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QUALITY: THEORY AND PRACTICE

Introduction

Quality technology is a term used to mean the tools, techniques, methods, and metrics that help us to plan, design, manage, control, and improve the quality of products and services. This technology is especially important now, because modern, worldwide markets make strong demands on suppliers.

This paper discusses the history and roles of quality technology, and summarizes the contents of this issue of the *AT&T Technical Journal*.

AT&T currently is engaged in a major way in the application of quality technology to all aspects of its business. This theme issue offers a sample of recent activities of the quality-technology community. Articles from several areas of AT&T give the reader an idea of the ways quality technology contributes to the work at AT&T.

The issue is intended to serve several audiences. Quality technologists should gain a perspective of how their discipline is used in our company. Members of the technical and managerial communities will see how quality technology can contribute to their endeavors. And, the growing population of students, engineers, and scientists might find that work in this field is challenging and rewarding.

Evolution of Quality Systems

Quality systems are understood to have traversed four phases: inspection, process control, quality improvement, and quality by design. These phases generally overlap.

In the first phase, the manufacturer relied on *inspection* as the last step before shipping the product; because inspection is imperfect, customers knew that they should inspect the product before accepting it.

Process control also uses measurement and inspection but includes them in the manufacturing cycle. Now, process parameters, parts for the product, and partial assemblies, not just the finished product, are measured. Statistical methods determine how many measurements constitute an adequate sample and how to tell if a process is in control, or if an entire batch is considered good.

Quality improvement goes even further. No longer is inspection or process control *to acceptable levels* the objective. Rather, process control and inspection data are analyzed to determine the source and causes of the errors, and the processes are improved to diminish the introduction of errors.

Quality by design embodies all this and more by designing quality into the product and into the manufacturing process, starting with the initial concept of the product.

The degree to which an industry or an individual enterprise emphasizes one phase or another in its current quality system depends on the maturity of the industry and the competitive posture of the enterprise.

For instance, industries such as automobiles and consumer electronics, which are in competitive, worldwide markets, contain businesses that have advanced to the third phase, quality improvement. Those that did not make the transition have failed or are about to fail. In those failing industries, corporate strategies that emphasize inspection or statistical process control do not yield competitive costs or competitive products. This is in contrast to

software-intensive industries, where quality methods still are primitive. Here, much emphasis still is placed on inspection and process control.

The transition from one phase to the next is generally a two-step process. The first step involves the development of new technology, which may be product, process, or quality technology. The second step is the implementation of new quality systems that meet the needs of or take advantage of the new technologies. For successful implementation of new quality systems, proper training is a necessity. This is sometimes helped by forming awareness and implementation teams, commonly called *quality circles*. An example or two may help.

Before the advent of large-scale-integrated (LSI) circuit technology, functionality in electronic systems was achieved by extensive interconnections of simple, active elements with wires and circuit assemblies. This was the case for relatively simple consumer products, such as radios, and for complicated systems, such as computers or transmission systems.

Although sophisticated hardware and software redundancy was used to enhance a complex system's reliability, the reliability of such products was largely affected by the quality of the manufacturing processes that produced them. Often, the predominant defect was attributed to poor soldering. With such technology, high-quality products are produced through careful and complete control of the manufacturing processes, augmented by small-sample inspections.

With the arrival of LSI, the functionality of electronic systems is largely contained in semiconductor structures, such as microprocessors, or in related software. For the

semiconductor components, reliability is determined by selecting robust design rules and architectures, and using robust process-design techniques.

The physical nature of semiconductor components is such that many failure mechanisms have activation energies that can be accelerated in time in predictable ways by heating the components above their ambient temperatures. Furthermore, within a substantial range of increased temperatures, the raised temperature does not harm components that do not contain incipient defects. New quality testing and reliability estimation methods have emerged to meet new needs that take advantage of these new characteristics.

For software, an entirely new discipline called software engineering has emerged, attended by its own emerging quality technology. Structured development methodologies—handbooks of well-defined procedures for developing the product—are found to have significant effects on both quality and productivity. Closely related to these methodologies are software quality-assurance plans. Often, these plans are integrated with or are subsets of the development methodology.

Testing and inspections currently loom large as vehicles for controlling and assuring software quality. Inspections range from informal peer reviews and formal peer-level inspections to formal design-process and product reviews. For large software systems, integration testing and system testing account for as much as half the total development costs. In cost-of-quality accountings, a large part of these costs are regarded as quality-appraisal costs.

Just as computer-aided engineering (CAE), computer-aided manufacturing (CAM),

and factory automation are regarded as vehicles for improved productivity and quality of hardware, so too are computer aids and automation improving the quality and productivity of software. Automatic code generation, self-testing, and standard, reusable software modules are examples of this technology.

Currently, quality management principles are being extended successfully to service industries and to other domains of industrial enterprises. *Integrated quality systems* have emerged that address the entire product life cycle, from market research and product planning at one end to delivery, billing, and product support at the other.

Evolution of Quality Technology

Quality technology was born in the United States in the 19th century and nurtured at AT&T in the 20th century. The rudiments of quality control began in the American armories in the antebellum period of the 19th century. The stimulus was the desire to develop production methods for small arms that would allow interchangeability of parts in the field. This led to the concepts of tolerances and gauging. After the Civil War, the same production techniques were adopted and improved by sewing machine manufacturers led by Singer and farm machinery manufacturers such as McCormick.¹

The next major innovation in quality technology did not come until the period surrounding World War I. This was the Ford Motor Company's use of the assembly-line method of mass production. By implementing techniques, such as systematic materials handling, machine-tool design and placement, factory layout, and final inspection, Ford was able to increase the production of Model T motorcars

from a little more than 10,000 in 1909 to almost 600,000 in 1916. At the same time, he reduced the price from \$850 to \$350.¹

The history of quality technology from the 1920s to the present often appears as major events in the history of AT&T, and Godfrey tells this story in fascinating detail, in this issue. A brief summary will suffice here.

One of the first important contributions was the control-chart method for statistical control of manufacturing processes. Previous approaches to quality control focused on product inspection with the inherent inefficiencies that result from separating the good from the bad and junking or reworking the bad. Here was an efficient technique for controlling the production processes that determine product quality in ways that minimize the resulting defective content. The methods were documented in the 1931 text, *Economic Control of Quality of Manufactured Product*, by Walter Shewhart of AT&T Bell Laboratories. It contained chapters on the presentation of statistical quality and on sampling methods and distributions, including novel results on non-normal assumptions.

The next major innovation arose out of work done by AT&T engineers and statisticians for the War Department during World War II. Key quality technologists, such as Harold Dodge of Bell Laboratories and Joe Juran of Western Electric, were on special assignment in Washington to assure the quality of material for the war effort. Out of their work came the sampling inspection plans that, after the war, were published as the MILSTD (military standard) series. This series of inspection plans was adopted by national and international standards bodies, and its lineal descendants are still used throughout the world.²

In This Issue

The topics in this issue logically and organizationally divide into four groups. One group gives both historical and current overviews of the research and development in quality technology at AT&T, and its application to quality systems within the corporation. For example, Godfrey's paper provides an historical perspective by tracing the evolution of quality technology within AT&T. In another paper, Surette presents AT&T's quality system in the context of the company's post-divestiture mission and strategy.

In a group of articles devoted to the quality process, Pettijohn provides a prescription for the design of quality systems. Eckel describes the quality-management process in AT&T's Network Systems line of business, while Secor and Robertson delve into the special characteristics of the software-development process.

Another group of papers presents a sampling of the important advances in quality technology: robust design, statistical reliability and in-process inspections.

The article by Kackar and Shoemaker is a primer for the new, powerful methods of robust product and process design. Hooper and Amster present recent advances in statistical reliability theory and tools. And, Fowler describes a newly developed methodology for in-process inspections for both software and hardware.

A fourth group of papers deals with applications of quality technology to real products and processes.

Phadke presents two case studies of applying robust-design methods. One case involves a production process—router bits used to drill printed wiring boards for electronic assemblies—and uses robust design to maximize their useful life. The other case study involves the design of an electronic circuit.

An article—by Goksel, Sekino, and Troutman—involves very-large-scale-integrated circuits, while another—by Inglls—describes the metrics used within AT&T to track the quality of software.

After World War II, AT&T quality technology was introduced into Japan. The Civil Communications Section (CCS) of the General Headquarters of the Supreme Commander for the Allied Powers was organized to rebuild the devastated Japanese telecommunications system and to improve its quality. Adequate telecommunications capabilities were considered by the high command to be necessary for the internal security of the country.

CCS arranged for Western Electric and Bell Laboratories engineers, under the supervision of Frank Polkinghorn of Bell Labo-

ratories, to prepare and deliver a course on quality fundamentals to executives of Japanese equipment manufacturers. The course was given three times and today's leaders of the Japanese electronics industry were students of those classes.³

In 1956, Western Electric published the *Statistical Quality Control Handbook*. The book was innovative in two ways. First, it was written for shop-floor managers in ways that they could understand and implement. Second, it emphasized engineering and operational activities to control quality, rather than product inspections.

Subsequent innovations include:

- multistate, sequential, and skip-lot sampling
- the Quality Measurement Plan and Universal Sampling Plan
- SUPER and STAR reliability prediction and analysis software
- and experimental design theory and methods.

These and other recent contributions are covered in Godfrey's report.

The knowledge and techniques derived from quality disciplines described in this issue will contribute to the high quality, low cost, high productivity, and high customer satisfaction that have become fundamental requirements for competing in a global marketplace.

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