REPORT:

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THE HISTORY AND EVOLUTION OF QUALITY IN AT&T

Introduction

The fundamental concepts and methods of quality control and quality assurance were developed in AT&T. For over 100 years researchers in AT&T Bell Laboratories, managers in AT&T, and engineering and operating personnel in Western Electric (now AT&T Technologies) have developed, applied, and improved methods for inspection, quality control, continuous quality improvement, and quality by design. These methods are used throughout the world today. In the past ten years, there has been a rewakening interest in the fundamental concepts of quality control and quality assurance and an intense effort to apply modern statistical methods to continuously improve quality and productivity. AT&T is still providing strong technical leadership in developing these new methods.

There are four overlapping and continuing phases in the history of quality methodology: the inspection phase, the quality control phase, the quality improvement phase, and the quality-by-design phase. The inspection phase started at the beginnings of artisanship and was practiced by the individual workers checking their own work, by the master inspecting the work of apprentices, and by buyers carefully inspecting items before purchasing. As products became more complex, special highly trained individuals or groups were often designated inspectors.

The quality control phase began in the 1920s through work done first in the Inspection Engineering department of Western Electric and then in the newly formed Bell Telephone Laboratories. This work is considered the start of modern quality control.

Many of the ideas in the third phase, continuous quality improvement, began in Japan under the leadership of two Americans, W. Edwards Deming and Joseph M. Juran—both with strong AT&T ties. As they worked with the leaders in Japanese industry to improve quality so that Japanese goods would be accepted in world trade, they developed many of the ideas used around the world today for continuous quality improvement.

The fourth phase, quality by design, has its roots in the 1940s and 50s, and is traceable to early work by Hugo Hamaker in the Netherlands and George Levenbach at Bell Laboratories. Many of the new ideas in this phase began to be applied in Japan in the 1950s. The last three decades have seen an increasing focus on pushing the quality efforts as far to the front of the product realization process as possible with AT&T researchers making significant contributions to reliability engineering, reliability prediction and estimation, and modern methods of experimental design (sometimes called robust product and process design or parameter design).

The history and evolution of quality concerns more than the development of methods. There has also been a continuous expansion in the use of the methods, both throughout the world and throughout each company. Inspection methods were originally used by a separate small inspection department at the end of the production or installation process. The development of quality control, especially of the Shewhart control chart, pushed quality control forward into the produc-

tion process and the charts were prepared and used by thousands of engineering and operating personnel in the Western Electric manufacturing plants. The concept of total quality control (TQC) originated by A. V. Feigenbaum in the 1950s in the General Electric Company and applied so successfully in Japan as TQC or CWQC (company-wide quality control) made clear the benefits of using quality methods throughout the company.

This idea of continuous quality improvement in the performance of every job function is characterized by the familiar slogan in AT&T, "Quality is Everybody's Business," and was stated very clearly recently by James Olson, the president of AT&T: "People want to be part of a quality company. And that means you get your people—every last worker—to realize that what they do is important. ... Getting the whole work force involved is crucial."[1]

The Building Blocks of a Quality System

These four phases have provided us with the four building blocks of our quality systems: inspection, process control, quality improvement, and quality by design.

Inspection. Inspection has been a fundamental technique used in quality control for thousands of years. Inspection still holds a valid and useful place in any quality system. Inspections (in the sense of measurement, test, observation, and so forth) provide the information that drives all other parts of our quality systems, and provide a still useful way of separating the bad from the good.

The development and application of new ideas in inspection started at the very beginning in AT&T. Even in 1882 it was obvious in AT&T that building a nationwide telephone network was going to demand quality and reliability previously unheard of for manufactured products. Even the very first telephone networks were going to be series systems of such complexity that exacting specifications and tolerances would have to be met by each piece for the system to function at all.

Harold Dodge speaks of the beginnings of the quality control research: "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."[2]

By 1922 the work of the Inspection department in the Western Electric Company was becoming well defined. The inspection of telephone products had been extended to factories of the Automatic Electric Company and the Stromberg-Carlson Company. Visiting inspectors made periodic inspections on material repaired at 27 distributing houses and at many non-Western Electric manufacturers' plants. These inspections began to be called routine check inspections, a term still in use.

The quality assurance function now clearly applied to all phases of quality: design, manufacture, and installation. The introduction of the panel switching machine, a very complex electromechanical device, led to the necessity for a great number of inspectors. The burden of making the product right was placed on the installers by the command "Do it right the first time."[3] Almost 60 years later, this has once again become a rallying cry for American industry in the battle for increased productivity and lowered costs.

In 1925, the members of the Inspection department were transferred to the newly formed Bell Telephone Laboratories. R. L.

Jones, the first director of this effort, explained that the duties of this department were to develop the theory of inspection, to develop methods for measuring and reporting quality, to set economic standards for quality, and to study the quality and performance of telephone plant in service as an aid to further and improved developments.[4]

This work led to the following developments:[5]

- The terminology of acceptance sampling (consumer's risk, producer's risk, probability of acceptance, OC curves, lot tolerance percent defective, average total inspection, double sampling, type A and type B risks)
- LTPD sampling tables
- AOQL sampling tables
- Multiple sampling
- The demerit rating system

In 1941 Dodge and Romig published *Single Sampling and Double Sampling Inspection Tables*, which provided plans based on fixed consumer risk (LTPD protection) and plans for rectification (AOQL protection) which guaranteed stated protection after 100 percent inspection of rejected lots. These plans[6] are still in use throughout the world. Other work by Dodge included sampling inspection plans for continuous production,[7,8] chain inspection plans,[9] and skip-lot sampling plans.[10] Many of these plans are still in use in AT&T and throughout the world. An extension of Dodge's work on skip-lot sampling by B. S. Liebesman and B. Saperstein (then with Bell Laboratories) is the basis for a new international standard.[11]

This growing effort in quality control and assurance was in turn supported by another group of brilliant young engineers in the Western Electric plants who worked closely with Dodge and Walter A. Shewhart. One of the most prominent of these was Juran in the Hawthorne Plant. Although Juran spent 17 years with Western Electric, he is best known for his work after World War II as an international consultant and received the highest Japanese award given to a foreigner for his work in Japan in establishing a modern quality control system.

Quality Control. In early 1924 Shewhart gave his boss, George Edwards, a short note and attached diagram that would change forever the practice of quality control. Edwards, who later became director of the Bell Laboratories Quality Assurance department and the first president of the American Society for Quality Control, stated in a dinner address: "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."[12]

Where inspection had focused much of its efforts on finding and removing bad products or lots of products before shipment to the customer, Shewhart saw how statistical techniques could be used to increase the amount of good product being manufactured. His 1925 paper in the *Journal of the American Statistical Association* introduced the control chart to the world.[13] In 1931 he published his classic text, *Economic Control of Quality of Manufactured Product*.[14] Within 25 years the control chart was a basic manufacturing tool used around the world.

From the very beginning Shewhart had a wide view of quality control. Deming states: "Quality control meant to him use of statistical

Case 18013

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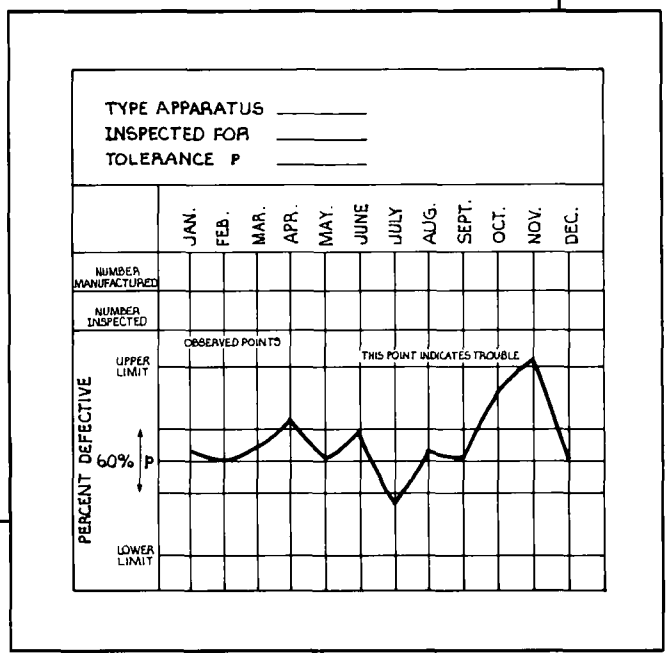
MR. R. L. JONES:-

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.



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."[15]

One of the more remarkable achievements in AT&T was the development of the "check inspection system" or the quality assurance audit. As practiced in AT&T, the quality assurance audit is a combination of ideas from quality inspection and statistical quality control in which small samples (audit inspections) are used to check the "adequacy of prior controls." Instead of using inspection to separate good and bad items or lots, small samples are tested by independent quality assurance auditors and decisions are made as to whether the quality system is working as intended.

The use of audit results to check the adequacy of prior controls enables manufacturing and engineering personnel to efficiently concentrate improvement efforts on production processes that are "out of control." The crowning achievement of this work was the creation of the quality measurement plan in the late 1970s by Bruce Hoadley and others.[16-18] The quality measurement plan uses sophisticated statistical methods for combining results over time to increase the accuracy of the estimates of the true quality and to improve the decisions made concerning where to concentrate quality improvement efforts.

In AT&T, quality assurance system summary reports are published every six weeks. The quality estimates are weighted averages of the six-week estimates for the previous nine months. The weights are functions of the sampling variability and the process variability.

Although a few leading U. S. companies are beginning to use the quality measurement plan, it is not yet widely used outside of AT&T. To use the quality measurement plan, a company must have a well defined system for setting quality standards or objectives; well understood and documented inspection practices, engineering requirements, and associated severity of deviations; and high-speed computing facilities, well-designed data bases, and good software. The

company's management must also be willing to understand that quality involves more complex concepts than percent defective.

Quality Improvement. The third building block is continuous quality improvement. This phase began in Japan but was inspired by two Americans with AT&T ties, Deming and Juran. Many people recognized after World War II that for Japan to quickly rebuild and to become a major trading nation an intense program of continuous quality improvement was needed. At the time Japanese products were far from competitive in quality and reliability and had to be sold only on the basis of very low prices. While working closely with top executives in Japan, Deming and Juran both realized that simple statistical quality control methods, widely applied throughout the company, could play a major part in making Japanese products more competitive.

Juran's ideas were put forth very well in 1964 in his now classic text, *Managerial Breakthrough*, in which he not only discusses many of the basic methods for continuous quality improvement but gives detailed instructions on how to manage quality improvement programs.[19] Deming has stressed in years of lectures and papers the importance of feedback and continually finding and eliminating the causes of failures. His recent text, *Quality, Productivity and Competitive Position*, beautifully summarizes many of these ideas.[20]

Another book that has had amazing impact in making these ideas known to people all over the world is Kaoru Ishikawa's *Guide to Quality Control*, first printed in 1974 and now in its nineteenth printing.[21] Ishikawa describes several basic statistical techniques that everyone in a company should know and frequently use to control and improve quality. These methods and others now form the basic techniques used in quality improvement. For example, H. M. Wadsworth, K. S. Stephens, ad A. B. Godfrey devote an entire section of their book to methods for quality improvement and an entire chapter just to graphical methods of improving quality with many examples from AT&T studies.[22]

Quality by Design. By the 1960s much work was being done in the reliability area.[23-25] The basic concepts of reliability modeling and prediction were described by R. E. Barlow and F. Proschan.[26,27] In the 1970s new work was being done on the statistical analysis of reliability (see for example Reference 28). In AT&T we have begun to combine a solid understanding of life testing, accelerated life testing, and field tracking with new work on reliability prediction. In the past few years we have developed new methods for predicting reliability for systems with components with nonconstant failure rates, for repairable systems, and for various maintenance strategies. These methods have been incorporated into easy-to-use software systems to hide their complexity and make them widely available to system designers. This software is being integrated with similar software that helps designers and test engineers estimate component failure rates from life tests, accelerated life tests and field performance studies.

Designed experiments to improve yield were used over 40 years ago in Bell Laboratories, but recent successes in Japan have reemphasized the power of these methods. As early as the 1950s some companies in Japan were beginning to realize there was another part of the quality system, the idea of making a product's design "robust" to the normal variations in materials, components, manufacturing, and

users' environments. Small changes in the product or process design could have a major impact on the manufacturing yield or the life of the product. Although in Bell Laboratories we first learned of these particular methods when Genichi Taguchi visited in 1962, it was not until his second visit in 1980 that we began to apply some of these methods to improve the yield of our most sophisticated manufacturing processes.

The basic ideas have been described by Taguchi, Y. Wu, and Madhav Phadke.[29-33] The first application to integrated circuit manufacture in AT&T was described in the *Bell System Technical Journal* in 1983.[34]

The basic ideas are fairly simple. In any manufacturing process there are many variables that must be controlled (called control factors) and others that can not be controlled (called noise factors). These noise factors may be either impossible to control or very expensive to control. In most manufacturing processes the level or mean of the output and the variability of the output are important. Some factors may be highly correlated with the mean and others with the variability. The task is to identify which factors are important, what the best settings for these factors are, and which factors affect the mean and which the variability. If we can determine which factors do not affect the variability but do affect the mean, we can use these factors to "adjust" the output after we minimize the variability. This leads to greatly improved designed experiments which are used to determine these critical factors and the best settings of the factors. The basic ideas of these experiments are explained in Reference 35.

The Widespread Application of Quality Methods

As with many other great discoveries, much of Walter Shewhart's early work was largely ignored in his own country. W. A. Golomski quotes General Leslie Simon: "During the late 1920s a number of important papers by Shewhart 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."[12]

Shewhart's visit to the University of London was at the invitation of E. S. Pearson who writes, "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?' 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."[36]

Pearson made much effort to bring these lectures to the attention of representatives of leading industrial firms. The result of these lectures was an awakening in Great Britain on the advantageous use of statistical methods in manufacturing processes. A committee led by Pearson in 1935 published British Standard No. 600, *Application of Statistical Methods to Industrial Standardization and Quality Control.*

Another driving force in the spread of quality methodology was Shewhart's book. R. E. Wareham states, "The publication of Shew-

hart's classic text, *Economic Control of Quality of Manufactured Product*, provided the basic literature needed for college training in scientific quality control."[37]

At the beginning of American involvement in World War II, there was an immediate need for large quantities of war materiel—everything from guns to radar equipment to shoes. American industry rapidly expanded at the same time that its armed forces were expanding. The quality of goods being manufactured suffered from a lack of skilled personnel. Many training courses were set up by individual companies and by government organizations. Several courses focused on the use of statistical quality control in industry. The War Department engaged Bell Telephone Laboratories people to go out to manufacturing plants and teach people simple methods of quality control.[38] Harold Dodge of Bell Laboratories led a team which produced the basic control chart standards still widely used throughout the world.

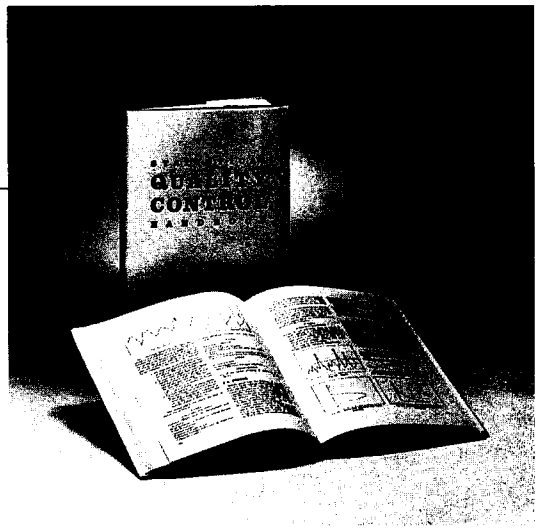
One of the best known people working with the War Department was Deming. He had worked in the Western Electric Hawthorne plant in the 1920s as a summer student, but it was not until he persuaded Shewhart to give a series of lectures in 1939 at the graduate school of the Department of Agriculture that Deming became aware of the possibilities of quality control. He published his notes of these lectures with Shewhart as a book.[39] Deming, who later became one of the leading international quality consultants (the top Japanese individual and company quality awards are called the Deming awards), became a close friend of Shewhart.

Another development during this period was the establishment of two groups of statisticians and engineers to do research in the use of statistics in quality control. One of these was located at the Aberdeen Proving Ground, Maryland. This group was formed by Shewhart and included several Bell Labs people. Their work resulted in three standards for the statistical control of quality.

The Army's Office of the Chief of Ordnance in 1942 asked Edwards, Dodge, and G. R. Gause, with the assistance of H. G. Romig and M. N. Torrey, to develop "Standard Inspection Procedures." This work later evolved into the Armed Service Forces tables and was later combined with the work for the Navy of the Statistical Research Group of Columbia University to form MIL-STD-105A in 1950. This military standard (now MIL-STD-105D) and its many national and international duplicates is the most widely used quality standard in the world today.

An indication of the importance of the quality control effort was the remark made by F. A. Lindemann (Lord Cherwell), Winston Churchill's science advisor during the war years, to M. B. Kelly, then president of Bell Laboratories, in a discussion after the war about Bell Laboratories' contributions to the British war effort. Lindemann asserted that by far the most important contribution was the development of quality control.

After the War. In 1946 the various local quality control groups throughout the United States banded together and founded the American Society for Quality Control. George D. Edwards, then director of quality assurance in Bell Laboratories, was elected its first president. In 1947 the Society created the Shewhart Medal in honor of the man whose "pioneering efforts in joining the forces of statistics, engineering and economics, opened the door to the science of statistical quality control."



The Shewhart Medal is given annually to "individuals who have made suitable outstanding contributions to the course of quality control." Shewhart received the first medal and six other AT&T employees or former employees have since received this honor. In 1949 the ASQC created the Edwards Medal to honor outstanding contributions to the management of quality.

In AT&T and in much of the country, the 1950s were a time of applying the many lessons in quality management learned during the war years and trying to get the new quality control techniques used throughout the company. Perhaps the most remarkable effort in this period was the creation of the *AT&T Statistical Quality Control Handbook* (known throughout the world as the *Western Electric Statistical Quality Control Handbook*). "This book is a working Handbook prepared by Western Electric people for Western Electric use. Its primary purpose is to provide a guide for applying statistical quality control principles to the company's manufacturing and other operations."[40] Bonnie Small chaired the writing committee that tried to capture a "description of those procedures which, if followed, will tend to preserve the essential features of the quality control programs at Western Electric." Much of the material for the handbook is based on training courses that were given to engineers, key shop personnel, and people at all levels of management in Western Electric from 1949 to 1956.

Perhaps the most remarkable aspects of the handbook are its emphasis on engineering and operating applications rather than inspection and its emphasis on the control chart, and particularly the process capability study, as the foundation of the entire program. A box on the first page, reproduced in Figure 1, puts the contents of the entire book in perspective.

The *AT&T Statistical Quality Control Handbook* is now in its ninth printing, and thousands of copies are sold annually. It is used throughout the world and has been translated into Japanese as well as into other languages.

Much effort in applying quality control was expended in Japan in the 1950s. Deming had been asked by the U. S. Government to help with Japan's rebuilding efforts. In 1950 Deming was invited by the Japanese Union of Scientists and Engineers to teach statistical methods in a series of eight-day courses. He realized very early in these courses that to get quality control widely implemented management must understand it. Juran was also invited to Japan to help with instituting quality control. The entire scope of managing quality was outlined by Juran. His pioneering work in postwar Japan has been credited with forming the basis for much of that country's recent success. Juran stressed the necessity for leadership by top management, extensive training programs to make basic quality control techniques available to every worker in the company, and a dedication to quality at every step.[41]

Many companies in Japan, especially those like the NEC Corporation with close AT&T ties, had begun using statistical quality

Statistical	With the help of numbers, or data,
Quality	We study the characteristics of our process
Control	In order to make it behave the way we want it to behave

Figure 1. The *AT&T Statistical Quality Control Handbook* offers this diagram in its first page.

control methods in the 1930s based on studies of Shewhart's work.[42] One person who studied Shewhart's methods first through written material, then by visiting Bell Laboratories was Ishikawa, now president of Masashi Institute of Technology. He writes, "It was when I visited the Bell 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 concepts devised by Dr. Shewhart were not being applied very much in those days. I wished to import his concepts into Japan ... so that Japanese products would improve in quality. ... the concepts of Dr. Shewhart had great influence on popularization of statistical quality control in Japan and on improvement in the quality of Japanese products."[43]

Toward an Integrated Quality System.

Already in the *AT&T Statistical Quality Control Handbook* in 1956 we see the emphasis on quality moving from inspection to process control, engineering, and operations. In fact, in the late 1930s Shewhart transferred to the research area at Murray Hill "to see if his statistical techniques can be used in the research laboratory."[44] In 1947 Shewhart was selected "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."[45]

By the 1960s the emphasis in quality control and quality assurance included reliability. This interest was not new in AT&T. Shewhart in 1931 had stated, "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. ... 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."[14]

Many statistical methods were used in early field studies. Mary N. Torrey "designed and analyzed an extensive sample survey on cable troubles in 1964-1965."[46] Much of the work in the 1970s on reliability was in connection with the extensive field tracking studies called product performance surveys.[47] These studies covered many major product lines and carefully recorded reliability data on numerous causes of failure. The results of these studies were used to make many design improvements to improve the life of products and greatly increase customer satisfaction. Reference 48

describes methods used in these studies.

Another area of concentration in the late 1970s and 1980s is in software quality. Much effort has been made to apply both the traditional methods of quality control and to develop effective new methods for improving the design quality and measuring the quality of software.[49-51]

The 1980s have been a time of focusing on making quality methods widely known and used throughout AT&T. Workshops are being given to all levels of management and professional and technical staff, administrative staff, and work force. We are using company publications, reports and seminars to introduce new methods and to reinforce the use of existing methods.[52-54] We are developing special software to support the application of modern methods for reliability prediction and estimation. The use of computers in quality control, quality assurance and reliability estimation and prediction is growing rapidly in AT&T.[54-56] We are building new tools for experimental design and robust product and process design. We are trying to make the use of all of the building blocks of a modern quality system standard practice throughout the entire corporation.

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