspectorless status to simple, routine, small part, machine outputs; although it implies no such limitations. Perhaps its purport was more particularly directed toward centralized inspection, because of the nature of the alleged cause of the latter's origin, in which a lack of ethical status and practice is inferentially involved. In this respect, unfortunately, the specific circumstances and reasons underlying the first inauguration of centralized inspection are not, to my knowledge, documented. My own opinion, a conclusion to which I came after considerable research some 40 years ago, and which I have not changed since, is that centralized inspection, like so many other specialties, evolved as a more effective and more economical way of doing the job. Thus I am in agreement with an earlier article* by Dr. Juran which ascribes its origin to technical considerations. To quote:

> "There was a pressing need to safeguard the integrity of measurement, of test, and of decisions on acceptance. The scattered inspectors were being rather trampled on by production supervisors. Under a chief inspector, much of this could be eliminated."

A catalytic origin of this latter character would explain why inspection has persisted so long and why it is likely to continue. At least the inaugurations of relevant and more recent specialities—such as Engineering Inspection and Quality Assurance—are well documented as to motivation. They represented supplementary efforts—initiated by top management, let it be noted—to improve the attainment of product and service quality.

Some of the prerequisites for the elimination of the inspector, if we are to construe them in the full connotation implied by today's terminology, are indeed formidable, as the author states. The operator must take on three added tasks, each currently regarded and pursued as a specialty itself. In addition to an operator, he must become a process set-up man, an inspector, and a good part of a quality control engineer. It impresses me that this jack-of-all trades movement would be heading us back to the time when industrial life was much less complicated: to the time when the artisan was at once designer, maker, and inspector—a status now generally confined to the field of the arts.

*"The Two Worlds of Quality"—J. M. Juran—*Industrial Quality Control*—Vol. 12, No. 5, November 1964, Pg. 241.

Pragmatic quality engineers are likely to be skeptical about the enigmatic approach and effectiveness of this newly robed "quality" auditor who audits "decisions" rather than quality. In its original use, Quality Audit represented a sort of "after all" type of inspection. In fact, one of its first, if not its first, users, the Western Electric Company, defines "Audit Inspection" in its now 10-year-old "Statistical Quality Control Handbook" as "Minimum (or Audit) Inspection". Here the auditor's function is to supplement rather than replace the prior and independent inspector. These "auditors" are very capable people. They *inspect* carefully, and comprehensively, for full compliance with the original design requirements, however these may have been translated for the convenience of manufacturing purposes. And it is worthy of note that this audit function represented largely a change in name for a practice which, for many years in the same company, had proceeded very effectively under the title "Check Inspection." Despite the fact that this new man audits decisions, it seems that he must in reality first audit product quality, because this is the only way in which he can determine whether the operator's decisions were good or bad. And if the operator's decisions were bad, and the product bad in consequence, one asks whether any corrective action is taken with respect to the bad product, and if so, by whom—the poor decider or the decision auditor? If, preferably, the latter, is he still auditing decisions, or is he not perhaps inspecting?

What is likely to cause greatest concern about the article, however, is that its tenets go counter to what, in the minds of many of us, are the basic principles which support and demand a separate and independent inspection function. Whether this independent function is centralized is a matter, to be determined by circumstances. Offhand, one would suspect that in most instances, especially those involving large-scale, multi-process, complex production, centralized inspection will prove to be more effective and economical. The desirable centralization, maintenance, calibration, qualification, and skilled use of much of the modern measuring and testing paraphernalia and techniques make this likely.

It seems to me that a quality assurance engineer, concerned with the needs of both the producer and consumer, should feel strongly that an independent inspection function is required to optimize two basic *desiderata*—competence and objectivity.

Most specialties have been prompted and developed because of a desire or need to do things better than before. No one could successfully contend that Quality, Reliability, or Value Engineers, for example, developed because others had given no thought or attention to quality, reliability, and value. These specialties originated as a means—by the development and application of specialized knowledge and effort—to improve these particular attributes of product. In fact, a quality engineer might quite properly consider himself as merely a specialized technical coordinator who, by the tricks and knowledge of his trade, tries to help the designer and producer do better what they themselves are always trying to do, and must do if product is to improve. Has one ever seen product improve except by the direct action of designer and/or producer, regardless of how their action may have been motivated?

Perhaps we are led to discount the value of inspection and the inspector by the fact that the terms are old and lack the glamour of innovation. But as quality engineers our primary interest is in product quality and the best and surest means of its attainment and assurance. We should not be impressed by the semantic gymnastics of terminology for its own sake. If, as has happened too often, organization charts or jobs are up-graded by retitling—without any change in corresponding task, personnel, or function—that is merely window-dressing. Window-dressing is a marketing function; it has no effect on the attainment of quality, nor has it any place in the area of quality assurance where it is likely to engender suspicion.

Despite the drawbacks and narrowing effects of specialization, its effectiveness for a specific purpose has not been questioned, even though it may tend to leave holes in the so-called "whole" man. Specialization has grown hand-in-hand with man's knowledge and capabilities—at no time more rapidly than the present. Specialization leads to increased competence—a narrowed competence, perhaps, but a competence rarely otherwise attainable. This is why we are likely to go to a surgeon, even to a specialized surgeon, rather than to a general practitioner for an operation. Special competence may exhibit itself in many forms, of which manual dexterity and particularized knowledge are good examples. It is in the area of particularized knowledge and experience that the inspector, and the inspection function, demonstrate their value—a unique value, in fact, and one unlikely to achieve its full potential in a dichotomized operator-inspector combination.

Basically, the generation of good product involves concept, production, and verification in terms of the concept. Verification requires examination; and to examine is to inspect. Aside from the special competence involved in the verification process, there is also the equally important aspect of objectivity. In an evaluation or verification process, optimum objectivity is best attained when we divorce the judging process from responsibility for the status of what is to be judged. With the inauguration of trial by jury, recognition of a somewhat analogous and potentially vitiating relationship undoubtedly underlay the careful screening of those jurors who might be subjectively motivated. Indeed, much of the value of the quality assurance effort as a whole rests in its objectivity. Since so much of the technique of quality assurance depends ultimately upon the use of unbiased inspection results, these must derive from a source which is not responsible for the actions which give rise to the results.

I have said nothing about the attitude of the customer in respect to an inspectorless regime. It is the customer who ultimately determines the controllable factors in the whole supply process. If purely technical considerations do not alone prove the continuing need for the inspector—and I think they do—then there is still an over-riding factor, consumer reaction, which seems to me to clinch the argument for independent inspectors.

In reviewing some of the pertinent literature in order to get a feeling for the general attitude toward the inspector, I reread an article "Government and the Inspector" which appeared in the April, 1964, issue of IQC under the authorship of Cmdr. R. W. Smiley, U.S.N. I cannot recall any article better expressing, from the consumer's standpoint, the need for the plain, old-fashioned inspector, without change in title, organization, or purpose. Cogent, clear, and emphatic, it points out those circumstances and unfortunate, but nevertheless expectable, events which make a careful, capable, comprehensive, independent inspection function mandatory from the standpoint of the customer. While the article is expectably related to experience with the procurement of Military product, its arguments and conclusions apply equally well to non-Military industry. One needs no imagination to conclude from it that, whether we advocate it or like it or not, we will have inspectors whenever we deal with a customer who insists that his own interests be suitably safe-guarded.

What inspection needs today is not elimination, absorption, or dilution by functional miscegenation; it needs, as do the rest of our technical specialties, improvement. And fortunately it has been getting it in large doses. The qualified inspector today must be a well-educated, well-informed, well-trained technologist; and his requirements in these respects are ever-increasing in scope and severity. But the inspector must also continue to be, as Cmdr. Smiley so well emphasizes, a careful, conscientious searcher for those ordinary, mundane discrepancies which result from carelessness, oversight, incompetence, and the many other potential shortcomings of man which can never be *assumed* to have been eliminated beyond question. The literature is full of examples, and our experiences remind us daily, of those various, recurring inadvertencies—so aptly described as boo-boos —which are responsible for so much of poor quality and unreliability. As two heads are better than one, so also are two looks. And the best looker, the more dependable looker, is the one whose mind is not prebiased as to what he hopes to see, nor responsible for what he sees, when he sees something that should not have been there for him to see. Admittedly, even the inspector does not catch all faults—he is human too. But despite the care and caution of others, he catches enough of them and provides an added degree of assurance sufficient not only to justify his continued existence but to *require* it.

The formalized function of Quality Assurance started out as "Engineering Inspection" with the aim of improving, not eliminating, inspection, and of better utilizing the fruits which independent inspection provides. While it has since developed many supplementary techniques to optimize the economic control and assurance of quality, it has done nothing which would justify it either in ostracizing its first line of defense or marrying it off to an everpotential, though unintentional, enemy. As one who has been closely involved in the specialized field of the assurance of quality since its inception, I should like to conclude my remarks with an unequivocal observation.

If the need arose to choose and be limited to only one of the many specialized devices presently at our disposal for the ultimate assurance of quality of completed product, I would choose that function which I still call inspection, and the well-trained, independent inspector to prosecute it. If this particular selection in such a forced choice seems to belittle the highly desirable preventive aspects of quality control, to relieve the operator from discharging his own responsibilities, or to represent a belated "after-the-fact" approach, it is well to keep in mind that effective quality assurance depends upon facts—final and unequivocal; facts whose source carries the added reliability of insulation from possible parental prejudice.

What Happened in Japan?

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Dedicated to my friend and colleague
WALTER A. SHEWHART
1891-1967
whose works have raised the quality of living the world over.

Introduction and Purpose of This Article

The competitive position of many Japanese products, according to the testimony of their own manufacturers, has been achieved largely through understanding and use of the statistical control of quality in the broad sense (*vide infra*). Statistical techniques were not wholly responsible for what happened, as deeper perspective of later paragraphs will bring forth, but statistical techniques certainly played an important role in the miracle. The first step was to fire up desire on the part of management to improve quality and to impart confidence that improvement was possible; that utilization of statistical techniques would help.

Dr. Deming is a Fellow of ASQC, and was the Shewhart Medalist in 1955.
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The purpose of this article is to offer some observations on the causes of success in Japan, from the viewpoint of the statistical control of quality, with the thought that energetic application of statistical techniques in other parts of the world, including the United States, might have healthy impact. Appreciation of what happened in Japan might also be taken seriously on programs of scientific and professional societies that are interested in statistical methods applied to production.

Nine Features of the Statistical Control of Quality in Japan

As I see it, there are nine main reasons for the success and speed of application of the statistical control of quality by Japanese manufacturers:

1. Genuine and resolute determination on the part of management to improve quality.

2. Confidence in their ability to lead Japanese industry forth from the bad reputation that Japanese products had built up in the past, confidence in Japanese scientific ability, and confidence in Japanese skills. Confidence also, I might add, in statistical methods.

3. They were Japanese, with industrial experience, and with an inbred pride of workmanship.

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

5. Management took immediate interest and learned something about the techniques of the statistical control of quality as well as about the possible results, and still more about what their own responsibilities would be. Proper arrangements for contact with top management, at the outset, was one of the fortunate features of statistical education in Japan.

6. 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.

7. The Japanese learned the difference between a statistical problem and one in engineering, chemistry, management, or marketing. They learned that statistical knowledge is not a substitute for knowledge of engineering or of other subject-matter, and that knowledge of engineering does not solve statistical problems.

8. 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.

9. Suggestions and technical information have a fairly clear channel from lower to higher levels of supervision and management. A Japanese executive is never too old or too successful to listen to the possibility of doing it a better way.

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.

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 in Asia was lost. The market for poor quality in the western world is a losing game.

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?

*Editor's Note: The American statistician is W. Edwards Deming.

No country is so able as Japan, I pointed out, with its vast pool of skilled and educated 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. Seeing their serious determination, I predicted at an assembly of Japanese manufacturers in Tokyo 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.

Statistical techniques became a living, vital, and essential force in all stages of Japanese industry. The whole world knows how well Japanese manufacturers met the predicted time-table.

Management must assume 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. Lectures 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 to accept these responsibilities.

Japanese manufacturers took these arguments seriously to the point of doing something about them with concerted effort. 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.

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 insulted 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.

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, by appropriate statistical design.

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 program of quality.

3. Control of process. Detection of special causes by statistical methods ($\overline{X}$- and R-charts, run-charts, design of experiment, and other techniques). Distinction between special causes and common causes, with examples. Separation of responsibility for finding and removing:

   a. Special causes of variability (local).
   b. Common or general causes of variability (upper management).

4. Use of acceptance sampling where appropriate.

5. Consumer research. Test of product in service.

6. Re-design of product.

7. Tests of new product, in the laboratory and in service.

8. Use of proper theory for finding optimum levels of inventory, and for economy in distribution.

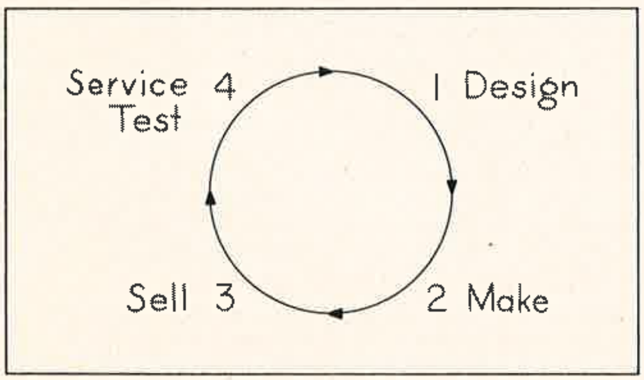

Figure 1—Cycle of Applied Statistical Methods

The statistical method shown in Fig. 1 was taught as 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.

Special (Assignable) Contrasted with Common (General) Causes of Variation or of Wrong Level

One of the important uses of statistical techniques is to help an engineer or scientist to distinquish 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 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 (of shoes, for example, because of breakage of thread), 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 right.

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, when 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 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.

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 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, namely, the common causes.

Special Causes 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 point outside limits on a control chart indicates the existence of a special cause. Special causes are what Shewhart called assignable causes. The name is not important: the concept is.

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. At the same time, they detect almost unerringly the existence of a special cause when it is worth searching for.

What statistical tests do, in effect, is not just to detect the existence of a special cause, or the absence of special causes: they do more: 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. The Japanese had the benefit of advanced thinking on the matter.

Common Causes of Variation and of Wrong Spread, Wrong Level

If we succeed in removing all special causes worth removing, then henceforth (until another special cause appears), 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, 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
- Lack of interest of management in a program 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

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 change the design of the product, to install new machinery? to change the lighting? to put in air-conditioning? Only management can take action on these things. If the trouble lies in management itself, who is going to make the correction?

Although the detection and removal of special causes are important, 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 and decrease in the cost of statistical data put out by the Census in Washington. For many years, effort has been directed at common causes of the system that lead to error and to 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 in this country pays out for similar surveys in consumer research.

Other Statistical Techniques

Consumer research was taught as an integral part of the statistical control of quality. In fact, small surveys of household inventories and requirements of pharmaceuticals, sewing machines, bicycles, and the like, constituted part of the course in sampling in the summer of 1951. These have been designated by the Japanese as the first studies in consumer research to be carried out by Japanese companies with the aid of modern methods of sampling.

Shewhart charts were taught in Japan as statistical tools for the economic detection of the existence of special 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. Once statistical control is established, then do something about common causes.

Acceptance sampling was taught as a scheme of protection (provided one will really reject and screen a lot when the sample contains more than the allowable number of defects). 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 proposed. One knows in advance, without spending a nickel on a 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.

The teaching of statistical methods in Japan did not confuse statistical estimation, nor Shewhart charts, with statistical tests of hypotheses.

The effectiveness of mass education in statistical methods in Japan was more pronounced and more rapid than results observed in the U. S. In the first place, Japan was in 1950 in desperate circumstances. Every minute must count. Second, management was more responsive. Third, practically everyone in attendance at technical sessions in Japan had studied calculus.

A vigorous system of courses for continuation and advancement in theory was instituted by the Union of Japanese Scientists and Engineers. 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, queueing theory, and other problems. The impact of the work of these committees has substantially changed much industrial practice in Japan.

Publication of a journal *Statistical Quality Control* (in Japanese) was started by the Union of Japanese Scientists and Engineers; the journal is now in its 18th year. *Research Reports*, a journal now in its 17th year, has a high reputation amongst mathematical statisticians the world over. A journal specifically for foremen has been started, and one for engineers.

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

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.

Power and Limitation of Statistical Techniques

Advances in uses of statistical techniques would come, the Japanese learned, not by searching a manufacturing plant for a chance to apply this or that technique, but to search the plant for problems, and then to enquire what statistical techniques might be helpful.

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. No statistical theory will tell anyone which quality-characteristic to test, although it is necessary to use statistical theory for reliability and economy in the design and interpretation of tests.

Statistical teaching in Japan put emphasis on the responsibility of management and of the engineer to foresee problems and to state them explicitly. Statistical techniques were taught, not as a kit of tools to try out here or there, but as an aid to solution of problems, aids to knowledge and creativity.

The Japanese learned something about what statistical techniques can do, and what they can't do.

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 for 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.

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. 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.

On this principle, the efforts of many of Japan's greatest statisticians (which is to say, some of the greatest in the world) found their place in industry.

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 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.

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

Specifying the Desired Distribution Rather than Maximum and Minimum Limits

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It is a great honor to have been asked to contribute to this issue, which is in honor of Dr. Walter A. Shewhart, whose original contributions have had a worldwide impact on industry and science. This article is affectionately dedicated to him.

Introduction

Maximum and minimum specification limits for parts dimensions are in extremely wide use. Nevertheless such specifications are often misused and even misinterpreted in industry. Furthermore they do not place the emphasis on what is most important; namely, maintaining distributions of the dimensions of component parts, which will achieve the desired characteristics for the assembly. By placing the emphasis where it belongs, it is possible to be more realistic and to achieve great economies. The price is close cooperation between Engineering, Production and Quality Control.

Field of Application of Article

Our primary concern in this article is under the following general conditions:

1. Individual piece parts.
2. The dimensions or characteristics of the parts can be measured.
3. The parts are manufactured for assembly with other parts and therefore typically subject to maximum and minimum limits.
4. The dimensions or characteristics of the component parts combine in a known fashion, determining characteristics of the assemblies.

The methods to be discussed can be used in other situations and on other products, but the foregoing is the broad field with which we are concerned.

Steps Toward Dimensional Specifications

The following stages of dimensional control have occurred in industrial history. Shewhart[6,7] gives a good discussion of them.

1. Each part made specially, and its dimensions worked down until it fits the particular part(s) with which it is to be assembled.
2. Need for interchangeable parts for large scale production, giving rise to the aim to make parts all "exactly alike".
3. As metrology improved it became apparent that it is not possible to make parts exactly alike. Thus there came about, first, single limits, and later maximum and minimum specification limits.
4. *All* parts to lie between the specification limits.
5. Since in a large lot, or the output of a machine, it is not possible to guarantee that all parts are between the specification limits, an acceptable percent outside the limits may be set; that is, an AQL or acceptable quality level.

The last is in wide use at present.

Shortcomings in Application of Present Specifications

Attempts to satisfy requirements, either that all parts should lie between the specification limits, or else a very high percentage between, have led to many undesirable practices. These take the form of not giving the engineer what he really wants and/or needs, and further of greatly increasing costs of production and inspection.

Design engineers tend to be conservative and commonly give specification limits for parts so that, as long as all parts lie within their respective limits, the assembly characteristics will lie between whatever limits are set for them. Thus this philosophy says in effect "any distribution of part dimensions between the limits is entirely satisfactory, as long as all or a very high percentage lie between." This leads to undesirable kinds of distributions such as shown in Fig. 1. Distribution (a) has its middle section removed by sorting out parts for another customer who has a tighter tolerance than we do. Distribution (b) is from a process in bad control but heavily sorted. Distributions (c) and (d) are typical of the inside and outside diameters, say, for a bearing and its fitting shaft. For the shaft, the process level is set to the high side because metal can be taken off but cannot be put back on. Then the shafts are sorted, reworked and sorted again. Meanwhile for the bearing the process has been set to the low side, then they are sorted and some reworked toward larger inside diameters. Distribution (e) is run with much better process capability than called for by the tolerance, and set low, perhaps to save material.

Dr. Burr is a Professor of Statistics and Mathematics, and was the Shewhart Medalist in 1958.

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Are these distributions what the design engineer really wants? Likely not, but knowing that they can and do occur he plays it conservative, *and must so play it,* by maintaining tight enough tolerances so that the parts will still assemble and work, if they all lie between the limits.

Another problem is that the requirement of an allowable percentage outside, that is, an AQL, says nothing about how *far* outside they may be. If one production head out of 40 is far off, only about 2.5 percent of the parts will be outside limits, which may be the AQL. But these few may be far enough out to cause real trouble. The designer may think of the AQL percentage as being of parts barely outside the limits, but in practice they may be way outside.

To emphasize this further, consider the two "utility" or "usefulness" curves shown in Fig. 2. Curve (a) is what the design engineer's philosophy may well lead to in the minds of production people. The parts outside the limits are thought to be unusable and thus of zero utility (until reworked or "material review approved"). Meanwhile those parts anywhere between the specification limits are all equally useful and in a sense perfect. At least this is what the specifications seem to mean. But this philosophy becomes corrupted so that inspectors pass parts which are only "a little outside". Some chief inspectors even hire people, not just to compare parts with specified limits, but to use "judgement". The question then arises as to how far outside a part can be permitted

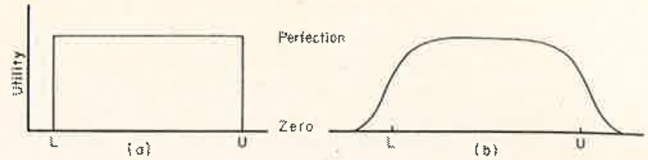

Figure 2—Two Utility or Usefulness Curves

and still be passed. But this is not a realistic nor easily controlled situation.

The other utility curve (b) of Fig. 2 gives a more realistic picture. The utility must be at its maximum around the middle of the tolerance range, gradually diminishing in each direction, but not hitting zero until well outside the typical limits. Isn't this curve much more realistic and practical?

The Solution—Specify the Desired Distribution

It must be quite clear by now that a real solution is to be sought by having the design engineer specify what distributions of part dimensions or characteristics will satisfy the design, so that the assembly will be satisfactory. He thus sets the desired distributions of the component part dimensions in the light of how they will be combined, making use of the statistics of combinations, and with knowledge of the

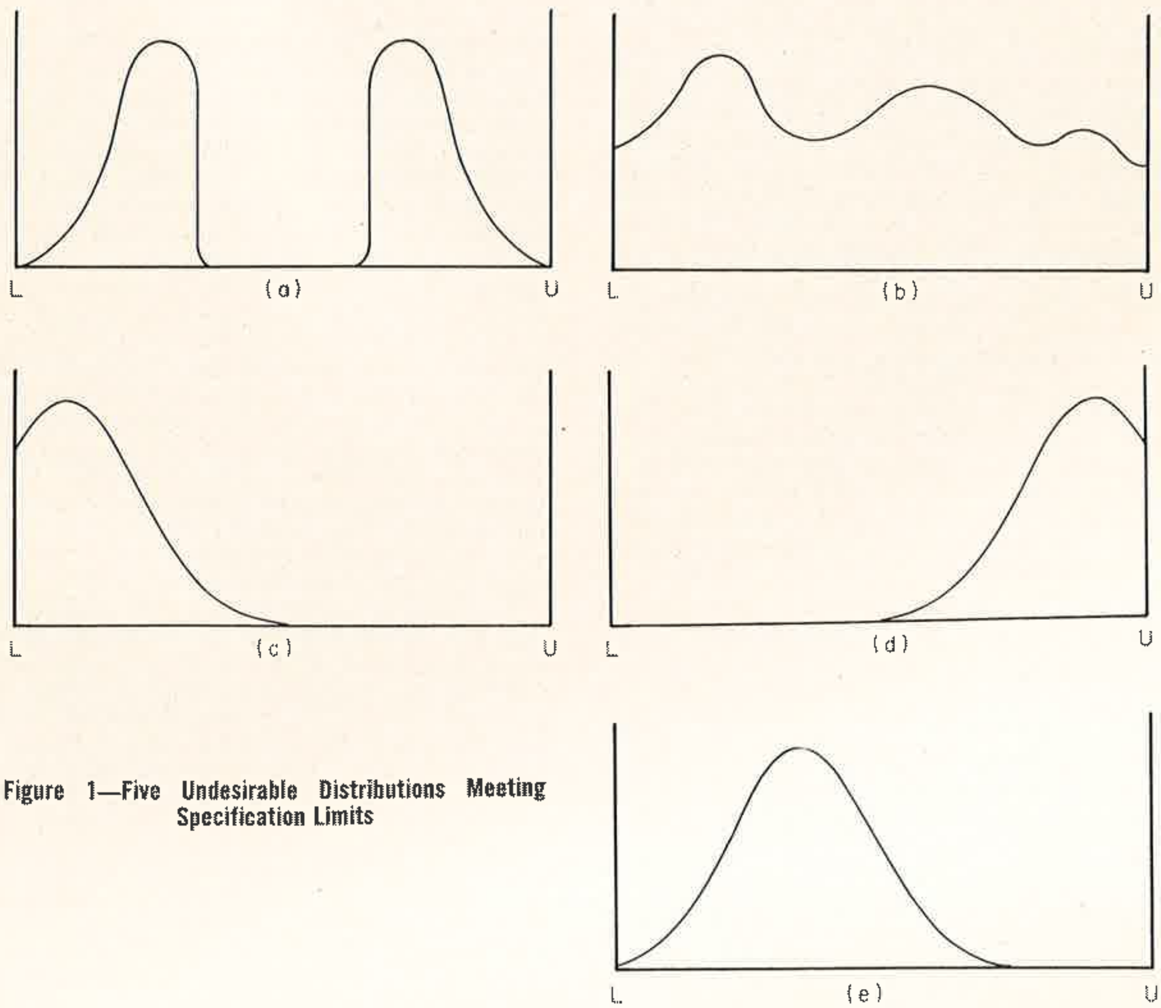

Figure 1—Five Undesirable Distributions Meeting Specification Limits

relative difficulty of manufacture. This provides initial specifications and is a first approximation. As process capabilities for manufacturing the parts become better known, a more economical allocation of distributions can be made.

Actually the recommendations here to be made call for something rather similar to upper and lower specification limits for parts, but with the further vital addition of practical ways of making sure that the process or lot mean is sufficiently close to the middle of the specified range and the variability sufficiently small to control the distribution properly. The latter controls *safely* permit the design engineer to make use of formulas such as

$$T_a = \sqrt{T_1^2 + T_2^2 + T_3^2 + T_4^2} \qquad (1)$$

where T_a is the total permissible variation for the assembly and T_1, T_2, T_3, T_4 the total ranges for the four parts. This permits the T_i's to be much bigger in the allocation than they can be in the traditional additive form of

$$T_a = T_1 + T_2 + T_3 + T_4 \qquad (2)$$

The former method (1) of combining tolerances cannot safely be used when one may have distributions such as in Fig. 1. But if adequate control is exercised over the process mean and standard deviation, then the design engineer can use the former square root formula (1), and can in almost all cases very considerably loosen up on the permissible variabilities of the parts.

As a simple illustration, suppose that for the assembly the total tolerance T_a is needed to be 0.006″, and that the four parts are about equally difficult to make. Under the traditional additive formula (2), each T_i would be set at 0.0015″. On the other hand the square root formula gives $T_a = \sqrt{4T_i^2}$ or 0.006″ $= 2T_i$ so that $T_i = 0.003$″; that is, twice as wide. (The relative gain is even greater if there are over four component parts, and is worthwhile even with but two components.) With at least some of the parts, a tolerance of 0.0015″ can probably only be met by 100 percent sorting, no matter how perfectly the process is controlled, whereas if the tolerance is set at 0.003″, 100 percent sorting and rejections may possibly be altogether eliminated. Or, possibly a less expensive production process may be feasible. But let us again emphasize that the price of this gain is in providing the design engineer with *assurance* that the *process mean will be close to the middle, and the variability will not be excessive*. We shall describe later on in this article the statistical tools which provide such assurance.

Characteristics for an Assembly*

During the rest of this article we shall be using the following notations:

μ_X = the process mean for the X's (or of whatever other subscript is used)

σ_X = the process standard deviation for the X's (or other subscript)

$\bar{X}$ = the sample mean of n X's

R = the sample range of n X's

*Some readers may wish to skip over to the section entitled "Summary of Approach from Design Engineer's Viewpoint" and the following sections, in order to see the general program.

These notations will be a bit easier than introducing as many primes as the standard ASQC notations[1] would call for.

Now let the characteristic of the assembly be Y. Then, for example, for X_1 the inside diameter of a bearing, X_2 the outside diameter of the shaft, the total clearance Y is given by

$$Y = X_1 - X_2$$

Or for the three thicknesses X_1, X_2, X_3 of three parts to be assembled on top of each other, Y the total thickness is given by

$$Y = X_1 + X_2 + X_3$$

(These two simple formulas have neglected out-of-roundness in the first case and out of parallel in the second, etc.) These are both illustrations of the very common relation for Y the assembly characteristic:

$$Y = X_1 \pm X_2 \pm \ldots \pm X_k \qquad (3)$$

if there are k component characteristics. The writer had occasion to see a thesis in which over a hundred papers were listed involving such relationships. Other relationships than purely additive and subtractive can also be handled. See for example Burr.[2]

Returning now to (3), it can easily be shown that the following are true, for example, Burr:[3]

$$\mu_Y = \mu_{X_1} \pm \mu_{X_2} \pm \ldots \pm \mu_{X_k} \qquad (4)$$

whether or not the X's are independent. If the X's are independent however, then also

$$\sigma_Y = \sqrt{\sigma_{X_1}^2 + \sigma_{X_2}^2 + \ldots + \sigma_{X_k}^2} \qquad (5)$$

"Independence" here means that, for example, whatever value the X_1 characteristic is for the first part tells nothing about what X_2 is for the second part. Such independence is achieved in practice if the processes are in control, or if assembly is done by random choice out of the respective lots. If the parts characteristics are not independent then we could have at least theoretically the two extremes

$$\sigma_Y = 0, \qquad (6)$$

or

$$\sigma_Y = \sigma_{X_1} + \sigma_{X_2} + \ldots + \sigma_{X_k} \qquad (7)$$

The right hand side of (7) is in general much larger than that of (5), and is like what the design engineer is assuming if he uses the additive tolerance technique (2).

A final fact from theoretical statistics also works to our advantage, namely, that subject to quite mild restrictions, as the number k of component characteristics increases, the distribution of Y becomes normal, regardless of the distributions of the X's.

Formulas (4) and (5) work very well for relationship (3) for the assembly characteristic Y, when we have large lots of articles to be assembled at random, or processes in good statistical control. Unfortunately processes often do not remain in good statistical control. Thus the process mean μ will commonly have a tendency to vary, and the process standard deviation may also change. Walter Shewhart's control charts are about the best and simplest techniques ever devised to secure and maintain such process control, and deserve to be even more widely used than they are now. Since careful control of processes is not universal, we shall want to extend formulas (4) and (5) somewhat to take account of lack-of-controlness and thereby facilitate use of tolerance allocation formulas such as (1).

Variation of the Characteristic for One Part

Consider the measurable characteristic of the first part X_1, which we will shorten to X. Suppose that the corresponding process mean, μ, varies. Now any series of numbers will have a mean and a standard deviation. Thus, for the varying μ values we have μ_μ and σ_μ. Let us further suppose that at any given moment the standard deviation of the X's around the process mean μ at that moment is σ_X, and that this σ_X is always the same no matter what μ is. At some later time, μ may have a different value, but the variation of X's around the new μ will still be this same σ_X.

Now let μ_0 be the desired nominal mean (often the middle of a specification range). It would be perfect if μ stayed at μ_0, but this cannot be expected. The next best thing would be for the instantaneous process mean μ to at least average μ_0. Thus we would like to have the expected value of the μ's, $E(\mu) = \mu_\mu$, to be equal to μ_0. Even this, however, will not always occur even though we will aim at it.

Let us now concern ourselves with the deviations of the individual characteristic X from μ_0:

$$X - \mu_0 = (X - \mu) + (\mu - \mu_\mu) + (\mu_\mu - \mu_0) \quad (8)$$

the right side being obtained by adding and subtracting. We thus have three deviations on the right side: of X around the instantaneous mean, of the instantaneous mean μ around the grand mean, and finally of the grand mean μ_μ around the desired μ_0. It may now be shown (see the Technical Appendix) that

$$E(X - \mu_0)^2 = \sigma_X^2 + \sigma_\mu^2 + (\mu_\mu - \mu_0)^2 \quad (9)$$

where, as above, E denotes the theoretical average value of the quantity that follows it. σ_μ^2 and μ_μ are the variance and mean of the distribution of instantaneous process averages, μ. Note that if the process is such that μ_μ is right at μ_0, then there are but two terms on the right side of (9). In the tests and process controls to be suggested later on, the third term will be almost always negligibly small. Either σ_X or $\pm 3\sigma_X$ has often been called the natural or instantaneous process capability. In at least some writings and approaches, insufficient allowance has been made for σ_μ^2, and too little attention paid to μ_μ vs. μ_0. One good discussion of this problem is given by Freund.[4]

Variation of the Assembly Characteristic

Carrying on from the preceding section, we now define the desired nominal for the assembly as μ_{0Y}. The design engineer should arrange that

$$\mu_{0Y} = \mu_{0X_1} \pm \mu_{0X_2} \pm \ldots \pm \mu_{0X_k} \quad (10)$$

Then we have, subtracting (10) from (3)

$$Y - \mu_{0Y} = (X_1 - \mu_{0X_1}) \pm (X_2 - \mu_{0X_2}) \pm \ldots \pm (X_k - \mu_{0X_k}) \quad (11)$$

It can then be shown (see the Technical Appendix) that similarly to (9)

$$E(Y - \mu_{0Y})^2 = \sigma_{X_1}^2 + \sigma_{\mu_1}^2 + \sigma_{X_2}^2 + \sigma_{\mu_2}^2 + \ldots + \sigma_{X_k}^2 + \sigma_{\mu_k}^2 + [(\mu_{\mu X_1} - \mu_{0X_1}) \pm \ldots \pm (\mu_{\mu X_k} - \mu_{0X_k})]^2 \quad (12)$$

The last bracketed term contains the various process biases. By the suggested controls, this term can be made negligibly small. Moreover the various process drifts, that is the $\sigma_{\mu_i}^2$ terms, can also be kept within bounds by appropriate controls. But some allowance for a σ_{μ_i} *should* be permitted, so that too tight a process control is *not* insisted upon. Thus economies are obtained in permitting some reasonable degree of drift as, for example, in tool wear. Specifically we here suggest that the drift in process mean be permitted to the extent of about $\sigma_{\mu_i} = 0.8\sigma_{X_i}$.

If then the bias, $\mu_{\mu X_i} - \mu_{0X_i}$, is negligible, (9) will give at most

$$E(X_i - \mu_{0X_i})^2 = \sigma_{X_i}^2 + (0.8\sigma_{X_i})^2 = 1.64\sigma_{X_i}^2 \quad (13)$$

Taking the square root gives

$$\sqrt{E(X_i - \mu_{0X_i})^2} = 1.28\sigma_{X_i} \quad (14)$$

Now, making a small allowance for process bias will bring (14) up to, say,

$$\sqrt{E(X_i - \mu_{0X_i})^2} = 1.33\sigma_{X_i} \quad (15)$$

Since the left side of (15) is very much like an ordinary standard deviation of the over-all or combined output of X_i's, around the nominal, the process spread for the X_i's is

$$6\sqrt{E(X_i - \mu_{0X_i})^2} = 8\sigma_{X_i} \quad (16)$$

Calling

$$T_i = 6\sqrt{E(X_i - \mu_{0X_i})^2} \quad (17)$$

we have

$$T_i = 8\sigma_{X_i} \quad (18)$$

or that the instantaneous process standard deviation should be $T_i/8$ or less. Comparing (9) and (12), it is seen that the contribution of the i'th part to the assembly variability, $E(Y - \mu_{0Y})^2$, is approximately $E(X_i - \mu_{0X_i})^2$, if the biases are small. Thus

$$E(Y - \mu_{0Y})^2 = \sum_{i=1}^{k} E(X_i - \mu_{0X_i})^2 \quad (19)$$

We now define

$$T_a = 6\sqrt{E(Y - \mu_{0Y})^2} \quad (20)$$

and then if we multiply both sides of (19) by $6^2 = 36$, we have, using (20) and (17) that

$$T_a^2 = T_1^2 + \ldots + T_k^2 \quad (21)$$

Considerations for Process Controls and Tests to Achieve the Desired Distributions

The aim of such controls and tests should be to provide assurance that the combined or overall distribution of parts will be satisfactory. These will take two forms: one for process control, and another where one is not close to the process; that is, for an acceptance-sampling situation. In the former case sample sizes of five are here recommended with a control-chart-like record maintained, while in the latter random samples of ten are suggested.

Two cases of process control have been studied while developing the methods; namely, (a) where there is a consistent tendency for μ to move in one direction or the other, as in tool wear, for example, and (b) where the process, if left alone, makes erratic random jumps to various levels at least some of which are undesirable. Control tests to handle these cases and provide assurance of the combined distribution proving satisfactory have been developed.

The program followed in the research has been to propose various production models in which μ and possibly σ vary, and then to see how the tests under study perform on them. Also various tests were developed and tried out. By taking badly controlled or highly erratic models, and applying the tests, assurance against undesirable process conditions is obtained.

No attempt has been made to try to optimize the tests for all situations since the field of application of the methods of this article is so broad. Thus wide applicability with simplicity is an important criterion and good performance against bad production conditions is basic, even if other tests might be a bit better in some situations.

Summary of Approach from Design Engineer's Viewpoint

The general approach here recommended for the design engineer is the following. Suppose that the engineer can allow a tolerance range of T_a for the assembly characteristic. He then uses the general form of (1), that is,

$$T_a = \sqrt{T_1^2 + T_2^2 + \ldots + T_k^2} \qquad (22)$$

and, according to the supposed difficulty of manufacture, decides on a value of the tolerance T_i for each part. For example, if there are three parts and the second and third are to be given twice the tolerance of the first, then $T_2 = 2T_1 = T_3$. This gives

$$T_a = \sqrt{T_1^2 + 4T_1^2 + 4T_1^2} = 3T_1$$

Thus

$$T_1 = T_a/3$$

and

$$T_2 = T_3 = 2T_a/3$$

(Note that $T_a = T_1 + T_2 + T_3$ would give $T_1 = T_a/5$ here.)

The design engineer now provides Production with the mean or nominal dimension μ_{0X_i} subject to (10), and the tolerance T_i for each part. These are *not* used to set maximum and minimum limits for the part, but instead *are* used to determine operational tests for insuring that the *distribution* of the part characteristic is desirable. That is, that the instantaneous process standard deviation σ_X meets

$$\sigma_{X_i} \leqq T_i/8 \qquad (23)$$

and also that

$$\sigma_{\mu_i} \leqq 0.1T_i \qquad (24)$$

and further that the process bias around the nominal μ_{0X_i} is small. With these tests being used the design engineer will be safe in using (22), instead of $T_a = T_1 + T_2 + \ldots + T_k$.

The form of the operational tests is in general to provide limits for the sample mean $\bar{X}$ and an upper limit for the sample range R, both sets being determined from μ_{0X_i} and T_i.

Acceptance Sampling Tests To Achieve a Desirable Distribution

Given a tolerance T and a nominal mean value μ_0 for a part, then the following plan will safely control the distribution of part dimensions for the accepted lots:

1. Choose a *random* sample of ten parts from the lot; that is, giving each one of the parts in the lot an equal chance of being chosen in the sample. Find the mean $\bar{X}$ and the range R for the sample data.
2. Then accept the lot if *both* of the following criteria are met:

a. $$R \leqq 0.521T \qquad (25)$$

b. $$\mu_0 - (0.174T) \leqq \bar{X} \leqq \mu_0 + (0.174T) \qquad (26)$$

3. Reject the lot if either one or both of the requirements in Step 2 is not met.
4. Report information on all rejected lots to producer. Such lots should also be sorted 100 percent to limits $\mu_0 \pm (3T/8)$, if lots are to be used.

Justification of the approach and description of what it does against various models is given in the Technical Appendix. The reason for the sorting in Step 4 to $\mu_0 \pm (3T/8)$ instead of $\mu_0 \pm (T/2)$ is that some lots may be badly off center and unless sorted to the narrower limits could bunch too much toward one limit or the other. This could give excessive values of $\sum_{i=1}^{N-K} (X_i - \mu_0)^2/(N-K)$, after sorting. (N = lot size, K the number of parts rejected in the sorting.)

Process Control Procedures for Achieving Desired Distributions

The ideal process for providing the desired distribution of part characteristics is one in which the process is in control with μ_X very close to μ_0 and sufficiently small σ_X. Shewhart control charts for $\bar{X}$ and R are about the most effective practical means of working toward such an ideal. Until such a goal is attained however, there are two typical cases of uncontrolled processes which we will consider. One is that of μ gradually changing as in tool or die wear. This is often rather easily controlled and allowed for. The other is of erratic changes in μ. (Of course there may also be combinations of these tendencies in the same process.)

In all cases it is expected that a control chart for sample ranges of n = 5 measurements will be kept and rejection made if R is above its upper control limit. Limits for $\bar{X}$ (n = 5) are also set, but action depends somewhat upon the case under consideration.

Case of Erratic Assignable Causes

Given a tolerance T and a nominal mean value μ_0 for a part, then the following plans will safely control the distribution of part dimensions:

1. For each periodic sample of five parts from the process, find the average $\bar{X}$ and the range R.
2. Process is considered satisfactory at this time if both of the following are met

a. $$R \leqq 0.615T \qquad (27)$$

b. $$\mu_0 - 0.168T \leqq \bar{X} \leqq \mu_0 + 0.168T \qquad (28)$$

3. Process is considered unsatisfactory at this time if either one, or both, of the requirements in Step 2 is not met.
4. Take appropriate remedial action in the event of

Step 3, and sort the production back to the previous sampling time, to limits of $\mu_0 \pm (3T/8)$.

When the requirement of Step 2a is not met, there is a clear indication that $\sigma_X > T/8$ and steps should be taken to find out why. On the other hand if $\bar{X}$ lies outside its limits, this can occasionally occur by an excessive σ_X, even with no change at all in μ. But ordinarily such a point indicates a change in level μ away from μ_0. Thus an adjustment or resetting is called for. This can take two forms, thus:

5. Reset the process level μ as follows
   a. Plan A, as closely as possible to μ_0
   b. Plan B, toward μ_0 by an amount equal to $0.8 \mid \bar{X} - \mu_0 \mid$.

Plan A requires careful resetting and a check of the setting. Plan B may be much more feasible in automatic control of a process.

It is of interest, especially in this issue of *Industrial Quality Control* commemorating Dr. Walter A. Shewhart, that the limits and technique of sections 1, 2 and 3 are precisely those of the Shewhart control charts for $\bar{X}$ and R with the standards, μ_0 and $\sigma_X = T/8$, given. These seemed to work out about best in the models studied.

Again, further discussion will be found in the Technical Appendix.

Case of Consistent Change in Process Level

Given a tolerance T and a nominal mean value μ_0 for a part, then the following plans will safely control the distribution of part dimensions:

1. For each periodic sample of five parts from the process find the average $\bar{X}$ and the range R.
2. Process is permitted to continue at this time if both of the following are met:
   a. $R \leqq 0.615T$
   b. $\mu_0 - 0.188T \leqq \bar{X} \leqq \mu_0 + 0.188T$
3. If either or both of the requirements in Step 2 is not met, action is required. If R is excessive the recent product should be sorted and the source of excessive process variability looked for. If $\bar{X}$ has crept beyond the respective limit (upper if μ increases, lower if μ decreases), then the process is to be reset, and 100 percent sorting is unnecessary.
4. Resetting of process mean μ can be done in either of two ways:
   a. Plan A, as closely as possible to a point $\mu_0 - 0.1T$ if μ rises or $\mu_0 + 0.1T$ if it falls.
   b. Plan B, by an amount 3T/8, down if μ rises or up if μ falls.

Again Plan A is more feasible for operator-controlled processes, but Plan B may be more feasible for automatic control. Plan A gives a bit more protection. Further discussion is given in the Technical Appendix.

Summary

Under most present production practices using maximum and minimum specification limits with no other control over the distribution of part dimensions it has not been possible for design engineers to take much advantage of the square formula (22) for tolerancing. Instead they have commonly continued to use purely additive formulas such as (2). This often proves very wasteful and costly and leads to undesirable practices. What is needed is emphasis instead upon controlling the distribution of the parts, specifically maintaining the average close to the desired nominal while preventing the variability from becoming excessive. It is then possible and *safe* for the design engineer to make use of formulas like (22). The approach then becomes quite similar to past practice in that the design engineer allocates tolerances T_i for each part along with desired nominal means μ_{0X_i}. The T_i's for the various parts can vary according to the supposed difficulty of manufacture but must meet (22). The assembly characteristic Y defined in (3) can then be expected to meet limits of $\mu_{0Y} \pm (T_a/2)$ in a "three-sigma" sense; that is, about 99.7 percent of the time or more. Meanwhile Production or Receiving Inspection can take μ_{0X_i} and T_i and begin using one of the appropriate plans as outlined. As process capability information becomes better known a more economical allocation of the T_i's by (22) may be possible. This program will in general permit Production to have wider variability to work to, will save a great amount of inspection and scrapping, and yet will produce assemblies meeting all that the design engineer needs.

Technical Appendix

Proof of Formula (9): There are two distributions to be concerned with in this proof, namely that of the X's which are assumed normally distributed around the instantaneous value of μ and with standard deviation σ_X. Then there is the distribution of the μ values, which vary having mean μ_μ and standard deviation σ_μ. Letting E, as before, stand for expectation or theoretical average, we now place subscripts to E for the random variables with respect to which the expectation is taken. Then for (9) we seek $E_{X,\mu}(X - \mu_0)^2$, where $X - \mu_0$ and μ are assumed independent. Then

$$E_{X,\mu}(X - \mu_0)^2$$
$$= E_{X,\mu}[(X - \mu) + (\mu - \mu_\mu) + (\mu_\mu - \mu_0)]^2$$
$$= E_{X,\mu}[(X - \mu)^2 + (\mu - \mu_\mu)^2 + (\mu_\mu - \mu_0)^2 + 2(X - \mu)(\mu - \mu_\mu)$$
$$+ 2(X - \mu)(\mu_\mu - \mu_0) + 2(\mu - \mu_\mu)(\mu_\mu - \mu_0)]$$

Taking first the expectations of the terms relative to the X = distribution, the first term has expectation σ_X^2 while the fourth and fifth terms have expectation zero. The expectation of the others is the same expression since they are constant relative to X. Now with respect to μ, the expectations of σ_X^2 and $(\mu_\mu - \mu_0)^2$ are the same things, that of $(\mu - \mu_\mu)^2$ is by definition σ_μ^2, and the last term has expectation zero. Thus we obtain the right hand side of equation (9).

Proof of Formula (12): This is similar to (9) but merely more complex, involving 2k distributions instead of but 2. For simplicity let us drop the X's from the subscripts for μ's; that is, $\mu_{X_1} = \mu_1$ etc. Further let us take $k = 2$, and take $Y = X_1 - X_2$ just to illustrate the manner of proof. Then

$$E(Y - \mu_{0Y})^2 = E(X_1 - X_2 - \mu_{01} + \mu_{02})^2$$
$$= E_{X_1, X_2, \mu_1, \mu_2}\{(X_1 - \mu_1) - (X_2 - \mu_2) + (\mu_1 - \mu_{\mu_1}) - (\mu_2 - \mu_{\mu_2})$$
$$+ [(\mu_{\mu_1} - \mu_{01}) - (\mu_{\mu_2} - \mu_{02})]\}^2$$

Upon squaring within the braces we will have five pure squared terms, and ten cross-product terms. Since we are assuming that $X_1 - \mu_1$, $X_2 - \mu_2$, μ_1 and

μ_{μ_2} are all independent we may always take the expectation of a cross product first with respect to some random variables so as to give zero. The expectations of the five pure squares are respectively $\sigma_{X_1}{}^2$, $\sigma_{X_2}{}^2$, $\sigma_{\mu_1}{}^2$, $\sigma_{\mu_2}{}^2$ and $[(\mu_{\mu_1} - \mu_{01}) - (\mu_{\mu_2} - \mu_{02})]^2$, which proves this example of (12). The general proof is exactly similar.

The Bias Term. The last term of (12) reflects the biases in the process controls being used. The right hand side of (12) is very similar to the sum of the right hand sides of k equations like (9). The discrepancy lies in the fact that

$$[(\mu_{\mu_1} - \mu_{01}) \pm \ldots \pm (\mu_{\mu_k} - \mu_{0k})]^2$$

is not exactly

$$(\mu_{\mu_1} - \mu_{01})^2 \pm \ldots \pm (\mu_{\mu_k} - \mu_{0k})^2,$$

since the former would have not only the latter terms, but also many cross product terms too. However, unless process controls yielding nearly all biases in one direction (taking account of the ±'s) the cross product terms will largely cancel out. Thus the right side of (9) is a good indication of the contribution of the i'th part to the right side of (12).

Acceptance Sampling Test and Appropriate Production Models. To pick out a pair of tests for R and $\overline{X}$ for samples of $n = 10$ for acceptance sampling, a number of models were devised and various tests applied. The tests were

$R \leq 30$: accept, $R > 30$: reject

$\overline{X}$ between $\mu_0 \pm 10k$: accept, otherwise : reject,

where k was 0.6, 0.7, 0.8, 0.9 and 1.0. These were basically for a nominal $\sigma_X = 10$. It would have been possible to vary the limit for R, but this was not necessary since the limits for $\overline{X}$ were varied which has the same effect.

The next step was to determine some *a priori* distributions of μ and of σ, some of which would be desirable relative to the tests and some undesirable and see how the tests operated; that is, what would the quality be like for the accepted lots? The incoming or *a priori* distributions chosen for σ were the following discrete ones

σ	5.25	5.75	6.25	6.75	7.25	7.75	
	8.25	8.75	9.25	9.75			. . . 19.75
Q_1	1/30	1/30					. . . 1/30
Q_2	0.1	0.1	0.1	0.1	0.1	0.1	
	0.1	0.1	0.1	0.1			. . . 0
Q_3	0.19	0.17	0.15	0.13	0.11	0.09	
	0.07	0.05	0.03	0.01			. . . 0
Q_4	0.25	0.25	0.25	0.25	0	0	. . . 0

Thus the first distribution is very spread relative to $\sigma_X = 10$, which level of quality will be accepted with probability 0.4878 by the acceptance criterion: accept if $R \leq 30$. See Harter and Clemm[5]. Meanwhile the last distribution will give almost all acceptances by the same test and hence be regarded by this test as highly satisfactory.

The distributions chosen for μ values were the following

Rectangular: $\mu_0 - 20$ to $\mu_0 + 20$
Normal: mean μ_0, std. dev. 20/3
Normal: mean μ_0, std. dev. 10/3
Rectangular: $\mu_0 - 5$ to $\mu_0 + 5$.

These were also made discrete with index values $\mu_0 \pm 0.5$, $\mu_0 \pm 1.5$, etc. In all, there were 40 possible values of μ and 30 of σ or 1200 combinations. A digital computer figured the operating characteristic *surface* for these 1200 combinations; that is, the probability that a lot with a given combination of μ and σ will pass both tests: $P(\text{acc.} \mid \mu,\sigma) = P_1(\text{acc.} \mid \mu,\sigma)\, P_2(\text{acc.} \mid \sigma)$, where P_1 is the probability for the $\overline{X}$-test and P_2 for the R-test. This is the probability of passing if such a combination of μ and σ should be offered. Then multiplying this by the probability of offering such a lot for acceptance; that is, the product of the probabilities for the respective distributions of μ and σ, we obtain the point *a posteriori* distribution of μ, σ, given that the lot was accepted. Finally from the marginal totals of this joint distribution the following could be found:

$$E(\sigma), \sigma_\sigma, E(\mu), \sigma_\mu.$$

This was done for all 16 combinations of distributions (4 for σ by 4 for μ), for each of the five $\overline{X}$-tests. This gave 80 sets of results. It was then possible to determine which test would meet the desired criteria. Finally, $k = 1.0$ was settled upon, and the tests redesigned to do the job relative to T_i as needed. By the last we mean that a typical average value of σ, 7.23, for the two intermediate *a priori* distributions of σ was equated to $T_i/8$ and appropriate adjustments made to the tests.

For the test on variability the range of $n = 10$ was used because of its simplicity, and because (a) it is a bit more efficient than $\overline{R}$ for two samples of $n = 5$, and (b) it is not much less efficient than the sample standard deviation.

Process Control Models and Tests. It appeared desirable to try more different process models and tests than seemed necessary for acceptance sampling. Basically a production process which is tested and modified periodically gives results which form a stochastic process. The models are a form of adaptive control.

The aim of the program was again the same; namely, to set up practical production models which would not be satisfactory, unless some corrective action were taken to make them meet the desired criteria of $\sigma_X \leq T/8$, $\sigma_\mu \leq 0.8\sigma_X$ and μ_μ near μ_0.

Since it is intended that a subsequent technical paper will describe the models and details more fully, we shall only summarize them here.

There were three models studied for *randomly acting assignable causes.* The first two were for discrete levels of μ; some of which would be unsatisfactory, since they were as much as 2.5 σ_X away from μ_0. Each level of μ remained for a random time period unless a rejection occurred, in which event the process level would be reset right at μ_0 and a new random time of run at this level begun. There were two random time distributions—the first continuous, following an exponential distribution (Model A 1), and the second (Model A 2) with random times which could only end at the time a test on $\overline{X}$ was made. A geometric distribution was chosen for the time distribution in A 2. Using a fixed or known value for σ_X, the test was on $\overline{X}$, accepting if it lay inside $\mu_0 \pm k\sigma_X$. Various values of k were studied along with average run life times of 2, 3, 5 and 10 test periods.

It was necessary to make a Monte Carlo study of Model A 1. However, it was possible to solve the stochastic model A 2 for exact results. Furthermore in the latter case it also proved possible to introduce a set-up error so that after a rejection there would be a 0.6 probability of a setting at $\mu = \mu_0$ and 0.2

of it being at $\mu_0 + 0.5\sigma_X$ and 0.2 of $\mu_0 - 0.5\sigma_X$. Exact results were still available.

The third model and test for randomly acting assignable causes, Model A 3, called for a normal distribution of levels with the *a priori* distribution of μ's having $\sigma_\mu = 1.0\sigma_X$ or $1.2\sigma_X$, and with a geometric distribution of run lengths at a given level μ. Resetting after a rejection was by an amount proportional to $(\bar{X} - \mu_0)$; that is, $-h(\bar{X} - \mu_0)$ added to μ. Values of 0.8, 0.9 and 1.0 were taken for h. Again Monte Carlo methods proved necessary.

Finally we describe two tool-wear models. In the first, B 1, where, say μ tends to rise and by an amount $0.1\sigma_X$ per time period, tests are made for $\bar{X}$ lying between $\mu_0 \pm k\sigma_X$. If a rejection occurs, then the process level μ is to be reset to a level of $\mu_0 - a\sigma_X$ where $a = 0, 0.2, \ldots, 1.6$. These results are capable of precise solution to any desired accuracy, but are quite long. It also proved possible from such results to superimpose a set-up error around the requested level.

The other tool-wear model was one in which the amount of resetting was always by a fixed amount. This amount was so taken in relation to the test criterion for $\bar{X}$ that μ_μ would be close to μ_0. The equations for this stochastic model could also be solved. In using $\mu_0 \pm k\sigma_X$ with $k = 1.5$ to permit considerable latitude for tool-wear, the values of σ_μ did prove to be a bit above $0.8\sigma_X$; namely a bit over $0.9\sigma_X$. Use of limits $\mu_0 \pm 1.342\sigma_X$ yields about $0.85\sigma_X$ for σ_μ. These results were without 100 percent sorting after $\bar{X}$ went out.

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Key Words: *Procedure, specifying, desired distribution, dimensions, characteristics, parts, assembly, maximum, minimum, limits, design engineer, r.m.s. formula, additive formula, tolerance allocation.*

Analysis of Means— A Graphical Procedure

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It is my pleasure to dedicate this article to the memory of Walter A. Shewhart, friend, fellow Rutger's professor (Honorary), scholar, scientist, the originator and innovator of quality control.

Introduction

The Shewhart control chart is a common introduction to statistical analysis for many engineers, inspectors, chemists, and other scientists. When these charts indicate the presence of an assignable cause (of non-random variability), an adjustment of the process is made if the remedy is known. When the nature of the assignable cause and the appropriate adjustment of the process are not known, there is a need and an opportunity to design production studies (or experiments). However, the majority of experimenters need professional guidance when they begin to analyze and interpret designed experiments using Analysis of Variance procedures; consequently, there might be a reluctance to plan and carry out a more sophisticated experimental program.

The methods of analysis described in this article are an extension of Shewhart control chart techniques. They tend to encourage the design of experiments and are an effective method of presenting the findings. They involve dealing directly with means in contrast to the Analysis of Variance in which means are compared by taking ratios of mean squares. The underlying concepts of these two procedures are basically the same; the conclusions are usually the same, but the nature of some differences

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are indicated in this article. Additional benefits of the Analysis of Means are outlined in the Summary.

One method of studying a scientific process is to hold constant all variables which are suspected of contributing to the variability of the process, and then decide whether the resulting pattern of data represents a stable source, or whether the data give evidence of "unstability" (non-randomness). Frequently, an experimenter will expect his own scientific process to indicate stability when his known independent variables are held constant; he expects, also, that the data obtained under these constant conditions will support his expectation and indicate only the presence of random variability. However, it is a common experience to find that the data, obtained under these process conditions considered to be stable (in control), indicate evidence of important non-randomness. Such evidence, if recognized, can be the basis of scientific discovery; if not recognized, it can lead to incorrect conclusions.

A second approach to experimentation is to vary deliberately and simultaneously, in a preplanned experimental pattern or design, different factors suspected of contributing to the variation of the process. A standard method of comparing effects observed from such experiments is Analysis of Variance.

The method of Analysis of Means, discussed in this article, has application to each of these two methods of experimentation. Beginning with k averages (means) of n measurements each, the analysis compares the individual means with the grand average of the k means; this is directly analagous to a control chart. Throughout this article the following symbols will be used:

Population Mean = μ (read "mu")
Population Standard Deviation = σ
Average of One Sample = $\bar{x}$
Grand Average of All Samples = $\bar{\bar{x}}$
An Estimate of the Population Standard Deviation = $\hat{\sigma}$ (read "sigma hat")

There are several different methods which can be used to obtain $\hat{\sigma}$. Some of these are included in Appendix.

The decision of a significant difference is made by comparison of points representing the k means with lines drawn parallel to the line of the grand mean. However, instead of *control limits* drawn at

$$\bar{\bar{x}} \pm 3\hat{\sigma}_{\bar{x}} = \bar{\bar{x}} \pm A_2\bar{R} \qquad (1)$$

as with the Shewhart control chart (where k is usually greater than 20), *decision lines* for the Analysis of Means are drawn at

$$\bar{\bar{x}} \pm H_\alpha \hat{\sigma}_{\bar{x}} \qquad (2)$$

where H_α is a factor given in Tables I and II for $\alpha = 0.05$ and 0.01, respectively. When there are exactly two means ($k = 2$), the Analysis of Means is simply a graphical form of Student's t-test.

A chart is constructed using the decision lines in equation (2). If all the plotted points fall between the upper and lower decision lines, it is interpreted as representing only random variability; i.e., no significant difference. If a point falls outside of either of these decision lines, it is considered evidence of non-randomness with risk α.

Non-Random Variability

A. Standard Given (This condition is represented by a process with a "long" record of stability or control.)

Given: a process in statistical control with known average μ and known standard deviation σ. The process may be a laboratory procedure where control of independent variables may be relatively easy, or it may be a production process. Let us select from the process k independent samples each of size n, and examine all k means simultaneously. Within what interval about μ

$$\mu \pm Z_\alpha \sigma_{\bar{x}} \text{ (where } \sigma_{\bar{x}} = \sigma / \sqrt{n}) \qquad (3)$$

can we predict that all k means will lie with probability $(1 - \alpha)$; i.e., with risk α? Values of Z_α corresponding to risks of $\alpha = 0.05$ and 0.01, on the assumption that means from the process are normally distributed†, are given in Table III. See Appendix II for the derivation.

It should be noted that when "control limits" are drawn, for example at $\mu \pm 2\sigma_{\bar{x}}$, it is commonly believed that a point outside these limits indicates an assignable cause with risk about 0.05 (5 percent). The risk is indeed about 0.05 provided the criteria are applied to a single point just observed; but it is an appreciably greater risk when applied to $k > 1$ means, simultaneously. If $k = 10$, for example, the risk is: $1 - (0.954)^{10} = 0.376$. This isn't even close to a five percent risk! Thus, it should be emphasized that the Analysis of Means given in this article provides correct probabilities for the analysis of *groups* of data. Monitoring a process by examining means one at a time as they become available would, of course, require limit lines set for individual means.

The values in Table III thus indicate where to draw lines at $\mu \pm Z_\alpha \sigma_{\bar{x}}$ in order to provide an overall risk of $\alpha = 0.05$ (or $\alpha = 0.01$) when a group of k means is to be analyzed.

B. No Standard Given. The preceding discussion has considered analysis of k groups of n each, considered simultaneously, standard given. More often, however, we need to make comparisons without such previous knowledge and then base our decisions on information (data) contained only in the experimental samples (*no standard given*).

Measurements from k different groups are obtained as before, and their means are computed. However, instead of a given mean μ, we use the average $\bar{\bar{x}}$ of the k means. And instead of a given σ, we need to obtain in some proper way an estimate of $\hat{\sigma}$ of the standard deviation of the process of individuals. Then the decision is made as to whether the data represent random samples from a common process (i.e., no significant difference) or whether

†When n is as large as 4, this assumption of normality of means is almost always adequate even if the population of individuals is rectangular, right-triangular, or "almost" any other shape.[18]

Tables I and II—Percentage Points for the Studentized Maximum Absolute in Normal Samples

$$H_\alpha = \mathrm{Max}\left[\frac{(\bar{x}_n - \bar{\bar{x}})}{\hat{\sigma}_{\bar{x}}}, \frac{(\bar{\bar{x}} - \bar{x}_1)}{\hat{\sigma}_{\bar{x}}}\right]$$

I: $\alpha = 0.05$, No Standard Given

Degrees of Freedom for Error	Number of Means Being Compared (k) 2	3	4	5	6	8	10	15	20	30
5	1.82									
6	1.73	2.59	2.94	3.19	3.37					
8	1.63	2.39	2.71	2.92	3.09	3.33				
10	1.58	2.29	2.58	2.78	2.93	3.15	3.31			
15	1.51	2.16	2.42	2.60	2.74	2.93	3.07	3.32		
20	1.48	2.10	2.35	2.52	2.64	2.83	2.96	3.18	3.33	
30	1.44	2.04	2.28	2.44	2.56	2.73	2.86	3.06	3.19	3.37
40	1.43	2.01	2.25	2.40	2.52	2.69	2.80	3.00	3.13	3.29
60	1.41	1.98	2.21	2.36	2.48	2.64	2.76	2.94	3.06	3.22
120	1.40	1.95	2.18	2.33	2.44	2.60	2.71	2.88	3.00	3.15
∞	1.39	1.93	2.15	2.29	2.40	2.55	2.65	2.82	2.94	3.08

II: $\alpha = 0.01$, No Standard Given

Degrees of Freedom for Error	Number of Means Being Compared (k) 2	3	4	5	6	8	10	15	20	30	40	60
5	2.85											
6	2.62	3.74	4.21	4.53	4.78							
8	2.37	3.31	3.70	3.97	4.17	4.47						
10	2.24	3.08	3.43	3.67	3.86	4.11	4.29					
15	2.08	2.81	3.12	3.32	3.47	3.69	3.84	4.11				
20	2.01	2.70	2.98	3.17	3.30	3.50	3.63	3.87	4.02			
30	1.94	2.58	2.85	3.02	3.15	3.33	3.45	3.66	3.79	3.96		
40	1.91	2.53	2.79	2.95	3.07	3.24	3.36	3.56	3.68	3.84	3.96	
60	1.88	2.48	2.73	2.88	3.00	3.16	3.27	3.46	3.58	3.73	3.84	3.97
120	1.85	2.43	2.67	2.82	2.93	3.09	3.20	3.37	3.48	3.62	3.72	3.86
∞	1.82	2.39	2.61	2.76	2.87	3.02	3.12	3.29	3.39	3.53	3.62	3.73

Note: The numbers corresponding to $k = 2$ are appropriate modifications of entries in Student's t-tables; other values in this table are the averages of the upper and lower bounds given in Reference 7.

at least one of the means departs significantly from the grand mean $\bar{\bar{x}}$ (i.e., whether there is at least one mean significantly different from the overall mean $\bar{\bar{x}}$). The k means are computed, an estimate $\hat{\sigma}$ obtained, and lines are drawn at $\bar{\bar{x}} \pm H_\alpha \hat{\sigma}_{\bar{x}}$.

Tables of H_α for $\alpha = 0.05$ and $\alpha = 0.01$ (Tables I and II, respectively) have been developed as a modification of tables by Halperin, et al.[7], for selected values of k from $k = 2$ to $k = 60$, and selected degrees of freedom. For example, when $k = 5$ with 20 degrees of freedom, the value of $H_{0.05}$ is 2.52.

Estimating the Standard Deviation from the Average Range of k Small Samples

A. Estimating σ from $\bar{R}$. When we have k samples of n each (and n is small, i.e., less than 6 or 7, usually), the procedure† for estimating σ begins with finding the average $\bar{R}$ for the k samples; then

Table III—Values for Calculating Decision Lines (Standard Given, Two-Tailed Risk)

Number of Means k	$Z_{0.05}$	$Z_{0.01}$
2	2.24	2.81
3	2.39	2.93
4	2.49	3.02
5	2.57	3.09
6	2.63	3.14
7	2.68	3.19
8	2.73	3.23
9	2.77	3.26
10	2.80	3.29
15	2.93	3.40
20	3.02	3.48
24	3.07	3.53
25	3.08	3.54
30	3.14	3.59
40	3.22	3.66
50	3.28	3.72
120	3.52	3.93

$$\hat{\sigma} = \bar{R}/d_2^* \quad (4)$$

where d_2^* is a constant for a given value of n and k. Values of d_2^* are given in Table IV.

There are different reasons why the range is useful in analyzing data, and since there is very little loss in statistical efficiency (See Table V), the use of the range is emphasized in this article.

B. Degrees of Freedom Associated with $\hat{\sigma} = \bar{R}/d_2^*$.

The computational procedures of both the Analysis of Means and the Analysis of Variance require reference to the number of degrees of freedom; the computational procedures do not require an understanding of the meaning of degrees of freedom. (For a discussion of degrees of freedom see a text in statistics, for example, Bennett and Franklin[2].)

Exact numbers of degrees of freedom associated with the estimates of σ based on the range are shown for the few sample sizes in Table IV. As was noted by Duncan[4], from whose work Table IV is taken,

†The standard control chart procedure for estimating σ is: $\hat{\sigma} = \bar{R}/d_2$, where d_2 is a constant which is independent of k. The value of k is usually as large as 20 or more in most control chart work. In this article we use a d_2^* factor instead of d_2, especially when k is small. There are different reasons why this is done, but one of them relates to the desire to conform closely with the authors of Ref. 7 on which our Tables I and II are slight modifications. The tables in Ref. 7 are based on the biased estimate of σ,

$$\hat{\sigma} = s = \sqrt{\Sigma(x_i - \bar{x})^2/(n-1)}$$

This estimate of the population σ is only slightly biased for large n but has a larger bias for small n. Because we use tables from Ref. 7, our estimates of σ should have a similar bias. Now $(\bar{R}/d_2^*)^2$ is an unbiased estimate of σ^2; and $\sqrt{(\bar{R}/d_2^*)^2} = \bar{R}/d_2^*$ is a biased estimate of σ appropriate to replace s in Tables I and II (See Ref. 4). The values of d_2^* are essentially independent of k and equal to d_2 provided k is large (certainly as large as 20), and either may be used. An adjustment is recommended for small values of k; actually, use of the d_2 factor to obtain $\hat{\sigma}$ gives a slightly larger estimate since values of d_2^* decrease as k increases. In practice then, some significant differences will be missed occasionally if d_2 is used instead of d_2^*.

Table IV—d_2^* Factors for Estimating the Standard Deviation from the Average Range and Associated Degrees of Freedom

$$\hat{\sigma} = \bar{R}/d_2^*$$

Size of Samples n	Number of Sample Means (k) 2 ν	2 d_2^*	3 ν	3 d_2^*	4 ν	4 d_2^*	5 ν	5 d_2^*	10 ν	10 d_2^*	∞ d_2^*
2	1.9	1.28	2.8	1.23	3.7	1.21	4.6	1.19	9.0	1.16	1.13
3	3.8	1.81	5.7	1.77	7.5	1.75	9.3	1.74	18.4	1.72	1.69
4	5.7	2.15	8.4	2.12	11.2	2.11	13.9	2.10	27.6	2.08	2.06
5	7.5	2.40	11.1	2.38	14.7	2.37	18.4	2.36	36.5	2.34	2.33
6	9.2	2.60	13.6	2.58	18.1	2.57	22.6	2.56	44.9	2.55	2.53

Where ν = Degrees of Freedom

there is a loss of about 10 percent in the number of degrees of freedom from that associated with the pooled variance procedure.† Thus, the degrees of freedom to be used with $\hat{\sigma} = R/d_2^*$ in entering Tables I and II can be taken as approximately equal to

$$\text{Degrees of Freedom} \approx 0.90k\,(n-1) \qquad (5)$$

Summary

An engineer frequently examines the behavior pattern of the last k points on a control chart to decide whether important assignable causes are affecting his process. The probabilities associated with his analysis are not necessarily what he believes them to be: 2-sigma and 3-sigma lines are correct decision criteria to use in judging whether the last single point, just observed and plotted, indicates the presence of non-random variability with respective probabilities of about 1/20 and 3/1000. However, corresponding decision lines to judge evidence of non-random variability of a set of k means *simultaneously* depend upon the number of means and upon the degrees of freedom in the estimate $\hat{\sigma}$ of the experimental error: Factors $H_{0.05}$ and $H_{0.01}$ are larger than most people would expect. Values are given in Tables I and II. (Some industrial practitioners have been applying control-chart techniques regularly to analyze experimental data, using 2-sigma and 3-sigma decision lines to approximate 0.05 and 0.01 risks, although recognizing an inability to assign "exact probabilities" to their decisions.)

There have been major developments in applying control charts to production data during the last two decades, and there has been a similar but essentially independent development in designing and analyzing experiments. The methods of analysis used in Appendix I are an effective means of relating the two.

†Note that when such estimates of the variance σ_i^2 of k samples of n each are used to obtain a pooled $\hat{\sigma}^2$, the total number of degrees of freedom is

$$\text{Degrees of Freedom} = k(n-1)$$

since each sample of n contributes $(n-1)$ degrees of freedom. The pooled $\hat{\sigma}^2$ is obtained as follows:

$$\hat{\sigma}^2 = (\hat{\sigma}_1^2 + \hat{\sigma}_2^2 + \ldots + \hat{\sigma}_k^2)/k = \left(\sum_{i=1}^{k} \hat{\sigma}_i^2\right)/k$$

where $\hat{\sigma}_i^2 = \sum_{j=1}^{n} (x_j - \bar{x}_i)^2/(n-1)$.

Table V—The Efficiency of the Range for Small Sample Sizes

Sample Size n	d_2 Factor	Efficiency
2	1.13	1.00
3	1.69	0.99
4	2.06	0.99
5	2.33	0.96
6	2.53	0.93

Advantages of Graphical Analysis of Means

1. It provides a *direct study* of possible effects of the factors by dealing with *means* instead of variances. The Analysis of Means thus provides a comparison of the relative importance and magnitude of the factors, as well as their statistical significance.

2. It provides a *graphical comparison* of effects. A primary function of industrial experimentation is not only to obtain information, but to present it in a way which will be accepted as a basis for decision and action by appropriate technical and administrative personnel. The graphical presentation encourages the translation of conclusions into scientific action; this is a critical advantage.

3. It provides a *pin-pointing* of sources of non-randomness. An Analysis of Variance may indicate certain factors which affect the response being studied; this analysis must usually be followed by some supplementary analysis to pin-point the important factors. The techniques of this article have been used to provide such a supplementary analysis. Many users of the techniques have later inverted their procedures and use the Analysis of Means as the primary analysis.

4. A graphical presentation of data is almost a necessity when interpreting the meaning of interactions whose presence have been indicated by an Analysis of Variance.

5. The Analysis of Means is more sensitive in detecting the non-randomness of a single mean than is Analysis of Variance (See Reference 6). Many industrial studies comparing the performance of several machines, heads, or operators indicate that it is important to have means of detecting a difference in behavior of one or two. (Conversely, the Analysis of Means is somewhat less sensitive in determining the overall variability of a group of k machines, heads, or operators.)

6. The Analysis of Means frequently provides a bonus by suggesting the unsuspected presence of certain types of non-random variability; these

suggestions can then be included in subsequent experiments for study.

7. The graphical Analysis of Means has frequently indicated *errors in calculation* in an Analysis of Variance. These errors are often apparent in a graphical presentation even to the untrained.
8. The Analysis of Means procedure can be (and has been) programmed for graphical printout on computers.

Variations and Extensions of the Analysis of Means

1. The comparison of k individual fraction defectives —an analog of a p-chart. (See Reference 9, 10.)
2. Procedures to use when the experiment was designed without replicates (i.e., $n_1 = n_2 = \ldots = n_k = 1$).
3. A procedure to study data exhibiting surprisingly little variability—non-random uniformity, (See Reference 13.)
4. The discussion in this article has usually implied a one-way classification of data (an exception is item 4 above). The Analysis of Means is not limited to one-way classification.

Appendix I

Example—A 2 x 3 x 4 Factorial Experiment

The inclusion of replicates in an experiment provides an immediate method of estimating the experimental error $\hat{\sigma}$, and allows a comparison of main effects by the Analysis of Means. The details will be illustrated by an analysis of data from Reference 1, which pertains to the lengths of steel bars. These bars were "made from two heat treatments and cut on four screw machines at three times (at 8:00 A.M., 11:00 A.M. and 3:00 P.M. all on one day; the time element involved fatigue on the part of the operator)." The following data (lengths of bars) have been reproduced in Table VI as in the published article except that the ranges R of the sub-groups have been included.

Procedure Using the Analysis of Means

Steps 1 and 2. Prepare an ordinary R-chart as in Fig. 1, with $\bar{R} = 5.29$ and $D_4\bar{R} = (2.28)(5.29) = 12.06$. All of the points lie below the control line, and we tentatively accept this as evidence of homogeneity of ranges. However, it may be noted that 7 of the 8 points for Time 3 are above the grand average, and there is thus a suspicion of increased variability with Time.

Step 3. $\hat{\sigma} = \bar{R}/d_2 = 5.29/2.06 = 2.57$. (Note: The estimate of σ' from the Analysis of Variance in Reference 1 is $\hat{\sigma} = \sqrt{6.2} = 2.49$. These are in good agreement.) We have estimated σ using the range with: $k = 24$ and $n = 4$. From equation 5, Degrees of Freedom $\approx 0.90k\ (n - 1) \approx 0.90(72) \approx 65$.

Step 4. The following averages have been computed from Table VI and drawn in Fig. 2.

Time (T)	Heat (H)	Machine (M)
$\bar{T}_1 = 3.75$	$\bar{W} = 4.97$	$\bar{A} = 3.35$
$\bar{T}_2 = 3.65$	$\bar{L} = 2.93$	$\bar{B} = 5.85$
$\bar{T}_3 = 4.45$		$\bar{C} = 0.85$
		$\bar{D} = 5.65$

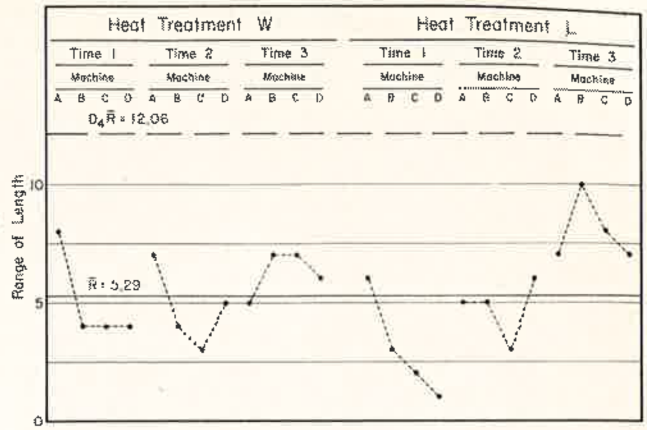

Figure 1—A Plot of the Ranges of Four Replicates

Step 5.

Each average is (T): of $n_T = 32$ measurements.

$\hat{\sigma}_T = \hat{\sigma}/\sqrt{32} = 2.57/\sqrt{32} = 0.454$

$k_T = 3$

65 degrees of freedom

$H_{0.05}\hat{\sigma}_T = (1.98)(0.454) = 0.90$

Each average is (H): of $n_H = 48$ measurements.

$\hat{\sigma}_H = \hat{\sigma}/\sqrt{48} = 2.57/\sqrt{48} = 0.371$

$k_H = 2$

65 degrees of freedom

$H_{0.01}\hat{\sigma}_H = (1.88)(0.371) = 0.70$

Each average is (M): of $n_M = 24$ measurements.

$\hat{\sigma}_M = \hat{\sigma}/\sqrt{24} = 2.57/\sqrt{24} = 0.524$

$k_M = 4$

65 degrees of freedom

$H_{0.01}\hat{\sigma}_M = (2.74)(0.524) = 1.43$

Step 6. Decision lines are computed at the 0.05 or 0.01 level (or both) around the grand mean, as shown in Fig. 2.

Time

3.95 ± 0.90

UDL(0.05) = 4.85

LDL(0.05) = 3.05

Heat

3.95 ± 0.70

UDL(0.01) = 4.65

LDL(0.01) = 3.25

Machine

3.95 ± 1.43

UDL(0.01) = 5.38

LDL(0.01) = 2.52

Table VI—Data on Lengths of Steel Bars from a 2 x 3 x 4 Factorial Experiment

	Heat Treatment W					Heat Treatment L				
	Machines					Machines				
Time	A	B	C	D	Ave.	A	B	C	D	Av.
1	6 9 1 3	7 9 5 5	1 2 0 4	6 6 7 3		4 6 0 1	6 5 3 4	−1 0 0 1	4 5 5 4	
Av.	4.8	6.5	1.8	5.5	4.6	2.8	4.5	0.0	4.5	2.9
R	8	4	4	4		6	3	2	1	
2	6 3 1 −1	8 7 4 8	3 2 1 0	7 9 11 6		3 1 1 −2	6 4 1 3	2 0 −1 1	9 4 6 3	
Av.	2.3	6.8	1.5	8.3	4.7	0.8	3.5	0.5	5.5	2.6
R	7	4	3	5		5	5	3	6	
3	5 4 9 6	10 11 6 4	−1 2 6 1	10 5 4 8		6 0 3 7	8 7 10 0	0 −2 4 −4	4 3 7 0	
Av.	6.0	7.8	2.0	6.8	5.6	4.0	6.3	−0.5	3.5	3.3
R	5	7	7	6		7	10	8	7	
Grand Av.	4.3	7.0	1.7	6.8	4.97	2.4	4.7	0.0	4.5	2.93
										$\bar{X} = 3.95$

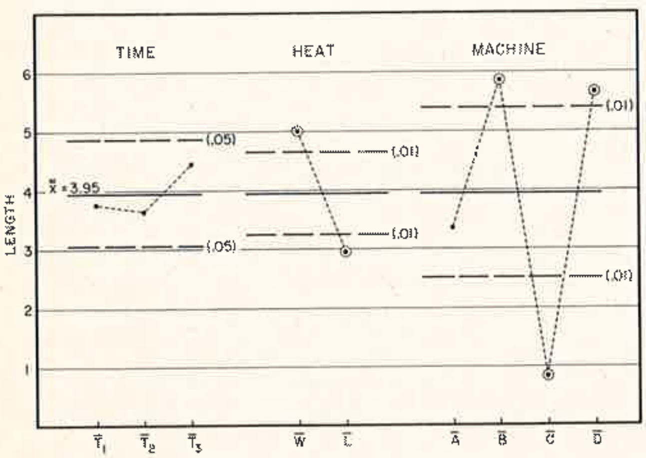

Figure 2—Graphical Analysis of Means Using 5 Percent and 1 Percent Decision Lines

Main Effects

The differences in *Machine* settings contribute most to the variability in the length of the steel bars; this can probably be reduced substantially by the appropriate factory personnel. Just which machines should be adjusted, and to what levels, can be determined by reference to the specifications on the item.

The effect of *Heat Treatments* is also significant (at the 0.01 level). Perhaps the machines can be adjusted to compensate for the effect of Heat Treatment; perhaps the variability of Heat Treatment can be reduced in that area of processing. The magnitude of the Machine differences is greater than the magnitude of the Heat Treatment differences.

Time did not show a statistically significant effect at either the 0.01 or 0.05 level. However, it may be worthwhile to consider the behavior of the individual Machines with respect to Time; this is discussed under "Interactions".

Whether the magnitudes of the various effects found in this study are enough to explain differences which were responsible for the study must be discussed with the responsible factory personnel. If they are not, then additional possible causative factors need to be considered.

Interactions

Certain combinations of these three factors (Heat, Machines, and Times) may produce an effect not explained by the factors considered separately; such effects are called *interactions*. The general question of whether a two-factor interaction exists—and whether it is of a magnitude to be of actual im-

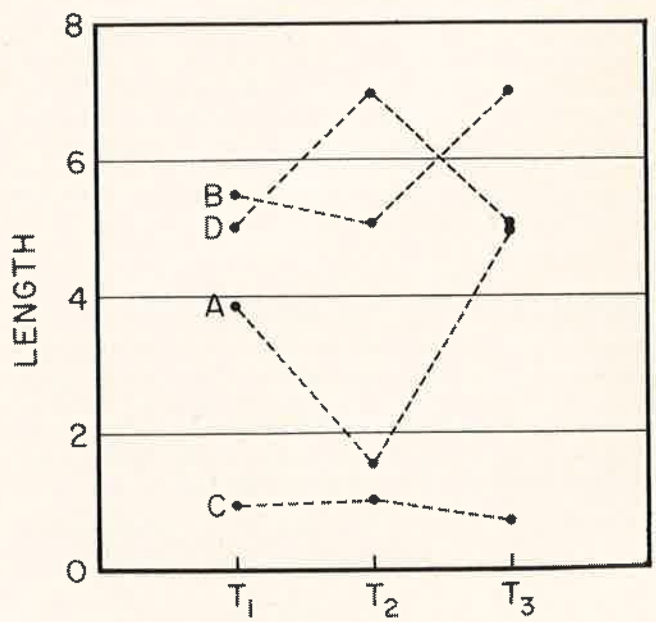

Figure 3—A Plot of the Averages of Times and Machines from Table VII

Table VII—Averages for Times and Machines

Machine	Time T_1	T_2	T_3
A	3.8	1.6	5.0
B	5.5	5.1	7.0
C	0.9	1.0	0.75
D	5.0	6.9	5.1

Table VIII—Joint Comparison of Machines A and B with Machines C and D (Averages of 16)

Machine	Time T_1	T_2	T_3
(a) A+B	4.65	3.40	6.00
(b) C+D	2.95	3.95	2.92
$\bar{\Delta} = (a-b)$	+1.70	−0.55	+3.08
	Average $= \bar{\bar{\Delta}} = +1.41$		

portance—can be presented graphically. Averages are found by ignoring all factors except the two being considered. (See Table VII.)

A visual inspection (See Fig. 3) indicates that the patterns of Machine A and B are rather similar (lower values at T_2 and higher at T_1 and T_3). The magnitudes of the differences in patterns do not appear to be of much practical interest; but in order to illustrate a method of considering interactions, let us agree to pool the Machines A and B and compare them jointly with Machines C and D. The results are given in Table VIII.

Decision lines at the 0.05 level are calculated as follows:

$\bar{\bar{\Delta}} \pm H_{0.05}\,\hat{\sigma}_{\bar{\Delta}}$ for k = 3, Degrees of Freedom = 65 (as before), n = 96/6 = 16, $H_{0.05} = 1.98$, and $\hat{\sigma}_{\bar{\Delta}} = [(\sqrt{2}\hat{\sigma})/\sqrt{n}] = [(\sqrt{2}\,(2.57)/\sqrt{16}] = 0.908.$

Then: 0.05 UDL

$$= \bar{\bar{\Delta}} + H_{0.05}(0.908) = 1.41 + 1.80 = 3.20$$

and 0.05 LDL

$$= \bar{\bar{\Delta}} - H_{0.05}(0.908) = 1.41 - 1.80 = -0.39$$

A graphical analysis of this joint comparison is shown in Fig. 4.

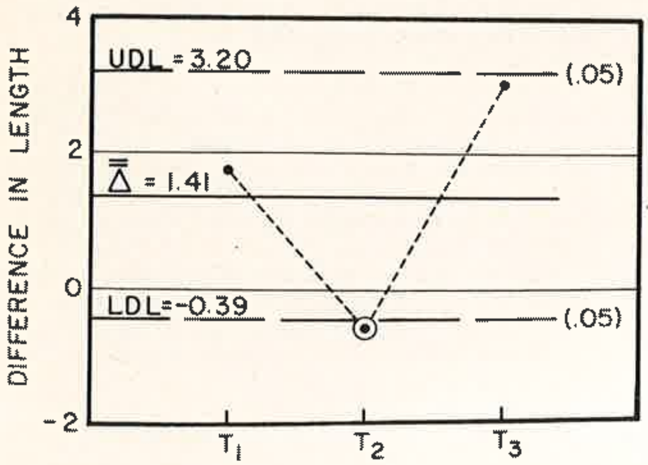

Figure 4—Graphical Analysis of the Joint Comparison of Machines A and B with Machines C and D Using 5 Percent Decision Lines (Data from Table VIII)

Table IX—Analysis of Variance of Example

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	95	1038	
Between Heat Treatment Averages	1	100	100.0*
Between Machine Averages	3	394	131.3*
Between Time Averages	2	13	6.5
Interaction—HxM	3	1	0.3
Interaction—HxT	2	2	1.0
Interaction—MxT	6	71	11.8†
Interaction—HxMxT	6	10	1.7
Error	72	447	6.2

*Significant at the 0.01 level
†Significant at the 0.10 level

Interpretation

If all three points had fallen inside the decision lines in Fig. 4, there would *not* be evidence, at the indicated level, of a statistically significant difference. Although there is one point (T_2) below the LDL, it should be remembered that it was an arbitrary choice to group Machines A with B and then C with D. There are three ways of comparing pairs of machines and the probabilities associated with this analysis are not exactly 0.05. How should this be handled? Perhaps Machines A and B *do* increase the length with Time enough to be of practical significance in the product quality—there is certainly some suspicion that these two machines behave differently from the other two. A simple follow-up study can be made to determine whether the effect is of importance. Of course, the major adjustment should be on the different machine effects; but the Time effect on Machines A and B is possibly as important, in magnitude, as the observed Heat effect.

Application of Analysis of Variance

The following Analysis of Variance of Lengths is presented in Reference 1, and is reproduced in Table IX.

On the basis of this analysis and some additional procedures (including the computation of averages for Machines and Heat Treatments as done initially in the graphical analysis) it was concluded that there were no significant interactions and no real differences between the Time averages.

Thus, the two methods of analysis give essentially the same conclusions for this example. The graphical method is more sensitive to assignable causes represented by one (or a few) of the subgroups departing from the group average.

Appendix II

Derivation of Z_α

Let p represent the probability that any one mean will lie between *decision lines* drawn at the previously designated values of

$$\mu \pm Z_\alpha \sigma_{\bar{X}} \qquad (3)$$

Then the probability that all k means will lie between the lines given by equation (3) is p^k, and the probability that at least one point will fall outside the lines is $1 - p^k$. Since we are seeking lines within which all k points will fall, with risk α, the value of p can be found from

$$1 - p^k = \alpha, \text{ or } p^k = 1 - \alpha \qquad (6)$$

From equation (6), we have $k(\log p) = \log (1 - \alpha)$. Corresponding to the value of p found from this equation, the value of Z_α is located in a table of areas under the normal curve such that the fraction of the area lying between ordinates given by equation (3) is p.

Example

Suppose $k = 3$ and $\alpha = 0.05$. Decision lines are required such that one point outside the lines shall be evidence (at the 0.05 level) of non-randomness of the means.

Solution:

$$p^3 = 0.95$$
$$\log p = \tfrac{1}{3} \log (0.95)$$
$$\log p = \tfrac{1}{3} (29.97772 - 30)$$
$$\log p = 9.99257 - 10$$
$$p = 0.98304$$

The value of $Z_\alpha = Z_{0.05}$ is then found from a table of areas under the normal curve corresponding to $p = 0.98304$ to be $Z_{0.05} = 2.39$ (See Table III, $k = 3$).

Appendix III

Comparison of Root Mean Square and Range Procedures for Estimating σ

Consider the sets of observations in Table X from which we would like to estimate the variability within groups.

Estimating σ Using Ranges

The ranges of the five samples are 4, 2, 6, 6, and 5, respectively. Thus,

$$\bar{R} = \left(\sum_{i=1}^{5} R_i\right)/5 = 4.6 \qquad (7)$$

From Table IV, for $k = 5$, $n = 5$, we find $d_2^* = 2.36$. Then

$$\hat{\sigma} = \bar{R}/d_2^* = 4.6/2.36 = 1.95 \qquad (8)$$

and

$$\hat{\sigma}_{\bar{X}} = \hat{\sigma}/\sqrt{n} = 1.95/\sqrt{5} = 0.872 \qquad (9)$$

$$\text{Degrees of Freedom} \approx 0.90k(n-1)$$
$$= 0.90(5)(4) = 18 \qquad (10)$$

For $k = 5$ and 18 degrees of freedom, the value of $H_{0.05}$ may be found by straightline interpolation between $H_{0.05} = 2.52$ for 20 degrees of freedom and $H_{0.05} = 2.60$ for 15 degrees of freedom. Hence, $H_{0.05} = 2.55$ for 18 degrees of freedom, and

$$H_{0.05}\hat{\sigma}_{\bar{X}} = (2.55)(0.872) = 2.22 \qquad (11)$$

[Compare with 2.24 in equation (17).]

Table X—Data for Comparing Range versus Root Mean Square Methods of Estimating Variability

	Group A	B	C	D	E
	42	48	46	48	50
	46	48	42	46	45
	46	46	42	42	49
	44	47	46	45	46
	45	48	48	46	48
Average =	44.6	47.4	44.8	45.4	47.6
Range =	4	2	6	6	5

Estimating σ Using Root Mean Square Procedure

The general formula for the root mean square estimate of σ is

$$\hat{\sigma} = \sqrt{\sum_{i=1}^{n} [(x_i - \bar{x})^2/(n-1)]} \qquad (12)$$

where $\bar{x}$ is the subgroup mean and n is the subgroup size. Thus, the variances $\hat{\sigma}_i^2$ of the five groups are:

$$\left.\begin{aligned} \hat{\sigma}_A^2 &= 2.80 \\ \hat{\sigma}_B^2 &= 0.80 \\ \hat{\sigma}_C^2 &= 7.20 \\ \hat{\sigma}_D^2 &= 4.80 \\ \hat{\sigma}_E^2 &= 4.30 \end{aligned}\right\} \qquad (13)$$

The average or pooled variance; i.e., our "best" estimate of σ^2 is

$$\hat{\sigma}^2 = \left(\sum_{i=1}^{5} \hat{\sigma}_i^2\right)/5 = 19.90/5 = 3.98 \qquad (14)$$

$$\text{or } \hat{\sigma} = \sqrt{3.98} = 1.99 \qquad (15)$$

$$\text{and } \hat{\sigma}_{\bar{X}} = \hat{\sigma}/\sqrt{n} = 1.99/\sqrt{5} = 0.890 \qquad (16)$$

For Degrees of Freedom $= k(n-1) = (5)(4) = 20$, $H_{0.05} = 2.52$

$$H_{0.05}\hat{\sigma}_{\bar{X}} = 2.52(0.890) = 2.24 \qquad (17)$$

[Compare with 2.22 in equation (11).]

Here, and in general, there is no practical difference between the decision limits obtained using the two procedures. The method using the average range of the subgroups is recommended.

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Key Words: *graphical procedure, analysis of means, analysis of variance, experimental, production, data, relative magnitudes, factors, interactions, decision lines, assignable causes, detection, risk, probability.*

Highlights in the Life of Walter A. Shewhart

Walter A. Shewhart was born in New Canton, Illinois on March 18, 1891. He attended the University of Illinois where he received a B. A. degree in 1913 and an M. A. degree the following year. On August 4, 1914 he married Edna Hart. In 1917 he received a Ph.D. in Physics from the University of California, Berkeley.

Listed below in outline form are the highlights of Dr. Shewhart's professional career.

Professional Societies

- Honorary Member
  - American Society for Quality Control
  - Royal Statistical Society (England)
  - Calcutta Statistical Association (India)
- Fellow
  - Institute of Mathematical Statistics (VP 1936, P 1937, 1944)
  - American Association for Advancement of Science (Council 1942-9)
  - American Statistical Association (P 1945)
  - Econometric Society
  - International Statistical Institute
  - New York Academy of Science
- Member
  - American Mathematical Society
  - Mathematical Association of America
  - American Physical Society
  - Psychometric Society
  - American Society for Testing and Materials
  - Association for Symbolic Logic
  - Philosophy of Science Association

Professional Career

- Assistant in Physics, University of California, 1914-15
- Whiting Fellow, University of California, 1914-16
- Assistant in Physics, University of Illinois, 1916-17
- Head, Physics Dept., LaCrosse, Wisconsin Normal School, 1917-18
- Engineer, Western Electric Company, 1918-24; in Engineering Department which became Bell Telephone Laboratories in 1925
- Research Engineer and Statistician, Bell Telephone Laboratories, 1925-56 (retired)
- Head, Inspection Theory group in Inspection Engineering Department, 1925-38
- Lecturer on Applied Statistics, Stevens Institute of Technology, 1930
- Lecturer on Applied Statistics, University of London, 1932
- Consultant on Ammunition Specifications, War Department, 1935-44

Lecturer on Quality Control, Graduate School, USDA, 1938
Research in Mathematical Research and Transmission Research Department, 1938-56
Member, Advisory Council, Mathematics Department, Princeton University, 1941-48
Consulting Editor, Mathematical Statistics Series, John Wiley and Sons, 1943-65
Member, National Research Council, 1944-46
United States Delegate, General Assembly, Inter-American Statistical Institute, 1947
Lecturer on Quality Control in India, 1948 (Calcutta and other centers)
Member, Visiting Committee, Department of Social Relations, Harvard University, 1950-56
Honorary Professor, Statistical Quality Control, Rutgers University, 1954-56

Honors and Awards

The Shewhart Medal was established by the American Society for Quality Control (see p. 74). The first medal struck was presented to Dr. Shewhart in 1948.

The American Society of Mechanical Engineers presented the Holley Medal for 1954 to Dr. Shewhart "for his unique genius in pioneering the application of statistical methods to the control of quality of manufactured products, an epoch-making contribution to economical mass production." He received an honorary Doctor of Science degree from the Indian Statistical Institute in Calcutta in 1962.

Achievements

1918-24 Development: soundproof aviation helmets (patent, 1921), granular carbon for telephone transmitters.

1924 The first control chart.

1925-30 Articles in *Bell Systems Technical Journal, Manufacturing Industries, Proceedings of American Society of Civil Engineers, Journal of the Franklin Institute, Journal of Forestry,* and *Journal of the American Statistical Association.*

1930 American Society of Mechanical Engineers, American Society for Testing and Materials, American Institute of Electrical Engineers, American Statistical Association, and American Mathematical Society sponsored the Joint Committee for the Development of Statistical Applications in Engineering and Manufacturing with Dr. Shewhart as chairman.

American Society for Testing and Materials established a Committee on Interpretation and Presentation of Data with Dr. Shewhart as chairman.

American Society of Mechanical Engineers established a subcommittee on Engineering and Scientific Graphs with Dr. Shewhart as chairman.

1931-39 Invited to participate in National Industrial Conference Board Conference of Business Economists.

1931 Published a book, *Economic Control of Quality of Manufactured Product,* D. Van Nostrand.

1932 Invited to lecture at Univeristy of London.

1932-34 Papers in *Mechanical Engineering, Proceedings of the American Society for Testing and Materials, and Econometrica.*

1935 Appointed consultant on ammunition specifications, War Department (advised Capt., later General, Simon on introducing Quality Control at Picatinny Arsenal).

Founding of Institute for Mathematical Statistics. Dr. Shewhart was made vice president in 1935 and elected president in 1937 and again in 1944.

1938 Invited lecturer for Graduate School, United States Department of Agriculture—these lectures became the book, *Statistical Method from the Viewpoint of Quality Control,* 1939.

1938-56 Research on Statistical Methods and Consumer Preferences.

1943-65 Editor, Mathematical Statistics Series, John Wiley and Sons—in the first twelve years, 33 books appeared in this series linking statistics with engineering and other sciences.

National Research Council: made chairman of Subcommittee on Engineering Applications of Statistics, Committee on Applied Mathematical Statistics.

1945-54 Joint Committee of National Research Council and Social Science Research Council on Measurement of Opinions, Attitudes and Consumer Wants.

1947 With his devoted wife, Edna, visited India three times. First, in 1947, invited to confer with leaders in government and industry and to deliver lectures.

United States Delegate to World Statistical Congress.

1952 President, Committee on Statistics in Industry and Technology, International Statistical Institute.

Arranged for team of four experts in Quality Control to visit India under the auspices of the United Nations.

1954 Invited by Government of India to revisit India to help evaluate progress in Quality Control.

1956 Retired from Bell Telephone Laboratories.

1959 Revisited India at request of Indian Government.

Dr. Walter A. Shewhart and Prof. P. C. Mahalanobis (second and third from left), shown with three of the members of the UN team that went to India in 1952: (L-R) Prof. Paul C. Clifford, Dr. Ellis R. Ott, and Dr. Mason E. Wescott.

Tributes to Walter A. Shewhart

Editor's Note: We will be pleased to receive additional communications from other people whose work Walter Shewhart influenced, and will be happy to publish these letters in the near future.

PHILIP A. ALGER

General Electric Company, Retired

Walter Shewhart had a radiant and benign personality. From him emanated rays of inspiration, sympathy, and fresh understanding that endeared him to all who knew him. He had intellectual ability that enabled him to clear away some of the dark clouds of ignorance that always surround us. He had the generosity of spirit that led him to so express and restate his pioneering ideas that other members of the profession could benefit from them. And, he had that warmth of human feeling that marks the true educator.

Although I had few contacts with Dr. Shewhart, I heard a great deal about him, and he seemed to me in many ways to resemble that other great scientific pioneer, Charles P. Steinmetz. The careers of Shewhart and Steinmetz had many similarities. Both were employed by large corporations and were given great freedom to pursue their own ideas, to write freely, and to gather students around them.

A story told me some years ago by Dr. Thornton C. Fry provides an example of Dr. Shewhart's influence.

Dr. Fry said that, when he was a young instructor in mathematics at the University of Wisconsin, a Bell Laboratories' representative offered him a position in New York. On accepting this and arriving in New York to begin his new duties, he was introduced around, taken into his new office, and told to set to work. However, very little advice was given him as to what he should do or how he should proceed — he was left completely free to follow his own ideas. But, his office was very near that of Dr. Shewhart, so that he soon became one of those who visited the Doctor frequently, and they became close friends.

At that time, Dr. Shewhart was just beginning to show how the laws of probability could be usefully applied in quality control, reliability predictions, and forecasting, but the mathematical theory was quite undeveloped.

Dr. Fry became deeply interested in Shewhart's ideas and was strongly influenced by them when, before long, he wrote his famous book entitled *Probability and Its Engineering Uses,* and a second book on *Differential Equations.* These books opened the way for a great many practical applications of probability theory. Thus, after a few years, Dr. Fry grew from being one of Shewhart's disciples into one of the most sought after and widely consulted members of the Bell Laboratories' staff.

* * *

A. O. BECKMAN

Beckman Instruments, Inc.

I am indeed happy to recall my days with Dr. Walter A. Shewhart. My introduction to him was an occurrence of low probability. I was a physical chemist (so my diploma stated), and happened to be in New York City in 1924 looking for a temporary job to earn a little money on the way to a doctorate in chemistry. I had virtually accepted an offer to work as a chemist for a well known oil company in Bayonne, N. J. when I stopped in one afternoon at the West Street laboratories of Western Electric to see a Caltech classmate. Somehow or other I was introduced to Dr. Shewhart, and before we departed at 5:00 p.m., he had signed me up to work with him. I believe I was the first "technical" employee he hired for his pioneering assault on the problems of statistical methods for quality control. He was a persuasive person!

I have never regretted that sudden change in plans. As my thoughts turn back nearly a half century, I'm not sure that I fully appreciated the privilege of participating in the birth of a new and important phase of modern technology. I do recall vividly, however, the confident and relentless vigor with which Dr. Shewhart pursued his objective of putting quality control upon a sound theoretical basis, supported by abundant experimental evidence.

In those embryonic days, we had to do our own flipping of coins and withdrawing of white and black balls to establish experimental curves. Bayes' theorem, *a posteriori* vs. *a priori* probability, the statistics of small numbers, etc., were subjects of intense interest and argument. In the confused sea of theoretical controversy, however, Dr. Shewhart steered a steady course toward practical utilization of statistical theory. I'll never forget the pride and feeling of accomplishment when he sent me, alone, to apply statistical methods to the inspection of soldered connections in the Pennypacker telephone exchange then under construction in Philadelphia, one of the "firsts" in practical statistical quality control.

Ultimately, my chemistry hormones became overpowering, and I left the field of quality control to return to the smells of the chemistry laboratory. My work with Dr. Shewhart, however, left an indelible mark on my career. Appreciation of the power of statistical techniques has been invaluable in many situations. Most treasured of all, however, has been my memory of Dr. Shewhart, the man. Quiet, unassuming, patient, steadfast — he was a respected and beloved leader whose subtle guidance has had a lasting influence on me.

* * *

C. C. CRAIG

University of Michigan

I first met Walter Shewhart on a visit to the Bell Telephone Laboratories in 1925. But I really got to know him beginning in the late thirties at meetings of the American Statistical Association and the Institute of Mathematical Statistics through long conversations on statistical matters in general and in particular on the applications of statistical methods in industry. I was impressed by his insistence that before one can trust inferences drawn from samples one must have assurance that the samples were drawn from a well-defined, stable population. Further, from his experience, one cannot merely assume that the output of a manufacturing process has quality characteristics that are, to use a term due to him, in statistical control. In spite of all the homage that has been and will be paid to Dr. Shewhart, this basic fact, that he thought most important, is, all too often, ignored.

During World War II he often expressed concern that in Detroit, in spite of its great importance in producing a vast volume of articles vital to the prosecution of the war, there was almost no use of statistical methods for the control of quality. This led me to believe that by doing missionary work in this direction I might make some contribution to the war effort. This resulted in my involvement in the science of quality control to which I have given a considerable portion of my time and energy for over two decades.

Despite the vast volume of publication on stochastic processes during recent years, so far as I am aware, there exists just one simple, usable, and effective way of testing that a stochastic process is stable over time or space. This is Shewhart's control chart method. It is also not as generally recognized as it should be that in many situations the sigma or range chart provides a simple and effective test for the homogeneity of variances.

His classic book, *Economic Control of Quality of Manufactured Product* has always struck me as remarkably scholarly for a man who was trained as a physicist. Dr. Shewhart was truly the father of scientific process control and we do well to pay homage to him for his original achievement whose importance we can hardly overrate.

* * *

W. EDWARDS DEMING

Consultant

I write as one outside the Bell System who had the privilege of working intimately with Dr. Shewhart over a period of years. This could happen only because he was always glad to help anyone. Actually, he never thought of himself as helping anyone: he was simply glad to talk and absorb thoughts from anyone who was genuinely struggling to improve his understanding of the statistical method — interchanging ideas was his way to put it. And to Dr. Shewhart it was the statistical method in the singular, not in the plural. Statistical methods are necessary, but they are the tools and pass-words by which the statistician works and communicates in applying the statistical method.

It was Dr. Shewhart who emphasized the theory of probability as the tool of the statistician. It is his knowledge and use of the theory of probability that distinguishes the statistician from the expert in chemistry, agriculture, bacteriology, medicine, production, consumer research, engineering, or anything else. Otherwise, the statistician would be merely another chemist, another agricultural scientist, or something else.

Quality control meant to him use of statistical methods all the way from raw material to consumer and back again, through redesign of product, re-working of specifications of raw materials, in a continuous cycle as results come in from consumer research and from other tests.

He was quick to see that quality must mean not necessarily high quality, but dependable and economic quality, which in turn meant quality suited to the purpose. But what quality is suited to the purpose? Statistical methods for discovery of what product is needed, what quality is needed, and for learning how a product performs in service and in the laboratory are thus necessary ingredients of the statistical control of quality.

The world knows him for the Shewhart control charts, and the world lives better for them. They are, however, only one of his statistical contributions. He leaves a rich legacy that it will take years to absorb. For example, his Rules 1 and 2 on the presentation of data:

> **Rule 1.** Original data should be presented in a way that will preserve the evidence in the original data for all the predictions assumed to be useful.

> **Rule 2.** Any summary of a distribution of numbers should not give an objective degree of belief in any one of the inferences or predictions to be made therefrom that would cause human action significantly different from what this action would be if the original distribution had been taken as a basis for evidence.

Then there is his Criterion of Meaning:

> Every sentence in order to have definite scientific meaning must be practically or at least theoretically verifiable as either true or false upon the basis of experimental measurements either practically or theoretically obtainable by carrying out a definite and previously specified operation in the future. The meaning of such a sentence is the method of its verification.

The above rules and criterion of meaning were to him a necessary ingredient of industrial research for the reason that, as he stated, industrial research is more exacting than pure science. His faith in the power of the statistical method in all human enquiry was unshakable.

He acknowledged an everlasting debt to C. I. Lewis's *Mind and the World Order* (Scribner 1929), which he recommended to me. I had the usual difficulty with it, and I recall saying to Dr. Shewhart at the end of the seventh reading that so far it had meant nothing to me. "Stay with it," he said, "I read it fourteen times before it began to mean anything." I wonder how he came upon it in the first place, and how he knew how important it was that he should pursue it.

Although operational difinitions, his criteria of meaning, and his Rules 1 and 2 for the presentation of data, have been known to scientists for several generations, no one to my knowledge has stated them so well as Shewhart. One sees in them C. I. Lewis in the background.

Hypothesis is necessary. Some knowledge must be *a priori*, even if shown later by observation to be untenable. Without theory (hypothesis), daat are meaningless or nonexistent. There is thus no true value of anything: true value is undefinable operationally. There are, however, numerical values that people can use with confidence if they understand their meaning (for the tensile strength of a batch of wire, for example, or for the proportion of the labor force unemployed last month).

There was to Shewhart no such thing as a random sample. There was and is, however, such a thing as a sample selected by a random operation. There may be a concept of randomness, but one cannot communicate it. What one can communicate is an operational definition of a random operation (for example, proper use of random numbers). Likewise, one can only define yellow, green, tired, unemployed, one inch, in terms of an operation. The particular operation will vary with the needs of the subject-matter.

There is accordingly no such thing as factual information, distinguished from (e.g.) judgments. Physical measurements are no exception. There are no facts except as man makes them. Man gets marks on a piece of paper in response to a stimulus. Such marks on paper and tabulations made from them are useful only if the method of investigation is suited to the purpose.

Although his explanations could be simple and clear in a face-to-face discussion, his greatest papers remain as difficult for the reader as they were for him to write. As he told me once, when he writes, he must make it foolproof. I replied in a particular instance that he had made it so foolproof that no one would understand it.

His book of 1931 will remain a monument, but it was his book *Statistical Method from the Viewpoint of Quality Control* (The Graduate School, Department of Agriculture, Washington 1939), based on his four lectures given in Washington in 1938, that exposed Shewhart to the statistical world. People then began to understand something about his contributions.

To appreciate a mite of his greatness, one must read not only the two books just mentioned, but his article, "Nature and origin of standards of quality," Bell System Technical Journal, xxxvii, 1958, pages 1-22. (Although this article was published in 1958, he actually wrote it in 1935.) One can only ask why schools of business don't require this article to be read by all professors and students. Why don't people engaged in consumer research and in advertising research read it? Some day they will.

There was a time when some people pushed the idea of probability limits on the control-chart, instead of Shewhart's 3-sigma limits. No one could appreciate more than Shewhart the ability of the theory of probability to adjust the limits to the requirements, but he had the uncanny prescience to see that because of fluctuations of level that must continually occur in a production-process, the 3-sigma limits would do the job. He saw further that statistical control is not a matter of estimation nor of testing a hypothesis, but rather a rule of behavior that will strike a balance for the net economic loss from two sources of mistake: (1) looking for special causes (he called them assignable causes) too often, or overadjusting; (2) not looking often enough.

Although use of the control chart for detection of special (assignable) causes of variability is extremely important, reduction of special causes is only the start on the road to quality. There is of course, besides special causes, the important problem of common causes of variability.

Although the writing of papers and books was difficult for him, and his efforts often went wide of the mark, nevertheless one of his great powers lay in his perseverance in communication by letter. He used this power to work through committees. He knew the importance of getting a strong man at the head of a committee, and he was adept at pushing him in the right direction, without himself being visible. He made his points not so much by giving his own point of view but by asking questions—embarrassing questions. Establishment of Committee E-11 on statistical methods in the American Society for Testing and Materials is an example of this type of accomplishment. The American Standards, *Guide for Quality Control* and *Control Chart Method of Analyzing Data*, written by a small committee under the guidance of Harold Dodge, and published by the American Standards Association in 1941 and 1942 (known as the Z-pamphlets from their code-numbers Z1.1, .2, .3) is another example. The Z-pamphlets met immediate acceptance, and are still best sellers. They were translated and adopted by standardizing bodies in practically all industrial nations of the world. The Shewhart statistical series published by Wiley is another example. He sought out the great thinkers and invited them to write. That an author might disagree with Shewhart's point of view made no difference to Shewhart, so long as a book would stimulate people to think.

A contribution of a technical nature is the formula

$$\bar{n} = \frac{\sigma_w}{\sigma_b}\sqrt{\frac{c_1}{c_2}}$$

for the optimum number of tests per unit, or for the optimum number of segments to cover in a block or other area. His book of 1931 and Tippett's book *The Methods of Statistics*, published also in 1931, both gave this formula, for the first time, I believe.

As a statistician, he was, like so many of the rest of us, self-taught, on a good background of physics and mathematics. He respected advanced knowledge of statistical theory, and studied daily, but he was not always happy the way people recommended statistical techniques for use.

As a man, he was gentle, genteel, never ruffled, never off his dignity. He knew disappointment and frustration, through failure of many writers in mathematical statistics to understand his point of view. He also knew success. He was President of the American Statistical Association in 1945, and was twice

President of the Institute of Mathematical Statistics, 1937 and 1944. One of the highlights of his life was an invitation from Karl Pearson to give lectures at University College in London in 1932. A visit to Japan later in life where he saw spectacular results of statistical methods applied in the broad sense of Shewhart must have been great satisfaction to him. He went to India three times as a guest of Professor Mahalanobis at the Indian Statistical Institute, and received therefrom in 1962 the honorary degree D. Sc.

(*The preceding originally appeared in the April 1967 issue of* The American Statistician *and is reproduced here by permission.*)

* * *

HAROLD F. DODGE

Rutgers—The State University

I want to include in this Memorial Issue a few words of appreciation for the many years that I worked closely with Walter Shewhart, as a fellow group leader in the newly organized department of Inspection Engineering of the Bell Telephone Laboratories, from 1925 to 1938. During most of this time we had adjacent offices, and had continuing deep discussions of the theoretical and practical aspects of applying statistical methods and particularly statistical quality control (SQC) to Bell System telephone plant problems. His group was designated Inspection Theory, and mine, Inspection Methods. And in the new department, many were the "bull sessions" that were held to discuss the technical problems of inspection engineering, along with new concepts of the goals to be sought and how to attain them. Included in these group sessions, truly quite a youthful group, were our first director R. L. Jones, our second and long-term director G. D. Edwards, D. A. Quarles, W. A. Shewhart, R. B. Miller, E. G. D. Paterson, H. G. Romig, P. S. Olmstead, Mary N. Torrey, and the writer.

The telephone plant was just then beginning to expand rapidly, new dialing systems were being installed, large quantities of precision apparatus and equipment would be needed, and there was need for a high standard of uniform quality and performance throughout the country. It was just the kind of situation that was wide open for new ideas.

Throughout the early developments, Walter Shewhart was the scholar, a source of inspiration for the scholarly approach. He brought to bear on our problems many kinds of learned probings and we found ourselves willingly and seriously poring over not only G. Udney Yule's *An Introduction to the Theory of Statistics*, but such books as *Mind and the World Order* by C. I. Lewis, *The General Theory of Value* by Ralph Barton Perry, and *The Elements of Physical Biology* by A. J. Lotka.

Walter's concept of statistical quality control was in the nature of an "ideal" for quality—something to be sought, something to be attained, and something to hold. As a concept to be applied to the quality of manufactured product, it was new. His control chart provided a tool to be used as a means to this end. It was a sort of utopian goal, one that envisioned the elimination of all "assignable causes" and the attainment of a quality of product so uniform that it behaved as though governed by chance causes alone, a truly random variable. Attainable? Perhaps not perfectly, at least not easily, but the production man could try. The control chart would tell him what went wrong and when, and enable him to improve his process. And the goal was something which, in the seeking, would result in removing wasteful causes of variation in quality, and lead to a more trouble-free and hence more economical process. Finally, the control chart provided a basis for determining when he had attained statistical control. With these things in mind, Shewhart developed the meaning of three aspects of statistical control—as a concept, as an operation, and as a judgment.

Early additions to the new language of quality control included such terms as "assignable causes", "rational subgroups", and "3-sigma limits." As we developed other basic QC techniques for sampling plans and quality rating procedures, other new terms such as "consumer's risk", "Lot Tolerance Percent Defective (LTPD)", and "Demerits-per-Unit (DPU)" came into regular use. It was all very exciting—new ideas, new approaches, new techniques that could be tried out right away. And soon the term "quality control" became the byword associated broadly with an important phase of the new developments in inspection engineering.

Throughout these years, Shewhart contributed much to fundamental thinking and development of principles. For example, an extremely useful analogy that he developed and included in his writings was his description of the three steps in the control process —specification, production, and inspection—as parallel to the three fundamental steps in scientific method, namely, hypothesis, experiment, and test of hypothesis. Further, by considering the three steps as the legislative function, the executive function, and the judicial function, many things are made clear. I myself have long found this an excellent basis for supporting the argument that how-much-inspection clauses should not be placed in the product specification; that is, the inspection requirements (representing the judicial function) should not be confused with the product requirements (representing the legislative function). As a matter of principle, they should be kept clearly separate.

And so, once more, I am glad to express my appreciation for the privilege of working closely with Walter Shewhart during the exciting times when the basic structure of statistical quality control (SQC) was being developed and his classic texts were being written. Not only this, it is a pleasure to note that the Dodges and the Shewharts have been neighbors and friends for well over 40 years in our nearly model community of Mountain Lakes.

* * *

GEORGE D. EDWARDS

First President, ASQC

I am honoured by your 23rd March invitation to write something of my appreciation of Walter Shewhart for your forth-coming "Special Issue" of *Industrial Quality Control*. Walter is probably the only person whose contributions to the profession would warrant such an "Issue", and I am happy to comply with your request.

My contacts with Shewhart began about 1918, when he came to the Western Electric Company and we both found ourselves in the then - newly - organized "Transmission Branch" of its Engineering Department. He was occupied with the statistical behaviour of telephone transmitters and their components, and I with the propagation of the impulses generated by those instruments. Even in those early days, his leaning toward the statistical was thus evident.

Our ways separated for a time thereafter until, in early 1924, upon my return from a three-year European assignment, I found myself in another newly-organized unit of the Western Electric Engineering Department. This time, the unit was known as Inspection Engineering, and there I found Walter Shewhart heading up a group called Inspection Theory. It was at that time that I began my efforts to persuade Harold Dodge to come over to the new unit. I like to think at least, that I thus had some small part in formation of the Shewhart-Dodge "team" which has contributed in such large measure to the Quality Control profession.

It was in this early period that Walter first put on paper his concept of the Control Chart, and there followed many exciting "bull-sessions", involving Don Quarles and myself as operating-group heads, with the Shewhart-Dodge "team" representing the Theory and Methods sides of the picture. It was always a source of real satisfaction to us to be able to feel that, with Walter Shewhart as our foundation, we never had to worry about the basic soundness of our position from a theoretical standpoint.

Walter was always the apostle for his chosen field—a missioner filled with zeal. One of his earliest "missionary" projects was a book which would "sell" the whole idea of statistical "control", and particularly of statistical "quality control". I was an enthusiastic supporter of this book project from the time that Shewhart first broached it. Some years later, after I had assumed responsibility for the whole of the "Inspection Engineering" effort of what had then become Bell Telephone Laboratories, this book became one of my major objectives. My impatience was restrained however, by Walter's quiet and proper insistence upon sufficient delay to permit and assure meticulous theoretical soundness in every detail and at every point. *Economic Control of Quality of Manufactured Product* appeared in 1931 however, and one of my treasured possessions is an autographed copy of the book with an over-generous acknowledgement of what was really a very small contribution to it on my part.

A concept which developed in the latter 1920s, was "control-at-an-economic-level". This idea of "the grand design", if you will, was perhaps best expressed by Shewhart's "Satisfactory - Adequate - Dependable-Economic Quality". Using its initial letters as his subject, Walter delivered to the Inspection Engineering Department in the early 1930s, a series of lectures on "SADE-Q". "Sadie was a lady" who was thus frequently discussed and highly respected by us all during that period.

While Shewhart was a real missionary, he had many of the characteristics of the lone wolf. In the early days, his chosen field was so incomprehensible, and often so unwelcome, to many of the very people to whom he most needed to sell it, that he was almost forced to be that way. But what a "one-man-show" he put on! ! !

With such a rich background of association with Walter, it was extremely easy for me to support Fred Halton's suggestion that ASQC found and sponsor the Shewhart Medal. But real credit for the successful fruition of this Medal project must go to Phil Alger. As a tribute to Walter's basic contributions to our profession, it is perhaps the most fitting recognition the Society could give him.

I am indeed grateful that I was privileged to be so closely associated with Walter Shewhart over so many years, and I thank you for the opportunity of expressing my great admiration for him.

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ENOCH B. FERRELL

Bell Telephone Laboratories, Retired

One morning in the late nineteen-thirties I was weeping on my boss' shoulder in the Bell Telephone Laboratories about our inability to understand some measurements we had made on a new type of relay—a glass sealed relay. He listened a while, silenced me, turned around and made a telephone call. He turned back to me and said:

"You have a lunch date with Walter Shewhart."

"Who is Walter Shewhart?"

"He is the man that invented Statistical Quality Control. Effective this morning he is transferring to the Research Department to see if his statistical techniques can be used in the research laboratory. You go eat lunch with him and give him his first problem in his new job."

That lunch was my introduction not only to one of the most interesting phases of my career as an engineer but also to one of the finest gentlemen I have ever known.

* * *

C. E. FISHER

Bell Telephone Laboratories

As one who knew Walter Shewhart, yet was not priviledged to work closely with him, I am keenly aware of the tremendous contribution he made and of the continuing impact of his work, even now, on the efforts of those of us who have followed him in the quality arena here at Bell Laboratories.

We become deeply enmeshed in day-to-day problems in attempting to exercise economic control of quality of products. In our efforts to resolve these problems, we often think that we have devised new and novel ways of extricating ourselves. Yet when we examine the principles underlying our solutions, we find that we have not strayed from the basic concepts of Walter Shewhart. More and more, we find it helpful to keep before us the fundamentals that he set forth.

Many have made important contributions to our technology, and many more will do so in the future. I see nothing on the horizon, however, that challenges the work of Walter Shewhart. It will serve us well in the future, as it has in the past, an enduring tribute to a great man.

* * *

CHARLES J. HUDSON

West Boylston, Mass

The American Society for Quality Control has lost a capable man, a fine gentleman and a friend to the Quality Control fraternity in the passing of Walter A. Shewhart.

I remember a pleasant evening and an all night visit my wife and I had at Walter's home a few years ago. He was concerned about publishing more facts about the usefulness of Quality Control methods in industry. He was searching for someone capable of carrying on the fundamental work he had started years ago. When I told him he himself was the man to do it, he said, in his modest way, he was no longer capable.

His patience with people and his own humbleness were characteristics which made him a truly great man. He will be greatly missed.

* * *

KAORU ISHIKAWA

University of Tokyo

About 1950, when I began to study quality control concepts, I developed a great respect for Dr. Shewhart through the study of his deep thoughts on quality control—his concepts of the control chart and standards—as expressed in his difficult books.

It was when I visited the Bell Telephone Laboratories as a member of the QC study team in 1958 that I first met Dr. Shewhart. Again in 1959, I had the opportunity to hear his talks here in Japan and again I was greatly impressed with the depth of his philosophy.

However, it was a little surprising for me to see that in the companies in the United States, where I visited for study, the methods and the concept devised by Dr. Shewhart were not being applied very much in those days. I wished to import his concepts into Japan and assimilate them to meet peculiar situations in Japan, so that Japanese products would improve in quality.

In 1955, I edited a book about the concept of control chart for the first time in Japan. It was *Control Chart Method*, (JUSE. 731pp, 1955). This control chart method and the concepts of Dr. Shewhart had great influence upon Japanese industry and since then have had great effects on popularization of statistical quality control in Japan and on improvement in the quality of Japanese products.

Especially, Dr. Shewhart's concepts of "state of control" and "out of control" have been applied for control of managerial administration by a number of managers in various companies in Japan and have been producing effective results. Thus the concepts devised by Dr. Shewhart have had great influence not only in the U.S. but also in Japan, and even all the world.

I express my deep regret over the death of Dr. Shewhart, man of greatness, on behalf of the world of Quality Control in Japan. Dr. Shewhart died, but his concepts will live long in every part of the Japanese industry.

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J. M. JURAN

Management Consultant

My association with Shewhart goes back to the mid-1920's. I was then a young engineer at the Hawthorne Works of Western Electric Company, and a charter member of the tiny, newly-formed Statistical (Quality Control) Department of the Inspection Branch of that huge works. Shewhart, a mathematical statistician, was a member of a newly-created Bell Telephone Laboratories team which had been given responsibilities to provide to the various telephone companies an "assurance" of the quality of Western Electric products. This team, whose intellectual leader was the late D. A. Quarles, undertook not only to measure and report quality performance; they also made creative proposals for improved control methodology (quality rating schemes; sampling theory; control chart theory).

At the time, Shewhart presented to the factory executives the image of a theorist, exhibiting some flashes of brilliance, but mainly impractical and unintelligible. At the outset I tended to share this view. When it fell to me to pilot Shewhart on his maiden voyage through a large assortment of factory operations, it was at once evident that his ignorance of such matters was quite extensive. Yet there was a youthful exuberance about him—a keen inquiring curiosity, leading to imaginative questions and proposals relative to application of control charts and sampling.

Over the years my image of Shewhart came to change radically. I came to feel that his contributions were of two very different kinds:

1. A conceptual approach to theory of control. This was mainly philosophical in nature, presented in general language, embellished with mathematical models, and largely beyond the grasp of the unsophisticated reader or listener.

2. Some specific practical tools for control, of which the most widely known is the Shewhart Control Chart, that elegant perpetual test of significance.

Shewhart was, in addition, a competent promoter. His inventions of practical, elegant tools gave him the aura of a doer and thereby made him immune from curt dismissal as a pure theorist. In addition, he possessed a mystique derived from the then-novel use of conceptual models. Moreover, he had no reticence about speaking or writing, so that he was increasingly in demand. However, the invitations, and they were international, came from the world of the intelligentsia rather than from the world of managers. In dealing with managers he had neither the operating experience nor the vocabulary to communicate effectively. This same lack of communication necessarily limited the dissemination of his concepts.

Shewhart's work remains very much among us. The tools which bear his name and which are in such widespread use would by themselves be enough to give his name an immortality. The effect of his more philosophical concepts is far more difficult to appraise. I do not happen to subscribe to the belief that in this respect Shewhart marked the beginning of a new era. He did indeed probe into the concepts of control, as did his predecessors and contemporaries. Some of these became more immediately effective because of their greater ease of communicating with practicing managers. At best (it seems to me) Shewhart's philosophical concepts have joined the numerous streams which collect and flow into our consciousness so thoroughly commingled that we cannot trace the sources.

* * *

JOHN E. KARLIN

Bell Telephone Laboratories

One of Walter Shewhart's major contributions to the control of quality of consumer products was the realization that human wants and preferences were an indispensable part of what needed to be specified. Through his efforts the Joint Committee on Measurement of Opinions, Attitudes and Consumer Wants of the Social Science Research Council and National Research Council was set up. This committee in turn was influential in the decision of the American Society for Testing Materials to appoint Committee E-18 on Sensory Evaluation of Materials and Products.

With this deep interest in the consumer, it was not surprising that Walter Shewhart was selected in 1947 to head up the newly formed User Preference Department in the Research Division at Bell Telephone Laboratories. This department was charged with the responsibility of finding out whether more valid methods of determining and measuring human wants and needs could be developed as a guide in the choice of new service offerings. Likewise it was in keeping with Dr. Shewhart's broad interests and interdisciplinary bent that he added to his own mathematical and statistical background the services of Robert Riesz, a physicist turned engineer and John Karlin, a psychologist with an interest in engineering, as the nucleus of the new group.

The type of interest in human factors stimulated by Walter has today become pervasive at Bell Telephone Laboratories. The Human Factors Engineering Research Department, the direct descendant of Walter's initial group, comprises some 20 people carrying on the same interdisciplinary approach and is consulted far and wide by many other parts of the Laboratories.

As with statistics in Quality Control, Walter performed a critical role in bringing human factors into effective perspective in equipment and system design.

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HAROLD R. KELLOGG

Western Electric Company

An era has ended with the death of Walter A. Shewhart. Since the 1920's Dr. Shewhart has been widely acclaimed as the "founder of statistical quality control" and "the father of the control chart." Those more familiar with the research and theory for which he was singularly responsible acknowledge Dr. Shewhart as one of the foremost scientists of our time — a scientist whose enormous contribution provides grist for the mill of practicing engineers for decades, if not centuries to come. In Professor Irving W. Burr's perceptive words, "The epoch-making discovery and development of the control chart were made in 1924 and the following years by a young physicist of the Bell Telephone Laboratories, Walter A. Shewhart. Then in 1931 came Dr. Shewhart's great book, *Economic Control of Quality of Manufactured Product* in which the whole field was laid out including its theory, philosophy, applications, and most pertinently, its economic aspects. Few fields of knowledge have ever been so completely explored and charted in the first exposition."

In a recent memorial to Dr. Shewhart, W. Edwards Deming who is himself one of the foremost scholars of Shewhart theory, has written, "He leaves a rich legacy that will take years to absorb." As an example, Dr. Deming quotes Shewhart's Rules one and two on the presentation of data:

> "Rule 1. Original data should be presented in a way that will preserve the evidence in the original data for all the predictions assumed to be useful."

> "Rule 2. Any summary of a distribution of numbers should not give an objective degree of belief in any one of the inferences or predictions to be made therefrom that would cause human action significantly different from what this action would be if the original distribution had been taken as a basis for evidence."

We see more of the rich legacy not yet absorbed in other quotations from Dr. Shewhart's writings:

> "Statistical research is a logical method for control of operations, for the research engineer, the plant superintendent, and the production executive."

> "Obviously, the ultimate objective is not only to detect trouble, but also to find it, and such discovery naturally involves classification. The engineer who is successful in dividing his data initially into rational subgroups based on rational hypotheses is therefore inherently better off in the long run than one who is not thus successful."

For each of these concepts there is an almost infinite number of applications. Ours is the legacy.

Walter Shewhart was a Bell System employee. Due to the tremendous interaction between his great mind and his Bell System assignment, the Bell System and the service it renders, together with industrial operations and product the world over, are immeasurably better off. As the absorption continues, greater benefits yet are sure to accrue.

As so many great men are, Shewhart was ahead of his time. He did not live to see his contributions understood or utilized to the degree they one day will. There is satisfaction in knowing that Dr. Shewhart was aware of this when, with amazing insight, on the second page of his great book, he wrote,

> "Progress in modifying our concept of control has been and will be comparatively slow."

A great man has left us but his legacy will continue to grow.

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MIRIAM HAROLD KNECHT

Bell Telephone Laboratories, Retired

Little did I know, when I first reported to Dr. Shewhart in 1926, that I was entering upon a career that was to prove so stimulating and enriching. In fact, I was much disturbed at the time; stirring metal-rimmed chips in a large brown mixing bowl seemed much beneath the dignity of one with a college degree in mathematics. I had never heard of a normal distribution, much less a rectangular or right-triangular one. It was not long, however, before his patient teaching and my study of the books he had at hand, brought me up to date on the relatively new science of statistical method. During the depression I became both secretary and data analyst and this I was, most happily, until his retirement in 1956. To Dr. Shewhart I am most grateful for many things:

For an education in statistical methods,

For an opportunity to meet most of the world's leading statisticians,

For the feeling that I was part of his contributions to the work of the Bell Telephone Laboratories, the war effort, and the founding of the American Society for Quality Control,

For his sympathy and understanding in any personal calamities that befell me,

For the fact that never once did he ask: How long have you worked for me? but always, How long have you worked with me?

* * *

FREDERICK MOSTELLER

President, American Statistical Association

At Carnegie Institute of Technology in the late 1930's, students of probability and statistics working with E. G. Olds, a great admirer of Walter Shewhart, studied the latter's *Economic Control of the Quality of Manufactured Product* along with Fry's *Probability and its Engineering Uses*. Soon after taking this course work, I met Shewhart at the Detroit meeting of the Institute of Mathematical Statistics and heard him speak. He was everything I expected of the author of a distinguished book: profound, serious, kindly, polite, and generous. He inquired into my work, listened while I told him, and cross-questioned me carefully. It's hard for any author to live up to the image Shewhart gave me.

When S. S. Wilks studied at Columbia on a post-graduate fellowship, he met Shewhart and they became lifelong firends. In the first paper that I published in mathematical statistics, "Note on an application of runs to quality control charts," the problem came to me from Shewhart by way of Wilks—and Shewhart provided me with a long footnote describing some of his ideas of the uses of runs. He also arranged to have me meet Paul Olmstead who had results on the same problem. Later Shewhart encouraged Wilks to invent the notion of tolerance regions to give a probabilistic basis for a statistical guarantee that at least a specified percentage of items made in a production process had measurements in a stated range. Shewhart was most pleased to have the theory opened up. Incidentally, he told me that he detected an error in Wilks's published tables because the value disagreed with records Shewhart had kept of results of well-controlled processes.

Shewhart's contributions to engineering and statistics have been made in many roles as stimulator, innovator, editor, applier, and developer and fortunately both professions have accepted his work eagerly.

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R. B. MURPHY

Bell Telephone Laboratories

My first acquaintance with Walter Shewhart was in Pittsburgh when I was a young instructor at Carnegie Tech and he was a visiting colloquium speaker. Some of my colleagues who heard his talk and had expected a subtle but powerful display of new mathematical and statistical tools were disappointed. One of them rather scornfully referred to W.A.S. as a "pundit". Although at that time I was inclined to be theoretical with a vengeance, the remark struck me as somewhat unfair and irrelevant. The fact was that he had presented a rather complex analysis of time dependent data, and certain effects thereby became visible in the data which at first could hardly have been suspected. Somehow his emphasis had been on the data themselves and not on the techniques. After the lecture, E. G. Olds, who was Professor of Mathematics there at the time and had invited Shewhart to visit, introduced me, and like many others before me I was charmed by his warmly polite manner. Later, when I came to work for the Bell Laboratories, I found myself in New York City, while Shewhart was located in New Jersey. Even so I felt his influence, not directly — geography was against it — But through the influence he had on others whom I knew. It seemed to me he was having a pronounced effect on the thinking of such independent-minded individuals as John Tukey and Milton Terry. On those few occasions when I did see Shewhart, the pleasure of our first meeting was rekindled and always the same sense of stimulation, heightened by the teasingly elliptical strings of words in which he wrapped his thoughts. Like many stimulating people he was not always easy to understand, but he had a marvelous and uncanny ability to make people think harder about their own problems.

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PAUL S. OLMSTEAD

Consultant

After preparing the Editorial for this issue (p. 73), I found I had not included my own personal recollections about Walter Shewhart's warm interest in the work of others. I first met him in the spring of 1920, when I was seeking a summer job before returning to graduate school. At that time, he was a physicist-engineer in charge of research on granular carbon. My strongest impression from that summer was the fact that I was asked to do a search of the literature on granular carbon and prepare a report covering each reference in detail. At least half of the articles had been in French and German, giving me needed experience to meet my reading knowledge in these languages. These articles were uncovered through references which were traced back from more current literature.

Two years later, I returned to work with him in the capacity of a research physicist. Although I did not realize it at the time, I was enrolled in a post-graduate course that was to continue for many years. The bright spots in this course were the lunch dates, almost always once a week and occasionally oftener. While we were in New York City, we would go to the Waverly Inn or to Helen Lane's in Greenwich Village and follow it with a walk over to one of the bookstores. Usually, he would return to the office with a new book on statistics, philosophy, psychology, economics, or some other subject that seemed foreign to me. But it was not long before I found that I too was returning with books of this nature.

These luncheons were the occasion of the "soft sell." After books and even courses in Cycles, my broadening experience led to membership in the American Mathematical Society, the American Statistical Association, the American Association for the Advancement of Science, the Econometric Society, the Institute of Mathematical Statistics and others. Each was presented to me as being necessary for the clearer understanding first of what was happening in Inspection Engineering and then of what needed to be done to advance the cause of quality control.

We discussed the art of "needling", how to get things started, how to select people who had interests in certain directions but lacked a full understanding of what could be accomplished. It was always hard to say, "No", to Walter Shewhart. He was so appreciative when you said, "Yes", particularly when he knew that this would mean hours and hours of work on your part. Lunch, of course, was a point of relaxing when one could become involved so easily, and usually did. Once the die was cast, it meant that more lunches were required to plot the strategy to involve others and push toward a final answer. In cases of discouragement, he would talk about what things should be like ten to twenty years ahead. In the case of the American Society for Quality Control, he was talking about the growth to 10,000 and even 20,000 before the Society was one year old. To him, the growing pains were inevitable. If faced with today's picture, I am certain that his thoughts would be on the time the Society would reach 50,000 or even 100,000.

Lunches were the times that his associates would meet the many visitors from abroad, from England, Scandinavia, the Netherlands, Australia, India, Japan, South Africa, to mention a few. All were interested in his concept of quality control. There seemed to be no area to which Quality Control thinking could not contribute. All of us, engineers, social scientists, natural scientists, or other, will benefit by looking at our data to see whether or not they show a pattern of control. If they do not, as is usually the case, we will be well advised to look for trouble, an assignable cause, or other source of variability. Only data in statistical control are satisfactory if precise predictions are to be made or if reliance is to be placed on operations research type calculations.

My association with Walter Shewhart has been one of the high points in my life. I have been needled into doing many things, not the least of which has been taking part in the development of the American Society for Quality Control. In all of this activity extending well beyond the normal time of retirement, I have attempted to bring to my associates the kind of encouragement and stimulation that I received from Walter Shewhart.

* * *

ELLIS R. OTT

Rutgers—The State University

In 1937 and again in 1944, Dr. Shewhart was elected by the members of the Institute of Mathematical Statistics to be their president; clearly, he was recognized by statisticians as a theoretician. But neither his own ability as a theoretician — nor that of his contemporaries — could satisfy his curiosity about some questions unanswered by theory, either then or now. And so it was that Dr. Shewhart simulated theoretical models by marking numbers on three different sets of metal-rimmed tags. Then he used an ordinary kitchen bowl — the Shewhart bowl — to hold each set of chips as different sized samples were drawn from his three different populations (normal, rectangular, and right-triangular). He learned then that not only does the "Central Limit Theorem" hold for "large n", but even for "n as small as four." *There was a bowl*; and it played a vital role in the development of ideas and formulation of methods culminating in the Shewhart control charts.

* * *

E. G. D. PATERSON

Secretary, Electrotechnical Commission Committee on Reliability

In the early 1920's, when Shewhart was developing those ideas which were later to appear in his first and now classic Text, it was my privilege to be one of the small group which met regularly to hear and discuss his original concepts of Quality Control, and their potential contributions to the over-all assurance of quality in the Bell System. My role was primarily that of a student, although I was free, and even organizationally committed, to play the part of a doubting Thomas. I recall vividly, and with gratitude especially for his gentlemanly example, that under many disconcerting questions and many provoking comments he never lost his calm or patience. His quiet, good-humored responses carried the conviction of knowledge, integrity, and sincerity.

Shewhart's technical contributions will, of course, receive world-wide tribute. But some of us will recall intimate vignettes illustrative of the many-sided, unobtrusive facets of his character and competence. One in particular stands out in my recollection, because it illustrates his subtle, although unconsciously exercised, power of persuasion. To appreciate it, one must keep in mind that in those early days not only was he developing a new concept for the control of quality, but, to carry his ideas to fruition, he must gain their acceptance by pragmatic engineers and production people. A physicist himself, I am sure that he recognized that the indefiniteness associated with "randomness" and "probability" is congenitally an anathema to the engineer, whose training leads him to believe that there is a "reason for everything" if we can but find it. To the engineer, all causes are potentially "assignable". And forty years ago it was a rare occasion, indeed, to find the subject of statistics and random variability a part of the engineer's educational diet. It is a testimony to Shewhart's recognition and sympathy with the engineer's attitude that he did not stress the precision of the $t\sigma$ probability for engineering purposes. He won the support of these skeptics by making the point that research and experiment had demonstrated that, for *practical* purposes, a search to isolate causes of variation in results confined within 3σ boundaries would, in general, prove to be fruitless. Not only was this a palatable argument to the engineer, but it represented the type of thinking and approach which did so much to meld Shewhart's theoretical foundations with practice. I am sure that his philosophical compromise has comforted many of us who have never had the experience of seeing an indisputably truly "normal" distribution in the real world. We can better appreciate today why, in the then absence of computers, he was not loath to have his people "playing with chips in a bowl", as we were wont to characterize his early experiments.

Nor, in our close attention to his solicitation for "Quality Control", should we overlook the comprehensive (and prophetic) character of his concept of quality, itself. Today, special attention is directed to one in particular of its components, Reliability. It is noteworthy that in his early descriptive acronym, "SADE", for the "quality" he envisioned, the "D" stands for Dependable, an almost identical-twin synonym for Reliable.

Nevertheless, despite his original, outstanding, and widely acknowledged contributions to Quality Control, and despite my personal indebtedness to him for his preceptoral counsel, I, and many others, will always think first of Walter Shewhart as a highly respected friend. He clothed his intellectual brilliance in a quiet personal character which endeared him to all, and especially to his close associates. In the truest sense he epitomized that praise-worthy combination of scholar and gentleman.

* * *

HARRY G. ROMIG

California State College at Long Beach

It is highly desirable that honor be given to our beloved Walter A. Shewhart for his work in science. My first knowledge concerning Dr. Shewhart came in 1922 when I joined the University of California at Berkeley as a Teaching Fellow in Physics. While I was serving the Bell Telephone Laboratories from 1926 until 1951 I was closely associated with him. We served for some time in the same department, the newly organized Inspection Engineering Department under Dr. Reginald Jones, which later became the Quality Assurance Department. Dr. Shewhart worked in the fields of transmission and reception by telephone and did a great amount of original work.

However, his most notable contribution was contained in a simple short Memorandum dated May 16, 1924 (reproduced on page 72). This memorandum contained the basic elements of all of modern Quality Control. I found when I joined the Laboratories that Dr. Walter A. Shewhart felt at that time that by properly charting all products for their most critical characteristics, then product at desired levels of quality would be produced. The concept was correct but it is a little difficult to secure complete compliance by the production groups. Later, when discussing the Quality Control movement with Walter, I found he was quite despondent because so many failed to follow carefully the rules and procedures that had been so carefully prepared for them. This accounts for much of Dr. Shewhart's programs. He desired to consolidate the position of all successful Quality Control activities.

Dr. Shewhart added several qualified engineers and scientists to his staff. Mr. Fred Winters joined the staff and worked with Dr. Shewhart in showing conclusively that averages of samples even as small as four when taken from rectangular or triangular distributions as well as from Normal Law distributions produced means that were essentially Normal in form. Colonel Nekrasoff joined with Dr. Shewhart in developing nomographs for simplifying the endless calculations required to properly chart all activities. The years from 1924-32 were rich in new developments. Dr. Shewhart served as a Lecturer at Stevens Institute of Technology and tried out the sections of his book covering Statistical Controls for Manufactured Products. Also many In-Hour courses were held within the Quality Assurance Department as well as many Out-of-Hour Courses. From these resulted better controls over the number of complaints handled, where such came from operating companies.

Dr. Shewhart was a prolific writer. Many of his papers were held internally and not released but many were made a part of the scientific literature of this period. One of the most important dealt with the subject, "When Shall A Thing Be Left To Chance?" These concepts were discussed in many internal seminars held within the Laboratories and sometimes at many of the Western Electric Plants. The notion of "Assignable Causes" was new. It was pointed out that many minor deficiencies may be neglected as superficial when and only when adequate controls are maintained. The application of this fundamental principle resulted in hundreds of thousands of dollars of savings by the Bell System. Also it resulted in improvements in the qualities of outgoing products. As a result of this particular paper and many others, representatives from many companies came to him for guidance in their fields of endeavor. This information was sometimes given directly but in most cases was covered by formal endeavors and directions, given in many letters written directly to individuals, but most often sent to committees for action. He served on the various Standards Committees and aided them in arriving at a solution to the problem concerning what really constitutes a specification.

One of the most interesting meetings was that held in New York where a representative from the Bureau of Standards and Dr. Shewhart argued concerning how best to measure precision and accuracy. This argument was enjoyed by a large audience, and it was felt that indeed it was possible to secure close replications of scientific measurements, each of which would truly be a representative random sample from the "Universe of Discourse". Dr. Shewhart wrote many book reviews and critiques concerning many procedures and technical standards prepared by other departments in the Bell Telephone Laboratories. In this connection he was given many awards and honors. These are listed in American Men of Science and need not be repeated in detail here.

In 1938 there appeared his U.S. Dept. of Agriculture lectures from Washington, DC, edited by W. Edwards Deming. This work contained the complete scientific pattern for all phases of any Total Quality Control Program. It extends the use of the scientific method to all patterns of life, not just manufactured product which was covered in Dr. Shewhart's first book. Within this framework is included many aspects of the Operations Research techniques. Also the economic aspect has been covered. Many of these same principles are now included in the new Value Engineering programs.

What has a scientist with the training and experience of Dr. Walter A. Shewhart contributed? Besides being the founder of Quality Control, Dr. Shewhart has been involved in the establishment of standards in ammunition, and in many fields of communication. He has made practical applications of statistics in textiles, in rubber products, in food supplies, and in inventory controls. He has sponsored the use of the scientific method in practically all fields of endeavor. His contributions have been voluminous. He will be greatly missed in the fields of science.

In addition to being a scientist of the first rank, Dr. Shewhart was also a philosopher and a very likable human being. He was a source of inspiration to many in this field. Many young men seeking careers in statistics owe their success to the aid and inspiration they received from Dr. Shewhart. I know of many individuals in the educational field that owe their start to Walter Shewhart. He was sometimes intensely annoyed when men he had recommended did not fulfill their complete contracts and then sought his aid again to obtain a new appointment. When he had individuals working for him that were not too successful, he made complete arrangements for new positions before releasing them. Thus, he was quite a humanitarian. I worked for him and with him even though I was an associate not a subordinate. Originally it had been planned that I should work for him but I was assigned to work for Mr. Harold F. Dodge. Associated with us was also Mr. George D. Edwards. The four of us worked together on many technical committees and in many areas, including the military. We also had Mr. Donald A. Quarles, who later became Assistant Secretary of Defense, working in the field of Quality Assurance. He went over to take charge of Research while Mr. Edwards took over the administration of Quality Assurance reporting eventually to Mr. Martin. Thus we find Dr. Shewhart as the center of activities in practically all fields of Industrial Engineering, Scheduling, Reliability Engineering, Operations Research, Systems Enginering, Human Engineering, Value Engineering, Product Effectiveness, and also Configuration Management.

Dr. Shewhart lived in a time of intellectual giants. During this period, he brought over Dr. Egon Pearson, L.H.C. Tippett, Brownlee, Swan, and Dr. Jerzy Neyman. Seminars and special lectures were arranged at Columbia University for R. A. Fisher and others. Sunday meetings were held at many homes. The statistical leaders were part and parcel of Dr. Shewhart's life, and he was one of the ablest of them in Statistics, Industry, and in Science.

* * *

LESLIE E. SIMON

Maj. Gen. USA (Ret'd.)

I think that it is a very fine idea to publish a special issue of *Industrial Quality Control* dedicated to Walter Shewhart. No doubt you know that Walter was my close and most generous friend, and I could say much. Instead, I shall try to be brief.

Four days before Walter died, I gave a paper on the profession of statistics at a meeting of the American Statistical Association in Winter Park, Florida, that was sponspored jointly by the Graduate School of Rollins College and the Florida Chapter of the ASA. In this paper I said:

"I think it probable that it was Walter A. Shewhart's book, *Economic Control of Quality of Manufactured Product*, published in 1931 that was most influential in promoting the growth of statistics."

In my own experience, Walter's help went far beyond his published work. In fact, without Walter's generous contributions of his time, personal guidance and advice, my early applications of quality control might have been failures. If this had happened, there might have been a lack of early stimulus for QC in the production of munitions. As you know, this pilot use of QC in munitions plus action on the part of Walter and others resulted in emergency training courses sponsored by the War Production Board that trained such a large number of engineers in quality control that a sufficient number of quality controllers was created to form the ASQC. Let me outline briefly how Walter influenced and made possible the work that I did at Picatinny Arsenal.

In 1934 the Chief of Manufacture at Picatinny Arsenal (the Army's ammunition center) was Colonel A. B. Johnson, a very competent, intelligent and forward-looking officer. Walter's book was brought to his attention, but Johnson had difficulty in reading it. I was his assistant, and he suggested that I read it. I still have that original and well-worn copy. After reading the book, I had what most superior officers would have judged to be a very silly idea.

We were in the worst part of the depression of the 1930's. Almost every month, orders came from Washington to cut our force by a certain number of people. This, of course, was an economy measure. The manufacture of munition in those days, was more of an art than a science. It almost broke our hearts to see separated employees walk out of the arsenal. They took with them the personal judgment and skills indispensable to good ammunition. They were irreplaceable, and it was unlikely that we would ever get them back.

My idea was one designed to stop the loss of skilled munitions makers. After reading *Economic Control of Quality of Manufactured Product*, I believed that with QC I could make ammunition better and cheaper than anyone else. Therefore, if I could get an authorization to bid for Navy orders in competition with civilian industry, I could win enough contracts to keep all of our people employed. My superior officers got the authorization at least in part. We not only stopped the loss of our people, but increased our force in slight degree; and made top quality munitions at distinctly lower costs.

However, this did not happen over night. Before I got things to really going, one difficulty after another arose. Since Walter lived at Mountain Lakes, New Jersey, which is only about ten miles from Picatinny, he frequently had a night-time visitor on his hands after he had done a day's work at the Bell Telephone Laboratories. For example, within the existing organization, I simply could not get enough men who could do squares and square roots to permit me to use the statistic, standard deviation. I proposed to use the much simpler statistic range, but I knew that this was a questionable procedure.* Of course, I went to see Walter. Instead of throwing me out, he listened to my whole story, warned me of the danger inherent in the use of range and suggested ways to guard against the dangers. Of course, we worked until after midnight (while our wives waited); and this occurred many times.

In those days, I attributed Walter's generosity to patriotism. I could not see why a man would do so much for even an enthusiastic friend and admirer. Later, I have decided that his motivation was partly patriotism, partly generosity to a friend, but also in large measure to the privilege and duty of a scientist to help and instruct for science's sake. Walter was a patriot, warm generous man, friend, and true scientist.

As a parting thought, a mild joke involving Shewhart.

*This matter is discussed in Appendix C of *An Engineers' Manual of Statistical Methods*, John Wiley & Sons, Inc., 1941

On one occasion, I was congratulating Walter on an article ("Some Aspects of Quality Control", *Mechanical Engineering,* December 1934); and added, "But Walter, it took me four hours to read it thoroughly." He replied, "Cheer up, it took me four years to write it." Incidentally, my statement was true, and I am convinced that his too was true. That is the kind of careful writing that he did, and probably also why he never published a thorough discussion of specifications.

* * *

FREDERICK F. STEPHAN

Princeton University

Walter Shewhart was an unusual man. His career started in the Twenties when "Bigger and Better" was a popular slogan but there were relatively few instances in which people asked "Is it really better?" or even "Is it actually as good as we suppose?" True, the Model T worked well enough for millions of drivers and riders but the introduction of machine switching in the telephone industry and increasing emphasis on higher performance in many industries was already ushering in the new era of strict inspection procedures, emphasis on prevention of scrapping losses and reworking costs, and rapid development of mass production methods. Walter Shewhart worked with insight, rigorous thinking and persistence to pioneer the methods of economic and statistical quality control that were needed. Indeed, when the defense program that preceded our entry into World War II rapidly accelerated these industrial developments, Shewhart's methods were ready for use throughout the defense industries and they provided the foundation for the rapid development of quality control engineering that culminated in the formation of ASQC.

I first met Walter Shewhart in 1935. He asked me many questions: Had I read Peirce? Would I trust data more when they come from a laboratory with an excellent reputation, or should such subjective matters carry no weight? and others I do not remember distinctly. At first it seemed that he was grilling me but then I discovered that this was his manner of thinking and scrutinizing problems—a clear, searching, inquiring, critical, yet positive approach to hard problems and important ones. He was a man of faith as well. I remember how he told me on a later occasion that he was confident that Sam Wilks (for whom I shared his admiration) and the young men he was developing at Princeton would play a very important part in the future of statistics both theoretical and applied. He was, himself, a great inspiration to Wilks and to ever so many of us who are dismayed that he has left us but ever grateful to have known him.

* * *

RALPH E. WAREHAM

Second President, ASQC

With sadness at the passing of Dr. Walter A. Shewhart, we in Quality Control must still count our blessings that this remarkable man maintained active work in Quality Control for so long a time.

In addition to Dr. Shewhart's great technical contributions to modern quality control, perhaps his greatest gift was the guidance which he freely provided to the early quality controllers. With patience and understanding, Walter listened to quality control problems of others, asked penetrating questions, and offered sage advice. This help started many a fledgling industrial quality control program on its way.

The publication of Dr. Shewhart's classic text, *Economic Control Of Quality Of Manufactured Product,* provided the basic literature needed for college training in scientific quality control; in fact, such courses largely started after publication of this book in 1931. The American War Standards on Quality Control (now ASQC Standards) were directly influenced by Dr. Shewhart's work and later literature has been similarly affected.

Walter Shewhart had much to do with the dedication of the early quality controllers and the present members of ASQC to the goal of providing satisfactory quality in all industrial products. The zeal we all share for protecting product quality is a reflection of the spirit of Walter A. Shewhart.

Walter took great pride in the growth of ASQC; he will be truly missed from his place of honor in our Society.

* * *

MASON E. WESCOTT

University of Rochester

Although I never had the privilege of anything beyond a quite infrequent and casual association with Walter Shewhart, there were occasions during the years I was on the faculty at Rutgers when I had an opportunity to meet him and share in some activity with which he was associated in the quality control field. Even with these few personal contacts, the impact of his personality is unforgettable. It was the quiet, kindly, persuasive way he had of making the weight of his authority felt that impressed me most and is best remembered. His genius consisted not only of his scholarly erudition, but also in his instinctive feel for and insight into the realities of problem situations.

Walter Shewhart will rank among the all-time greats in the history of industrial progress because of the strategies he created and promoted so effectively for making possible an *understanding* of the nature and role of variation in the defense-in-depth warfare it wages in the repetitive operations along the industrial front where the basic objective is to optimize the quality/cost ratio.

* * *

A. E. R. WESTMAN

Ontario Research Foundation

I first met Walter Shewhart when I was preparing the Refractories Test Manual (1929) for ASTM Committee C-8 in conjunction with J. Spotts McDowell. This was the forerunner of the ASTM Manual for Presentation of Data (1933) and the present ASTM Manual of Quality Control of Materials.

Walter not only gave me a great deal of encouragement and advice but throughout the preparation of these manuals constituted a court of last resort when deciding questions of principle in regard to statistical quality control.

He was always charming, enthusiastic, friendly, modest and helpful. Society is greatly in his debt and so are his many friends who were fortunate enough to be associated with him in the development of statistical quality control as a revolutionary and effective technique.

* * *

W. BRADFORD WILEY

John Wiley and Sons

Some thirty years ago I was a young, enthusiastic, and inexperienced editor who had, among my diverse subject responsibilities, the problem of deciding what books John Wiley and Sons should publish in statistics. Many of the authors, in fact or in prospect, were not much older than I, relatively inexperienced in the subject area, but nonetheless enthusiastically attempting to provide textbooks for a wide variety of courses. We were receiving for consideration manuscripts and prospectuses for books to be used in courses for mathematicians, economists, educationists, sociologists, psychologists, engineers, and biologists. The hopeful authors came from all of those disciplines, often inviting a mathematician as collaborator to provide the "theory" as a departure from the "application." The required level of mathematical competence seldom went beyond high school algebra. The intended user was likely to be found anywhere in the undergraduate curriculum. I was confused — and had little trouble confusing my superiors!

Happily, someone directed me to Walter Shewhart as a reviewer. He was, of course, a severe, but fair and constructive critic. More happily, my youthful enthusiasm and determination appealed to him, prompting him to undertake my further education. This led to our mutual confidence and understanding.

In retrospect, the problem was a simple one, for it divided neatly into three parts. The first was to raise the discipline of statistics to the highest possible intellectual level; the second was to bring to an end the running feud between the followers of Fisher and those of Pearson; and, finally, to plan a comprehensive publishing program, initially national and ultimately international in authorship.

In 1941, Walter Shewhart led us out of the wilderness with a plan for a Series in Probability and Mathematical Statistics, using the simple concept of concentric circles. In the center were the basic books which became Feller's *Introduction to Probability Theory and its Application* (1950, second edition 1957), Hoel's *Introduction to Mathematical Statistics* (1947, third edition 1962), and Wilks' *Mathematical Statistics* (1962). World War II proved only a temporary setback, with Samuel S. Wilks joining Walter Shewhart as co-editor soon after the war. Today, the Series includes more than seventy-five titles grouped as Probability and Mathematical Statistics, Applied Probability and Statistics, and Tracts. The Wiley catalog has a section of sixteen pages headed "Probability and Statistics," which in the present year includes more than eighty titles. Walter Shewhart generously and modestly contributed to the discipline far beyond his historic Series concept. Those of us at Wiley who worked with him will always cherish his personal friendship and take pride in the honor of sharing in his great achievements.

* * *

W. J. YOUDEN

George Washington University

There are many who had the good fortune to know Dr. Shewhart or his work. In the 1920's there were few sources of statistical enlightenment to which the young scientist or engineer could turn. My copies of his Bell Telephone reprints have been bound together for more than thirty years.

I was doubly blessed because, twenty years later when Dr. Shewhart was editor of the Wiley Statistical Series, he asked me to contribute a book on statistics for chemists. Naturally I was pleased but I lacked confidence to try. After several reminders I told him that I was not qualified to write a book on statistics. He replied "I never asked you to do that." Startled, I said, "You didn't?" "No", he said, "I want you to write a book that could be called 'This is Jack Youden'". Thus deftly Shewhart taught his authors to write on what they knew — and got the manuscripts he wanted.

Long after those who were priviledged to know Shewhart have left this scene his work will continue to serve as a quality control for young men.

* * *

1967 EDWARDS MEDAL NOMINATIONS

Nominations are now being received by the Edwards Medal Committee for consideration. Anyone may submit a nomination for the Edwards Medal Award. Biographical information must be submitted supporting the nomination. Nominees are considered over a three year period. Beyond this time, fresh supporting information must be submitted.

A major award of a professional society is properly an award based on service to society generally, in the area of professional cognizance. In keeping with this concept, consideration will be given to all forms of contributions for progress in quality including, but not limited to:

- A government official who contributes importantly to solution of broad quality problems
- An industrial executive who is identified with bringing his company to a position of quality leadership in his industry
- A quality manager who sets up and administers an outstandingly effective quality control program
- An inventor who works out a new process or system of measurement which is a breakthrough in quality control
- An educator who creates new courses, seminars, etc., which become an outstanding contribution to education in quality control
- A consultant who provides leadership in cross-fertilization of practice among companies and industries
- An author who makes outstanding contributions to permanent quality control literature.

Membership in the American Society for Quality Control or service therein is not to be considered a prerequisite. Send the name of your nominee with nine copies of supporting information (one copy if duplicating facilities are not available) through your Section Chairman, or send direct to Edward M. Schrock, Chairman of the Edwards Medal Committee, 412 Beechfield Avenue, Baltimore, Maryland, 21229. To receive consideration the nomination must reach the Chairman by October 27, 1967.

Rutgers to Host QC Conference

The Metropolitan Section, ASQC and the Rutgers University Statistics Center with support of the North Jersey Section, ASQC, will hold its 19th Annual All Day Conference on Quality Control at the Rutgers University Campus in New Brunswick, New Jersey on Saturday, September 9, 1967. Ten concurrent technical sessions and a complete Ladies' Program will be featured.

The technical sessions will include: Basic Concepts of SQC, Practice of QC (including Motivation), Management of QC, Experimental Design and Interlaboratory Testing, and Computer Applications of SQC among others.

Luncheon speaker for the conference will be Harold A. Sutphen, President, U.S. Envelope Co., and Serving as Toastmaster will be Horace J. DePodwin, Dean of the Rutgers University Graduate School of Business.

For further information and a conference brochure contact: K. S. Stephens, Conference Chairman, Western Electric Co., P.O. Box 900, Princeton, New Jersey 08540.

Akron-Canton Section Presents Conference

The Akron-Canton Section, ASQC, presented its Ninth Annual Spring Conference recently at the Sheraton Hotel, Akron, Ohio. This year's program was planned to make a professional contribution to the ever-expanding technological and managerial advances taking place in today's industrial society.

Included in the conference were a seminar covering the primary purpose and wide scope of today's varied quality control activities, conducted by Dorian Shainin, and several sessions concerned with the full scope of quality control activities.

Speaking at the luncheon was Tennyson Guyer, Ohio State Senator, shown above; at right is George W. Johnson, Section Chairman.

A. G. Brooks Receives Lisy Award

Alvin G. Brooks—ASQC Fellow and Regional Director—recently received the Chicago Section's Joe Lisy Award, in recognition of his leadership and distinguished service in the field of Quality Control. The Award was established in memory of one of the Society's founders, Joe Lisy, and is presented annually to a local member whose contribution of time and effort has extended significantly beyond the call of duty.

Mr. Brooks, who is a department chief at Western Electric's Hawthorne Works in Cicero, Ill., has specialized in Quality Control for 30 years.

Sam L. Grasso Receives Testimonial Award

Prof. Niles Barnard, University of Nebraska, recently presented a testimonial award of the Board of Directors to Sam L. Grasso, Vice President of Inland Manufacturing Co., and Director-at-Large of ASQC, for his chairmanship of the Edwards Medal Committee for 1965-66, and for his time and effort contributed toward making the Omaha-Lincoln Section and the National ASQC more meaningful to its members in the field of Quality Control.

Mr. Grasso, a charter member of the Omaha-Lincoln Section of ASQC, has served as a National Director of ASQC and is a past chairman of the Midwest Conference Board of ASQC. He also serves as a member of the Industrial Committee of the Omaha Chamber of Commerce and is a senior member and former Chairman of the National Committee of the American Society of Tool and Manufacturing Engineers.

Chemical Division Offers Course

The Chemical Division of ASQC will offer a two-day short course entitled "Nonlinear Estimation" to be held in Chicago on August 11-12, 1967.

The topics to be covered are: Linear Estimation in Matrix Form, Introduction to Nonlinear Estimation, Reparametrization of the Model, Geometrical Aspects of Linear and Nonlinear Least Squares, The Marquandt Compromise, and Worked Out Practical Examples.

Instructors for the course are Norman R. Draper, University of Wisconsin, and Donald W. Marquandt, E. I. DuPont De Nemours and Company. These men have prepared the course and have had numerous papers published on nonlinear estimation.

For further information, please contact:
Mr. Frank Medgin
Research and Development Center
Swift and Company
Exchange and Packers Aves.,
Chicago, Illinois, 60609.

ASQC Film List

For a list of films on quality control which may be rented from ASQC, or from individual contacts, see **pp. 498-499** of the April, 1967 issue of *Industrial Quality Control*. See also p. 628 of the June issue for the films available from ASQC.

HAVE YOU READ?

William M. Wooding, *Editor*

APPLICATIONS—MISCELLANEOUS

"Gaseous Decontamination of Instruments in Plastic Bags," by Allan Claghorn (Union Carbide Corporation), *Contamination Control*, 5, No. 4 (May, 1967), discusses the rationale and operating procedures for ethylene oxide sterilization of "electronic parts and other instruments which go into medical devices, rockets for interplanetary exploration, etc., which are deleteriously affected when decontaminated by heat or radiation" as well as by cold chemical agents or soaks. The plastic shipping bags may be simultaneously decontaminated. An extensive bibliography and an appendix describing the procedure in detail are given.

APPLICATIONS—PHARMACEUTICALS

In "Contributions to Testing and Control of Pharmaceutical Preparations. Evaluations of Rheograms of Galenic Preparations on Projectively Transformed Graph Papers," *Scientiae Pharmaceuticae II, Proceedings of the 25th Congress of Pharmaceutical Sciences, Prague, (24-27 August, 1965)* pp. 459-464 (edited in 1967, Butterworth Publishers, Inc., Washington, D.C.) (in German), H. Zacek describes a method for the evaluation of data when the response variable is a curve. The method is based on the use of projectively transformed double logarithmic papers, suggested by J. Fischer in East Germany.

APPLICATIONS—PLASTICS AND RESINS

______, "Weatherability of Plastics," *Modern Plastics, 44*, 8:141-162, 204-219 (April, 1967), is a series of twenty abstracts of papers given at a Symposium sponsored by the National Bureau of Standards in February. The full papers are scheduled for publication in the *Journal of Polymer Science Symposium Series* later this year.

E. Schwartz and J. C. Hartley, "The Acetic Acid Test—Useful Tool for Stress Control and Plating Quality," *SPE Journal, 23*, 3:110-112 (March, 1967), describes a relatively simple means of determining before metal plating ABS plastic, that the plated surface will have good adhesion. The only special equipment required is a simple bending jig and a 50X microscope. Verbal summary is given of experimental work with a fixed time cycle, using three levels of fill speed, five material temperatures and three mold temperatures.

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*A list of addresses of the magazines reviewed is available from this editor. *Copies* of articles are *not*. Note: "USGPO" means order from Supt. of Documents, U.S. Govt. Printing Office, Washington, D.C. 20402. "USDC" means available from (make check payable to) U.S. Dept. of Commerce, Washington, D.C. 20230 (or any field office) but *not* USGPO.

Contributions for this department should be addressed to: W. M. Wooding, Carter-Wallace, Inc., Carter Products Div., Half Acre Road, Cranbury, New Jersey 08512.

COMPUTERS AND DATA PROCESSING

______, *Chemical and Engineering News, 45*, 13:102-108 (March 20, 1967) reports on some of the activity in the computer field as covered by the Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy. The report points out that although instrumental analysis (gas chromatography, infra-red spectrophotometry, etc.) is rapidly heading for electronic data processing, broad-scale computer handling of data is too new for there to be much coherence at present. The report also covers the potential market for the smaller general-purpose computers as well as the latest advances in new instrumental hardware.

Brenton R. Groves, in *Science, 155*, 3370:-1662-1663 (March 31, 1967), reports that a motion picture of the electromagnetic field pattern of a prolate spheroid antenna was produced by him using an IBM 7094 computer and an SC 4020 microfilm plotter. The technique of illustrating complex mathematical concepts by means of computer pictures should be of considerable aid in electrical engineering and other fields.

DESIGN OF EXPERIMENTS

In "Quantitative Infra-Red Determination of the cis-Isomer in a Mixture of cis- and trans-β-(4-Aminocyclohexylpropionic) Acids; The Design of Experiments for the Estimation of Errors Arising from the Instability of Analysis Conditions," *Zhurnal Analiticheskoi Khimii, 21*, 11:1363-1366 (November, 1966) (in Russian), I. A. Titova and Yu. I. Volodarskaya show how fractional factorial experiments can be used in carrying out chemical analyses. It is suggested that the errors arising from various stages of an analysis be estimated on the basis of the coefficients of the regression equation resulting from the data obtained in the fractional factorial experiment.

INSPECTION AND TESTING—GENERAL

A special issue of *Statistical Quality Control, 118*, No. 3 (March, 1967) (in Japanese), is devoted entirely to testing and measurement in a quality control milieu. Articles by both academic and industrial contributors appear, covering many phases of the subject, including methodology, errors, sampling plans, automated testing, sensory testing, handling of outliers, vendor-vendee relationships, process control, and instrumentation.

PROCESS ANALYSIS AND CONTROL

Control of chemical reaction systems in an engineering milieu is discussed by Leon Lapidus in "Control, Stability and Filtering", which appeared in *Industrial & Engineering Chemistry, 59*, 4:28-38 (April, 1967). The paper discusses the theory of control of linear systems

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HAVE YOU READ?

which are subject to quadratic performance indices.

PURCHASING

The system used by American Motors to assure a quality job by their suppliers is described by R. A. Maass in "The Point of Control is the Supplier's Plant!", *Quality Assurance*, *6*, 2:18-21 (February, 1967). Vendor surveillance is heavily stressed, since, as Dick Miller, Director of Quality at Kenosha, points out: "With lead times so short, and inventory so low, incoming inspection is too late to stop trouble. At best, incoming inspection is only a monitoring function. We make our vendors realize that the point of control is the supplier's plant!."

QUALITY CONTROL PROGRAMS AND PLANNING

In "Standardization Helps to Realize Statistical Quality Control," *Standardisierung* (East Germany), *13*, 1:4-7 (January, 1967) (in German), K. Wendt reports on experiences obtained in various branches of East German industry during the introduction of quality standards involving the use of statistical quality control methods.

Robert J. Scott describes "A Quality Information Center", in *Quality Assurance*, *6*, 4:24-25 (April, 1967), which was set up by the Chicago Rawhide Manufacturing Company. A small group of employees handles all quality data from the standpoints of input, analysis, and reporting. Other activities of the QIC include maintenance of the quality manuals, "periodic audits of the quality system and the evaluation, preparation and issuance of all quality standards and standard practices."

The close tie-in between design and QA activities at Teletype Corp is discussed by R. A. Maass in "QA and Design at Teletype", *Quality Assurance*, *6*, 4:34-37 (April, 1967). The company's philosophy is that "the assurance of quality must begin at the early design stage."

The Amphenol Corporation's reliability and quality control operations are the subject of "Take Quality Assurance to the Customer!", again by R. A. Maass, in *Quality Assurance*, *6*, 3:26-28 (March, 1967). These operations center in an organization that "covers the life of the connector from its conception, through manufacture and into the field."

At GM's Central Foundry Division, "Process Controls Assure Quality Castings", *Quality Assurance*, *6*, 4:28-30 (April, 1967). Ralph Eshelman describes the various phases of the program in effect at this GM plant.

RECORDS AND DATA HANDLING

Texas Instruments' new Tacticom (tactical communication) data collection system is described in "Know What's Happening in Your Plant", by Ralph von Osinski, in *Quality Assurance*, *6*, 4:42-44 (April, 1967). This highly flexible system, made up of a central station and a series of input stations, is used to log in shipment data, incoming inspection results and material disposition information.

RELIABILITY AND FAILURE ANALYSIS

In "Assuring Quality and Reliability with Mathematical Programming," *Quality Assurance*, *6*, 3:30-33 (March, 1967), N. L. Enrick uses an example involving provision of an adequate number of spare components to illustrate how MP can be employed to accommodate the many variables involved in quality and reliability problems. Several other applications of MP are shown.

STANDARDS AND SPECIFICATIONS

———, "Plastics Standards Digest," *SPE Journal*, *23*, 4:95-6 (April, 1967) summarizes all standards on plastics issued by NBS, ISO, SPI, GSA and SAE in 1966. For each, the identification number, name, source, and addresses from which they may be obtained are given.

STATISTICAL AND MATHEMATICAL METHODS

Marc de Chazal, *Chemical Engineering*, *74*, 8:182-184 (April 10, 1967), discusses how, on the basis of a few measurements, one may decide that one or more data points should be discarded as being invalid. The method discussed, sometimes known as Chauvernet's criterion, uses a test value that depends on the number of data used in the analysis. It may easily be programmed on a digital computer for aid in computations.

In *Color Engineering*, *5*, 2:29-29, 44 March-April, 1967), Isadore Nimeroff discusses "The Variability of Color Measurement." The components in the equations for computing chromaticity coordinates in spectrophotometric colorimetry are measured, and therefore subject to measurement uncertainty. The theory of propagation of errors was applied to determine the chromaticity uncertainty resulting from the spectral irradiance of a source, the spectra emittance of an object, and the spectral response of normal human observers. It is recommended that a complete standard observer system, consisting of means, variances, and covariances of the spectral tristimulus values, in xyz and uvw coordinates, be adopted by the Commission Internationale de l'Eclairage (CIE) for use in color measurement.

In "Estimation of Error," *Feingeratetechnik* (East Germany), *16*, 4:156-162 (April, 1967) (in German), P. Kirsten and W. Siegel describe a new method for treating small samples in the presence of systematic error. The method is based on the evaluation of "maximum error" which is defined as the sum of the largest systematic and random deviations from the true value.

Mr. K. C. J. B. Lind analyzes the components of variation in the determination of the viscosity of nylon solutions in formic acid. His paper, "Where Does that Spread Come From?", *Sigma*, *13*, 1:7-10 (February, 1967) (in Dutch) discusses a particular example in detail. An appendix provides the derivation of the formulae used.

Dr. R. Doornbos, in "Statistical Aspects of Blending," *Sigma*, *13*, 1:4-6 (February, 1967) (in Dutch), provides some references to the European literature for readers who may wish to explore mixing problems in depth.

A. Bok, "How to Control Blenders for Dry Materials as to Mixing Accuracy," *Sigma*, *13*, 1:2-4 (February, 1967) (in Dutch), provides a general description of the methods of analysis based on samples of mixed products.

Section Calendar

AUGUST

17—Akron-Canton Section meeting, to be held at Mergus Restaurant, Canton, 7:00 p.m. R. H. Shoemaker will give the "Akron-Canton Section Report."

24—San Francisco Section executive committee meeting at DECASR Headquarters, Burlingame, at 7:30 p.m.

29—Los Angeles Section meeting. William A. Golomski will speak on "Education in Quality—It's Needed!"

29—Pittsburgh Section dinner-meeting to be held at Oliver Restaurant, 6:30 p.m. Gayle W. McElrath will speak on "The Big Picture."

PROBLEMS DEPARTMENT

Harry Smith, Jr. *Editor*

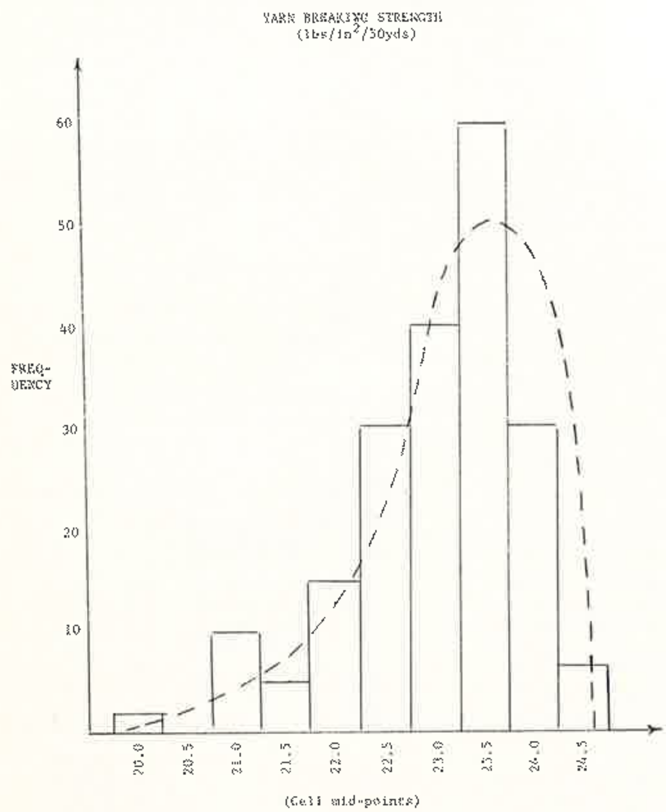


Figure 1

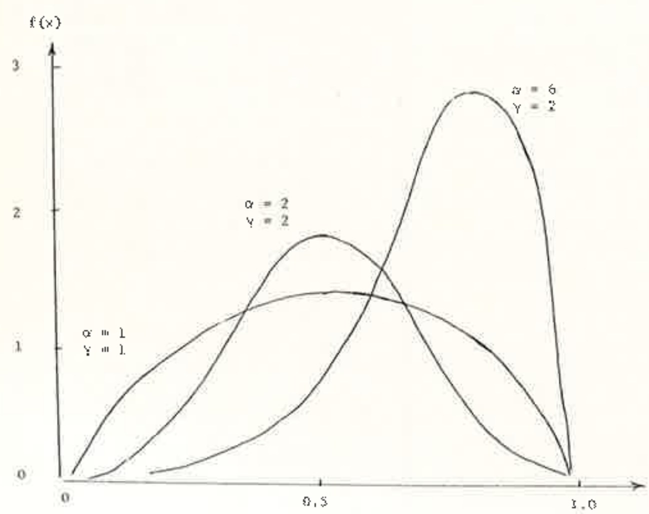


Figure 2

PROBLEM 5-67

I have tried to represent yarn breaking strength by a Beta probability distribution. Somehow, somewhere, I have been making a mistake, and I need some help.

I collected the data on yarn-break in lbs./in.^{2}/50 yds. which I have summarized in the following table:

cell mid-point m	observed frequency y
20.0	2
20.5	0
21.0	10
21.5	5
22.0	15
22.5	30
23.0	40
23.5	60
24.0	30
24.5	8

A plot of the data indicates the following shape curve (Fig. 1).

I noted immediately that this curve is very similar to a Beta Distribution density function, as shown in the following graph for some representative sets of parameter values (Fig. 2).

The mathematical form of the Beta density function f(x) is

$$f(x) = \frac{\Gamma(\alpha+\gamma+2)}{\Gamma(\alpha+1)\ \Gamma(\gamma+1)} \cdot x^{\alpha}(1-x)^{\gamma},$$
$$\text{where } \alpha > -1, \gamma > -1, \quad 0 < x < 1; \qquad (1)$$
$$f(x) = 0 \text{ elsewhere}$$

How do I proceed from here on?

REPLY 5-67

(Answered by Dr. Roy Kuebler, University of North Carolina, Chapel Hill, North Carolina.)

1. The Beta distribution gets its name from the mathematical *Beta function,* which is defined as $B(a,b) = \int_0^1 x^{a-1}(1-x)^{b-1}\,dx$, $a > 0$, $b > 0$, and for which $B(a,b) = \Gamma(a+b)/[\Gamma(a) \cdot \Gamma(b)]$. Thus, (1) is often written in the form

$$f(x) = \frac{1}{B(\alpha+1, \gamma+1)} x^{\alpha}(1-x)^{\gamma},$$
$$\alpha > -1, \gamma > -1; 0 < x < 1,$$
$$= 0 \text{ elsewhere} \qquad (2)$$

Contributions for this department should be addressed to: Dr. Harry Smith, Jr., Department of Biostatistics, University of North Carolina, Chapel Hill, North Carolina.

Finding areas under this curve involves integrating from $x = 0$ to $x =$ various values less than 1. Such integrals constitute the *incomplete Beta function*. The best published tables for this are in *Tables of the Incomplete Beta Function*, by Karl Pearson, Cambridge University Press, 1932. Interpolation in the tables is difficult, and one is well advised to seek results from a high-speed computer, for which the calculation is usually a standard program.

2. The first operation in fitting data to a Beta distribution is to convert the original data on y, which here has a range of 19.75 to 24.75, to data on x with a range 0 to 1. This can be done directly as:

$$x = \frac{y - 19.75}{24.75 - 19.75} = \frac{y - 19.75}{5}$$

Using this transformation, we can show the data as follows:

y-interval	x-interval	x-interval mid-point	observed frequency f	fx	fx²
19.75-20.25	0-0.1	0.05	2	0.10	0.0050
20.25-20.75	0.1-0.2	0.15	0	0.00	0.0000
20.75-21.25	0.2-0.3	0.25	10	2.50	0.6250
21.25-21.75	0.3-0.4	0.35	5	1.75	0.6125
21.75-22.25	0.4-0.5	0.45	15	6.75	3.0375
22.25-22.75	0.5-0.6	0.55	30	16.50	9.0750
22.75-23.25	0.6-0.7	0.65	40	26.00	16.9000
23.25-23.75	0.7-0.8	0.75	60	45.00	33.7500
23.75-24.25	0.8-0.9	0.85	30	25.50	21.6750
24.25-24.75	0.9-1.0	0.95	8	7.60	7.2200
			200	131.70	92.9000

3. The next task is to estimate the parameters of the Beta distribution. The easiest and most straight-forward procedure for this is the method of moments.

The first and second moments about the origin of the $B(\alpha + 1, \gamma + 1)$ distribution are:

$$\mu_1 = E(x) = \frac{\alpha + 1}{\alpha + \gamma + 2}, \qquad (3)$$

$$\mu_2 = E(x^2) = \frac{(\alpha + 1)(\alpha + 2)}{(\alpha + \gamma + 2)(\alpha + \gamma + 3)} \qquad (4)$$

If $x_1, x_2, \ldots, x_n$ are observations on x, the estimates of μ_1 and μ_2 are

$$\hat{\mu}_1 = \frac{\sum_{i=1}^{n} x_i}{n}; \qquad \hat{\mu}_2 = \frac{\sum_{i=1}^{n} x_i^2}{n}$$

The method of moments then estimates α and γ by solving for α and γ in the following:

$$\frac{(\alpha + 1)}{\alpha + \gamma + 2} = \hat{\mu}_1 = \frac{\sum_{i=1}^{n} x_i}{n},$$

$$\frac{(\alpha + 1)(\alpha + 2)}{(\alpha + \gamma + 2)(\alpha + \gamma + 3)} = \hat{\mu}_2 = \frac{\sum_{i=1}^{n} x_i^2}{n}$$

The general solution is

$$\hat{\alpha} = \frac{2\hat{\mu}_1^2 - \hat{\mu}_2(1 + \hat{\mu}_1)}{\hat{\mu}_2 - \hat{\mu}_1^2} \qquad (5)$$

$$\hat{\gamma} = \frac{\hat{\mu}_1(1 + \hat{\mu}_2) - 2\hat{\mu}_2}{\hat{\mu}_2 - \hat{\mu}_1^2} \qquad (6)$$

In our present case, the data shown above now give

$$\hat{\mu}_1 = \frac{131.70}{200} = 0.6585,$$

$$\hat{\mu}_2 = \frac{92.9000}{200} = 0.4645$$

Substituting in (5) and (6), we have

$$\hat{\alpha} = 3.137251, \qquad \hat{\gamma} = 1.145590.$$

$\therefore$ The Beta distribution has estimated parameters:

$$\hat{\alpha} + 1 = 4.137251 \text{ and } \hat{\gamma} + 1 = 2.145590.$$

Thus,

$$f(x) = \frac{1}{B(4.137251, 2.145590)} x^{3.137251} (1 - x)^{1.145590}$$

Using a computer or the tables to give the fitted proportions for the various intervals, the goodness of fit is shown as follows:

y-interval	x-interval	observed frequency	fitted frequency	(0-E)²/E
19.75-20.25	0-0.1	2	0.08 } 1.28	0.405
20.25-20.75	0.1-0.2	0	1.20 }	
20.75-21.25	0.2-0.3	10	4.90	5.308
21.25-21.75	0.3-0.4	5	11.7	3.837
21.75-22.25	0.4-0.5	15	21.1	1.764
22.25-22.75	0.5-0.6	30	31.3	0.054
22.75-23.25	0.6-0.7	40	39.6	0.004
23.25-23.75	0.7-0.8	60	42.0	7.714
23.75-24.25	0.8-0.9	30	34.4	0.563
24.25-24.75	0.9-1.0	8	13.7	2.372
	χ^2(6 d.f.) ⟶			22.021

Prob. $(\chi^2 > 22.021) = 0.001$

Conclusion: Although the Fit of the Data using $B(4.137251, 2.145590)$ is not a particularly good one, the method of fitting has been explained, which was the *purpose* of doing the exercise. Also, the last column above is a guide to pinpointing the places where the fit fails: the intervals centered at 21.0 and 23.5.

IQC

PERSONAL NOTES

. . . AKRON-CANTON—At the Hoover Company, **R. M. Archer**—formerly Production Manager—was promoted to Ass't. Works Manager, and **D. W. Turske**—formerly a Production Foreman and a Quality Control Engineer—was made a Training Specialist in the Industrial Relations Department. **C. B. Aldenderfer** formerly a Quality Engineer, and **A. J. Fister,** formerly a Tire Design Engineer, were both made Quality Assurance Engineers in the Wheel and Brake Division at the Goodyear Aerospace Corp.

. . . ALBUQUERQUE—**Myron Calkins,** AEC, has received the Commission's citation and cash award for Special Act of Service in recognition of outstanding performance while Chairman of a Study Group investigating existing national Quality Control/Quality Assurance programs for Isotope Heat Sources. The two ASQC scholarships awarded this year went to **Ramesh Ganeriwal,** a University of New Mexico (Albuquerque) student from Gwalior, India, and to **Daryl Jones,** an industrial engineering student at New Mexico State University (Las Cruces).

. . . BLUE RIDGE—**Fred H. Sieg** has joined the Boone Division of IRC, Inc. as Senior Quality Control Engineer. He was formerly Works Engineering Manager at Universal Electric Company.

. . . CLEVELAND—**Terrence L. Carraher** has been named Manager of Quality Control for the Glastic Corporation.

. . . DAYTON—The Section recently cosponsored an all day seminar on "The Weibull Distribution and Its Practical Applications" with the Engineers' Club of Dayton.

. . . HARRISBURG—**J. D. Wiedensaul** has been promoted to Quality Mgr. of Military Products at Hamilton Watch Co., Lancaster. **Lester Toon** was promoted to Production Mgr. of Hamilton Watch Co., Military Products Division. The following Section members recently received Quality Engineering certificates: **Clifford S. Charles, Marriott B. Fasnacht, Kenneth A. Gainer, Nicholas Gekas, William D. Hardesty, Jr., Paul R. Kulp, Richard C. Patterson, Bert C. Quasnosky, Paul A. Rohlf, Hermann F. Singer, Juergen Walbrecht,** and **Robert B. Whitney.**

The following Society members are recently deceased:

Cincinnati Section: Joseph R. Yerina, 35, member of ASQC Cincinnati Section, died April 26. He was Manager-Quality Control Unit, Controls and Accessories at the General Electric Company's Jet Engine Plant, Evendale, Ohio. Mr. Yerina is survived by his wife Sally, and five children, Linda, Mary Kay, David, John and James.

Dayton Section: Louis R. Zimov, 50, Senior member of ASQC, died May 15 at a Dayton, Ohio hospital. He was corporate vice president of Avco Corp. in charge of the Ordnance Division at Richmond, Ind. Mr. Zimov, a charter member of ASQC, also belonged to the IEEE, the Engineering Society of Cincinnati, the American Ordnance Assn. and the Assn. of the U. S. Army. He is survived by his wife, Jeannette, two daughters, Mrs. Stewart L. Richards and Miss Alta Zimov, both of Cincinnati, and other relatives.

. . . HUNTSVILLE—**Alvin Steinberg** was given an ASQC tie clip in appreciation of his service by this Section as Chairman this year. **R. W. Holleman** is now Manager of Quality and Reliability at Sperry. **James H. Brown** transferred to the Boeing Atlantic Test Center at Cape Kennedy. **John Kanon** addressed the Section on "Environmental Factor in Reliability Predictions" at a recent meeting. **Charles F. Owens** is President of the Thiokol Management Club.

. . . ORANGE EMPIRE—**Joe Stein** has joined Hughes Aircraft Co., Ground Systems Division as Senior Research Engineer. **Ken Admire** was promoted to Chief, Inspection Dept., and **R. L. Larkin** to Unit Supervisor, Quality Evaluation both at Aeronutronics Division, Philco Ford. **John Voss** joined IBM, San Jose, as Quality Engineer. The following changes in Navigation Systems positions have taken place: **C. L. Smith,** appointed Senior Project Administrator of non-Minuteman programs; **G. Dolphin,** appointed Supervisor of Assembly and Test Production Inspection; **V. P. Lariviere,** promoted to Supervisor of Quality Assurance Cost Analysis; **R. J. Scharbach,** promoted to Supervisor, Product Inspection; **T. E. Kepley,** assigned as Program Administrator for Mark II programs; **J. Sharp,** appointed Program Administrator for Minuteman II programs; **P. Smart,** appointed Supervisor, Process Quality Engineering; **D. Currie,** appointed Supervisor, Test Quality Engineering.

. . . SAN BERNARDINO—**Jordan Paul Onorato,** Aerojet-General, Azusa, is now Mgr. of QA and Mgt. Controls. **Roy Wood,** Aerojet Downey Reliability Mgr., spoke before Prof. Robert Quaney's Reliability Engineering class at Cal PolyTech, Pomona on "Design Reliability Through Failure mode and Effect Analysis." **Pete P. Kuemmler,** Aerojet, received a QE Certificate. **Ray Allen** has been assigned to the QC Directors Staff of Bourns, Riverside, Trimpot Division. Fifty were in attendance at the first Las Vegas Subsection meeting, and 80 at the second. There are 42 members. There were several advancements at General Dynamics/Pomona: **Philip K. Bassham,** from SQC Function Leader, to Project Coordinator; **Thomas L. Keith** to QA Function Leader; **Mike Enfield** to Ass't. Inspection Supervisor; **B. G. Yahne** to Inspection Supervisor of the second and third shifts. **Bob Seidel** joined as a reliability engineer in the SQC group. **Dale R. Conner**

PERSONAL NOTES

is a candidate for service on the national ASQC Education and Training Committee. **Don Jones** left this area to join the Quality Department of Xerox.

. . . SAN FRANCISCO—**Bob Channing,** formerly QC Engineer with Dalmo Victor, San Carlos, has recently joined Kemetrics, Sunnyvale, as QA Manager. An article by **William M. Benz,** Supervisor of QA at Fireman's Fund American Insurance Companies, titled "Quality Control in the Office," appeared in the May issue of IQC. The San Francisco Section has been accepted as a full-fledged member of San Francisco Bay Area Engineering Council and is participating in Engineering Career Counseling efforts for high schools in the Bay Area.

. . . STATE UNIVERSITY OF IOWA—**R. E. Cannon,** Eagle Signal, recently was awarded the ASQC Quality Engineer certificate. **E. J. Carney,** Assistant Professor at Iowa State University, earned a PhD in Statistics there. **Dr. L. A. Knowler** was appointed to fill an unexpired one-year term on the Board of Directors. The Quality Control course at Iowa State University conducted in conjunction with the Des Moines Subsection recently had a registration of 22 persons.

Award Made to L. S. Eichelberger

Leslie S. Eichelberger (above, left), a community instructor for the University of Wisconsin Extension's Department of Commerce in Milwaukee, received the first University Extension certificate of teaching excellence and achievement recognizing his 18 years of teaching service. Presenting the award is George B. Strother, Assistant Chancellor, University Extension. Mr. Eichelberger is a Quality Control Consultant.

CALL FOR PAPERS

22nd Annual Technical Conference & Exhibit

American Society for Quality Control

What new technique will the quality engineer and quality manager need in 1968-69? Right now we don't know but they might need one developed by you. If you have devised a new quality assurance method or concept, or a novel application for an established technique, publicize it at the 22nd Annual ASQC Technical Conference in Philadelphia, May 6, 7, 8, 1968. Provided it has not been previously published, your paper may be selected by one of the Divisions or Technical Committees listed below for inclusion in its program:

Administrative Applications Division
Aircraft and Missile Division
Automotive Division
Chemical Division
Electronics Division
Food and Allied Industries Division
Textile and Needle Trades Division

Configuration Assurance Committee
Cost Effectiveness Committee
Drug and Cosmetics Committee
Inspection Engineering & Management Committee
Metals Technical Committee
Metrology Technical Committee
Non-Destructive Testing Technical Committee
Process Control Engineering Committee
Quality Cost Committee
Quality Information Equipment Committee
Quality Motivation Committee
Reliability Engineering Technical Committee
Research Programs Technical Committee
Statistics Technical Committee
Systems Engineering Committee
Vendor-Vendee Technical Committee

This is how you can submit your paper for consideration by the 22nd Annual Technical Conference Program Committee:

1. Request the speaker's data sheet, available from ASQC, 161 West Wisconsin Avenue, Milwaukee, Wisconsin 53203.
2. Send speaker's data sheet and an abstract (300-500 words) of your paper not later than September 1, 1967.
3. Indicate on the speaker's data sheet the Division or Technical Committee to which you would like your paper submitted for review. In the event you select more than one committee, please indicate your order of preference. Authors will be notified of acceptance or rejection of their papers by December 1, 1967.

Send abstracts and speaker's data sheets to:

A. S. Wall, Chairman
Technical Conference Program Committee
American Society for Quality Control
161 W. Wisconsin Ave.
Milwaukee, Wisconsin 53203

R&M Course Offered By Crowell Collier Institute

A six-day intensive course in "Applications of Mathematics and Statistics to Reliability and Maintainability Problems" will be given November 27-December 2 at the Sheraton West, Los Angeles, California, by Crowell Collier Institute of Continuing Education.

The special program is designed for professional engineers, mathematicians and scientists.

Limited to professionals working in areas of reliability, quality control, operations research and statistics, the course will be conducted by two of the country's leading specialists in the field—Dr. Benjamin Epstein, statistical consultant, and Dr. Frank Proschan of the Mathematics Research Laboratory, Boeing Scientific Research Laboratories, Seattle, Wash.

Professor Richard E. Barlow of the University of California at Berkeley, will be guest lecturer.

The $275 fee for the course includes books, workbooks and other relevant learning aids. Further information on the program can be obtained from: Dr. Aaron Feinsot, Director, Crowell Collier Institute of Continuing Education, 866 Third Ave., New York, N.Y. 10022. Telephone (212) 935-3250.

QC Foreman Receives Honors

Anthony J. Kovac, foreman of quality control in Coleman's Wichita Heating and Air Conditioning plant, was recently honored twice for his knowledge and outstanding capabilities in the field of quality control.

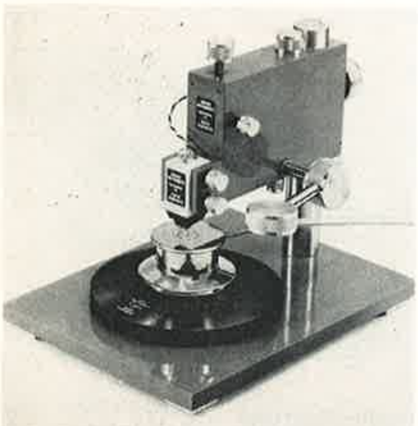
First, the American Society for Quality Control certified Mr. Kovac as a Quality Engineer, the five hundred forty second person in the United States to be so certified.

The second award was in the form of a framed diploma from the Coleman College of Acquired Knowledge and confers upon Mr. Kovac (shown below, holding the award) the degree of Practical Professional in Quality Control Engineering.

This certificate was presented in recognition of his outstanding work in developing and improving the quality control program in the Heating and Air Conditioning plant.

NEW PRODUCTS

Thomos W. Mitchell, *Editor*



New Semiconductor Test-Probe Stand

Several utility features for semiconductor resistivity and other electrical probe tests are included in this new test-probe stand.

The new unit will hold any standard probe and features true vertical travel of the probe arm to prevent errors and the time-consuming need for re-positioning.

A Universal Traversing Stage for device measurement featuring a vacuum chuck and spring-loaded design to permit large scale manual adjustment in all directions and a variety of measurement probes are also available.

For further information write: Alessi Associates, 8710 Pershing Drive, Playa Del Rey, California.

CIRCLE NO. 101 ON QIE CARD

* * *

Thread Analyzer for Gaging to MIL-S-8879A

MIL-S-8879A imposes new requirements for the inspection of controlled radius root screw threads with increased minor diameter. The Johnson Gage Company states that their Model 900 Thread Analyzer accurately checks the thread elements and characteristics specified in MIL-S-8879A. These include maximum and minimum-material-limit, minor diameter, cylindricity, lead deviation, flank-angle deviation and drunkenness.

Descriptive literature may be obtained by writing: The Johnson Gage Company, P. O. Box 81, Bloomfield, Connecticut 06002.

CIRCLE NO. 102 ON QIE CARD

* * *

To Avoid Errors "Write It"

Accurate analysis reporting from laboratory to processing areas and defect reporting from processing inspection points to assembly areas permits speedy correction of defective production and fixes responsibility with a written record at each location.

For further information write to: Victor Comptometer Corporation, Business Machines Group, 3900 N. Rockwell Street, Chicago, Illinois 60618.

CIRCLE NO. 103 ON QIE CARD

* * *

A "People Tester," New Psycho-Motor Tester

A new self-contained dynamic man-machine tester which incorporates highly advanced psycho-engineering concepts, has been introduced by Systems Technology, Inc.

Designated as the MK IV Critical Task Tester, the device consists of a computer, CRT display assembly and a control stick.

Task selection of increasing difficulty is computer programmed to evaluate the test subject's ability to track a dynamically displayed line on the CRT.

Details may be obtained by writing: Mr. Joseph Durand — Product Mgr., Systems Technology, Inc., 13766 South Hawthorne Blvd., Hawthorne, California.

CIRCLE NO. 104 ON QIE CARD

* * *

Leak Detector for Fuels and Oils

A wrap-on leak detector for fuels, hydraulic fluids, oils and organic solvents is now available.

Known as JET/TEC, it is supplied in strips 2½ inches wide and 4½ feet long. It can be cut to size and crimp-fitted with hand pressure.

Any leak becomes apparent at the exact point of leakage by the appearance of a bright, irreversible red coloring.

Available from: American Gas & Chemicals, Inc., 511 East 72nd Street, New York, N. Y. 10021.

CIRCLE NO. 105 ON QIE CARD

* * *

American Society for Quality Control Education and Training Institute

sponsors the following courses in 1967:

Co-sponsored with the Electronics Division

RELIABILITY ENGINEERING

September 18-22 — Sheraton Hotel — Philadelphia, Pa.

in cooperation with Philadelphia Section

Registration fee is $200 for ASQC members; $225 for non-members.

QUALITY CONTROL ENGINEERING

September 25-29 — Sheraton Hotel — Louisville, Ky.

in cooperation with the Midwest Conference and the Louisville Section

Registration fee is $175 for ASQC members; $200 for non-members.

PRINCIPLES OF MAINTAINABILITY ENGINEERING

October 23-25 — Los Angeles, Calif.

in cooperation with the Los Angeles Section

Registration fee is $150 for ASQC members; $175 for non-members

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MAINTAINABILITY ENGINEERING MANAGEMENT

October 26-27 — Los Angeles, Calif.

in cooperation with the Los Angeles Section

Registration fee is $100 for ASQC members; $125 for non-members.

PRODUCT QUALITY AUDITING

November 10-11 — Ramada Inn — Milwaukee, Wis.

in cooperation with the Milwaukee Section

Registration fee is $100 for ASQC members; $125 for nonmembers.

American Society for Quality Control
161 W. Wisconsin Ave.
Milwaukee, Wis. 53203

Gentlemen:

Please register me for the ____________ Course in ________ on ________, 1967. Enclosed is my check for $______

Name ____________

Position ____________

Company ____________

Street ____________

City ________ State ________ Zip ________

Member ☐ Non-Member ☐

NEW PRODUCTS

New Plastic Vernier Caliper

The PAV Swiss Plastic Caliper is lightweight, flexible and less sensitive to temperature. This new precision caliper could be a boon to shop inspectors.

For an illustrated brochure write: A. O. K. Tool Corporation, 82-21 Sutter Avenue, Ozone Park, New York, N. Y. 11417.

CIRCLE NO. 106 ON QIE CARD

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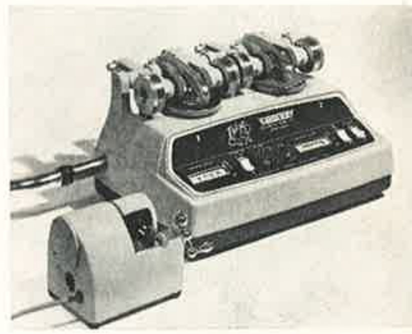

Abrasion resistance

A 12-page catalog covering a new Dual Abraser and accessories that performs abrasion resistance tests on two samples simultaneously is available from: Taber Instrument Corp., 455 Braant Street, North Tonawanda, N. Y.

Ask for Bulletin 66505.

CIRCLE NO. 107 ON QIE CARD

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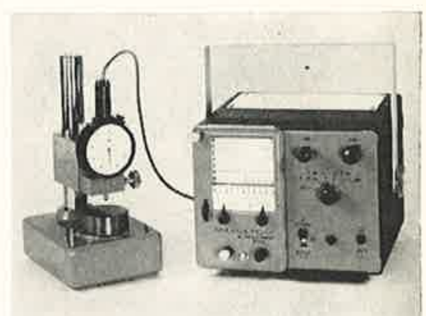

New Electromechanical Recording Gage "Dial Indicator With a Memory"

A new compact, portable electromechanical gage simultaneously provides visual readout and permanent recording of comparative measurements. The recording feature makes it extremely useful for applications where a continuous record of measurements is required.

The mechanical dial comparator uses a transducer to convert the dial reading to a permanent chart record.

Four range selections are provided on the recorder with incremental divisons of 0.00005", 0.0001", 0.0002" and 0.005" on the chart.

NEW PRODUCTS

Over or under tolerance conditions can be indicated by warning lights or audible signal.

Ten chart speeds and selective or automatic recording are available.

Pressure-sensitive chart paper, eliminates the need for ink.

Write for additional information: Mr. Richard F. Charles, Hamilton Watch Company, Lancaster, Penna. 17604.

CIRCLE NO. 108 ON QIE CARD

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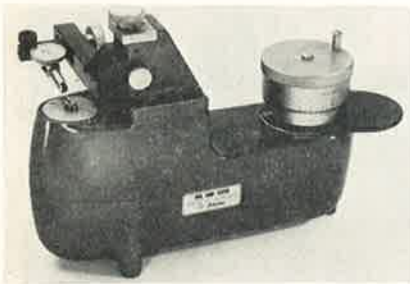

Spur and Helical Gear Measurement

Base pitch measurements for spur and helical gears can be made of gears still mounted on the production machine.

The MAHR Base Pitch Measuring Instrument features tungsten carbide measuring tips and reads to 50 micro inches. The measuring range of the instrument covers 36 to 1½ D.P.

Illustrated folder with complete price information may be obtained from: Mahr Gage Company, 274 Lafayette Street, New York, N.Y. 10012.

CIRCLE NO. 109 ON QIE CARD

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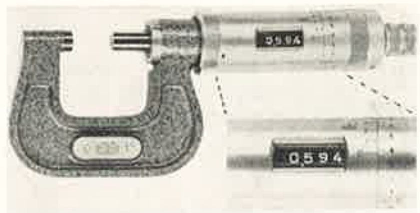

New Digital Read-Out Micrometer

These micrometers feature direct digital read-out to one-thousandth of an inch with a parallax free vernier providing readout to one-ten thousandth of an inch.

Ranges from 0-1" through 11" to 12" are available. All micrometers feature sensitive ratchet operation, non-rotating measuring spindles and carbide tips.

For further information write: Dyer Company, Oberlin, Ohio 44074.

CIRCLE NO. 110 ON QIE CARD

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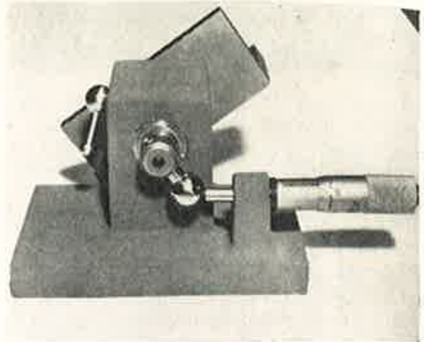

Angle Measuring and Checking Instrument

Fast and accurate setting of a known angle, or determination of an unknown angle is possible with this micrometer actuated instrument.

The simplicity of two moving parts plus spring loaded design is said to eliminate operator "feel." Repeatability to 20 seconds of arc is claimed by the manufacturer.

Details may be obtained by writing: Mic-Sine Corp., 27260 Southfield Road, Lathrup Village, Michigan 48075.

CIRCLE NO. 111 ON QIE CARD

* * *

Gage Calibration

A new Calibration Tester for checking the continuing accuracy of more precisely graduated dial gages, dial test indicators and elec-


NEW PRODUCTS

tronic inspection gages having divisions of 0.0005" and smaller has been announced by MTI Corp.

The larger micrometer head of the unit reads directly to 0.00001" and the ultra precise mechanism results in a very high degree of accuracy in the checking or recalibrating of all types of gages.

For further information write: MTI Corporation, 11 East 26th Street, New York, N.Y. 10010.

CIRCLE NO. 112 ON QIE CARD

* * *

Remote Temperature Measurements

A new infrared microscope which makes fast, accurate, non-contact temperature measurements of extremely small targets at distances up to 13 feet has been developed by Barnes Engineering Company.

A wide range of matched long-focus objective lenses make it possible to select target areas down to 0.0007-inch and working distances up to 13 feet.

Temperature readout is from 15° C to 165° C. Resolution is 0.5° C. Response time is 10 milliseconds. Spectral range is 2 to 20 microns.

For further information write: Barnes Engineering Company, 30 Commerce Road, Stamford, Connecticut 06904.

CIRCLE NO. 113 ON QIE CARD

* * *

Infrared Calibration Source

A precise infrared source calibrated in degrees F. and degrees C., is now available for the calibration of pyrometers, radiometers and other infrared instruments.

It features a direct-reading temperature setting dial and an SCR controller. The cavity remains stable to within 0.2° of the setting temperature and accuracy is as high as 0.5° C or 0.3 percent.

For further information write: William O. Hamlin, Huggins Laboratories, 999 E. Arques Avenue, Sunnyvale, California 94086.

CIRCLE NO. 114 ON QIE CARD

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NEW LITERATURE

ISA

The Instrument Society of America (ISA) announced availability of its 1967 Publications Catalog, and the 21st Annual ISA Conference Proceedings and Preprints Catalog.

Both catalogs are valuable reference sources and may be obtained at no cost by writing to: Instrument Society of America, Publications Department, 530 William Penn Place, Pittsburgh, Pa. 15219 U.S.A.

CIRCLE NO. 115 ON QIE CARD

* * *

Radiography

A comprehensive eight-page bulletin on the use and advantages of "on-stream" radiography inspection.

Write on company letterhead to: Technical Editor, Radiography Inspection Inc., 6 Woodbridge Ave., Woodbridge, N.J. 07095.

CIRCLE NO. 116 ON QIE CARD

* * *

NEW PRODUCTS

Ultrasonic Resonant Frequency Measurement Testing

A four-page, data sheet describing E-Systems, a recently developed ultrasonic, non-destructive resonant frequency measurement testing system of materials, is offered by James Electronics, Inc.

Applications include measurement of concrete thickness, wood product condition determination, internal indication of metal parts and castings and ceramic and plastic composition.

Request data sheet F-5075 from Marketing Department, James Electronics, Inc., 4050 North Rockwell Street, Chicago, Illinois 60618.

CIRCLE NO. 121 ON QIE CARD

* * *

Electronic Gaging Systems

The 28-page brochure on electronic gaging systems for high speed, automatic parts feeding, gaging and segregating contains photographs and descriptions of the many systems available. Air gaging and special purpose units are included.

Write to: Radio Corporation of America, Industrial and Automation Products, Dept. 102, 41225 Plymouth Rd., Plymouth, Michigan 48170.

CIRCLE NO. 122 ON QIE CARD

* * *

Electronic Dimensional Gaging

A 32-page catalog of dimensional gaging equipment includes height-gage-type and rotary indicators, high-speed production gage, micro-comparators and differential gaging systems. All equipment is illustrated and complete specifications are given on each item, plus features of design and operation.

To obtain a copy write Micrometrical Division of the Bendix Corporation, 3621 S. State Road, Ann Arbor, Michigan 48106.

CIRCLE NO. 123 ON QIE CARD

* * *

Air Bearing Table Brochure

An eight-page, illustrated brochure describing Air Bearing Tables designed to permit X and Y translation, with straightness of travel of ±0.1 micron over the entire range for micro-positioning, precision measuring, and other gaging applications is available from Link Group, General Precision, Inc., Advertising and Sales Promotion Department, Binghamton, New York 13902.

CIRCLE NO. 124 ON QIE CARD

* * *

An Introduction of pH

The 12-page pamphlet gives a quick, not-too-technical picture of what pH is and how it may be used to lower production costs, improve product quality, and reduce corrosion and maintenance.

Copies of Bulletin 92-I are available from Technical Information Section. Scientific and Process Instruments Division, Beckman Instruments. Inc., 2500 Harbor Blvd., Fullerton. Calif. 92634.

CIRCLE NO. 125 NO QIE CARD

* * *

Rochester Section Makes Donations

The Rochester Section of the American Society for Quality Control donated a total of $1,850 to various programs and projects in the community for the advancement of Quality Control, for the 1966-67 season. These included: Rochester Institute of Technology library for the new graduate course in Applied Mathematics and Statistics, $1,000; Scholarships, $500 (University of Rochester Institute of Technology); University of Rochester, $100; Rochester Council of Scientific Societies, $100; and Rochester Public Library, $150.

Classified Advertising

Positions Wanted: ASQC Members $1.50, non-members $4.00 per line. Minimum Space Charge — 5 lines. Positions Available: $4.00 per line. Minimum Space Charge — 5 lines. General advertising rates apply to all display sizes (1/8 page minimum space. Deadline is 22nd of second month preceding publication. Replies to box numbers and copy should be addressed to American Society for Quality Control, 161 W. Wisconsin Ave., Milwaukee, Wis. 53203.

POSITIONS AVAILABLE

STAFF QUALITY CONTROL

This is a challenging opportunity for an expanding Q.C. program at our Petersburg, Virginia, Branch. Applicant should have background in process capability studies, control chart techniques, tests of significance, and sufficient statistical knowledge to adequately analyze factory test and evaluation results. Position will report to Factory Manager and will involve overall responsibility for Q.C. Department of about 50 personnel.
Our employees are aware of this ad. Remuneration commensurate with experience.

Send resume to:
Mr. W. W. Townes, Jr.
BROWN & WILLIAMSON
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ASQC ANNUAL TECHNICAL CONFERENCES

May 6-8,	1968	Philadelphia
May 5-7,	1969	Los Angeles
May 4-6,	1970	New York

IQC

CLINICS, CONFERENCES, AND COURSES

AUGUST

. . . 7-11—Course in Management of Quality Control, by J. M. Juran, to be held at the Drake-Oakbrook, Chicago. Fee is $300. Contact: J. M. Juran, 866 United Nations Plaza, New York, N.Y. 10017.

. . . 7-11 — Basic Comprehensive Course in Ultrasonic Testing, offered by Krautkramer Ultrasonics Inc., to be held at Louisiana State University, Baton Rouge, La. Fee is $200 and includes a copy of the "Krautkramer Blue Book." Contact: Krautkramer Ultrasonics Inc., One Research Drive, Stratford, Conn. Tel. 203-335-2504.

. . . 7-17 — Quality Control by Statistical Methods course sponsored by the University of Michigan in co-operation with the Greater Detroit Section, ASQC. Presented at the University of Michigan. Fee is $225. Contact: Engineering Summer Conference, West Engineering Building, The University of Michigan, Ann Arbor, Michigan 48104 Tel: (313) 764-8490

. . . 7-18—Applied Stochastic Processes course presented at the University of California, Los Angeles. Fee is $300. Contact: R. E. Garrels, Physical Sciences Extension, Room 6532, Boelter Hall, University of California, Los Angeles, Calif. 90024.

. . . 14-18 — Basic Comprehensive Course in Ultrasonic Testing, offered by Krautkramer Ultrasonics Inc., to be held in Houston, Texas. Fee is $200 and includes a copy of the Krautkramer Blue Book." Contact: Krautkramer Ultrasonics Inc., One Research Drive, Stratford, Conn. Tel. 203-335-2504.

. . . 14-25 — Functional Analysis and Numerical Methods course sponsored by the School of Mathematics, Georgia Institute of Technology. To be held at the Georgia Institute of Technology. Fee is $300. Contact: Director, Department of Continuing Education, Georgia Institute of Technology, Atlanta, Georgia 30332. Tel: (404) 873-4211, Ext. 343.

SEPTEMBER

. . . 5-15—"Theory, Simulation, and Compufer Processing of Statistical Data" is a short course offered by UCLA. Fee is $300. Contact: University of California Extension, 405 Hilgard Ave., Los Angeles, Calif. 90024.

. . . 9—19th Annual All Day Conference on Quality Control sponsored by the Metropolitan Section, ASQC and the Rutgers University Statistics Center with support of the North Jersey Section, ASQC. To be held at the Rutgers University campus, New Brunswick, N.J. Contact: K. S. Stephens, Conference Chairman, Western Electric Co., P.O. Box 900, Princeton, N.J. 08540.

. . . 10-22—18th Annual Statistical Quality Control Institute, sponsored by the New England Sections, ASQC, and the University of Connecticut. Contact: Richard M. Story, University of Connecticut, Storrs, Conn.

. . . 11-14—Paper Physics Workshop on Microscopy, sponsored by TAPPI, to be held at the Pick Congress Hotel, Chicago. Contact: T. S. McConnell, TAPPI, 360 Lexington Ave., New York, N.Y. 10017.

. . . 14-15—Fall meeting of the Metals Technical Committee, ASQC. To be held in Montreal, Quebec, Canada. Contact: L. G. Ekholm, United States Steel Corp., 525 William Penn Place, Pittsburgh, Pa. 15230.

. . . 15-16—ASQC Western Regional Conference, to be held at the Hilton Hotel, San Francisco. Contact: L. L. Gooch, D/84-53, Lockheed Missiles & Space Co., Sunnyvale, Calif.

. . . 18-22—"Operations Analysis and Research" is a short course offered by UCLA. Fee is $225. Contact: University of California Extension, 405 Hilgard Ave., Los Angeles, Calif. 90024.

. . . 25-28 — CIRP International Conference on Manufacturing Technology, sponsored by ASTM in cooperation with the University of Michigan, to be held at the Rackham Building, Ann Arbor, Mich. Fee is $175 and includes luncheons, coffee breaks, banquet, and a bound volume of the prepared papers. Contact: CIRP Conference Registration, American Society of Tool and Manufacturing Engineers, 20501 Ford Road, Dearborn, Mich. 48128.

. . . 26-28—"Package Testing" is the theme of the 18th Testing Conference sponsored by TAPPI. To be held at the Pick Congress Hotel, Chicago. Contact: M. A. Burnston, TAPPI, 360 Lexington Ave., New York, N.Y. 10017.

. . . 28-29—4th Annual Joint Technical Conference, co-sponsored by the Orange Empire Section, ASQC, and AIAA, ASME, SAE, SAVE. To be held at the Disneyland Hotel, Anaheim, Calif. Contact: F. B. Johnson, 5232 Valencia Drive, Orange, Calif.

. . . 29-30 — 22nd Midwest Quality Control Conference, to be held at the Sheraton Hotel, Louisville, Ky. Contact: Charles I. Davis, Jr., Box 10081, Louisville, Ky. 40210.

OCTOBER

. . . 9-10 — Joint Engineering Conference, co-sponsored by ASQC, AIME, IEEE, AIIE, ASCE, AIAA, ISA, EIC, and ASME at the Jack Tar Hotel, San Francisco. Contact: Bernard B. Winer, General Conference Chairman, Westinghouse Electric Corp., East Pittsburgh, Pa. 15112.

. . . 9-13 — Course in Management of Quality Control, by J. M. Juran, to be held in Stockholm, Sweden. Contact: Svenska Kommitten for EOQC, Artillerigatan 34, Stockholm 0, Sweden.

. . . 16-19 — 26th National Conference, Society for Nondestructive Testing. To be held at Hotel Hollenden, Cleveland, Ohio. Contact: SNT, 914 Chicago Ave., Evanston, Ill. 60202.

. . . 16-19 — National Metal Exposition and Congress of the American Society for Metals, to be held at Cleveland's Convention Center. Contact: American Society for Metals, Metals Park, Ohio 44703.

. . . 18-20—21st Annual New England Quality Control Conference, to be held in Bridgeport, Conn., at the Stratfield Motor Inn. Contact: Alexander J. Vincze, 187 Berwick Ave., Fairfield, Conn. 06430.

. . . 22-27—9th Quality Control Management Institute, sponsored by the New England Sections, ASQC, and the University of Connecticut. Contact: Richard M. Story, University of Connecticut, Storrs, Conn.

. . . 25-27 — "Print Quality" conference sponsored by TAPPI at the Rochester Sheraton Hotel, Rochester, N.Y. Contact: M. A. Burnston, TAPPI, 360 Lexington Ave., New York, N.Y. 10017.

. . . 30-Nov. 3 — Course in Management of Quality Control, by J. M. Juran, to be held at the Ambassador Hotel, Los Angeles. Fee is $300. Contact: J. M. Juran, 866 United Nations Plaza, New York, N.Y. 10017.

NOVEMBER

. . . 1-3 — 32nd National Meeting Operations Research Society of America, to be held at the Sheraton-Chicago Hotel, Chicago. Contact: Operations Research Society of America, Mt. Royal and Guilford Aves., Baltimore, Md. 21202.

. . . 6-7 — First Technical Conference on Photopolymers, sponsored by the Mid-Hudson Section, Society of Plastics Engineers, Inc. To be held at the Nevele Country Club, Ellenville, N.Y. Contact: Julius M. Schiller, General Chairman, IBM Corp., Route #52, Hopewell Junction, N.Y. 12533.

Nominations for Society Officers

The Nominating Committee of the American Society for Quality Control is soliciting from the members suggestions for eligible candidates for the offices of President, five Vice Presidents, Executive Secretary, and Treasurer of the Society. In addition they would appreciate your suggestions for nominees for three Directors-at-Large.

Qualifications for the above offices are as follows: All officers shall be Fellows or Senior Members of the Society in good standing. Directors-at-Large shall be Fellows or Senior Members in good standing and generally shall be past officers or past directors of the Society; one must be a past division officer.

Please address your suggestions for nominees to R. L. Fiaschetti, Chairman ASQC Nominating Committee, 13628 E. Camilla St., Whittier, Calif. 90601, to be in the Committee's hands by **September 15, 1967.**

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