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Total Quality Management

Revised Third Edition

FOR ANNA UNIVERSITY

Dale H. Besterfield | Carol Besterfield-Michna | Glen H. Besterfield
Mary Besterfield-Sacre | Hemant Urdhwareshe | Rashmi Urdhwareshe

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Total Quality Management

REVISED THIRD EDITION

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Preface to the Revised Edition

We are glad to present this revised edition of *Total Quality Management (TQM)* to the readers in the Indian subcontinent. Within the framework of the original book, several technical contents have been revised in the present day context and their relevance to the Indian industry has been emphasized.

Many case studies of TQM exemplary organizations have been taken from renowned organizations such as CDAC, SEARCH, Infosys, Orchid, and Cummins India Limited. Significant examples from India have also been added in many chapters.

Quality management standards have now matured and an integrated approach is emerging towards quality. The revisions and updated information on standards such as ISO 9000, ISO 14000 have therefore been incorporated. Wherever available, information such as American Customer Satisfaction Index (ACSI) is also updated. Business excellence approaches like Balanced Score Card are included. The criteria for Malcolm Baldrige National Quality Award are also revised and information about other Indian national awards like Rajiv Gandhi National Quality Award is included.

Brief information about Design for Six Sigma (DFSS) is added in Chapter 13, "Quality by Design". Failure Mode and Effect Analysis (FMEA) is revised as per the fourth revision of FMEA manual by Automotive Industry Action Group (AIAG). A new topic on "Measurement Systems Analysis" is included in Chapter 18, "Statistical Process Control". Graphical tools and illustrations are given in Chapter 19, "Experimental Design". Brief information about Taguchi's latest thinking is added in Chapter 20, "Taguchi's Quality Engineering".

In order to facilitate learning and comprehension, objectives and summary have been added in all the chapters. Multiple choice questions are also provided at the end of chapters, where relevant. While examples and case studies have been changed to some extent, sincere efforts have been made to ensure that the original content and spirit are retained.

India is one of the fastest growing economies in the world. Organizations adopt different approaches to achieve excellence and quality. TQM is one of the basic and sound approaches. There is tremendous potential for applying principles of TQM in the various sectors of business. We do hope that those who wish to learn about TQM or enhance their knowledge of TQM will immensely benefit from this book.

We are thankful to Pearson Education and the authors of the original book for giving us an opportunity to take up the revision of the book and also for granting us technical freedom and flexibility in achieving the task.

Hemant Urdhwareshe
Rashmi Urdhwareshe

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Preface

This book provides a fundamental, yet comprehensive, coverage of Total Quality Management (TQM). It covers not only the principles and practices, but also the tools and techniques. A practical state-of-the-art approach is stressed throughout. Sufficient theory is presented to ensure that the reader has a sound understanding of the basic concepts. Mathematical techniques are reduced to simple mathematics or developed in the form of tables and charts.

The book will serve the instructional needs of business, education, engineering, health-care, and technology students in higher education institutions. All sizes and types of organizations—service, manufacturing, government, military, construction, education, small business, health care, and nonprofit entities—will find this book an excellent training and reference manual for all personnel.

The book is divided into two parts. Part I covers the principles and practices of TQM. After an introductory chapter, the next six chapters cover the basic TQM concepts of leadership, customer satisfaction, employee involvement, continuous process improvement, supplier partnership, and performance measures.

Part II of the book covers the tools and techniques of TQM. Chapters discuss benchmarking, information technology, quality management systems, environmental management systems, quality function deployment, quality by design, failure mode and effect analysis, products liability, total productive maintenance, management tools, statistical process control, experimental design, and Taguchi's quality engineering.

The authors wish to express their sincere appreciation to Alan Lasley for his contributions on total productive maintenance; Ron Bathje, who drew many of the figures; and Gloria Aiello, who did the index.

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1

Introduction

Chapter Objectives

- Understanding the basic concepts of Total Quality Management (TQM)
- Brief overview of TQM framework
- Contribution of quality gurus in the TQM journey
- Benefits of TQM

Definition

Total Quality Management (TQM) is an enhancement to the traditional way of doing business. It is a proven technique to guarantee survival in world-class competition. Only by changing the actions of management will the culture and actions of an entire organization be transformed. TQM is for the most part common sense. Analyzing the three words, we have

Total—Made up of the whole.

Quality—Degree of excellence a product or service provides.

Management—Act, art, or manner of handling, controlling, directing, etc.

Therefore, TQM is the art of managing the whole to achieve excellence. The Golden Rule is a simple but effective way to explain it: Do unto others as you would have them do unto you.

TQM is defined as both a philosophy and a set of guiding principles that represent the foundation of a continuously improving organization. It is the application of quantitative methods and human resources to improve all the processes within an organization and exceed customer needs now and in the future. TQM integrates fundamental management techniques, existing improvement efforts, and technical tools under a disciplined approach.

Basic Approach

TQM requires six basic concepts:

1. A committed and involved management to provide long-term top-to-bottom organizational support.
2. An unwavering focus on the customer, both internally and externally.
3. Effective involvement and utilization of the entire work force.
4. Continuous improvement of the business and production process.
5. Treating suppliers as partners.
6. Establish performance measures for the processes.

These concepts outline an excellent way to run an organization. A brief paragraph on each of them is given here. The next six chapters cover these concepts in greater detail.

1. Management must participate in the quality program. A quality council must be established to develop a clear vision, set long-term goals, and direct the program. Quality goals are included in the business plan. An annual quality improvement program is established and involves input from the entire work force. Managers participate on quality improvement teams and also act as coaches to other teams. TQM is a continual activity that must be entrenched in the culture—it is not just a one-shot program. TQM must be communicated to all people.

2. The key to an effective TQM program is its focus on the customer. An excellent place to start is by satisfying internal customers. We must listen to the "voice of the customer" and emphasize design quality and defect prevention. Do it right the first time and every time, for customer satisfaction is the most important consideration.

3. TQM is an organization-wide challenge that is everyone's responsibility. All personnel must be trained in TQM, statistical process control (SPC), and other appropriate quality improvement skills so they can effectively participate on project teams. Including internal customers and, for that matter, internal suppliers on project teams is an excellent approach. Those affected by the plan must be involved in its development and implementation. They understand the process better than anyone else. Changing behavior is the goal. People must come to work not only to do their jobs, but also to think about how to improve their jobs. People must be empowered at the lowest possible level to perform processes in an optimum manner.

4. There must be a continual striving to improve all business and production processes. Quality improvement projects, such as on-time delivery, order entry efficiency, billing error rate, customer satisfaction, cycle time, scrap reduction, and supplier management, are good places to begin. Technical techniques such as SPC, benchmarking, quality function deployment, ISO 9000, and designed experiments are excellent for problem solving.

5. On the average 40% of the sales dollar is purchased product or service; therefore, the supplier quality must be outstanding. A partnering relationship rather than an adversarial one must be developed. Both parties have as much to gain or lose based on the success or failure of the product or service. The focus should be on quality and life-cycle costs rather than price. Suppliers should be few in number so that true partnering can occur.

6. Performance measures such as uptime, percent nonconforming, absenteeism, and customer satisfaction should be determined for each functional area. These measures should be posted for everyone to see. Quantitative data are necessary to measure the continuous quality improvement activity.

The purpose of TQM is to provide a quality product and/or service to customers, which will, in turn, increase productivity and lower cost. With a higher quality product and lower price, competitive position in the marketplace will be enhanced. This series of events will allow the organization to achieve the objectives

TABLE 1-1
New and Old Cultures

Quality Element	*Previous State*	*TQM*
Definition	Product-oriented	Customer-oriented
Priorities	Second to service and cost	First among equals of service and cost
Decisions	Short-term	Long-term
Emphasis	Detection	Prevention
Errors	Operations	System
Responsibility	Quality control	Everyone
Problem Solving	Managers	Teams
Procurement	Price	Life-cycle costs, partnership
Manager's Role	Plan, assign, control, and enforce	Delegate, coach, facilitate, and mentor

of profit and growth with greater ease. In addition, the work force will have job security, which will create a satisfying place to work.

As previously stated, TQM requires a cultural change. Table 1-1 compares the previous state with the TQM state for typical quality elements. This change is substantial and will not be accomplished in a short period of time. Small organizations will be able to make the transformation much faster than large organizations.

Gurus of Total Quality Management

Shewhart

Walter A. Shewhart, PhD, spent his professional career at Western Electric and Bell Telephone Laboratories, both divisions of AT&T. He developed control chart theory with control limits, assignable and chance causes of variation, and rational subgroups (see Chapter 15). In 1931, he authored *Economic Control of Quality of Manufactured Product*, which is regarded as a complete and thorough work of the basic principles of quality control. AQ 1 He also developed the PDSA cycle for learning and improvement.

Ronald Fisher

In the conventional sense, Fisher is not known as a quality guru. However, he created a solid foundation of statistical methods, such as design of experiments (DOE) and analysis of variance (ANOVA) in the 1930s. DOE is one of the most powerful tools used by many organizations in problem solving and process improvements. Analysis of variance became widely known after being included in his book *Statistical Methods for Research Workers* in 1925. Fisher also published *The Design of Experiments* in 1935 and *Statistical Tables* in 1947.[1]

[1] http://www-history.mcs.st-and.ac.uk/Biographies/Fisher.html.

Deming

W. Edwards Deming, PhD, was a protégé of Shewhart. In 1950, he taught statistical process control and the importance of quality to the leading CEOs of Japanese industry. He is credited with providing the foundation for the Japanese quality miracle and resurgence as an economic power. Deming is the best-known quality expert in the world. His 14 points provide a theory for management to improve quality, productivity, and competitive position (see Chapter 2). He has authored a number of books including *Out of the Crisis* and *Quality, Productivity, and Competitive Position* as well as 161 scholarly studies.

Juran

Joseph M. Juran, PhD worked at Western Electric from 1924 to 1941. There he was exposed to the concepts of Shewhart. Juran traveled to Japan in 1954 to teach quality management. He emphasized the necessity for management at all levels to be committed to the quality effort with hands-on involvement. He recommended project improvements based on return on investment to achieve breakthrough results. The Juran Trilogy for AQ 2 managing quality is carried out by the three interrelated processes of planning, control, and improvement. In 1951, the first edition of *Juran's Quality Control Handbook* was published.

Feigenbaum

Armand V. Feigenbaum, PhD, argues that total quality control[2] is necessary to achieve productivity, market penetration, and competitive advantage. Quality begins by identifying the customer's requirements and ends with a product or service in the hands of a satisfied customer. In addition to customer satisfaction, some of Feigenbaum's quality principles are genuine management involvement, employee involvement, first-line supervision leadership, and company-wide quality control. In 1951, he authored *Total Quality Control*.

Ishikawa

Kaoru Ishikawa, PhD, studied under Deming, Juran, and Feigenbaum. He borrowed the total quality control concept and adapted it for the Japanese. In addition, he authored SPC texts in Japanese and in English. Ishikawa is best known for the development of the cause and effect diagram (see Chapter 15), which is sometimes called an Ishikawa diagram. He developed the quality circle concept (see Chapter 4) in Japan, whereby work groups, including their supervisor, were trained in SPC concepts. The groups then met to identify and solve quality problems in their work environment.

Crosby

Phillip B. Crosby authored his first book, *Quality is Free*, in 1979, which was translated into 15 languages. It sold 1.5 million copies and changed the way management looked at quality. He argued that "doing it right the first time" is less expensive than the costs of detecting and correcting nonconformities. In 1984, he authored *Quality Without Tears*, which contained his four absolutes of quality management. These absolutes are: quality is conformance to requirements, prevention of nonconformance is the objective not appraisal, the performance standard is zero defects not "that's close enough," and the measurement of quality is the cost of nonconformance.

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[2] The term total quality control was used rather than TQM during the early years of the movement.

Taguchi

Genichi Taguchi, PhD, developed his loss function concept that combines cost, target, and variation into one metric. Because the loss function is reactive, he developed the signal to noise ratio as a proactive equivalent. The cornerstone of Taguchi's philosophy is the robust design of parameters and tolerances. It is built on the simplification and use of traditional design of experiments. These concepts are described in Chapter 16.

TQM Framework

Figure 1-1 shows the framework for the TQM system. It begins with the knowledge provided by gurus of quality: Shewhart, Deming, Juran, Feigenbaum, Ishikawa, Crosby, and Taguchi. As the figure shows, they contributed to the development of principles and practices and/or the tools and techniques. Chapters 2 through 6 provide information on principles and practices, and their titles are given at the bottom of the figure. Chapters 7 through 16 provide information on tools and techniques and their titles are given in the upper right of the figure. Some of these tools and techniques are used in the product and/or service realization activity. Feedback from internal/external customers or interested parties provides information to continually improve the organization's system, product and/or service.

Awareness

An organization will not begin the transformation to TQM until it is aware that the quality of the product or service must be improved. Awareness comes about when an orga-nization loses market share or realizes that quality and productivity go hand-in-hand. It also occurs if TQM is mandated by the customer or if management realizes that TQM is a better way to run a business and compete in domestic and world markets.

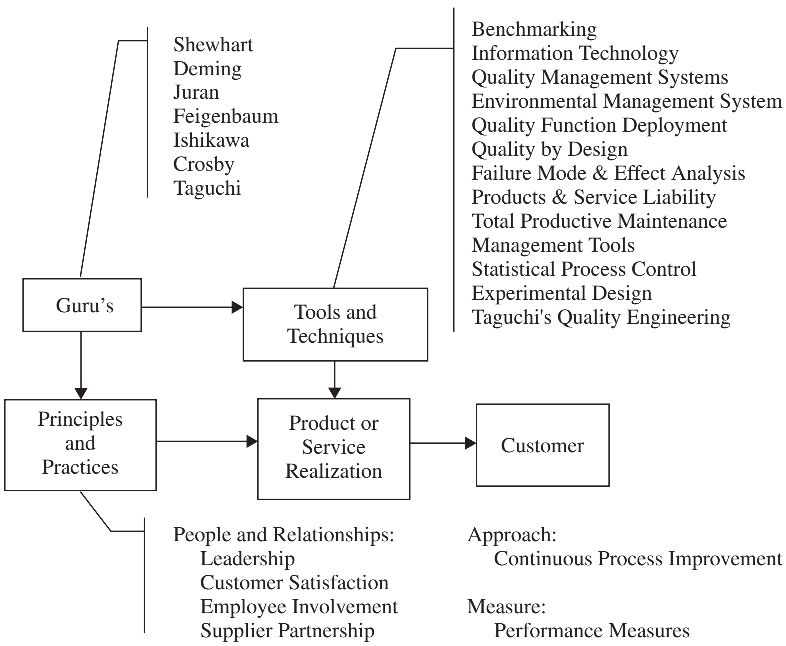

Figure 1-1 TQM Framework

TABLE 1-2
Gain in Productivity with Improved Quality

Item	*Before Improvement 10% Nonconforming*	*After Improvement 5% Nonconforming*
Relative total cost for 20 units	1.00	1.00
Conforming units	18	19
Relative cost for nonconforming units	0.10	0.05
Productivity increase		(100)(1/18) = 5.6%
Capability increase		(100)(1/18) = 5.6%
Profit increase		(100)(1/18) = 5.6%

Adapted from W. Edwards Deming, *Quality, Productivity, and Competitive Position* (Cambridge, Mass.: Massachusetts Institute of Technology, Center for Advanced Engineering Studies, 1982).

Automation and other productivity enhancements might not help a corporation if it is unable to market its product or service because the quality is poor. The Japanese learned this fact from practical experience. Prior to World War II, they could sell their products only at ridiculously low prices, and even then it was difficult to secure repeat sales. Until recently, corporations have not recognized the importance of quality. However, a new attitude has emerged—quality first among the equals of cost and service. To sum it up, the customer wants value.

Quality and productivity are not mutually exclusive. Improvements in quality can lead directly to increased productivity and other benefits. Table 1-2 illustrates this concept. As seen in the table, the improved quality results in a 5.6% improvement in productivity, capacity, and profit. Many quality improvement projects are achieved with the same work force, same overhead, and no investment in new equipment.

Recent evidence shows that more and more corporations are recognizing the importance and necessity of quality improvement if they are to survive domestic and world-wide competition. Quality improvement is not limited to the conformance of the product or service to specifications; it also involves the inherent quality in the design of the system. The prevention of product, service, and process problems is a more desirable objective than taking corrective action after the product is manufactured or a service rendered.

TQM does not occur overnight; there are no quick remedies. It takes a long time to build the appropriate emphasis and techniques into the culture. Overemphasis on short-term results and profits must be set aside so long-term planning and constancy of purpose will prevail.

Defining Quality

When the expression "quality" is used, we usually think in terms of an excellent product or service that fulfills or exceeds our expectations. These expectations are based on the intended use and the selling price. For example, a customer expects a different performance from a plain steel washer than from a chrome-plated steel washer because they are a different grade. When a product surpasses our expectations we consider that quality. Thus, it is somewhat of an intangible based on perception. Quality can be quantified as follows:

$$Q = P / E$$

where Q = quality
P = performance
E = expectations

TABLE 1-3
The Dimensions of Quality

Dimension	*Meaning and Example*
Performance	Primary product characteristics, such as the brightness of the picture
Features	Secondary characteristics, added features, such as remote control
Conformance	Meeting specifications or industry standards, workmanship
Reliability	Consistency of performance over time, average time for the unit to fail
Durability	Useful life, includes repair
Service	Resolution of problems and complaints, ease of repair
Response	Human-to-human interface, such as the courtesy of the dealer
Aesthetics	Sensory characteristics, such as exterior finish
Reputation	Past performance and other intangibles, such as being ranked first

Adapted from David A. Garvin, *Managing Quality: The Strategic and Competitive Edge* (New York: Free Press, 1988).

If Q is greater than 1.0, then the customer has a good feeling about the product or service. Of course, the determination of P and E will most likely be based on perception with the organization determining performance and the customer determining expectations.

A more definitive definition of quality is given in ISO 9000: 2000. It is defined as the degree to which a set of inherent characteristics fulfills requirements. *Degree* means that quality can be used with adjectives such as poor, good, and excellent. *Inherent* is defined as existing in something, especially as a permanent characteristic. *Characteristics* can be quantitative or qualitative. *Requirement* is a need or expectation that is stated; generally implied by the organization, its customers, and other interested parties; or obligatory.

Quality has nine different dimensions. Table 1-3 shows these nine dimensions of quality with their meanings and explanations in terms of a slide projector.

These dimensions are somewhat independent; therefore, a product can be excellent in one dimension and average or poor in another. Very few, if any, products excel in all nine dimensions. For example, the Japanese were cited for high-quality cars in the 1970s based only on the dimensions of reliability, conformance, and aesthetics. Therefore, quality products can be determined by using a few of the dimensions of quality.

Marketing has the responsibility of identifying the relative importance of each dimension of quality. These dimensions are then translated into the requirements for the development of a new product or the improvement of an existing one.

Historical Review

The history of quality control is undoubtedly as old as industry itself. During the Middle Ages, quality was to a large extent controlled by the long periods of training required by the guilds. This training instilled pride in workers for quality of a product.

The concept of specialization of labor was introduced during the Industrial Revolution. As a result, a worker no longer made the entire product, only a portion. This change brought about a decline in workmanship. Because most products manufactured during that early period were not complicated, quality was not greatly affected. In fact, because productivity improved there was a decrease in cost, which resulted in lower customer expectations. As products became more complicated and jobs more specialized, it became necessary to inspect products after manufacture.

In 1924, W. A. Shewhart of Bell Telephone Laboratories developed a statistical chart for the control of product variables. This chart is considered to be the beginning of statistical quality control. Later in the same decade, H. F. Dodge and H. G. Romig, both of Bell Telephone Laboratories, developed the area of acceptance sampling as a substitute for 100% inspection. Recognition of the value of statistical quality control became apparent by 1942. Unfortunately, U.S. managers failed to recognize its value.

In 1946, the American Society for Quality Control was formed. Recently, the name was changed to American Society for Quality (ASQ). This organization, through its publications, conferences, and training sessions, has promoted the use of quality for all types of production and service.

In 1950, W. Edwards Deming, who learned statistical quality control from Shewhart, gave a series of lectures on statistical methods to Japanese engineers and on quality responsibility to the CEOs of the largest organizations in Japan. Joseph M. Juran made his first trip to Japan in 1954 and further emphasized management's responsibility to achieve quality. Using these concepts the Japanese set the quality standards for the rest of the world to follow.

In 1960, the first quality control circles were formed for the purpose of quality improvement. Simple statistical techniques were learned and applied by Japanese workers.

By the late 1970s and early 1980s, U.S. managers were making frequent trips to Japan to learn about the Japanese miracle. These trips were really not necessary—they could have read the writings of Deming and Juran. Nevertheless, a quality renaissance began to occur in U.S. products and services, and by the middle of 1980 the concepts of TQM were being publicized.

In the late 1980s the automotive industry began to emphasize statistical process control (SPC). Suppliers and their suppliers were required to use these techniques. Other industries and the Department of Defense also implemented SPC. The Malcolm Baldrige National Quality Award was established and became the means to measure TQM. Genechi Taguchi introduced his concepts of parameter and tolerance design and brought about a resurgence of design of experiments (DOE) as a valuable quality improvement tool.

Emphasis on quality continued in the auto industry in the 1990s when the Saturn automobile ranked first in customer satisfaction (1996). In addition, ISO 9000 became the worldwide model for a quality management system. ISO 14000 was approved as the worldwide model for environmental management systems.

The new millenium brought about increased emphasis on worldwide quality and the Internet.

Obstacles

Implementation of TQM is described in the next chapter, on leadership. This section gives information concerning the obstacles associated with implementation.

Many organizations, especially small ones with a niche, are comfortable with their current state. They are satisfied with the amount of work being performed, the profits realized, and the perception that the customers are satisfied. Organizations with this culture will see little need for TQM until they begin to lose market share.

Once an organization embarks on TQM, there will be obstacles to its successful implementation. The first eight most common were determined by Robert J. Masters after an extensive literature search and the last obstacle added by the authors.[3] They are given below.

[3] Robert J. Masters, "Overcoming the Barriers to TQM's Success," *Quality Progress* (May 1996): 53–55.

Lack of Management Commitment

In order for any organizational effort to succeed, there must be a substantial management commitment of management time and organizational resources. The purpose must be clearly and continuously communicated to all personnel. Management must consistently apply the principles of TQM.

Robert Galvin of Motorola said that only the CEO can ensure, even in times of great pressure, that quality and customer satisfaction are preserved. In a survey of 188 quality professionals, 66% reported that management's compensation is not linked to quality goals such as failure costs, customer complaints, and cycle time reduction.[4]

Inability to Change Organizational Culture

Changing an organization's culture is difficult and will require as much as five years. Individuals resist change—they become accustomed to doing a particular process and it becomes the preferred way. Management must understand and utilize the basic concepts of change. They are:

1. People change when they want to and to meet their own needs.
2. Never expect anyone to engage in behavior that serves the organization's values unless adequate reason (why) has been given.
3. For change to be accepted, people must be moved from a state of fear to trust.

It is difficult for individuals to change their way of doing things; it is much more difficult for an organization to make a cultural change.

Management by exhortation and inspiration will fail. Speeches, slogans, and campaigns that are supposed to motivate people are only effective for a short period of time. Impediments to a cultural change are the lack of effective communication and emphasis on short-term results. Organizations that spend more time planning for the cultural aspects of implementing a TQM program will improve their chances of success.[5]

Improper Planning

All constituents of the organization must be involved in the development of the implementation plan and any modifications that occur as the plan evolves. Of particular importance is the two-way communication of ideas by all personnel during the development of the plan and its implementation. Customer satisfaction should be the goal rather than financial or sales goals. Peterson Products, a metal stamping firm near Chicago, improved on-time delivery, which resulted in a 25% increase in sales. Focus on quality and the other goals will follow.

Lack of Continuous Training and Education

Training and education is an ongoing process for everyone in the organization. Needs must be determined and a plan developed to achieve those needs. Training and education are most effective when senior management conducts the training on the principles of TQM. Informal training occurs by communicating the TQM effort to all personnel on a continual basis.

[4] Nabil Tamimi and Rose Sebastianelli, "The Barriers to Total Quality Management," Quality Progress (June 1998): 57–60.

[5] Gary Salegna and Farzaneh Fasel, "Obstacles to Implementing Quality," Quality Progress (July 2000): 53–57.

In the study by Tamimi and Sebastianelli previously cited, lack of training in group discussion and communication techniques, quality improvement skills, problem identification, and the problem-solving method was the second most important obstacle.

Incompatible Organizational Structure and Isolated Individuals and Departments

Differences between departments and individuals can create implementation problems. The use of multifunctional teams will help to break down long-standing barriers.

Restructuring to make the organization more responsive to customer needs may be needed. Individuals who do not embrace the new philosophy can be required to leave the organization. Adherence to the six basic concepts will minimize the problems over time.

At Spartan Light Metal Products, Inc. in Sparta, IL, product support teams composed of three members from design, quality, and production are assigned to each customer segment.

Ineffective Measurement Techniques and Lack of Access to Data and Results

Key characteristics of the organization should be measured so that effective decisions can be made. In order to improve a process you need to measure the effect of improvement ideas. Access to data and quick retrieval is necessary for effective processes.

Peoples Bank of Bridgeport, CT found that extra inspection, training, and management encouragement did not help a high error rate. Finally the bank investigated the root causes of the problem and corrected them, which virtually eliminated the problem.

Paying Inadequate Attention to Internal and External Customers

Organizations need to understand the changing needs and expectations of their customers. Effective feedback mechanisms that provide data for decision making are necessary for this understanding. One way to overcome this obstacle is to give the right people direct access to the customers. Maruti Suzuki, the leading car manufacturing company in India, takes significant efforts in training their service technicians and dealers' sales staff in order to ensure that their actions and interactions are in synchronization with the changes in customer profiles and expectations.[6] When an organization fails to empower individuals and teams, it cannot hold them responsible for producing results.

Inadequate Use of Empowerment and Teamwork

Teams need to have the proper training and, at least in the beginning, a facilitator. Whenever possible, the team's recommendations should be followed. Individuals should be empowered to make decisions that affect the efficiency of their process or the satisfaction of their customers. Solar Turbines, Inc. flattened its organization by restructuring into work teams and delegating authority to the point of customer contact or to the work performed.

Failure to Continually Improve

It is tempting to sit back and rest on your laurels. However, a lack of continuous improvement of the processes, product, and/or service will even leave the leader of the pack in the dust. Will Rogers said it best, "Even if

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[6] Annual Report of Maruti Suzuki 2008–09.

you're on the right track, you'll get run over if you just sit there." Even though Champion Mortgage's 1998 business volume increased 59%, it continues to address culture, staff, and service issues.[7]

Benefits of TQM

According to a survey of manufacturing firms in Georgia, the benefits of TQM are improved quality, employee participation, teamwork, working relationships, customer satisfaction, employee satisfaction, productivity, communication, profitability, and market share.[8]

TQM is a good investment as shown by a ten-year study by Hendricks and Singhai. They showed that there is a strong link between TQM and financial performance. The researchers selected a group of 600 publicly traded organizations that had won awards for effectively implementing TQM. They then selected a control group similar in size and industry to the award winners. Performance of both groups was compared during the five years prior to the award and five years after winning the award. No difference was shown between the two groups prior to the award. However, as shown below the award group far outstripped the control group during the five-year period after the award.

Description	*Control*	*Award*
Growth in Operating Income	43%	91%
Increase in Sales	32%	69%
Increase in Total Assets	37%	79%

The study also showed that stock price performance for the award winners was 114% while the S&P was 80%. In addition, the study showed that small organizations out performed larger organizations. Recent studies have shown that only about 30% of manufacturing organizations have successfully implemented TQM.[9]

TQM Exemplary Organization[10]

Employing 99,000 workers at 53 major facilities worldwide and based in Schaumburg, Illinois, Motorola is an integrated company that produces an array of electronic products, distributing most through direct sales and service operations. Products include two-way radios and pagers; wireless telephones; semiconductors; and equipment for defense and aerospace applications, data communications, information processing, and automotive and industrial uses.

In 1981, Motorola launched an ambitious drive for a tenfold improvement in the quality of its products and services. They succeeded, and now many of its products are the best in their class. The company's quality goal is simply stated: "Zero defects in everything we do." Motorola's managers literally carry with them the corporate objective of "total customer satisfaction"—it's on a printed card in their pockets. Corporate officials and business managers wear pagers to make themselves available to customers, and they regularly visit customers' businesses to find out their likes and dislikes about Motorola products and services.

[7] Mark R. Hagan, "Complacency—the Enemy of Quality," *Quality Progress* (October 1999): 37–44.

[8] Christopher M. Lowery, et. al., "TQM's Human Resource Component," *Quality Progress* (February 2000): 55–58.

[9] Kevin B. Hendricks and Vinod R. Singhai, "Don't Count TQM Out," *Quality Progress* (April 1999): 35–42.

[10] Malcolm Baldrige National Quality Award, 1988 Manufacturing Category Recipient, NIST/Baldrige Homepage, Internet.

The information, along with data gathered through an extensive network of customer surveys, complaint hotlines, field audits, and other customer feedback measures, guides planning for quality improvement and product development. Pagers supplied to Nippon Telegraph and Telephone is a major share of that market.

Key initiatives are six-sigma quality and reducing total cycle time. Six sigma is a statistical measure that translates into a target of no more than 3.4 defects per million products and includes customer service. Motorola's cycle-time reduction is even more ambitious; the clock starts ticking the moment the product is conceived. This calls for an examination of the total system, including design, manufacturing, marketing, and administration.

Employees contribute directly through Motorola's Participative Management Program (PMP), which is composed of employees who work in the same area or are assigned to achieve a specific aim. PMP teams meet often to assess progress toward meeting quality goals, identify new initiatives, and work on problems. To reward high quality work, savings that stem from team recommendations are shared. PMP bonuses over the past four years have averaged about three percent of Motorola's payroll. About 40 percent of worker training is devoted to quality matters, ranging from general principles of quality improvement to designing for manufacturability.

Summary

TQM encompasses all aspects of business. Its key concepts are emphasis on management commitment, customer focus, involvement of all, continuous improvement, treating suppliers as partners and performance metrics.

The philosophy of TQM has evolved through the contribution of many quality gurus, including Shewhart, Deming, Juran, Feigenbaum, Ishikawa, Crosby and Taguchi. The principles and tools laid down by these experts provide a solid foundation for the TQM framework. The journey to TQM starts when the management realizes the need. The need could be due to some external factors such as loss of market share or some internal factors such as loss of productivity.

There are nine different dimensions to quality. Marketing should identify the relative importance of these in developing new products and improving current products.

There are several obstacles in implementing TQM, the most important being the lack of management commitment.

Sustained implementation of TQM can result in benefits such as improvement in quality, productivity, reliability, market share, revenue, profits and growth. A study has shown that companies winning excellence awards outperformed the S&P index. In spite of this, the proportion of companies implementing TQM is low.

Exercises

1. Describe how the golden rule does or does not influence each of the six concepts of TQM.
2. Of the six basic TQM concepts, which were the most effective in World War II? Explain.
3. Which of the gurus would be the father of quality control? Which had the greatest impact on management? Which is noted for robust design?
4. Select a product or service and describe how the dimensions of quality influence its acceptance.

5. Working as an individual or in a team of three or more people, determine two or more obstacles to implementing TQM in one or more of the organizations listed below:

   (a) Large bank
   (b) Health-care facility
   (c) University academic department
   (d) University nonacademic department
   (e) Large department store
   (f) Grade school
   (g) Manufacturing facility
   (h) Large grocery store

6. Match the following pairs:

1.	Juran	A	Company-wide Quality-control
2.	Crosby	B	Quality Circles
3.	Taguchi	C	Control Charts
4.	Ishikawa	D	14 points of management
5.	Feigenbaum	E	Trilogy
6.	Deming	F	Zero Defect
7.	Shewhart	G	Robust Design

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2

Leadership

Chapter Objectives

- Understand the definition of a leader and the characteristics of a quality leader
- Importance of principle-centered leadership based on character ethics rather than personality ethics
- Role of leadership in building a foundation of ethical standards in the organization
- Appreciate and understand Deming's philosophy and 14-points as a framework for TQM
- Importance of commitment and involvement of leadership and management in TQM implementation
- Understand the structure and functions of quality council in order to drive TQM implementation
- Setting direction for TQM efforts, creating vision, mission, quality policy and establishing strategic objectives

Definitions

There is no universal definition of leadership and indeed many books have been devoted to the topic of leadership. In his book *Leadership*, James MacGregor Burns describes a leader as one who instills purposes, not one who controls by brute force. A leader strengthens and inspires the followers to accomplish shared goals. Leaders shape the organization's values, promote the organization's values, protect the organization's values and exemplify the organization's values. Ultimately, Burns says, "Leaders and followers raise one another to higher levels of motivation and morality . . . leadership becomes moral in that it raises the level of human conduct and ethical aspiration of both the leader and the led, and thus has a transforming effect on both."[1] Similarly, Daimler Chrysler's CEO Bob Eaton defines a leader as " . . . someone who can take a group of people to a place they don't think they can go." "Leadership is we, not me; mission, not my show; vision, not division; and community, not domicile."[2] As the above illustrates, leadership is difficult to define in anything other than lofty words.

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[1] James M. Burns, *Leadership* (New York: Harper & Row, 1978).

[2] Rick L. Edgeman, et. al., "On Leaders and Leadership," *Quality Progress* (October 1999): 49–54.

According to Narayana Murthy, Chairman and Chief Mentor of Infosys "A great leader is one who is not only good in creating vision, creating the big picture, but also ensuring that he goes into the nitty-gritty, into the details of making sure that his vision is actually translated into reality through excellence of execution. In other words, great leaders have great vision, great imagination, great ideas but they also implement these ideas through hard work, commitment and flawless execution. In doing so, they motivate thousands of people."[3]

The criteria of Ramkrishna Bajaj National Quality Award (RBNQA) are based on Malcolm Baldrige Award. These are built upon the following set of interrelated core values and concepts:

- visionary leadership
- customer-driven excellence
- organizational and personal learning
- valuing employees and partners
- agility
- focus on the future
- managing for innovation
- management by fact
- social responsibility
- focus on results and creating value
- systems perspective

These values and concepts are embedded beliefs and behaviors found in high-performing organizations. They are the foundation for integrating key business requirements within a result-oriented framework. A framework, that creates a basis for action and feedback. As stated in its core values and concepts, visionary leadership is:

> "The organization's senior leaders should set directions and create a customer focus, clear and visible values, and high expectations. The directions, values and expectations should balance the needs of all your stakeholders. The leaders should ensure the creation of strategies, systems and methods for achieving performance excellence, stimulating innovation, building knowledge and capabilities and ensuring organizational sustainability. The defined values and strategies should help guide all of your organization's activities and decisions."
>
> Senior leaders should inspire, motivate and encourage your entire workforce to contribute, to develop and learn, to be innovative, and to embrace change. Senior leaders should be responsible to your organization's governance body for their actions and performance. The governance body should be responsible ultimately to all your stakeholders for the ethics, actions and performance of your organization and its senior leaders. Senior leaders should serve as role models through their ethical behavior and their personal involvement in planning, communicating, coaching the workforce, developing future leaders, reviewing organizational performance and recognizing members of your workforce. As role models, they can reinforce ethics, values and expectations while building leadership, commitment and initiative throughout your organization."[4]

Leadership can be difficult to define. However, successful quality leaders tend to have certain characteristics.

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[3] Interview of Narayana Murthy by Yasmin Taj published in *The Times of India Ascent* on 14 October 2009.

[4] RBNQA Criteria 2009.

Characteristics of Quality Leaders[5]

There are 12 behaviors or characteristics that successful quality leaders demonstrate.

1. They give priority attention to external and internal customers and their needs. Leaders place themselves in the customers' shoes and service their needs from that perspective. They continually evaluate the customers' changing requirements.
2. They empower, rather than control, subordinates. Leaders have trust and confidence in the performance of their subordinates. They provide the resources, training, and work environment to help subordinates do their jobs. However, the decision to accept responsibility lies with the individual.
3. They emphasize improvement rather than maintenance. Leaders use the phrase "If it isn't perfect, improve it" rather than "If it ain't broke, don't fix it." There is always room for improvement, even if the improvement is small. Major breakthroughs sometimes happen, but it's the little ones that keep the continuous process improvement on a positive track.
4. They emphasize prevention. "An ounce of prevention is worth a pound of cure" is certainly true. It is also true that perfection can be the enemy of creativity. We can't always wait until we have created the perfect process or product. There must be a balance between preventing problems and developing better, but not perfect, processes.
5. They encourage collaboration rather than competition. When functional areas, departments, or work groups are in competition, they may find subtle ways of working against each other or withholding information. Instead, there must be collaboration among and within units.
6. They train and coach, rather than direct and supervise. Leaders know that the development of the human resource is a necessity. As coaches, they help their subordinates learn to do a better job.
7. They learn from problems. When a problem exists, it is treated as an opportunity rather than something to be minimized or covered up. "What caused it?" and "How can we prevent it in the future?" are the questions quality leaders ask.
8. They continually try to improve communications. Leaders continually disseminate information about the TQM effort. They make it evident that TQM is not just a slogan. Communication is two way—ideas will be generated by people when leaders encourage them and act upon them. For example, on the eve of Desert Storm, General Colin Powell solicited enlisted men and women for advice on winning the war. Communication is the glue that holds a TQM organization together.
9. They continually demonstrate their commitment to quality. Leaders walk their talk—their actions, rather than their words, communicate their level of commitment. They let the quality statements be their decision-making guide.
10. They choose suppliers on the basis of quality, not price. Suppliers are encouraged to participate on project teams and become involved. Leaders know that quality begins with quality materials and the true measure is the life-cycle cost.
11. They establish organizational systems to support the quality effort. At the senior management level a quality council is provided, and at the first-line supervisor level, work groups and project teams are organized to improve the process.

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[5] Adapted from Warren H. Schmidt and Jerome P. Finnigan, *The Race Without a Finish Line* (San Francisco: Jossey-Bass Publishers, 1992).

12. They encourage and recognize team effort. They encourage, provide recognition, and reward individuals and teams. Leaders know that people like to know that their contributions are appreciated and important. This action is one of the leader's most powerful tools.

Leadership Concepts

In order to become successful, leadership requires an intuitive understanding of human nature—the basic needs, wants, and abilities of people. To be effective, a leader understands that:

1. People, paradoxically, need security and independence at the same time.
2. People are sensitive to external rewards and punishments and yet are also strongly self-motivated.
3. People like to hear a kind word of praise. Catch people doing something right, so you can pat them on the back.
4. People can process only a few facts at a time; thus, a leader needs to keep things simple.
5. People trust their gut reaction more than statistical data.
6. People distrust a leader's rhetoric if the words are inconsistent with the leader's actions.

Leaders need to give their employees independence and yet provide a secure working environment—one that encourages and rewards successes. A working environment must be provided that fosters employee creativity and risk-taking by not penalizing mistakes.

A leader will focus on a few key values and objectives. Focusing on a few values or objectives gives the employees the ability to discern on a daily basis what is important and what is not. Employees, upon understanding the objectives, must be given personal control over the task in order to make the task their own and, thereby, something to which they can commit. A leader, by giving the employee a measure of control over an important task, will tap into the employee's inner drive. Employees, led by the manager can become excited participants in the organization.

Having a worthwhile cause such as total quality management is not always enough to get employees to participate. People, (and, in turn, employees) follow a leader, not a cause. Indeed, when people like the leader but not the vision, they will try to change the vision or reconcile their vision to the leader's vision. If the leader is liked, people will not look for another leader. This is especially evident in politics. If the leader is trusted and liked, then the employees will participate in the total quality management cause. Therefore, it is particularly important that a leader's character and competence, which is developed by good habits and ethics, be above reproach. Effective leadership begins on the inside and moves out.

The 7 Habits of Highly Effective People*[6]

Stephen R. Covey has based his foundation for success on the character ethic—things like integrity, humility, fidelity, temperance, courage, justice, patience, industry, simplicity, modesty, and the Golden Rule. The personality ethic—personality growth, communication skill training, and education in the field of influence

[6] This section is adapted from Stephen R. Covey. *The 7 Habits of Highly Effective People*, Simon & Schuster: New York, 1989. © 1989 Stephen R. Covey.

strategies and positive thinking—is secondary to the character ethic. What we *are* communicates far more eloquently than what we *say* or do.

A *paradigm* is the way we perceive, understand, and interpret the world around us. It is a different way of looking at people and things. To be effective we need to make a paradigm shift. Most scientific breakthroughs are the result of paradigm shifts such as Copernicus viewing the sun as the center of the universe rather than earth. Paradigm shifts are quantum changes, whether slow and deliberate or instantaneous.

A habit is the intersection of knowledge, skill, and desire. Knowledge is the *what to do* and the *why*; skill is the *how to do*; and desire is the motivation or *want to do*. In order for something to become a habit you have to have all three. The 7 Habits* are a highly integrated approach that moves from dependency (you take care of me) to independence (I take care of myself) to interdependence (we can do something better together). The first three habits deal with independence—the essence of character growth. Habits 4, 5, and 6 deal with interdependence—teamwork, cooperation, and communication. Habit 7 is the habit of renewal.

The 7 Habits are in harmony with a natural law that Covey calls the "P/PC Balance,"* where P stands for production of desired results and PC stands for production capacity, the ability or asset. For example, if you fail to maintain a lawn mower (PC) it will wear out and not be able to mow the lawn (P). You need a balance between the time spent mowing the lawn (desired result) and maintaining the lawn mower (asset). Assets can be physical, such as the lawn mower example; financial, such as the balance between principal (PC) and interest (P); and human, such as the balance between training (PC) and meeting schedule (P). You need the balance to be effective; otherwise, you will have neither a lawn mower nor a mowed lawn.

Habit 1: Be Proactive*

Being proactive means taking responsibility for your life—the ability to choose the response to a situation. Proactive behavior is a product of conscious choice based on values, rather than reactive behavior, which is based on feelings. Reactive people let circumstances, conditions, or their environment tell them how to respond. Proactive people let carefully thought-about, selected, and internalized values tell them how to respond. It's not what happens to us but our response that differentiates the two behaviors. No one can make you miserable unless you choose to let them.

The language we use is a real indicator of our behavior. Comparisons are given in the table below.

Reactive	***Proactive***
There's nothing I can do.	Let's look at our alternatives.
She makes me so mad.	I control my own feelings.
I have to do that.	I will choose an appropriate response.
I can't.	I choose.
I must.	I prefer.
Things are getting worse.	What initiative can we use?

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Habit 2: Begin with the End in Mind*

The most fundamental application of this habit is to begin each day with an image, picture, or paradigm of the end of your life as your frame of reference. Each part of your life can be examined in terms of what really matters to you—a vision of your life as a whole.

All things are created twice—there's a mental or first creation and a physical or second creation to all things. To build a house you first create a blueprint and then construct the actual house. You create a speech on paper before you give it. If you want to have a successful organization you begin with a plan that will produce the appropriate end; thus leadership is the first creation, and management, the second. Leadership is doing the right things and management is doing things right.

In order to begin with the end in mind, develop a personal philosophy or creed. Start by considering the example items below:

Never compromise with honesty.

Remember the people involved.

Maintain a positive attitude.

Exercise daily.

Keep a sense of humor.

Do not fear mistakes.

Facilitate the success of subordinates.

Seek divine help.

Read a leadership book monthly.

By centering our lives on correct principles, we create a solid foundation for the development of the life-support factors of security, guidance, wisdom, and power. Principles are fundamental truths. They are tightly interwoven threads running with exactness, consistency, beauty, and strength through the fabric of life.

Habit 3: Put First Things First*

Habit 1 says, "You're the creator. You are in charge." Habit 2 is the first creation and is based on imagination—leadership based on values. Habit 3 is practicing self-management and requires Habits 1 and 2 as prerequisites. It is the day-by-day, moment-by-moment management of your time.

The Time Management Matrix is diagrammed on the following page. Urgent means it requires immediate attention, and important has to do with results that contribute to your mission, goals, and values. Effective, proactive people spend most of their time in Quadrant II, thereby reducing the time spent in Quadrant I. Four activities are necessary to be effective. First, write down your key roles for the week (such as research manager, United Way chairperson, and parent). Second, list your objectives for each role using many Quadrant II activities. These objectives should be tied to your personal goals or philosophy developed in Habit 2. Third, schedule time to complete the objectives. Fourth, adapt the weekly schedule to your daily activities.

Habit 4: Think Win-Win*

Win-Win is a frame of mind and heart that constantly seeks mutual benefit in all human interactions. Both sides come out ahead; in fact, the end result is usually a better way. If Win-Win is not possible, then the

Time Management Matrix*

	Urgent	Not Urgent
Important	**I** Crises, fire-fighting Pressing problems Deadline driven projects	**II** Prevention, PC Relationship building Recognizing new opportunities Planning, recreation
Not Important	**III** Interruptions, pressing matters Some mail, calls, reports Some meetings, proximate Popular activities	**IV** Trivia, busy work Time wasters Pleasant activities

alternative is no deal. It takes great courage as well as consideration to create mutual benefits, especially if the other party is thinking Win-Lose.

Win-Win embraces five interdependent dimensions of life—character, relationships, agreements, systems, and processes. Character involves the trains of integrity; maturity, which is a balance between being considerate of others and the courage to express feelings; and abundance mentality, which means that there is plenty out there for everyone. Relationships means that the two parties trust each other and are deeply committed to Win-Win. Agreements require the five elements of desired results, guidelines, resources, accountability, and consequences. Win-Win agreements can only survive in a system that supports it—you can't talk Win-Win and reward Win-Lose. In order to obtain Win-Win, a four-step process is needed: (1) see the problem from the other viewpoint, (2) identify the key issues and concerns, (3) determine acceptable results, and (4) seek possible new options to achieve those results.

Habit 5: Seek First to Understand, Then to Be Understood*

Seek first to understand involves a paradigm shift since we usually try to be understood first. Empathic Listening* is the key to effective communication. It focuses on learning how the other person sees the world, how they feel. The essence of Empathic Listening is not that you agree with someone; it's that you fully, deeply understand that person, emotionally as well as intellectually. Next to physical survival the greatest need of a human being is psychological survival—to be understood, to be affirmed, to be validated, to be appreciated.

The second part of the habit is to be understood. Covey uses three sequentially arranged Greek words—ethos, pathos, and logos. Ethos is your personal credibility or character; pathos is the empathy you have with the other person's communication; and logos is the logic or reasoning part of your presentation.

Habit 6: Synergy*

Synergy means that the whole is greater than the parts. Together, we can accomplish more than any of us can accomplish alone. This can best be exemplified by the musical group The Beatles, who as a group created more music than each individual created after the group broke up. The first five habits build toward Habit 6. It focuses the concept of Win/Win and the skills of empathic communication on tough challenges that bring about new alternatives that did not exist before. Synergy occurs when people abandon their humdrum presentations and Win/Lose mentality and open themselves up to creative cooperation. When there is genuine understanding, people reach solutions that are better than they could have achieved acting alone.

Habit 7: Sharpen the Saw (Renewal)*

Habit 7 is taking time to Sharpen the Saw so it will cut faster. It is personal PC—preserving and enhancing the greatest asset you have, which is you. It's renewing the four dimensions of your nature—physical, spiritual, mental, and social/emotional. All four dimensions of your nature must be used regularly in wise and balanced ways. Renewing the physical dimension means following good nutrition, rest and relaxation, and regular exercise. The spiritual dimension is your commitment to your value system. Renewal comes from prayer, meditation, and spiritual reading. The mental dimension is continuing to develop your intellect through reading, seminars, and writing. These three dimensions require that time be set aside—they are Quadrant II activities. The social and emotional dimensions of our lives are tied together because our emotional life is primarily, but not exclusively, developed out of and manifested in our relationship with others. While this activity does not require time, it does require exercise.

In the 7 habits book, Covey states that correct principles are natural laws and that God, the Creator and Father of us all, is the source of them and also the source of our conscience. He submits that to the degree people live by this inspired conscience, they will grow to fulfill their natures; to the degree that they do not, they will not rise above the animal plane.

Ethics[7]

Ethics is not a precept that is mutually exclusive from quality. Indeed, quality and ethics have a common care premise, which is to do right things right.

Definition

Ethics is a body of principles or standards of human conduct that govern the behavior of individuals and organizations. It is knowing what is the right thing to do and is learned when one is growing up, or at a later date during an organization's ethics training program. Ethics can mean something different to different people, especially given an organization's international workforce and the varying cultural norms. Because individuals have different concepts of what is right, the organization will need to develop the standards or code of ethics for the organization. Leadership of many Indian companies such as Tata Steel, Infosys, Wipro and HDFC are known for their ethical practices. On the other hand, consider the example of Satyam Computers. It was one of fastest growing software companies in India until its CEO Ramlingum Raju publicly admitted that a large amount was siphoned from the company and the profits shown in the books were not real!

The Root Causes of Unethical Behavior

Much of the unethical behavior in organizations occurs when:

1. Organizations favor their own interests above the well-being of their customers, employees, or the public.
2. Organizations reward behavior that violates ethical standards, such as increasing sales through false advertising.

[7] This section is adapted from Dean L. Bottorff, "How Ethics Can Improve Business Success," *Quality Progress* (February 1997): 57–59. © 1997 American Society for Quality. Reprinted with permission.

3. Organizations encourage separate standards of behavior at work than at home, such as secrecy and deceit versus honesty.
4. Individuals are willing to abuse their position and power to enhance their interests, such as taking excessive compensation for themselves off the top before other stakeholders receive their fair share.
5. Managerial values exist that undermine integrity, such as the pressure managers exert on employees to cover up mistakes or to do whatever it takes to get the job done, including cutting corners.
6. Organizations and individuals overemphasize the short-term results at the expense of themselves and others in the long run; for example behavior is good based on the degree of utility, pleasure, or good received, regardless of the effect on others.
7. Organizations and managers believe their knowledge is infallible and miscalculate the true risks, such as when financial managers invest organizational funds in high-risk options trading.

Tendency toward unethical behavior most likely comes from the interaction of the root causes of pressure, opportunity, and attitude.

Unethical behavior is especially prevalent if employee morale is low. For example, poor working conditions, employee downsizing, unacknowledged good work, and denied promotions can all contribute to an employee's poor attitude.

Ethics Management Program

An ethics management program needs to address pressure, opportunity, and attitude. Managing ethical behavior requires commitment, new policies and procedures, continuous improvement, and investments in appraisal, prevention, and promotion.

The first step is *appraisal*, which is the analysis of the costs associated with unethical behavior. These costs can be divided into the three root causes of pressure, opportunity, and attitude.

- Costs from pressure are those costs from well-intended but unethical decisions made under pressure. They include but are not limited to errors, waste, rework, lost customers, and warranties.
- Costs from opportunity are those costs from intentional wrongdoing. They include but are not limited to theft, overstated expenses, excessive compensation, and nepotism.
- Costs from attitudes are those costs from mistaken beliefs in unethical forms of behavior. They include but are not limited to errors, waste, rework, lost customers, and health care.

In order to obtain these costs, use the information given in the Quality Costs section of Chapter 6.

The second step is *prevention*, which is the development of a system that will minimize the costs. Because management has a good idea of the appraisal costs, this step can proceed concurrently with Step 1.

- Pressure can be addressed by being involved in the development of goals and values and developing policies that allow for individual diversity, dissent, and decision-making input.
- Opportunity can be addressed by developing policies that encourage and protect whistleblowers and require the existence of ombudsmen who can work confidentially with people to solve ethical problems internally.
- Attitude can be addressed by requiring ethics training for all personnel, recognizing ethical conduct in the workplace, requiring performance appraisals to include ethics, and encouraging open discussion concerning ethical behavior issues.

The third step is *promotion*, which is the continuous advertising of ethical behavior in order to develop an ethical organizational culture that is clear, positive, and effective.

- To be clear the philosophy needs to be written, with input from all personnel, and posted. Standardized ethics training should be given to everyone to: (1) teach them how to clarify ethical issues, (2) encourage them to get the facts before acting, (3) encourage them to consider all the consequences before acting, and (4) show them how to test their actions in advance. This testing can be accomplished by asking (1) Is it legal? (2) Is it right? (3) Is it beneficial for all involved? and (4) How would I feel if it was published on the front page of the newspaper?
- To be positive, the culture should be about doing what is right, encouraging principled organizational dissent, and rewarding ethical behavior.
- To be effective, the philosophy must be set and adopted by senior management, with input from all personnel. Senior management should act as they would want others to act and make no exceptions.

Final Comment

Quality is dependent on ethical behavior. Doing what is right in the first place is a proven way to reduce costs, improve competitiveness, and create customer satisfaction. Many companies are hiring ethics consultants to help them achieve their goals.

Unethical behavior by Enron and Worldcom executives in 2002 resulted in bankruptcy for those companies.

The Deming Philosophy[8]

Deming's philosophy is given in his 14 points. Most of these points were given in a seminar for 21 Presidents of leading Japanese industry in 1950. The rest were developed and the original ones modified over a period of three decades.

1. Create and Publish the Aims and Purposes of the Organization

Management must demonstrate constantly their commitment to this statement. It must include investors, customers, suppliers, employees, the community, and a quality philosophy. The statement is a forever-changing document that requires input from everyone. Organizations must develop a long-term view of at least ten years and plan to stay in business by setting long-range goals. Resources must be allocated for research, training, and continuing education to achieve the goals. Innovation is promoted to ensure that the product or service does not become obsolete. A family organizational philosophy is developed to send the message that everyone is part of the organization.

2. Learn the New Philosophy

Top management and everyone must learn the new philosophy. Organizations must seek never-ending improvement and refuse to accept nonconformance. Customer satisfaction is the number one priority,

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[8] Adapted from *Out of the Crisis* by W. Edwards Deming by permission of MIT and the W. Edwards Deming Institute. Published by MIT, Center for Advanced Engineering Study, Cambridge, MA 02139. Copyright 1986 by W. Edwards Deming.

because dissatisfied customers will not continue to purchase nonconforming products and services. The organization must concentrate on defect prevention rather than defect detection. By improving the process, the quality and productivity will improve. Everyone in the organization, including the union, must be involved in the quality journey and change his or her attitude about quality. The supplier must be helped to improve quality by requiring statistical evidence of conformance and shared information relative to customer expectations.

3. Understand the Purpose of Inspection

Management must understand that the purpose of inspection is to improve the process and reduce its cost. For the most part, mass inspection is costly and unreliable. Where appropriate, it should be replaced by never-ending improvement using statistical techniques. Statistical evidence is required of self and supplier. Every effort should be made to reduce and then eliminate acceptance sampling. Mass inspection is managing for failure and defect prevention is managing for success.

4. Stop Awarding Business Based on Price Alone

The organization must stop awarding business based on the low bid, because price has no meaning without quality. The goal is to have single suppliers for each item to develop a long-term relationship of loyalty and trust, thereby providing improved products and services. Purchasing agents must be trained in statistical process control and require it from suppliers. They must follow the materials throughout the entire life cycle in order to examine how customer expectations are affected and provide feedback to the supplier regarding the quality.

5. Improve Constantly and Forever the System

Management must take more responsibility for problems by actively finding and correcting problems so that quality and productivity are continually and permanently improved and costs are reduced. The focus is on preventing problems before they happen. Variation is expected, but there must be a continual striving for its reduction using control charts. Responsibilities are assigned to teams to remove the causes of problems and continually improve the process.

6. Institute Training

Each employee must be oriented to the organization's philosophy of commitment to never-ending improvements. Management must allocate resources to train employees to perform their jobs in the best manner possible. Everyone should be trained in statistical methods, and these methods should be used to monitor the need for further training.

7. Teach and Institute Leadership

Improving supervision is management's responsibility. They must provide supervisors with training in statistical methods and these 14 points so the new philosophy can be implemented. Instead of focusing on a negative, fault-finding atmosphere, supervisors should create a positive, supportive one where pride in workmanship can flourish. All communication must be clear from top management to supervisors to operators.

8. Drive Out Fear, Create Trust, and Create a Climate for Innovation

Management must encourage open, effective communication and teamwork. Fear is caused by a general feeling of being powerless to control important aspects of one's life. It is caused by a lack of job security, possible physical harm, performance appraisals, ignorance of organization goals, poor supervision, and not knowing the job. Driving fear out of the workplace involves managing for success. Management can begin by providing workers with adequate training, good supervision, and proper tools to do the job, as well as removing physical dangers. When people are treated with dignity, fear can be eliminated and people will work for the general good of the organization. In this climate, they will provide ideas for improvement.

9. Optimize the Efforts of Teams, Groups, and Staff Areas

Management must optimize the efforts of teams, work groups, and staff areas to achieve the aims and purposes of the organization. Barriers exist internally among levels of management, among departments, within departments, and among shifts. Externally, they exist between the organization and its customers and suppliers. These barriers exist because of poor communication, ignorance of the organization's mission, competition, fear, and personal grudges or jealousies. To break down the barriers, management will need a long-term perspective. All the different areas must work together. Attitudes need to be changed; communication channels opened; project teams organized; and training in teamwork implemented. Multifunctional teams, such as used in concurrent engineering, are an excellent method.

10. Eliminate Exhortations for the Work Force

Exhortations that ask for increased productivity without providing specific improvement methods can handicap an organization. They do nothing but express management's desires. They do not produce a better product or service, because the workers are limited by the system. Goals should be set that are achievable and are committed to the long-term success of the organization. Improvements in the process cannot be made unless the tools and methods are available.

11a. Eliminate Numerical Quotas for the Work Force

Instead of quotas, management must learn and institute methods for improvement. Quotas and work standards focus on quantity rather than quality. They encourage poor workmanship in order to meet their quotas. Quotas should be replaced with statistical methods of process control. Management must provide and implement a strategy for never-ending improvements and work with the work force to reflect the new policies.

11b. Eliminate Management by Objective

Instead of management by objective, management must learn the capabilities of the processes and how to improve them. Internal goals set by management, without a method, are a burlesque. Management by numerical goal is an attempt to manage without knowledge of what to do. An excellent analysis supporting this point is given by Castellano and Roehm.[9]

[9] Joseph F. Castellano and Harper A. Roehm, "The Problems With Managing By Objectives and Results." *Quality Progress* (March 2001): 39–46.

12. Remove Barriers That Rob People of Pride of Workmanship

Loss of pride in workmanship exists throughout organizations because (1) workers do not know how to relate to the organization's mission, (2) they are being blamed for system problems, (3) poor designs lead to the production of "junk," (4) inadequate training is provided, (5) punitive supervision exists, and (6) inadequate or ineffective equipment is provided for performing the required work. Restoring pride will require a long-term commitment by management. When workers are proud of their work, they will grow to the fullest extent of their job. Management must give employees operational job descriptions, provide the proper tools and materials, and stress the workers' understanding of their role in the total process. By restoring pride, everyone in the organization will be working for the common good. A barrier for people on salary is the annual rating of performance.

13. Encourage Education and Self-Improvement for Everyone

What an organization needs is people who are improving with education. A long-term commitment to continuously train and educate people must be made by management. Deming's 14 points and the organization's mission should be the foundation of the education program. Everyone should be retrained as the organization requirements change to meet the changing environment.

14. Take Action to Accomplish the Transformation

Management has to accept the primary responsibility for the never-ending improvement of the process. It has to create a corporate structure to implement the philosophy. A cultural change is required from the previous "business as usual" attitude. Management must be committed, involved, and accessible if the organization is to succeed in implementing the new philosophy. Hillerich & Bradsby Co., the makers of the Louisville Slugger baseball bat, have used Deming's 14 points since 1985 and now have 70% of the professional baseball bat market.[10]

Role of TQM Leaders

Everyone is responsible for quality, especially senior management and the CEO; however, only the latter can provide the leadership system to achieve results. For instance, in the 1980's, General Electric's CEO, Jack Welch, instituted leadership training courses at all levels of the organization. The General Electric training courses taught leadership approaches and models and provided the opportunity for teams to develop solutions to real business problems. Many of the solutions the teams developed were implemented. Jack Welch supported the development of a leadership system whereby quality control leaders were developed at all levels in all functions of the organization, including research, marketing, manufacturing, sales, finance, and human resources. Senior managers need to be provided with the skills to implement quality control techniques and actively participate in the quality council.

Senior management has numerous responsibilities. Senior management must practice the philosophy of Management by Wandering Around (MBWA). Management should get out of the office and visit customers, suppliers, departments within the organization, and plants within the organization. That way, managers learn what is happening with a particular customer, supplier, or project. MBWA can substantially reduce paperwork. Encourage subordinates to write only important messages that need to be part of the permanent record. For example,

[10] March L. Jacques, "Big League Quality," *Quality Progress* (August 2001): 27–34.

Kinko's executives perform normal operating duties for two or three days at one location. This approach is an excellent technique for gaining firsthand information.

The idea is to let employees think for themselves. Senior management's role is no longer to make the final decision, but to make sure the team's decision is aligned with the quality statements of the organization. Push problem solving and decision making to the lowest appropriate level by delegating authority and responsibility.

Senior managers must stay informed on the topic of quality improvement by reading books and articles, attending seminars, and talking to other TQM leaders. The leader sends a strong message to subordinates when that leader asks if they have read a particular book or article.

The needed resources must be provided to train employees in the TQM tools and techniques, the technical requirements of the job, and safety. Resources in the form of the appropriate equipment to do the job must also be provided.

Senior managers must find time to celebrate the success of their organization's quality efforts by personally participating in award and recognition ceremonies. This activity is an excellent opportunity to reinforce the importance of the effort and to promote TQM. A phone call or handshake combined with a sincere "thank you for a job well done" is a powerful form of recognition and reward. One of the duties of the quality council is to establish or revise the recognition and reward system. In particular, senior management's incentive compensation must include quality improvement performance. Also, provisions must be made to reward teams as well as creative individuals.

Senior managers must be visibly and actively engaged in the quality effort by serving on teams, coaching teams, and teaching seminars. They should lead by demonstrating, communicating, and reinforcing the quality statements. As a rule of thumb, they should spend about one-third of their time on quality.

A very important role of senior managers is listening to internal and external customers and suppliers through visits, focus groups, and surveys. This information is translated into core values and process improvement projects.

Another very important role is communication. The objective is to create awareness of the importance of TQM and provide TQM results in an ongoing manner. The TQM message must be "sold" to personnel, for if they don't buy it, TQM will never happen. In addition to internal efforts, there must be external activities with customers and suppliers, the media, advertising in trade magazines, and interaction with the quality community.

By following the preceding suggestions, senior managers should be able to drive fear out of the organization, break down barriers, remove system roadblocks, anticipate and minimize resistance to change, and, in general, change the culture. Only with the involvement of senior management can TQM be a success.

Implementation

The TQM implementation process begins with senior management and, most important, the CEO's commitment. The importance of the senior management role cannot be overstated. Leadership is essential during every phase of the implementation process and particularly at the start. In fact, indifference and lack of involvement by senior management are frequently cited as the principal reasons for the failure of quality improvement efforts. Delegation and rhetoric are insufficient—involvement is required.

Senior management needs to be educated in the TQM concepts. In addition to formal education, managers should visit successful TQM organizations, read selected articles and books, and attend seminars and conferences. The next step is for senior management to develop an implementation plan.

Timing of the implementation process can be very important. Is the organization ready to embark on the total quality journey? There may be some foreseeable problems, such as a reorganization, change in senior management personnel, interpersonal conflicts, a current crisis, or a time-consuming activity. These problems may postpone implementation to a more favorable time.

The next step is the formation of the quality council. Initiation of these duties is a substantial part of the implementation of TQM. The development of core values, a vision statement, a mission statement, and a quality policy statement, with input from all personnel, should be completed first.

The active involvement of middle managers and first-line supervisors is essential to the success of the TQM effort. They are accountable for achieving many of the organization's performance goals and objectives, and they form enduring links in the communication chain from senior management to the front-line workers. Without middle management's early and active support, the TQM effort could fail. Senior management needs to ensure that managers at all levels have an opportunity, as soon as possible, to develop ownership in the TQM effort and a chance to acquire the insight and skills necessary to become leaders. One way to accomplish this concept is to have a retreat. The retreat will focus on TQM training, leadership skills, and active involvement in the development of the organization's statements.

If there is a union, there should be early discussions with the representatives on TQM. Managers should involve union leaders by sharing with them implementation plans for TQM. As the quality effort progresses, managers and union leaders should work together on quality improvement activities. For example, the United Auto Workers have worked closely with the big three automakers in their TQM activities.

At this stage of the implementation process, it is important to communicate TQM to the entire organization. Communication is important throughout the implementation stage. Communication is necessary to create TQM awareness, interest, desire, and action.

Everyone needs to be trained in quality awareness and problem solving. This training is conducted when the employee is placed on a project team or the work group is ready for the training.

Customer, employee, and supplier surveys must be conducted to benchmark the attitudes of these three stakeholders. Information from these surveys provides ideas for quality improvement projects. The quality council determines the quality improvement projects. In addition the council establishes the project teams and work groups and monitors their progress. The organization has to be patient and not rush the teams for solutions that don't eliminate the root causes. There is often a tendency to rush the implementation process. TECSTAR, a small business, was able to achieve savings of more than $3 million the first year of its TQM program. On the other hand, Karlee, a Malcolm Baldrige National Quality Award winner, did not achieve results until the third year, but then there was more than a 300% increase in the organization's bottom line.[11]

Quality Council

In order to build quality into the culture, a quality council is established to provide overall direction. It is the driver for the TQM engine.

In a typical organization the council is composed of the chief executive officer (CEO); the senior managers of the functional areas, such as design, marketing, finance, production, and quality; and a coordinator or consultant. If there is a union, consideration should be given to having a representative on the council. Some organizations, such as Friendly Ice Cream of Wilbaham, MA, include front-line representatives from every area. A coordinator is necessary to assume some of the added duties that a quality improvement activity requires. The individual selected for the coordinator's position should be a bright young person with executive potential. That person will report to the CEO.

[11] Laura Struebing and Leigh Ann Klaus, "Small Businesses Thinking Big," *Quality Progress* (February 1997): 23–27.

The responsibility of the coordinator is to build two-way trust, propose team needs to the council, share council expectations with the team, and brief the council on team progress. In addition, the coordinator will ensure that the teams are empowered and know their responsibilities. The coordinator's activities are to assist the team leaders, share lessons learned among teams, and have regular leaders' meetings.

In smaller organizations where managers may be responsible for more than one functional area, the number of members will be smaller. Also, a consultant would most likely be employed rather than a coordinator.

In general, the duties of the quality council are to:

1. Develop, with input from all personnel, the core values, vision statement, mission statement, and quality policy statement.
2. Develop the strategic long-term plan with goals and the annual quality improvement program with objectives.
3. Create the total education and training plan (see Chapter 4).
4. Determine and continually monitor the cost of poor quality (see Chapter 7).
5. Determine the performance measures for the organization, approve those for the functional areas, and monitor them (see Chapter 7).
6. Continually determine those projects that improve the processes, particularly those that affect external and internal customer satisfaction (see Chapter 5).
7. Establish multifunctional project and departmental or work group teams and monitor their progress (see Chapter 4).
8. Establish or revise the recognition and reward system to account for the new way of doing business (see Chapter 4).

In large organizations, quality councils are also established at lower levels of the corporation. Their duties are similar but relate to that particular level in the organization. Initially these activities will require additional work by council members; however, in the long term, their jobs will be easier. These councils are the instruments for perpetuating the idea of never-ending quality improvement.

Once the TQM program is well established, a typical meeting agenda might have the following items:

Progress report on teams.

Customer satisfaction report.

Progress on meeting goals.

New project teams.

Recognition dinner.

Benchmarking report.

Eventually, within three to five years, the quality council activities will become so ingrained in the culture of the organization that they will become a regular part of the executive meetings. When this state is achieved, a separate quality council is no longer needed. Quality becomes the first item on the executive meeting agenda.

Core Values, Concepts, and Framework

Unity of purpose is key to a leadership system. Core values and concepts provide that unity of purpose. The core values and concepts enable a framework for leaders throughout the organization to make right decisions. They foster TQM behavior and define the culture. Each organization will need to develop its own values. Given here are the core values, concepts, and framework for the Malcolm Baldrige National Quality Award. They can be used as a starting point for any organization as it develops its own.

Visionary Leadership

An organization's senior leaders need to set directions and create a customer orientation, clear and visible quality values, and high expectations. Values, directions, and expectations need to address all stakeholders. The leaders need to ensure the creation of strategies, systems, and methods for achieving excellence. Strategies and values should help guide all activities and decisions of the organization. The senior leaders must commit to the development of the entire workforce and should encourage participation, learning, innovation, and creativity by all employees. Through their personal roles in planning, communications, review or organization performance, and employee recognition, the senior leaders serve as role models, reinforcing the values and expectations, and building leadership and initiative throughout the organization.

Customer-Driven Excellence

Quality is judged by customers. All product and service characteristics that contribute value to the customer and lead to customer satisfaction, preference, and retention must be the focus of an organization's management system. Customer-driven excellence has both current and future components: understanding today's customer desires and marketplace offerings as well as future innovations. Value and satisfaction may be influenced by many factors throughout the customer's overall purchase, ownership, and service experiences. These factors include the organization's relationship with customers that helps build trust, confidence, and loyalty. This concept of quality includes not only the product and service characteristics that meet basic customer requirements, but it also includes those features and characteristics that differentiate them from competing offerings. Such differentiation may be based upon new or modified offerings, combinations of product and service offerings, customization of offering, rapid response, or special relationships.

Customer-driven quality is thus a strategic concept. It is directed toward customer retention, market-share gain, and growth. It demands constant sensitivity to changing and emerging customer and market requirements and the factors that drive customer satisfaction and retention. It also demands awareness of developments in technology and of competitors' offerings, and rapid and flexible responses to customer and market requirements.

Success requires more than defect and error reduction, merely meeting specifications, or reducing complaints. Nevertheless, defect and error reduction and the elimination of causes of dissatisfaction contribute to the customers' view of quality, and they are important parts of customer-driven quality. In addition, the organization's success in recovering from defects and errors (making things right for the customer) is crucial to building customer relationships and to retaining customers.

Organizational and Personal Learning

Achieving the highest levels of performance requires a well-executed approach to organizational and personal learning. Organizational learning refers to both continuous improvement of existing approaches and adaptation to change, leading to new goals and approaches. Learning needs to be embedded in the way the organization functions. Learning must be (1) a required part of the daily work; (2) practiced at personal and organizational levels; (3) directed at solving problems; (4) focused on sharing knowledge throughout the organization; and (5) driven by opportunities to effect significant change and to do better. Sources for learning include employees' ideas, research and development (R & D), customers' input, best practice sharing, and benchmarking.

Organizational learning can result in (1) enhancing value to customers through new and improved products and services; (2) developing new opportunities; (3) reducing errors, defects, waste, and related costs; (4) improving responsiveness and cycle time performance; (5) increasing productivity and effectiveness in the use of all resources; and (6) enhancing your organization's performance in fulfilling its public responsibilities and service as a good citizen.

Employees' success depends increasingly on having opportunities for personal learning and practicing new skills. Organizations invest in employees' personal learning through education, training, and other opportunities for continuing growth, such as job rotation. On-the-job training offers a cost-effective way to train and to better link training to your organizational needs and priorities.

Personal learning can result in (1) more satisfied and versatile employees who stay with the organization, (2) organizational cross-functional learning, and (3) an improved environment for innovation. Thus, learning is directed not only toward better products and services but also toward being more responsive, adaptive, and efficient—giving your organization marketplace sustainability and performance advantages.

Valuing Employees and Partners

An organization's success depends increasingly upon the skills, knowledge, creativity, and motivation of its employees and partners. Valuing employees means committing to their satisfaction, development, and well-being. Increasingly, this involves more flexible, high-performance work practices tailored to employees with diverse workplace and home life needs. Major challenges in the area of valuing employees include (1) demonstrating your leaders' commitment to your employees' success, (2) recognition that goes beyond the regular compensation system, (3) development and progression within your organization, (4) sharing your organization's knowledge so your employees can better serve your customers and contribute to achieving your strategic objectives, and (5) creating an environment that encourages risk-taking. For example, Southwest Airlines always puts customers second, and employees first. Southwest lives up to its promises to employees, so there is no sense of betrayal to keep people from enthusiastically contributing. It refuses to lay off employees even when airline workers are laid off industry wide. Southwest has the most productive workforce servicing twice the number of passengers per employee of any other airline.

Organizations need to build internal and external partnerships to better accomplish overall goals. Internal partnerships might involve creating network relationships among your work units to improve flexibility, responsiveness, and knowledge sharing. External partnerships might be with customers, suppliers, and education organizations. Strategic partnerships or alliances are increasingly important. Such partnerships might offer entry into new markets or a basis for new products or services. Also, partnerships might permit the blending of your organization's core competencies or leadership capabilities with the complementary strengths and capabilities of partners. For instance, because of Southwest Airlines' spirit of cooperation with co-workers, they requested three advertising companies to work together to develop Southwest's marketing campaign.

Successful internal and external partnerships develop longer-term objectives, thereby creating a basis for mutual investments and respect. Partners should address the key requirements for success, means for regular communication, approaches to evaluating progress, and means for adapting to changing conditions. In some cases, joint education and training could offer a cost-effective method for employee development.

Agility

Success in global markets demands agility. All aspects of e-commerce require and enable more rapid, flexible, and customized responses. Organizations face ever-shorter cycles for the introduction of new and improved products and services, as well as for faster and more flexible response to customers. Major improvements in response time often require simplification of work units and processes and the ability for rapid changeover from one process to another. Cross-trained and empowered employees are vital assets in such a demanding environment.

A major success factor in meeting competitive challenges is the design-to-introduction cycle time. To meet the demands of rapidly changing markets, organizations need to carry out stage-to-stage integration, such as concurrent engineering of activities, from the research concept to commercialization.

All aspects of time performance are critical, and cycle time has become a key process measure. Time improvements often drive simultaneous improvements in organization, quality, cost, and productivity. For example, Southwest Airlines reduced each plane's time at the terminal to ten minutes after a court ruling forced Southwest to sell one of its four planes. The ten-minute turn allowed Southwest to continue its four plane schedule with only three planes and also helped the company achieve the best on-time performance in the airline industry. One less plane translates into a 25% reduction in operating expenses.

Focus on the Future

Focus on the future requires understanding the short- and long-term factors that affect an organization and the marketplace. Pursuit of sustainable growth and market leadership requires a strong future orientation and a willingness to make long-term commitments to key stakeholders. An organization's planning should anticipate many factors, such as customers' expectations, new business and partnering opportunities, the increasingly global marketplace, technological developments, the evolving e-commerce environment, new customer and market segments, evolving regulatory requirements, societal expectations, and strategic moves by competitors. Strategic objectives and resource allocations need to accommodate these influences. A focus on the future includes developing employees and suppliers, creating opportunities for innovation, and anticipating public responsibilities.

Managing for Innovation

Innovation means making meaningful change to improve an organization's products, services, and processes and to create new value for the organization's stakeholders. Innovation should lead an organization to new dimensions of performance. Innovation is no longer strictly the purview of research and development departments; innovation is important for all aspects of your business and all processes. Organizations should be led and managed so that innovation becomes part of the culture and is integrated into daily work.

Management by Fact

Organizations depend on the measurement and analysis of performance. Such measurements should derive from business needs and strategy, and they should provide critical data and information about key processes, outputs, and results. Many types of data and information are needed for performance management. Performance measurement should include customer, product, and service performance; comparisons of operational, market, and competitive performance; and supplier, employee, and cost and financial performance.

Analysis refers to extracting larger meaning from data and information to support evaluation, decision making, and operational improvement. Analysis entails using data to determine trends, projections, and cause and effect relationships that might not otherwise be evident. Analysis supports a variety of purposes, such as planning, reviewing overall performance, improving operations, change management, and comparing your performance with competitors' or with "best practices" benchmarks.

A major consideration in performance improvement and change management involves the selection and use of performance measures or indicators. *A comprehensive set of measures or indicators tied to customer and/or organizational performance requirements represents a clear basis for aligning all activities with your organization's goals*. Through the analysis of data, measures or indicators themselves may be evaluated and changed to better support an organization's goals.

Public Responsibility and Citizenship

An organization's leaders should stress the need to practice good citizenship. Basic expectations to adhere to business ethics and protection of public health, safety, and the environment should be maintained. Protection of health, safety, and the environment includes an organization's operations, as well as the life cycles of products and services. Also, organizations should emphasize resource conservation and waste reduction at the source. Planning should anticipate adverse impacts from production, distribution, transportation, use, and disposal of products. Effective planning should prevent problems, provide for a forthright response if problems occur, and make available information and support needed to maintain public awareness, safety, and confidence.

For many organizations, the product design stage is critical. Effective design strategies should anticipate growing environmental concerns and responsibilities. Organizations should not only meet all local, state, and federal laws and regulatory requirements, but they should treat these and related requirements as opportunities for improvement "beyond mere compliance."

Practicing good citizenship refers to leadership and support—within the limits of an organization's resources—of publicly important purposes. Leadership as a corporate citizen also entails influencing other organizations. For example, an organization might lead or participate in efforts to help define the obligations of its industry to its communities.

Focus on Results and Creating Value

An organization's performance measurements need to focus on key results. Results should be used to create and balance value for your key stakeholders—customers, employees, stockholders, suppliers and partners, the public, and the community. By creating value for key stakeholders, an organization builds loyalty and contributes to growing the economy. To meet the sometimes conflicting and changing aims that balancing value implies, organizational strategy should explicitly include key stakeholder requirements. This will help ensure that actions and plans meet differing stakeholder needs and avoid adverse impacts on any stakeholders. The use of a balanced composite of leading and lagging performance measures offers an effective means to communicate short- and long-term priorities, monitor actual performance, and provide a clear basis for improving results.

Systems Perspective

Criteria for various business excellence awards including Malcolm Baldrige, RGNQA and RBNQA provide perspective for managing an organization to achieve performance excellence. The Core Values form the building blocks and the integrating mechanism for the system. However, successful management of overall performance requires organization-specific synthesis and alignment. Synthesis means looking at an organization as a whole and builds upon key business requirements, including strategic objectives and action plans. Alignment means using the key linkages among requirements given in the Baldrige Categories, including the key measures/indicators.

Alignment includes senior leaders' focus on strategic directions and on customers. It means that senior leaders monitor, respond to, and manage performance based on business results. Alignment includes using measures/indicators to link key strategies with key processes and align resources to improve overall performance and satisfy customers.

Thus, a systems perspective means managing the whole organization, as well as its components, to achieve success.

Quality Statements

In addition to the core values and concepts, the quality statements include the vision statement, mission statement, and quality policy statement. Once developed, they are only occasionally reviewed and updated. They are part of the strategic planning process. The utilization of the three statements varies considerably from organization to organization. In fact, small organizations may use only the quality policy statement. Additionally, there may be considerable overlap among the statements. One of the common characteristics of Malcolm Baldrige National Quality Award winners is that all have a vision of what quality is and how to attain it.

Vision Statement

The vision statement is a short declaration of what an organization aspires to be tomorrow. It is the ideal state that might never be reached but which you continually strive to achieve. Successful visions are timeless, inspirational, and become deeply shared within the organization, such as IBM's service, Apple's computing for the masses, Disney theme park's the happiest place on earth, and Polaroid's instant photography.[12] These shared visions usually emerge over time. Ideally, visions are elevated to a cause.

Successful visions provide a succinct guideline for decision-making. Having a concise statement of the desired end provides criteria for sound decision making. Tim Frye of Motorola, Inc. once remarked that he used the company's vision statement when faced with difficult decisions in gray areas that were not covered by company policy.[13] It is important that the leader articulate and act upon the vision and that employees understand the vision and can connect their work with the well-being of the organization. One way to reinforce the significance of the vision statement is to include it (or a portion of it) on employee badges.

An example of a simple, one-sentence vision statement is

> "To be world-class enterprise in professional electronics"[14]
>
> BHARAT ELECTRONICS

An example of a more elaborate vision statement is

> L&T shall be a professionally-managed Indian multinational, committed to total customer satisfaction and enhancing shareholder value.
>
> L&T shall be an innovative, entrepreneurial and empowered team constantly creating value and attaining global benchmarks.
>
> L&T shall foster culture of caring, trust and continuous learning while meeting expectations of employees, stakeholders and society.[15]
>
> LARSEN & TOUBRO

[12] Arthur R. Tenner and Irving J. DeToco, *Total Quality Management* (New York: Addison-Wesley, 1992).

[13] John R. Latham, "Visioning: The Concept Trilogy and Process," *Quality Progress* (April 1995): 65–68.

[14] BEL Annual Report 2008–09.

[15] L&T Annual Report 2008–09.

Mission Statement

The mission statement answers the following questions: who we are, who are the customers, what we do, and how we do it. This statement is usually one paragraph or less in length, is easy to understand, and describes the function of the organization. It provides a clear statement of purpose for employees, customers, and suppliers.

An example of a mission statement is

> Ford Motor Company is a worldwide leader in automatic and automotive-related products and services as well as the newer industries such as aerospace, communications, and financial services. Our mission is to improve continually our products and services to meet our customers' needs, allowing us to prosper as a business and to provide a reasonable return to our shareholders, the owners of our business.
>
> FORD MOTOR COMPANY

A simpler mission statement is

> Our mission is to help our customers achieve their business goals through excellence in global product realization. We will enable this through solutions based on innovative technologies, efficient processes and world-class competencies in our people.
>
> GEOMETRIC SOFTWARE

Quality Policy Statement

The quality policy is a guide for everyone in the organization as to how they should provide products and service to the customers. It should be written by the CEO with feedback from the work force and be approved by the quality council. Common characteristics are

Quality is first among equals.
Meet the needs of the internal and external customers.
Equal or exceed the competition.
Continually improve the quality.
Include business and production practices.
Utilize the entire work force.

A quality policy is a requirement of ISO/QS 9000.

A simple quality policy is

> Xerox is a quality company. Quality is the basic business principle for Xerox. Quality means providing our external and internal customers with innovative products and services that fully satisfy their requirements. Quality is the job of every employee.
>
> XEROX CORPORATION

A more elaborate quality policy statement is

> Tata Motors is committed to maximizing customer satisfaction and strives to achieve the goal of excellence, by continual improvement, through ongoing design and development, manufacture and sale of reliable, safe, cost-effective,

> quality products and services of international standards, using environmentally sustainable technologies, for improving levels of efficiency and productivity within its plants and ancillaries.
> Tata Motors also has commitment towards improving the quality of life of its employees, both within and outside its plants and offices, through improved work practices and social welfare schemes.
>
> RATAN N. TATA, CHAIRMAN

In summary, the quality statements consist of the core values and concepts given in a previous section, the vision statement, the mission statement, and the quality policy statement. The core values and concepts should be condensed considerably for simplicity and publication.

An example of a statement that includes vision, mission, quality policy, and core values is

> Geon has a clear corporate vision . . . To be the benchmark company in the polymers industry through superior performance, demonstrated by:
>
> - Living up to its established principles of excellence in environmental protection, health and safety
> - Fully satisfying the expectations of its customers
> - Developing and commercializing innovative polymer technology
> - Utilizing all resources productively
> - Continually improving processes and products
> - Generating sustained value for customers, employees, suppliers and investors
> - Creating an environment of Trust, Respect, Openness and Integrity
>
> THE GEON COMPANY

Strategic Planning

Many organizations are finding that strategic quality plans and business plans are inseparable. For instance, at Corning, the 1995 Malcolm Baldrige National Quality Award winner, if you ask them to show you their quality strategy, they will show you their business strategy; if you ask them to show you their quality plans, they will show you their business plans. In fact, the term quality is not used too much. The time horizon for strategic planning is for three to ten years, and short-term planning is for one year or less.

Goals and Objectives

Goals and objectives have basically the same meaning. However, it is possible to differentiate between the two by using goals for long-term planning and objectives for short-term planning. The goal is to win the war; the objective is to capture the bridge.

Concrete goals are needed to provide a focus, such as improve customer satisfaction, employee satisfaction, and processes. Goals can force changes in leadership style from reward and punishment to identifying and improving system problems.[16]

Goals must be based on statistical evidence. Without statistical knowledge of the system, goals merely reflect the assumption that slogans, exhortations, and hard work will miraculously change the system. Goals must be definitive, specific, and understandable, using concrete results rather than behaviors or attitudes. The most important characteristic of goals is that they be measurable. Only measurable goals can be evaluated.

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[16] George P. Bohan, "Focus the Strategy to Achieve Results," *Quality Progress* (July 1995): 89–92.

Goals must have a plan or method with resources for its achievement. If there is not a cause-and-effect relationship between the goals and the method, then the goal is not a valid one. In addition, a specific time-frame or deadline for achieving the goal should be given.

Goals must be challenging yet achievable. Those individuals, work groups, departments, and functional areas that are affected by the goals should be involved in their development. Stretch goals are satisfactory, provided they are based on benchmark data.[17]

The characteristics of objectives are identical to those given here for goals. They are operational approaches to attain the goals.

Seven Steps to Strategic Planning[18]

There are seven basic steps to strategic quality planning. The process starts with the principle that quality and customer satisfaction are the center of an organization's future. It brings together all the key stake-holders.

1. *Customer Needs*. The first step is to discover the future needs of the customers. Who will they be? Will your customer base change? What will they want? How will the organization meet and exceed expectations?

2. *Customer Positioning*. Next, the planners determine where the organization wants to be in relation to the customers. Do they want to retain, reduce, or expand the customer base? Products or services with poor quality performance should be targeted for breakthrough or eliminated. The organization needs to concentrate its efforts on areas of excellence.

3. *Predict the Future*. Next, the planners must look into their crystal balls to predict future conditions that will affect their product or service. Demographics, economic forecasts, and technical assessments or projections are tools that help predict the future. More than one organization's product or service has become obsolete because it failed to foresee the changing technology. Note that the rate of change is continually increasing.

4. *Gap Analysis*. This step requires the planners to identify the gaps between the current state and the future state of the organization. An analysis of the core values and concepts, given earlier in the chapter, is an excellent technique for pinpointing gaps.

5. *Closing the Gap*. The plan can now be developed to close the gap by establishing goals and responsibilities. All stakeholders should be included in the development of the plan.

6. *Alignment*. As the plan is developed, it must be aligned with the mission, vision, and core values and concepts of the organization. Without this alignment, the plan will have little chance of success.

7. *Implementation*. This last step is frequently the most difficult. Resources must be allocated to collecting data, designing changes, and overcoming resistance to change. Also part of this step is the monitoring activity to ensure that progress is being made. The planning group should meet at least once a year to assess progress and take any corrective action.

Strategic planning can be performed by any organization. It can be highly effective, allowing organizations to do the right thing at the right time, every time.

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[17] Adapted from John Pessico Jr. and Gary N. McLean, "Manage With Valid Rather Than Invalid Goals," *Quality Progress* (April 1994): 49–56.

[18] Adapted, with permission, from John R. Dew, "Seven Steps To Strategic Planning," *Quality Digest* (June 1994): 34–37.

Annual Quality Improvement Program

An annual program is developed along with a long-term strategic plan. Some of the strategic items will eventually become part of the annual plan, which will include new short-term items.

In addition to creating the items, the program should develop among all managers, specialists, and operating personnel

A sense of responsibility for active participation in making improvements.

The skills needed to make improvements.

The habit of annual improvements so that each year the organization's quality is significantly better than the previous year's.

As pointed out in the section on goals and objectives, operating personnel should be involved with setting objectives, and management should support them with training, projects, and resources. Employees should be asked for suggestions on what they need to improve their process.

Most likely there will be more quality objectives than available resources for accomplishing them. Therefore, those that have the greatest opportunity for improvement should be used. Many objectives will require multifunctional project teams.

Some organizations have well-structured annual quality improvement programs. In organizations that lack those programs, any improvements must come from the initiative of managers and specialists. It takes a great deal of determination by these people to secure results, because they lack the legitimacy and support that comes from an official, structured program designed by the quality council.

Communications[19]

All organizations communicate with their employees in one manner or another. Communications deliver the organization's values, expectations, and directions; provide information about corporate developments; and allow feedback from all levels. It is very important to keep information flowing back and forth between employees and various levels of management. For instance, managers at different levels communicate messages much in the same way as the head football coach communicates to the assistants who call the plays. The assistants assess what is happening on the field and communicate that back to the head coach, who further directs and motivates.

In order for the communication system to be effective, there must be feedback. The culture must encourage two-way communication so that information flows up the ladder as well as down. Communication barriers in an organization need to be removed. Managers should never tell employees not to talk to upper management and can facilitate communication by walking around to allow feedback from employees. A formal system to communicate employee concerns to the appropriate person can be instituted. Improving quality will be hampered if poor communications impedes the flow of information to and from the employees.

Also, the organization must know what message it wants to communicate and what the goals and consequences of the message are before it concerns itself with the various modes to transmit the message. Much has been spent on extensive media that is bankrupt of a substantive message. Communications must be effective and not just information overload. Communications must be evaluated to determine that the message was understood and changed attitudes and behaviors. Surveys can be conducted periodically to determine if the organization's key messages are being understood and supported by the employees.

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[19] This section is adapted from Laura Rubach and Brad Stratton, "Mixing Mediums Is the Message," *Quality Progress* (June 1995): 23–28. © 1995 American Society for Quality. Reprinted with permission.

The organization must have a consistent, congruent message. If there are mixed or contradictory messages, the result is confusion in the organization. All communication must be clear: from top management to supervisors to operators. Focused messages articulated simply, clearly, and repetitively are key.

The purpose of communications is to influence attitudes and behaviors to achieve goals and objectives. Different communication methods are better for different communication needs. Communication is not just providing information, but using the best communication method to motivate people to act upon the message. The available communication methods should be coordinated in a wise manner, being careful not to entirely circumvent the human element of direct communications with impersonal methods. There are two basic communication techniques—interactive and formal.

Interactive

Perhaps the most effective communication allows for discussions between the employees and their supervisor, not just management talking to employees. The immediate supervisor is in the best position to initiate the transfer of information and create discussions on what needs to be improved, how to do it, and why it needs to be done. Indeed, employees consistently report their preferred source of information is their immediate supervisor. The primary communication tool used by Xerox, The Ritz-Carlton Hotel, IBM, Texas Instruments, and many more is face-to-face communications supplemented by newsletters. Motorola, for instance, uses immediate managers to communicate company goals because they know what the information means to the employees on a daily basis and can best answer questions and address employee concerns and ideas. GTE Directories Corporation's vice president and general managers spent the better part of a year on the road to give employees the opportunity for face-to-face contact with headquarters to learn the companies priorities and goals.

There is no one-way to communicate and all supervisors are not equally effective as communicators. Generally, a supervisor's communication will be successful if the supervisor is honest, clear, and inclusive. Communications training programs can also be helpful.

Managers can communicate one-on-one or in a group setting. The group setting would most likely occur at the beginning of the shift and would cover topics such as quality, productivity, schedule, and cost. Brief organizational information might also be imparted at these settings. Meetings of all employees can be held quarterly. These meetings provide the executives the opportunity to explain the "state of the company" and answer questions from employees. Organizations with a large number of employees may need to take the meeting off-site or have the sessions at a number of sites. Another effective communication technique is to have team meetings. These can occur at an informal breakfast or lunch. Questions and answers usually flow freely in these meetings. Interactive communication also occurs electronically by instant messaging and video conferencing.

Formal

Although face-to-face interaction may be a primary communication method, it is best to supplement it with other communication methods to reinforce the message. Formal communication can occur using the printed page or electronics. The most common printed communications are periodic publications such as e-mail or a weekly newsletter. Graphics in the form of charts and diagrams can be used to enhance e-mail and publications. These publications can reach the employees simultaneously and can be targeted to special groups. In multinational organizations, messages must be tailored for different cultures and languages. The Internet can be used for external communications, and the intranet can be used for internal communications. Posted information on the web allows greater individual freedom to obtain information whenever it is needed.

Large, multi-site organizations have found that satellite television can be an effective medium. These programs can be interactive by allowing questions by telephone or fax during the presentation. The presentation should not be too long, and it should be professionally done. These presentations can be videotaped and replayed at other times for the convenience of the employees.

Video is becoming more and more important, because visual messages are a very powerful way to disseminate information. Videos can be produced by the organization, or commercial tapes can be purchased, such as Juran's videotapes on quality. If the organization decides to produce their own videos, they should be professionally done. People are accustomed to television being flashy and full of excitement. A poorly-produced video can distort or dilute the company's message. Producing video is expensive, so there should be an important business purpose for the use of producing a personalized video for an organization. Scripting the information in a video will ensure that no necessary information is left out and that clarity is enhanced. Regardless of the media used, communication has been effective when the employees know as much about the organization as the CEO.

Decision Making

Making poor decisions is one of the deadliest threats to the success of the organization and to one's career. When they act haphazardly without regard to the values and goals of an organization, people fail. In order to make correct decisions, it is best to use the problem-solving method given in Chapter 5.

Leadership Survey

In order to evaluate a manager's performance, a survey of the manager's workers should be taken periodically. On the following page is a manager performance survey used by Xerox.[20]

TQM Exemplary Organization[21]

Xerox Business Systems (XBS), a 14,000-person division of Xerox Corporation, provides document outsourcing and consulting services to businesses worldwide. Document outsourcing services, such as on-site management of mailrooms and print shops, account for 80 percent of revenues. The remainder is derived from "document solutions" —customized services designed to meet customers' specialized requirements for creating, producing, distributing, and storing paper and digital documents. In 1996, XBS provided services at about 2,300 customer locations in the United States. It also serviced 2,000 accounts in 35 foreign countries. XBS has grown into a $2 billion business in less than five years. Revenues and profits have increased by more than 30 percent annually, and XBS's share of the U.S. document-outsourcing market has grown to 40 percent, nearly three times the share of its nearest competitor.

For virtually every business goal, customer requirement, and improvement target, there is an XBS process, measure, and expected result. The division's Senior Leadership Team achieves this clarity of organizational focus through "managing for results"—an integrated planning and management process that cascades action plans into measurable objectives for each manager, supervisor, and front-line associate. The entire process, the company says, is designed to "align goals from the customer's line of sight to the empowered employee and throughout the entire organization."

Yielding five-year and three-year strategic plans and a one-year operating plan, the process attends to the past, present, and future. To encourage organizational learning, for example, the Senior Leadership Team diagnoses the past year's business results and reassesses business practices. The reviews generate the "vital few"—priorities for process and operational improvements. XBS also develops strategic initiatives based

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[20] *Leadership Through Quality: The Way We Work*, Xerox, pages B6–B7.

[21] Malcolm Baldrige National Quality Award, 1997 Service Category Recipient, NIST/Baldrige Homepage Internet.

Circle the numeral 1, 2, 3, or 4 for each statement based on your perception of your manager's performance. SA—Strongly agree with the statement; A—Agree with the statement; D—Disagree with the statement; SD—Strongly disagree with the statement.

My manager frequently. . .	SA	A	D	SD
1. provides me with honest feedback on my performance	1	2	3	4
2. encourages me to monitor my own efforts	1	2	3	4
3. encourages me to make suggestions	1	2	3	4
4. provides me with an environment conductive to teamwork	1	2	3	4
5. gives me the information I need to do the job	1	2	3	4
6. clearly defines his/her requirements of me	1	2	3	4
7. acts as a positive role model for Leadership Through Quality	1	2	3	4
8. openly recognizes work well done	1	2	3	4
9. listens to Family Group members before making decisions affecting our area	1	2	3	4
10. makes an effort to solve my work-related problems	1	2	3	4
11. encourages the group to work as a team	1	2	3	4
12. informs our department regularly about the state of the business	1	2	3	4
13. displays an understanding of Xerox objectives and strategic directions	1	2	3	4
14. summarizes progress during meetings to seek understanding	1	2	3	4
15. encourages me to ask questions	1	2	3	4
16. asks questions to ensure understanding	1	2	3	4
17. encourages an environment of openness and trust	1	2	3	4
18. behaves in ways which demonstrate respect for others	1	2	3	4
19. makes an effort to locate and remove barriers that reduce efficiency	1	2	3	4
20. ensures regularly scheduled reviews of progress toward goals	1	2	3	4
21. monitors the quality improvement process	1	2	3	4
22. monitors department progress through competitive benchmarks	1	2	3	4
23. rewards those who clearly use the quality improvement process	1	2	3	4
24. sets of objectives based on customer requirements	1	2	3	4
25. uses the quality improvement process	1	2	3	4
26. uses the problem-solving process to solve problems	1	2	3	4
27. treats Leadership Through Quality as the basic Xerox business principle	1	2	3	4

on its understanding of the division's strengths and weaknesses as well as its reading of opportunities and threats. This analysis draws on the division's extensive competitive intelligence, "voice of the customer," and "voice of the market" information systems. Other inputs include benchmarking data and storyboarding scenarios, which help the division to refine future customer requirements, anticipate potential risks and challenges, and quantify the resources and action plans necessary to accomplish strategic goals. Strategic planning generates a "strategy contract," priorities for investment, and business partnership plans. These are distilled into a human resources plan, an investment plan, and operational plans for each organizational unit, customer account, and employee.

Through XBS's 10-Step Selling Process, on-site services are customized to meet the unique needs of each account. Dedicated account teams develop "standards of performance" according to customer service priorities. These standards, which XBS pledges to meet through its "total satisfaction guarantee," are formalized in operations handbooks developed specifically for each customer.

In addition to leading its competitors in overall customer satisfaction, the XBS division tops the industry in seven of the ten high motivators of customer satisfaction. Performance in all four key categories of customer requirements continues to improve; average scores in 1996 ranged from 8 to 9 on a 10-point grading scale.

Employee satisfaction has increased from 63 percent in 1993 to 80 percent in 1996, which is significantly higher that the average for a peer group of companies.

Summary

Senior leadership of an organization should set direction, create clear vision, inculcate customer focus, nurture values and set clear expectations to motivate employees and suppliers. Stephen Covey's *The Seven Habits of Highly Effective People* provides a foundation of ethical and principle centered leadership to drive TQM implementation. Deming's 14 points also provide guidance to decide the policies and direction.

It is critically important that leadership and senior management demonstrates their commitment and involvement through their actions for the success of TQM.

A quality committee consists of leadership and functional leaders. This committee establishes the objectives and roadmap and provides resources for TQM implementation.

Exercises

1. Define leadership.
2. Write a plan to implement TQM in a community college.
3. Working as an individual or in a team of three or more people, evaluate one or more of the following organizations concerning the role of the senior managers.
   (a) Large bank
   (b) Health-care facility
   (c) University academic department
   (d) University nonacademic department
   (e) Large department store
   (f) Grade school
   (g) Manufacturing facility
   (h) Large grocery store
4. Select one or more of Deming's 14 points and describe how you would achieve or implement it.
5. Develop a code of ethics for one of the organizations listed in Exercise 3.
6. Visit one of the organizations given in Exercise 3 and determine if they have a quality council or similar structure.
7. If the organization visited in Exercise 6 has a quality council, describe its composition and duties.
8. Working as an individual or in a team of three or more people, determine the quality statements for one or more of the organizations listed in Exercise 3.
9. Write a strategic planning goal and an annual objective.
10. Working as an individual or in a team of three or four people, write a strategic quality plan for one of the organizations listed in Exercise 3.

11. Working as an individual or in a team of three or four people, write an annual quality improvement program for one of the organizations listed in Exercise 3.
12. Working, as an individual or in a team of three or more people, write a communications plan for a small organization and one for a large organization. How do they differ?
13. Write your personal philosophy or creed.
14. Keep a record of your activities including time for a week. Place them in Covey's four quadrants, and analyze the results.
15. Give an example of a Win/Win and Win/Lose situation in your life.
16. Give an example of Covey's Habits 5 and 6.
17. Describe how a supervisor from one of the organizations listed in Exercise 3 measures up to the characteristics of leaders.
18. For one of the organizations listed in Exercise 3 and working as an individual or in a team, modify the leadership survey instrument, conduct the survey, and analyze the results.
19. Arrange the following habits in the correct sequence:

A	Think win-win
B	Sharpen the saw
C	Begin with the end in mind
D	Be proactive
E	Put first things first
F	Seek first to understand, then to be understood
G	Synergy

20. Which of the following is not a part of Deming's philosophy?

    (a) Constancy of purpose
    (b) Management by objectives
    (c) Drive fear
    (d) Abolish quotas

21. A study by Hendricks and Singhai revealed that companies which implemented TQM had

    (a) similar financial performance and growth as compared to those which did not implement TQM
    (b) better productivity than those which did not implement TQM
    (c) better growth in operating income and increase in sales than those which did not implement TQM
    (d) better labor relations than those which did not implement TQM

22. Which of the habits refer to the mission statement?

    (a) Think win-win
    (b) Begin with the end in mind
    (c) Put first things first
    (d) Be proactive

3

Customer Satisfaction

Chapter Objectives

- Understanding what is customer satisfaction
- Identifying the customer: internal and external
- Factors which influence customer satisfaction
- Measurement of customer satisfaction and dissatisfaction
- Service quality and customer satisfaction
- Role of leader and frontline people
- Understanding the Kano model

Introduction

The most important asset of any organization is its customers. An organization's success depends on how many customers it has, how much they buy, and how often they buy. Customers that are satisfied will increase in number, buy more, and buy more frequently. Satisfied customers also pay their bills promptly, which greatly improves cash flow—the lifeblood of any organization. The organizational diagram in Figure 3-1 best exemplifies just how important the customer is to any organization.

Increasingly, manufacturing and service organizations are using customer satisfaction as the measure of quality. The importance of customer satisfaction is not only due to national competition but also due to worldwide competition. This fact is reflected in Malcolm Baldrige National Quality Award where customer satisfaction has high importance in the criteria. Similarly, customer satisfaction standards are woven throughout ISO 9000: 2005. Customer satisfaction is one of the major purposes of a quality management system.[1]

Total Quality Management (TQM) implies an organizational obsession with meeting or exceeding customer expectations, so that customers are delighted. Understanding the customer's needs and expectations is essential to winning new business and keeping existing business. An organization must give its customers a quality product or service that meets their needs at a reasonable price, which includes on-time delivery and outstanding service. To attain this level, the organization needs to continually examine their quality system to see if it is responsive to ever-changing customer requirements and expectations.

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[1] Craig Cochran, "Customer Satisfaction: The Elusive Quarry," *Quality Digest* (November 2001): 45–50.

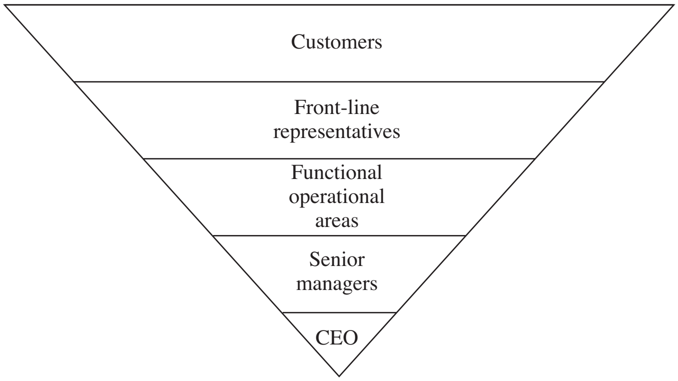

Figure 3-1 Customer Satisfaction Organizational Diagram

The most successful TQM programs begin by defining quality from the customer's perspective. As defined in Chapter 1, quality means meeting or exceeding the customer's expectations. Dr. Deming added that quality also means anticipating the future needs of the customer. Customer satisfaction, not increasing profits, must be the primary goal of the organization. It is the most important consideration, because satisfied customers will lead to increased profits.

A simplistic definition of customer satisfaction is illustrated by the Teboul model, which is shown in Figure 3-2. The customer's needs are represented by the circle, and the square depicts the product or service offered by the organization. Total satisfaction is achieved when the offer matches the need, or the circle is superimposed on the square. The goal is to cover the expected performance level better than the competitors.

That part of the square that lies within the circle is perceived by the customer as satisfying, and the part of the square outside the circle is perceived as unnecessary. It is important that the organization listen to the "voice of the customer" and ensure that its marketing, design, production, and distribution processes truly meet the expectations of the customer.

Customer satisfaction seems simple enough, and yet it is far from simple. Customer satisfaction is not an objective statistic but more of a feeling or attitude. Although certain statistical patterns can be developed to represent customer satisfaction, it is best to remember that people's opinions and attitudes are subjective by nature.

Because customer satisfaction is subjective, it is hard to measure. There are so many facets to a customer's experience with a product or service that need to be measured individually to get an accurate total picture of customer satisfaction. Whether or not a customer is satisfied cannot be classed as a yes or no answer. Errors can occur when customer satisfaction is simplified too much. The Teboul model, for instance, describes customer satisfaction as the degree to which the customer's experience of a service or product matches her expectations. Using this model, a customer's satisfaction level would be the same if the experience were mediocre in the context of low expectations, or if the experience were superior in the context of high expectations. Customer satisfaction's focus is creating superior experiences, not mediocre experiences.

Since customer satisfaction is hard to measure, the measurement often is not precise. As with most attitudes, there is variability among people, and often within the same person at different times.[2] Often, due to the difficulty of measuring feelings, customer satisfaction strategies are developed around clearly stated, logical customer opinions, and the emotional issues of a purchase are disregarded. This can be a costly mistake.

[2] Jarrett Rosenberg, "Five Myths About Customer Satisfaction," *Quality Progress* (December 1996): 57–60.

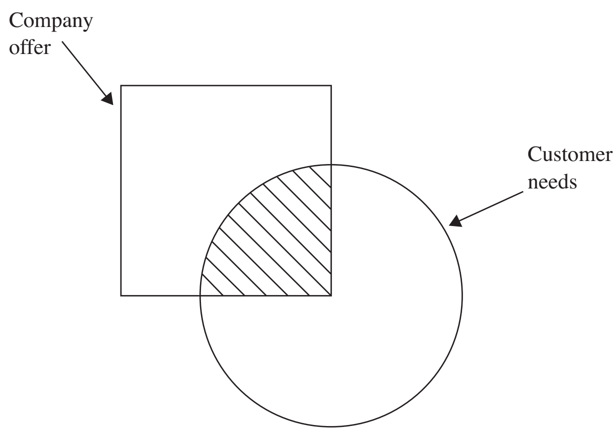

Figure 3-2 Customer Satisfaction Model
Reproduced, with permission, from James Teboul, *Managing Quality Dynamics* (Englewood Cliffs, N.J.: Prentice Hall, Hemel Hampstead, 1991).

Customer satisfaction should not be viewed in a vacuum. For example, a customer may be satisfied with a product or service and therefore rate the product or service highly in a survey, and yet that same customer may buy another product or service. It is of little benefit to understand a customer's views about a product or service if the customer's views about competitors' product or service are not understood. The value customers place on one product compared to another may be a better indicator of customer loyalty. Customer loyalty can be sustained only by maintaining a favorable comparison when compared with competitors.[3] As mentioned before customer satisfaction is not a simple concept to understand or to measure.

Who is the Customer?

There are two distinct types of customers—external and internal. An external customer can be defined in many ways, such as the one who uses the product or service, the one who purchases the product or service, or the one who influences the sale of the product or service. For instance, McDonald's determined the customer to be the child when they introduced their Happy Meals. The child never paid for the meals but the child influenced the sale. Oftentimes, parents purchase mobile phones and yet the teenage children use the mobile phones. The identity of the external customer is not always easy to determine.

An external customer exists outside the organization and generally falls into three categories: current, prospective, and lost customers. Each category provides valuable customer satisfaction information for the organization. Every employee in the organization must know how their job enhances the total satisfaction of the external customer. Performance must be continually improved in order to retain existing customers and to gain new ones.

An internal customer is just as important. Every function, whether it be engineering, order processing, or production, has an internal customer—each receives a product or service and, in exchange, provides a product or service. Every person in a process is considered a customer of the preceding operation. Each worker's goal is to make sure that the quality meets the expectations of the next person. When that happens throughout the manufacturing, sales, and distribution chain, the satisfaction of the external customer should be assured.

All processes have outputs, which are used by internal or external customers, and inputs, which are provided by internal or external suppliers. Each supplier performs work that produces some service or product

[3] Robert Gardner, "What Do Customers Value," *Quality Progress* (November 2001): 41–48.

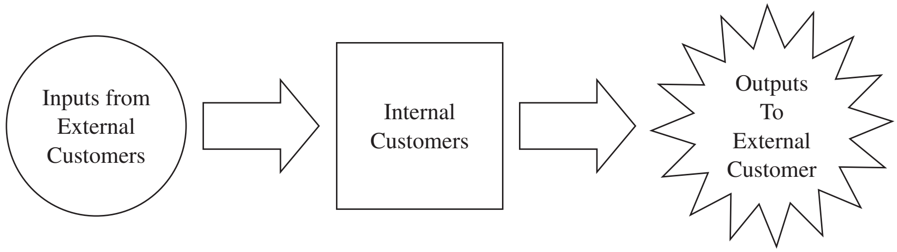

Figure 3-3 Customer/Supplier Chain

that is used by another customer. As shown by Figure 3-3, each forms a link in the customer/supplier chain, where every chain ends with an external customer and starts with an external supplier. Every employee throughout the organization is part of the chain of internal customers and suppliers.

One basic concept of TQM is an unwavering focus on customers, both internal and external. Most employees know about the external customer or end user but may not think of other employees as internal customers of their output.

In the ideal organization, every employee would have direct contact with customers and be effective at meeting their needs. But the reality is that most employees are shielded from customers by organizational layers. For example, the first-line supervisor in a computer factory may never speak with the businessperson who buys and depends on the organization's product. However, that supervisor and countless other employees who lack direct contact must still contribute to the businessperson's satisfaction.

The formula for successful internal customer/supplier relationships varies. But it always begins with people asking their internal customers three basic questions:[4]

1. What do you need from me?
2. What do you do with my output?
3. Are there any gaps between what you need and what you get?

The leader's role is to process work through the internal customer-supplier chain by helping workers guarantee that the end product or service fully satisfies the end user. Rather than strive for personal objectives, each individual or group must identify and satisfy the internal customer(s) while fostering a team effort where all people help the organization. Each department must determine what activities are important to both external and internal customers and manage quality every step of the way. All quality management systems start with the basic need of ensuring that the external customer's requirements are adequately documented. Similarly, the organization must document explicitly what each internal customer expects. In addition, clear criteria must be provided for measuring success in meeting the expectations of both internal and external customers.

Customer Perception of Quality

One of the basic concepts of the TQM philosophy is continuous process improvement. This concept implies that there is no acceptable quality level because the customer's needs, values, and expectations are constantly changing and becoming more demanding.

Before making a major purchase, some people check consumer magazines that rate product quality. During the period 1980 to 1988, the quality of the product and its performance ranked first, price was second, and

[4] George H. Labovitz, "Keeping Your Internal Customers Satisfied," *Wall Street Journal* (July 6, 1987): 12.

service was third. During the period 1989 to 1992, product quality remained the most important factor, but service ranked above price in importance.

An American Society for Quality (ASQ) survey on end user perceptions of important factors that influenced purchases showed the following ranking:

1. Performance
2. Features
3. Service
4. Warranty
5. Price
6. Reputation

The factors of performance, features, service, and warranty are part of the product or service quality; therefore, it is evident that product quality and service are more important than price. Although this information is based on the retail customer, it appears, to some extent, to be true for the commercial customer also.

Performance

Performance involves "fitness for use"—a phrase that indicates that the product and ser-vice is ready for the customer's use at the time of sale. Other considerations are (1) availability, which is the probability that a product will operate when needed; (2) reliability, which is freedom from failure over time; and (3) maintainability, which is the ease of keeping the product operable.

Features

Identifiable features or attributes of a product or service are psychological, time-oriented, contractual, ethical, and technological. Features are secondary characteristics of the product or service. For example, the primary function of an automobile is transportation, whereas a car stereo system is a feature of an automobile.

Service

An emphasis on customer service is emerging as a method for organizations to give the customer-added value. However, customer service is an intangible—it is made up of many small things, all geared to changing the customer's perception. Intangible characteristics are those traits that are not quantifiable, yet contribute greatly to customer satisfaction. Providing excellent customer service is different from and more difficult to achieve than excellent product quality. Organizations that emphasize service never stop looking for and finding ways to serve their customers better, even if their customers are not complaining. For instance, at Baptist Hospital in Pensacola, FL, janitors, after cleaning a room, ask if there is anything they can do for the patient. Often patients will have a request for a window shade to be drawn or a door closed.[5]

Warranty

The product warranty represents an organization's public promise of a quality product backed up by a guarantee of customer satisfaction. Ideally, it also represents a public commitment to guarantee a level of service sufficient to satisfy the customer.

[5] 2000 RIT/USA Today Quality Cup for Health Care.

A warranty forces the organization to focus on the customer's definition of product and service quality. An organization has to identify the characteristics of product and service quality and the importance the customer attaches to each of those characteristics. A warranty generates feedback by providing information on the product and service quality. It also forces the organization to develop a corrective action system.

Finally, a warranty builds marketing muscle. The warranty encourages customers to buy a service by reducing the risk of the purchase decision, and it generates more sales from existing customers by enhancing loyalty.

Price

Today's customer is willing to pay a higher price to obtain value. Customers are constantly evaluating one organization's products and services against those of its competitors to determine who provides the greatest value. However, in our highly-competitive environment, each customer's concept of value is continually changing. Ongoing efforts must be made by everyone having contact with customers to identify, verify, and update each customer's perception of value in relation to each product and service.

Reputation

Most of us find ourselves rating organizations by our overall experience with them. Total customer satisfaction is based on the entire experience with the organization, not just the product. Good experiences are repeated to six people and bad experiences are repeated to 15 people; therefore, it is more difficult to create a favorable reputation.

Customers are willing to pay a premium for a known or trusted brand name and often become customers for life. Because it costs five times as much to win a new customer as it does to keep an existing one, customer retention is an important economic strategy for any organization. Although it is difficult for an organization to quantify improved customer satisfaction, it is very easy to quantify an increase in customer retention. Investment in customer retention can be a more effective bottom-line approach than concentrating on lowering operational costs. An effective marketing retention strategy is achieved through using feedback from information collecting tools.

Feedback

Customer feedback must be continually solicited and monitored. Customers continu-ally change. They change their minds, their expectations, and their suppliers. Customer feedback is not a one-time effort; it is an ongoing and active probing of the customers' mind. Feedback enables the organization to:

Discover customer dissatisfaction.

Discover relative priorities of quality.

Compare performance with the competition.

Identify customers' needs.

Determine opportunities for improvement.

Even in service industries, such as insurance and banking, customer feedback has become so important that it drives new product development. There are programs to identify and analyze errors, take corrective action, and make ongoing enhancements. All these efforts are justified when the consumers' expectation levels are very high. Effective organizations take the time to listen to the voice of the customer and feed that information back to the idea stage. For instance, listening to the voice of the customer changed how the Internal Revenue Service does business. Previously, the IRS thought that good customer service was mailing tax forms out right after New Year's Day. Then, the IRS asked its customers what good customer service was. The IRS found out that the customers wanted fast refunds and very little contact with the IRS. Now, about 20 million taxpayers can forget using the 1040EZ form and file on their touch-tone phone. There is no contact with the IRS, it takes about six minutes, and the phone system does the math. Refunds are received within 21 days.[6]

Listening to the voice of the customer can be accomplished by numerous information-collecting tools. The principal ones are comment cards, questionnaires, focus groups, toll-free telephone lines, customer visits, report cards, the Internet, employee feedback, mass customization and the American Customer Satisfaction Index.

Comment Card

A low-cost method of obtaining feedback from customers involves a comment card, which can be attached to the warranty card and included with the product at the time of purchase. The intent of the card is to get simple information, such as name, address, age, occupation, and what influenced the customer's decision to buy the product. However, there is very little incentive for buyers to respond to this type of card, and the quality of the response may not provide a true measure of customers' feelings. Generally, people respond only if something very good or very bad has happened. Comment cards are also used in the hospitality industry. Restaurants and hotels provide them at the ends of tables and in hotel rooms. They can even be found on the bottom of restaurant sales receipts. Often, free meals or hotel stays are provided to rectify a poor experience noted on a comment card. Free meals and hotel stays can generate significant customer loyalty provided the organization also fixes the problem.[7]

Customer Questionnaire

A customer questionnaire is a popular tool for obtaining opinions and perceptions about an organization and its products and services. However, they can be costly and time-consuming. Surveys may be administered by mail or telephone. In the form of questionnaires, the customer is asked to furnish answers relating to the quality of products and services. Most surveys ask the customer to grade the question on a one-to-five scale or a one-to-ten scale, where the highest number typically has a description like "highly satisfied." One of the reasons the one-to-five or one-to-ten scale is used is because it easily produces a metric. For example, see Figure 3-4 the Spouse Satisfaction Survey.

Although the "1 to 5" scale is a typical approach to surveys, it probably is not entirely effective. It does not tell the surveyor how important trash removal is relative to other qualities, nor does it tell the surveyor what the spouse wants or expects. See Figure 3-5 for a better way to do a Spouse Satisfaction Survey.

Although the most detailed and most useful information may come from a mail survey, the results are usually not representative of a normal population. This result occurs because the only people who will take the time to fill out a survey are those who feel very strongly about a subject and, therefore, tend to be biased. To further enhance a mail survey, the survey may be followed up with a phone call to nonresponders.

To make surveys more useful, it is best to remember eight points.

1. Clients and customers are not the same.
2. Surveys raise customers' expectations.

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[6] National Performance Review Staff, "Making the Big U-Turn," *Quality Progress* (March 1996): 59–62.

[7] Cochran.

	Highly Satisfied		Neutral	Highly Dissatisfied	
1. Trash removal	5	4	3	2	1
2. Personal hygiene	5	4	3	2	1
3. Lawn maintenance	5	4	3	2	1
4. Romance	5	4	3	2	1
5. Thoughtfulness	5	4	3	2	1
6. Listening skills	5	4	3	2	1
7. Faithfulness	5	4	3	2	1
8. Respect for mother-in-law	5	4	3	2	1
9. Overall, how satisfied are you with your marriage?	5	4	3	2	1

Figure 3-4 Spouse Satisfaction Survey—Typical Approach
Reproduced with permission of International Management Technologies, Inc., www.imtc3.com, based on Creating a Customer-Centered Culture: Leadership in Quality, Innovation and Speed (1993, Quality Press).

3. How you ask a question will determine how the question is answered.
4. The more specific the question, the better the answer.
5. You have only one chance and only 15 minutes.
6. The more time you spend in survey development, the less time you will spend in data analysis and interpretation.
7. Who you ask is as important as what you ask.
8. Before the data are collected, you should know how you want to analyze and use the data.

Clients are the people for whom you are doing the survey, and customers are the ones who use the product or service. The customers must be surveyed to provide information for the clients to take action. It is important to note that customer satisfaction surveys are different from traditional public-opinion polls. For instance, public-opinion polls are based on respondent anonymity, whereas customers don't necessarily want to remain anonymous. Customer satisfaction surveys need to be sensitive to the management of customer relationships, which is not necessary when doing traditional public-opinion polls. "Customer satisfaction survey respondents are more than survey participants, they are cherished customers of an organization. Their relationship with the organization should be strengthened as a result of the survey, not taxed."[8]

Surveys should focus on what is within the client's abilities or desires to accomplish because surveys do raise customers' expectations. For instance, an employee survey that asks employees what would be a good internal reward system creates expectations in the employee that a reward system will be instituted in some

[8] Terry G. Vavra, "Is Your Satisfaction Survey Creating Dissatisfied Customers?" *Quality Progress* (December 1997): 51.

Trash removal

1. How often do you expect the trash to be taken out by your spouse?
_____ Not at all _____ Daily _____ When it's full _____ When reminded
_____ When the stench arouses the anger of the neighbors

2. How often would you like the trash to be taken out by your spouse?
_____ Not at all _____ Daily _____ When it's full _____ When reminded
_____ When the stench arouses the anger of the neighbors

3. How often is the trash taken out by your spouse?
_____ Not at all _____ Daily _____ When it's full _____ When reminded
_____ When the stench arouses the anger of the neighbors

4. How satisfied are you with your spouse's trash removal?
_____ Very Dissatisfied _____ Dissatisfied _____ Neutral _____ Satisfied
_____ I fantasize about it

On a scale of 1 to 8, please rank the importance of the following to the happiness of your marriage, where 1 equals most important.

_____ Trash removal	_____ Thoughtfulness
_____ Personal hygiene	_____ Listening skills
_____ Lawn maintenance	_____ Faithfulness
_____ Romance	_____ Respect for mother-in-law

Figure 3-5 Spouse Satisfaction Survey—The Right Way
Reproduced with permission of International Management Technologies, Inc., www.imtc3.com, based on Creating a Customer-Centered Culture: Leadership in Quality, Innovation and Speed (1993, Quality Press).

form by the company. If the company has no intention of instituting an employee internal reward system, then this question should not be asked. Raising expectations and then doing nothing only serves to disappoint or anger customers. If at all possible, customer survey participants should be informed of the survey results and the changes implemented to remedy problems.

There are different categories of questions that provide different types of information. For instance, a question that begins with "Do you like Chinese food?" provides information on a customer's feelings or attitudes, whereas a question that asks, "How often do you dine out?" provides information on a customer's behavior. Information on a customer's knowledge about the product can be obtained by a question that has only one correct answer (for instance, "Is there a McDonald's within five miles of your house?"). The type of question asked will determine the type of information received.

Likewise, the more specific the question, the better the answer. If the question asked is too broad, it will provide scattered answers. For example, "How would you improve food?" can produce answers ranging from "reduce the cost" to "cook everything in butter." A more tailored question gives the customer a focus for the kind of information that you are interested in. However, questions should be carefully crafted so that the marketing people do not contaminate the questions (and thereby the answers) with their own thinking. The survey should determine what customers think is important, not what the organization thinks is important.

Customers are giving their most precious commodity when they fill out a survey—their time. The very most a customer will give of their time is 15 minutes. Customers who send back a survey should be thanked profusely for their time. Surveyors sometimes include one dollar along with the survey as a token measure of their gratitude.

When writing a survey, it is best to remember that more multiple-choice questions can be answered in 15 minutes than open-ended questions. To illustrate this point, compare the following multiple-choice question to the open-ended question.

How many times do you dine out in a month?

a. 1–2 times
b. 3–5 times
c. 6–10 times
d. more than 10 times

The open-ended question requires the customer to calculate the answer, which takes more time. If an exact answer is required, then the open-ended question should be asked even though it takes more time to answer. However, if a good estimate does not compromise your data needs, then the multiple-choice question may be better. Whether the client wants yes or no information or more detailed information will determine the type of questions asked. In summary, how the data is going to be used will determine how the questions will be asked.

Who are asked the survey questions is just as important as what is asked. The customers in a sample should be chosen to best represent the population so that inferences can be made about the population. Customers who can be surveyed are either current customers, past customers, potential customers, or competitors' customers.

Customer surveys should also measure a customer's views of the competition's performance. It is more useful for an organization to know that it has gained points relative to the competition than it is to know that its customers have gone from "somewhat satisfied" to "satisfied." For example, Apple's Macintosh computer has extraordinarily satisfied customers, yet the company's market share continues to decline.[9] A company needs to survey its competitor's customers.

Surveys can be data rich but information poor. The next step is to sift through all the data to get to the useful information. The collected data must be turned into actionable information. The survey analysis must not only identify problems and opportunities; it must also suggest the magnitude of the customer base at risk and the revenue implication of inaction. The final analysis should yield a specific course of action.[10,11,12]

A second method of administering a survey involves telephoning customers. Almost everyone has a few minutes to answer questions on the telephone. Rapidly changing telecommunications are creating customer information instantly. The Gallup organization has developed an automated, voice-gathering polling service called the Gallup 800 Survey. Organizations can now effectively reach large populations, analyze the results quickly, and determine what their customers are thinking on a near real-time basis. The survey consists of a series of multiple-choice questions that provide information for a customized report, which includes recommendations. Results are available within 24 hours.

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[9] Ken Miller, "Are Your Surveys Only Suitable for Wrapping Fish?" *Quality Progress* (December 1998): 47–51.

[10] Vavra.

[11] Glenda Nogami, "Eight Points for More Useful Surveys," *Quality Progress* (October 1996): 93–96.

[12] Karl Albrecht, "The Use and Misuse of Surveys," *Quality Digest* (November 1994): 21–22.

Focus Groups

Customer focus groups are a popular way to obtain feedback, but they too can be very expensive. These groups are very effective for gathering information on customer expectations and requirements.

Surveying a focus group is a research method used to find out what customers are really thinking. A group of customers is assembled in a meeting room to answer a series of questions. These carefully structured questions are asked by a skilled moderator, who probes into the participants' thoughts, ideas, perceptions, or comments. The moderator has a clear understanding of the type of information wanted and a plan for obtaining it. Meetings are designed to focus on current, proposed, and future products and services. The people selected to participate have the same profile as the customers that the organization is trying to attract. As an incentive to participate, these people are reimbursed for their time. Focus groups are sometimes used with an organization's employees to examine internal issues.

Imprint analysis is an emerging technique used in focus groups. This is a good way to obtain the intrinsic feelings associated with a product or service. Feelings are not as easily obtained from customer questionnaires, because customers often hold back information on surveys. Word association, discussions, and relaxation techniques can identify a customer's emerging needs, even if the participants are unable to directly articulate those needs. Imprint analysis helps in understanding the human emotions involved in a purchase decision. For instance, a major ice cream company discovered through customer satisfaction surveys that their customers wanted to eat healthier. Before implementing a line of low fat ice cream, the company decided to do an imprint analysis. The imprint analysis discovered that these customers would consume low fat foods and deprive themselves of desserts during the week. But, on the weekends, these same people wanted a super rich ice cream, containing more fat than any ice cream presently on the market. These customers wanted to reward themselves for eating healthy during the week. Needless to say, the ice cream company launched a new, full fat and extra creamy product and sold it at a premium. Their market share increased significantly, creating many loyal customers due to the extra insight that the imprint analysis provided.[13]

Toll-Free Telephone Numbers

Toll-free (1800/1600) telephone numbers are an effective technique for receiving complaint feedback. Organizations can respond faster and more cheaply to the complaint. Such a number does not, however, reach those who decided not to buy the product or those who discovered some likable feature on a competitor's product. Toll-free numbers are in use by at least 50% of all organizations with sales of at least $10 million.

Implementation of toll-free numbers has increased tremendously in India and many other developing countries, thanks to the revolution in telecommunication that was triggered after the appointment of Dr. Sam Pitroda as advisor to the Indian Prime Minister Rajiv Gandhi in 1987. Today mobile networks are extensively used for marketing purposes and mass communication.

Customer Visits

Visits to a customer's place of business provide another way to gather information. An organization can proactively monitor its product's performance while it is in use and thereby identify any specific or recurring problems. Senior managers should be involved in these visits and not delegate them to someone else. However, it is

[13] Cristina Afors and Marilyn Zuckerman Michaels, "A Quick Accurate Way to Determine Customer Needs," *Quality Progress* (July 2001): 82–87.

a good idea to take along operating personnel so they can see firsthand how the product is performing. One site visit L-S Electro Galvanizing Company made to its customer, General Motors, produced a surprisingly simple idea. An arrow was needed on the finished 25-ton rolls of steel to show which way the steel unrolled. Previously, GM employees had to guess and often times had to resummon a crane to turn the roll around, which wasted 30 minutes.[14] Another example of a productive customer visit is when U.S. Steel sent an hourly worker, who applied anti-corrosion coating, to the Ford auto plant that used their steel. The worker found flaking zinc and knew there was too much zinc buildup on the edges of the steel. The rods that trimmed the steel were not properly aligned. U.S. Steel also discovered that Ford was wasting steel and money by scraping the bottom sheet of each pile of steel. Ford mistook the harmless white residue on the bottom sheets for rust, when in fact the residue was caused by tremendous pressure from the heavy pile and could easily be wiped off.[15]

The organization should also continually keep informed about new developments in the customer's industry by reading their journals and attending their conferences. Brainstorming sessions with the customers about future products and services should be held at least annually.

Report Card

Another very effective information-gathering tool is the report card. Figure 3-6 shows a typical one. It is usually sent to each customer on a quarterly basis. The data are analyzed to determine areas for improvement. For instance, the University of California in San Diego uses a report card to grade the quality of campus business services, such as the payroll department and the bookstore.[16]

The Internet and Computers

Some managers are beginning to monitor discussions that take place on the Internet to find out what customers are saying about their products. Internet users frequently seek advice regarding their everyday activities or activities related to specific interests, hobbies, or sports. Newsgroups, electronic bulletin boards, and mailing lists can be scanned using keyword searches if one knows that a company's product is of interest to participants in certain activities, hobbies, or professions. Ideally, messages that compare a company's products with those of its competitors can be uncovered. In the newsgroups it is best to read the views and discussions of others and not intervene in the discussion with the organization's perspective on the product or ser-vice. Intervening will most likely end the discussion. Monitoring Internet conversations is timely, the cost is minimal, and it can be a source of creative ideas. One of the drawbacks of monitoring Internet conversations, however, is that the conversations can be unfocused.[17]

There are even Internet sites that take consumer complaints and compliments about businesses and gives organizations grades based on their ratio of complaints to compliments. Planetfeedback.com also sends letters to companies on behalf of consumers. The organization's web page also provides an easy way for customers to e-mail the company with their thoughts on the organization's products and services.

Computers can be used to detect patterns in seemingly chaotic data. For instance, the sales data from a convenience store chain showed that the peak hours for selling diapers and for selling beer were the same. The diapers were put next to the beer and sales increased for both.[18]

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[14] 1992 RIT/USA Today Quality Cup for Small Business.

[15] 1992 RIT/USA Today Quality Cup for Manufacturing.

[16] 1999 RIT/USA Today Quality Cup for Education.

[17] Byron J. Finch, "A New Way to Listen to the Customer," *Quality Progress* (May 1997): 73–76.

[18] Virginia Baldwin Hick, "Technology is Redefining the Meaning of Customer Service," *St. Louis Post Dispatch* (May 1, 1999): Business Section 26.

QUARTERLY REPORT CARD

To our Customers:

We are continually striving to improve. To assist us in this endeavor, we need your feedback. Would you please grade our performance in each category? The grading scale is

A = Excellent
B = Very Good
C = Average
D = Poor
F = Failing

I. PRODUCT QUALITY Grade _____
Comments: ____

II. ON-TIME DELIVERY Grade _____
Comments: ____

III. SERVICE Grade _____
Comments: ____

IV. OVERALL Grade _____
Comments: ____

Signed ______________________________ Date ____________
Title ____________________ Organization ______________

Figure 3-6 Sample Report Card

Employee Feedback

Employees are often an untapped source of information. Companies are listening more to the external customer but still are not listening to employees. Employees can offer insight into conditions that inhibit service quality in the organization. Employee groups can brainstorm ideas to come up with solutions to problems that customers have identified.

Although customer research reveals what is happening, employee research reveals why it is happening. Employee feedback should be proactively solicited, instead of checking the wooden suggestion box once a year.[19] For instance, Chrysler regularly surveys employees for issues, because employee surveys are timely compared to customer surveys. When staff members cannot get what they need or have low morale, then they cannot provide good service. Chrysler requires that management share the survey results with employees and uses the findings to make substantial changes.

[19] Stanley G. Aman, "The Essence of TQM: Customer Satisfaction," *Journal of Industrial Technology* (Summer 1994): 2–4.

Mass Customization[20]

The ultimate in customer satisfaction is giving customers exactly what they want. In the past, the price tag for this was prohibitive, but mass customization is a way to provide variety at an affordable cost. Mass customization is a direct result of advances made in manufacturing, such as flexible manufacturing technologies, just-in-time systems, and cycle time reduction. It has been done in the car industry for years. Customers determine what type of seat coverings, color, and stereo system they want. Mass customization is now being used in many other industries. For instance, Levi Strauss customers are measured for jeans, choose the fabric, and choose the pattern at a local store. The custom fit jeans are then manufactured to order at a central factory and sent to the local store. The voice of the Levi Strauss customer is heard at the fabrication stage of production. Dell assembles computers according to each customer's requirements by adding or subtracting components from one of several base systems. In this way, customers get the computer they want at a reasonable price through mass customization at the assembly stage. Modular furniture is a customized product at the delivery stage. Different customers can adapt modular furniture to meet their changing needs long after the initial purchase.

The voice of the customer can be captured in mass customized products by using the hard data of what the customer bought instead of what the customer was thinking about buying. The customer satisfaction information obtained from mass customization can be used to provide more standardized products. The voice of the purchasing customer, however, provides no information about the non-purchasing customer. See Figure 3-7 to better understand the customer's involvement in mass customization.

The American Customer Satisfaction Index[21]

The American Customer Satisfaction Index (ACSI), established in 1994 as a joint project between the University of Michigan and the American Society for Quality, quantifies quality and customer satisfaction and relates them to firms' financial performance. Firms can now measure the value that increased customer satisfaction adds to the bottom line. ACSI looks at products sold in the United States and not just those produced in the United States. In this way, the United States' quality is compared to international quality.

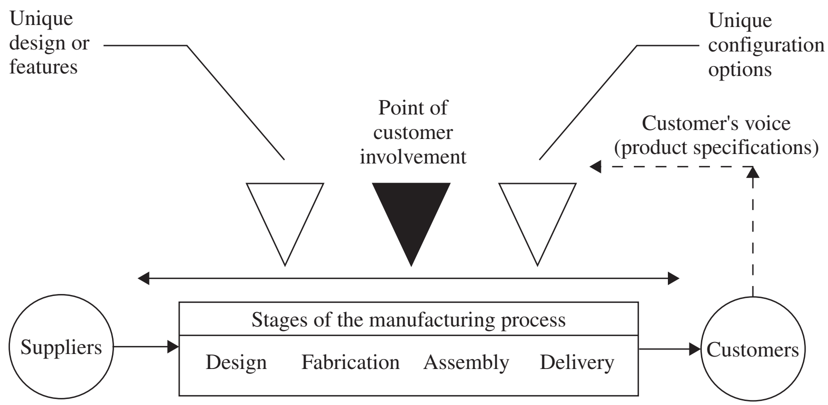

Figure 3-7 Point of Customer Involvement

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[20] This section adapted, with permission, from Rebecca Duray and Glenn W. Milligan, "Improving Customer Satisfaction through Mass Customization," *Quality Progress* (August 1999): 60–66.

[21] Jon Brecka, "The American Customer Satisfaction Index," *Quality Progress* (October 1994): 41–44.

ACSI reports scores on a 0–100 scale at the national level. It also produces indexes for 10 economic sectors, 44 industries (including e-commerce and e-business) and for more than 200 companies and federal or local government agencies. The measured companies, industries and sectors are broadly representative of the U.S. economy serving American households. Smaller companies are grouped together in an "All Others" category for each industry. The ten sectors of the economy are:

1. Transportation and warehousing
2. Manufacturing (nondurable)
3. Manufacturing (durables)
4. Healthcare and social assistance
5. Accommodation and food services
6. Information
7. Public administration/government
8. Retail trade
9. Finance and insurance
10. E-commerce

Each sector has industries, and under each industry are specific companies. For example, under the nondurable manufacturing sector is the industry soft drinks. Under the industry soft drinks are Coca Cola, Pepsi, and various other companies. ACSI score structure is regularly reviewed and updated to add newer sectors and industries. Whenever new sectors are added, the year of addition is taken as baseline scores. Sector, industry, and company ACSI scores can be found on ASQ's website at www.asq.org. See Table 3-1 for a yearly comparison of scores in some of the industries.

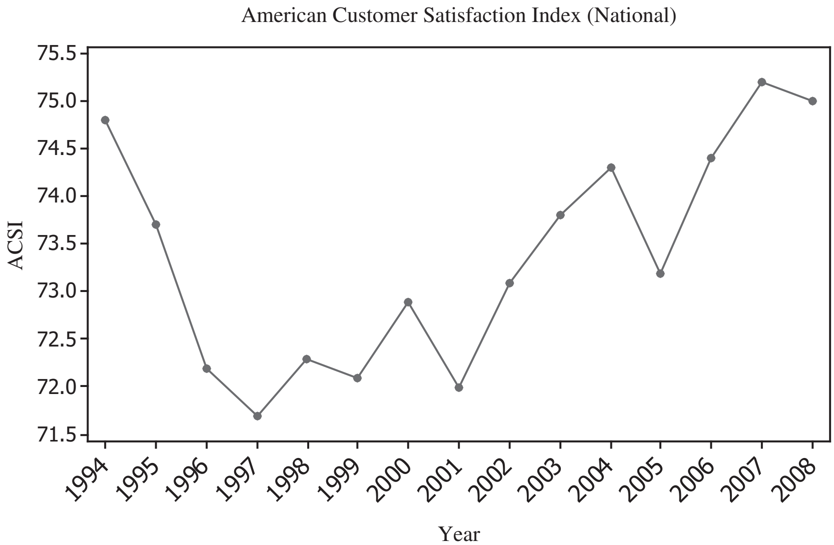
The ACSI allows comparisons between individual firms, comparisons between firms and the industry average, and comparisons over time. The ACSI is considered to be one of the forecasts of consumer spending in the United States. There is a strong correlation between ACSI changes in one quarter and changes in consumer spending in the next quarter. It can be observed that satisfaction ratings for airlines are the lowest among all industries and have dropped by 13.9% since the baseline of 1994. Internet portals and search engines have recorded an improvement of 27% over the baseline of 2000! Other industries recording moderate gains are health and insurance, wireless telephone service and automobiles/light vehicles.

Customer Satisfaction Surveys in India

An elaborate and structured customer satisfaction measurement similar to ASCI does not happen in India and many other countries. Independent companies such as J. D. Power Asia Pacific have been conducting surveys in automotive industry in India. According to the survey of service quality at dealers carried out in 2008, Maruti has been ranking highest in automotive customer satisfaction with authorized dealer service in India for nine consecutive years. This survey measures satisfaction among vehicle owners who visited their authorized dealership service centre for maintenance or repair work during the first 12 to 18 months of ownership, which typically represents the warranty period. Overall, satisfaction is determined by examining seven measures (listed in order of importance): problems experienced; service quality; user-friendly service; service advisor; service initiation; service delivery; and service experience.

According to 2009 J. D. Power Asia Pacific India *Vehicle Dependability Study*, Ford models rank highest in the entry midsize and SUV segments and Toyota models rank highest in the premium midsize and MUV/MPV segments. Honda and Maruti models also earned highest-ranking achievements in other

ACSI National Scores (*)



(*) Third quarter measures for every year

TABLE 3-1

National and Industry ACSI Scores

Industries	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*Previous Year % Change*	*First Year % Change*	*Baseline Year*
Airlines	61	66	67	66	66	65	63	62	–1.6%	–13.9%	1994
Automobiles & light vehicles	80	80	80	79	80	81	82	82	0.0%	3.8%	1994
Banks	72	74	75	75	75	77	78	75	–3.8%	1.4%	1994
Electronics (TV VCR DVD)	81	81	84	82	81	80	83	83	0.0%	0.0%	1994
Food manufacturing	82	81	81	81	82	83	81	83	0.0%	0.0%	1994
Health insurance	68	69	70	67	68	72	71	73	2.8%	7.4%	2001
Hospitals	68	70	73	76	71	74	77	75	–2.6%	1.4%	1994
Hotels	71	71	73	72	73	75	71	75	5.6%	0.0%	1994
Internet portals & Search engines	65	68	71	72	76	77	75	80	6.7%	27.0%	2000
Soft drinks	82	85	84	83	83	84	84	83	–1.2%	–3.5%	1994
Supermarkets	75	75	74	73	74	75	76	76	0.0%	0.0%	1994
Wireless telephone service	NM	NM	NM	65	63	66	68	68	0.0%	4.6%	2004
National	72.0	73.1	73.8	74.3	73.2	74.4	75.2	75.0	–0.3%	1.8%	1994

Source: http://www.theacsi.org.

segments. The study, which measures the dependability of three-year-old vehicles, ranks vehicles in 10 segments and examines more than 150 problem symptoms across nine categories: vehicle exterior; driving experience; features, controls and displays; audio and entertainment; seats; heating, ventilation and cooling (HVAC); vehicle interior; engine; and transmission. Overall, dependability is based on the number of problems reported per 100 vehicles, with lower scores indicating a lower rate of problem incidence and higher long-term vehicle quality.

J. K Tyre ranks highest in customer satisfaction with original equipment tires in India, according to the J. D. Power Asia Pacific 2009 India Original Equipment Tire Customer Satisfaction Index (TCSI). With an overall score of 811 on a 1,000-point scale, J. K Tyre performed particularly well in all factors that drive overall satisfaction. MRF followed the ranking with 804 points.

In the survey of auto insurance companies conducted in 2009, ICICI Lombard ranked highest in customer satisfaction with auto insurance providers, according to the J. D. Power Asia Pacific 2009 India Auto Insurance Customer Satisfaction Index (AIS). The inaugural study measures auto insurance policy holder experiences with their primary insurers. Customer satisfaction is measured across six factors: interaction; claims; product/policy offerings; renewal/purchase of policy; billing and payment process; and premium/price for coverage offered. ICICI Lombard ranks highest with a score of 775 on a 1,000-point scale, performing particularly well in three factors: product/policy purchase experience; product/policy offerings; and premium/price for coverage offered. The Oriental Insurance follows closely in the rankings with 772. Overall, satisfaction across the industry averages 761.[22]

Using Customer Complaints

For the most part, the information on feedback given in the previous section is proactive. Although complaints are reactive, they are very vital in gathering data on customer perceptions. A dissatisfied customer can easily become a lost customer. Many organizations use customer dissatisfaction as the primary measure to assess their process improvement efforts.

Table 3-2 shows information from a survey conducted by ASQ of dissatisfied customers. Only about 1.5% took the time to complain to management, about 20% took out their dissatisfaction on front-line personnel, and almost 80% did nothing. This data indicates that it is very easy for management to perceive that customers are satisfied with the product or service. Actually, when satisfied customers are included in the data, the number of formal complaints to management is much lower than 1.5%. Frequently, dissatisfied customers switch to a competitor and don't say anything. For this reason, the customers who don't complain are the ones who should worry an organization the most. The average organization takes its customer base for granted, assuming that no complaints is good news. Every single complaint should be accepted, analyzed, and acted upon, for it represents the tip of the iceberg.

Small organizations have a tremendous advantage in this area, because the top ranking officer is often in personal contact with key customers. Thus, information on customer dissatisfaction is received into the organization at the highest level, thereby providing a fast response.

Results of another study indicated that more than half of dissatisfied customers will buy again if they believe their complaint has been heard and resolved. Only 20% will buy again if their complaint is heard but not resolved. Fewer than 10% will be repeat buyers when a complaint is not heard. And even though such complaints may not reach the organization's management, they do reach other potential customers.

[22] http://businesscenter.jdpower.com/news/pressrelease.aspx?ID=2009096

TABLE 3-2
Survey of Dissatisfied Customers

	COMPLAIN TO		
Product	***Management***	***Front-line***	***No One***
Auto	2%	21%	77%
Mail order	1%	22%	77%
Groceries	1%	15%	84%
Clothing	0%	13%	87%
Home repair	4%	21%	74%
Appliances	0%	12%	88%
Auto repair	1%	28%	71%

By taking a positive approach, complaints can be seen as an opportunity to obtain information and provide a positive service to the customer. In reality, the customer is giving the organization a second chance. Some actions organizations can take to handle complaints are as follows:

- Investigate customers' experiences by actively soliciting feedback, both positive and negative, and then acting on it promptly.
- Develop procedures for complaint resolution that include empowering front-line personnel.
- Analyze complaints, but understand that complaints do not always fit into neat categories.
- Work to identify process and material variations and then eliminate the root cause. "More inspection" is not corrective action.
- When a survey response is received, a senior manager should contact the customer and strive to resolve the concern.
- Establish customer satisfaction measures and constantly monitor them.
- Communicate complaint information, as well as the results of all investigations and solutions, to all people in the organization.
- Provide a monthly complaint report to the quality council for their evaluation and, if needed, the assignment of process improvement teams.
- Identify customers' expectations beforehand rather than afterward through complaint analysis.

Ninety percent of all customer contact comes through an organization's front-line employees. A petty complaint voiced to a front-line employee often becomes a major complaint when it gets to the management level.

An organization can save both customers and money by training front-line employees to solve problems directly with customers. Customers want problems solved quickly and efficiently; therefore, employees should know how to handle a wide range of situations that arise in the customer relationship. Customer focus and listening skills are not easily learned. Training becomes a top management priority, because front-line employees must have the skills to encourage customers to discuss their complaints and deal with them. Recognition and reward should be linked to service quality performance and the ability to satisfy customers. Front-line employees should have the responsibility and authority to provide the services necessary to satisfy the customer.

For example, a cashier in a restaurant should be empowered to discount the meal price of a dissatisfied customer without seeking management's approval. Management should encourage employees to take risks, make decisions, and not be afraid of making a mistake.

Studies have shown that the better the service at the point of sale, the fewer the complaints and the greater the sales volume. Employees who are dissatisfied with their organization are as noticeable as dissatisfied customers. It's just as important to focus on employee satisfaction as customer satisfaction. A measurement system is necessary to evaluate the improvement in customer satisfaction.

Service Quality

Strategies that have produced significant results in production are often harder to implement in a service environment. Thanks to the teachings of Deming, Juran, and others, significant strides have been made in manufacturing. The same results have been slower in service organizations or service activities in manufacturing.

Customer service is the set of activities an organization uses to win and retain customers' satisfaction. It can be provided before, during, or after the sale of the product or exist on its own. Elements of customer service are:

Organization

1. Identify each market segment.
2. Write down the requirements.
3. Communicate the requirements.
4. Organize processes.
5. Organize physical spaces.

Customer Care

6. Meet the customer's expectations.
7. Get the customer's point of view.
8. Deliver what is promised.
9. Make the customer feel valued.
10. Respond to all complaints.
11. Over-respond to the customer.
12. Provide a clean and comfortable customer reception area.

Communication

13. Optimize the trade-off between time and personal attention.
14. Minimize the number of contact points.
15. Provide pleasant, knowledgeable, and enthusiastic employees.
16. Write documents in customer-friendly language.

Front-line people

17. Hire people who like people.
18. Challenge them to develop better methods.
19. Give them the authority to solve problems.

20. Serve them as internal customers.
21. Be sure they are adequately trained.
22. Recognize and reward performance.

Leadership

23. Lead by example.
24. Listen to the front-line people.
25. Strive for continuous process improvement.[23]

Service sector now accounts for about 54% of India's GDP. Some of the industries which have been growing rapidly include mobile communication, software, hotels, insurance, call centers, healthcare and retails. Importance of service sector has therefore, increased significantly in the Indian industry.[24]

Organization

To ensure the same level of quality for all customers, the organization must record and then communicate to its employees the directions for all tasks. A service quality handbook should be created with the description of each service quality standard. Communicating the service quality standard for each task can be done by formal training, videos, personal coaching, or meetings. Also, intranet sites can be developed so employees can find answers to commonly-asked questions and contact people for more information.

Sometimes, the entire process used by an organization to do business must be changed in order to better serve the customer. For example, Indian Railways have completely revolutionized their reservation system during the last 10 years. It is difficult to believe that one can reserve train seats/births from any station to any other station sitting at home and print his/her own ticket. The banking system revolution also has been phenomenal and made our lives much easier.

Other times, physical space must be reorganized to better serve the customer. Harris Methodist Hospital in Fort Worth redesigned its emergency room around the patient. It designed a "quick care" unit for emergency room patients with less serious injuries. The average "quick care" patient now spends 55 minutes in the emergency room instead of 137 minutes. Unfortunately, patients now wonder why treatment is so costly when it took so little time.[25]

Likewise, Belmont University reorganized its physical space to better serve its customers, the students. After many years of student complaints, Belmont created a one-stop Belmont Central where students can add or drop classes, get transcripts, file financial forms, cash checks, and do a myriad of other administrative tasks. Previously, students had to visit several buildings located at opposite ends of the campus to accomplish simple administrative tasks.[26]

Customer Care

An organization should revolve around the customer, because customers are the key to any business. A customer, any customer, should be valued and treated like a friend. Responses to customer complaints should be immediate and should be more than the customer expected to receive. If they are treated with respect

[23] Adapted from Jacques Horovitz and Chan Cudennec-poon, "Putting Service Quality into Gear," *Quality Progress* (January 1991): 54–58.

[24] http://www.indiaonestop.com/serviceindustry.htm, http://theviewspaper.net/, service_sector_ growth_in_india_and_china/

[25] 1996 RIT/USA Today Quality Cup for Not-For-Profit.

[26] 1997 RIT/USA Today Quality Cup for Education.

customers will simply forgive errors and positively promote the organization. Employees must understand that, as Henry Ford said, "It is not the employer who pays wages—he only handles the money. It is the customer who pays the wages." Employees must please customers, not bosses, management committees, or headquarters. Employees should not follow mind-numbing rules that provide no benefit to the customer.

Fairview-AFX requires its employees to sign a customer code of ethics. It is also given to all customers in order to hold Fairview-AFX employees accountable. Their code of ethics is to:

- Keep promises to customers.
- Return calls to customers in an expedient manner.
- Give customers assistance with their concerns, referring an appropriate staff member for problem-solving action when necessary.
- Treat our customers with respect, courtesy and professionalism at all times.
- Remain aware and evaluate customer satisfaction regularly.
- Continually search for customer-related improvements.
- Deliver service and products quickly and efficiently.
- Give every customer involved and personal attention.
- Maintain a clean and neat appearance, including the workplace, at all times.
- Review and implement customer feedback and suggestions into current procedure when appropriate.
- Engage in any training or education that will enhance our job performance and our commitment to customer care.
- Treat every customer just as we would want to be treated ourselves.[27]

Communication

An organization's communication to its customers must be consistent with its level of service quality. A customer will become dissatisfied if there is a difference between what has been advertised and what has been received. An organization communicates to its customers in many subtle ways. For instance, an organization communicates to its customers even by such means as an employee's telephone manners, or an automated voice response system that is fast and easy for the customer to use. Customer relationships are based on communication. An organization must listen to its customers and establish a level of trust.

Frequently, the first impression a customer has of an organization is its website. If the organization's website is not customer-friendly, the customer will have a bad first impression. Iomega, the manufacturer of zip drives, improved both the content and the navigation and support tools on the organization's website. Within one year, customer satisfaction increased 40%, problem resolution rate was up 320%, and the cost per solution fell from $10.00 to $0.69.[28]

Front-Line People

Customers are the most valuable asset of any company and should not be referred to employees who have not been properly trained to handle their complaints. Only the best employee is worthy of a company's customers. It is best to remember three things about front-line employees:

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[27] 1995 RIT/USA Today Quality Cup for Small Business.

[28] 2000 RIT/USA Today Quality Cup Finalist for Manufacturing.

1. Hire the best.
2. Develop the best employees into professionals.
3. Motivate the professionals to stay and excel.

To get that "best employee" on the front line, someone with a personality should be hired. For example, in real estate, the most important aspect is location, location, location. In front-line employees, the most important aspect is personality, personality, personality. If employees are not happy, this will be reflected to the customers. Generally, customers are frustrated by small things. Front-line employees need to care, smile, possess a pleasant voice, and thank the customer often for their business. In sum, it's having a positive attitude. Finding good employees who want to serve customers is not an easy task.

Front-line employees also need training. Managers who conduct training classes or participate in class along with employees develop a more effective working relationship and therefore convey the importance of customer satisfaction to new employees.

Of course, front-line employees should possess written and oral communication skills and problem-solving skills, and they should be empowered to resolve complaints. But more importantly, front-line employees should genuinely care for their customers. Customers understand and know when someone empathizes with their feelings and is genuinely trying to help. The ideal is being overly fair with your customers, putting customers before costs. For instance, when a physician found a seam had split on a recently-purchased business suit from an upscale department store, she returned it. Upon returning the suit, the salesperson gave her a 33% discount coupon for her next purchase because it wasn't fair that she had to take time from her schedule to return the suit. Of course, the physician has been a loyal customer ever since. Ritz Carlton hotel employees may spend up to $2000 to correct a deficiency or rectify a customer complaint.[29]

At Nordstrom, the company policy is simply stated: "Use your good judgment in all situations, keeping in mind that there are strict orders to be obsessed with the customer rather than with Nordstrom's costs." Salespeople at Nordstrom are so obsessed with the customer that when a customer left her airline ticket at the counter of the Nordstrom's women's apparel department, the sales associate took a cab to the airport to locate the customer and deliver the ticket to her.[30] Using good judgment is key to customer relations. Sometimes one customer's needs must be balanced with other customers' needs. For instance, on a commuter flight one passenger wanted to board with a huge elk rack that wouldn't fit through the doorway much less in the carry on luggage compartment. The passenger was irate when the flight attendant, pilot, and baggage handler calmly explained why the elk rack wouldn't fit, as if it needed explaining. Finally, the baggage handler firmly stated that the passenger was either to take her seat or leave the aircraft. The passenger quickly left and the remaining fifteen passengers gave a round of applause. Despite one unhappy customer, the airline was left with fifteen very happy customers.[31]

In summary, front-line people deal with the customers every day. Front-line people are also a valuable source of information; they know better than management what the customer wants. Front-line staff also needs information and support from management to effectively deal with the public. Management can support front-line staff in various ways. For example, management can coach newcomers to help integrate them into the organization quickly. Management can also give front-line people the authority to resolve customer problems. Rewards should be given to encourage front-line employees' efforts.

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[29] Jaclyn R. Jeffry, "Preparing the Front Line," *Quality Progress* (February 1995): 79–82.

[30] Robert Spector and Patrick D. McCarthy, *The Nordstrom Way*, Audio-Tech Business Book Summaries Vol. 4 No. 8 Sec. 1 (August 1995): 6–7.

[31] Scott Madison Paton, "Unhappy Employees and Unhappy Customers," *Quality Digest* (January 1999): 4.

Leadership by Example

No quality improvement can succeed without management's involvement and, more importantly, commitment. Managers can best show their commitment to service quality by example. Texas Namplate Co. customer-care personnel, including the company president, are available to customers 24 hours a day. Every CEO should be required to spend at least four hours each month behind a service desk. It is hard to understand the customer when you're looking down at him from a 43^{rd} floor window. The American Airlines CEO should have to eat the food he feeds to weary travelers. The General Motors CEO should spend time in a dealer repair shop. Or better yet, the CEO should be the customer. For example, the CEO of Harley Davidson rides his bike to work. He commented that if you build motorcycles for a living, you shouldn't ride to work in a Rolls-Royce.[32]

Indian President Abdul Kalam, the supreme commander of Indian armed forces, visited Siachen glacier in 2004 at the age of 72. Siachen is the world's highest battleground at 18,000 feet above sea level. Describing the glacier as one of the water arteries of the country, he commended the efforts of the soldiers of Indian armed forces in standing guard in such inhospitable conditions. Adverse weather conditions at Siachen with temperatures as low as -50^{o} at the posts located at the height of 20,000 feet have claimed the lives of more Indian and Pakistani soldiers than the exchange of fire. Indian Ex-Railway Minister Laluprasad Yadav used to travel sometimes by second class to understand difficulties faced by passengers. Vijay Mallya, the Chairman of Kingfisher Airlines is often spotted at airports meeting the crew members and finding out how they are providing services to the passengers.

Additional Comments

Gaining new customers can be a lengthy process involving research, targeting, advertising, promotion, and networking. Current customers provide organizations with established business relationships, knowledge and predictability in buying behaviors, and short-term opportunities for expanded sales. Thus, an organization's most likely target for new business is its current customers.

Service quality is an activity; therefore, it can be controlled and improved. Organizations with higher-quality service can charge up to 20% more and still retain customers. Satisfied customers not only continue to patronize the organization, they also add to profits by referring new customers. Referrals can be twice as effective as advertising.

An essential part of customer satisfaction occurs after the sale. Table 3-3 shows various characteristics and expectations.

Many organizations emphasize traditional or reactive service after the sale. Examples include:

Preventive maintenance (service provided according to a prescribed timetable).

Service contract (service provided as required).

No service contract (service requires labor and material billing).

Combinations of the above.

An organization striving to upgrade its service quality must move to the proactive level. Proactive organizations contact their customers and determine their service quality needs and expectations. This information is used to develop the organization's strategy. Management must continually improve the methods for obtaining input from customers to better determine their needs.

For instance, the federal government is improving service quality. Former President Bill Clinton released a report titled, "Putting Customers First '95: Standards for Serving the American People." The 232-page

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[32] H. James Harrington, "Looking Down at the Customer," *Quality Digest* (February 2001): 24.

TABLE 3-3
Characteristics and Expectations

Characteristic	*Expectation*
Delivery	Delivered on schedule in undamaged condition
Installation	Proper instructions on setup, or technicians supplied for complicated products
Use	Clearly-written training manuals or instructions provided on proper use
Field repair	Properly-trained technicians to promptly make quality repairs
Customer service	Friendly service representatives to answer questions
Warranty	Clearly stated with prompt service on claims

report lists the customer service standards that have been formulated by more than 200 federal government agencies. The standards are designed to please the customers—the American people. For instance, the Occupational Safety and Health Administration (OSHA) promises that inspectors will be respectful and helpful and focus on only the most serious hazards. The Bureau of Labor Statistics promises data any way you want it: from a live person, a recorded message, fax, microfiche, diskette, tape, Internet, or telecommunications device for the deaf. The Internal Revenue Service promises tax refunds due on complete and accurate paper returns in 40 days, or 21 days if the return is filed electronically. Delivering what has been promised builds the American people's confidence that their government can work effectively. After all, if a government office cannot answer the phone and give quick, courteous ser-vice, how can it handle defense, commerce, and education?[33]

Although publishing the standards was risky, service in many government offices improved. In 1996, *Business Week* reported that an independent survey of the country's best telephone customer service ranked the Social Security Administration top in the nation.[34]

Translating Needs into Requirements

The Kano model, which is shown in Figure 3-8, conceptualizes customer requirements. The model represents three major areas of customer satisfaction. The first area of customer satisfaction, represented by the diagonal line, represents explicit requirements. These include written or verbal requirements and are easily identified, expected to be met, and typically performance related. Satisfying the customer would be relatively simple if these were the only requirements.

The second area of customer satisfaction represents innovations, as shown by the curved line in the upper left corner of the figure. A customer's written instructions are often purposefully vague to avoid stifling new ideas during conceptualization and product definition. Because they are unexpected, these creative ideas often excite and delight the customer. These ideas quickly become expected.

The third and most significant area of customer satisfaction represents unstated or unspoken requirements, as shown by the curve in the lower right corner of the figure. The customer may indeed be unaware of these

[33] National Performance Review Staff, "Making the Big U-Turn," *Quality Progress* (March 1996): 59–62.

[34] "Top Providers of Telephone Customer Service," *Business Week* (May 29, 1995): 6.

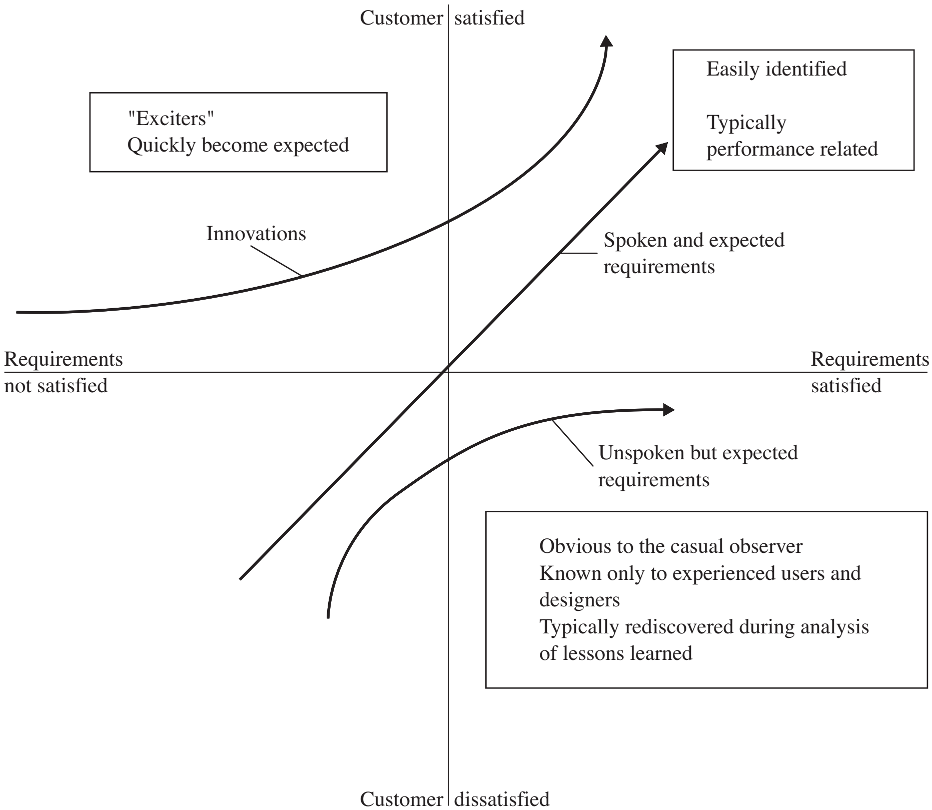

Figure 3-8 Kano Model
Reproduced, with permission, from *Quality Function Development: Implementation Manual for Three-day Workshop* (Allen Park, Mich.: American Supplier Institute, Inc.).

requirements, or they may assume that such requirements will be automatically supplied. Basic specifications often fail to take real-world manufacturing requirements into account; many merely are based on industry standards or past practice. These implied requirements are the hardest to define but prove very costly if ignored. They may be rediscovered during an after-the-fact analysis of lessons learned.

Realistically, the customer doesn't buy a specification; the customer buys the product or service to fulfill a need. Peter Drucker once said, "Customers don't buy products, they buy results." People don't buy products; they buy transportation or status. Customers are loyal to whatever best helps them achieve their desired outcome.[35] Just meeting a customer's needs is not enough; the organization must exceed the customer's needs. Figure 3-9, the voice of the customer diagram, summarizes much of the material in this chapter.

Customer Retention

Customer retention is more powerful and effective than customer satisfaction. Customer retention represents the activities that produce the necessary customer satisfaction that creates customer loyalty, which

[35] Miller.

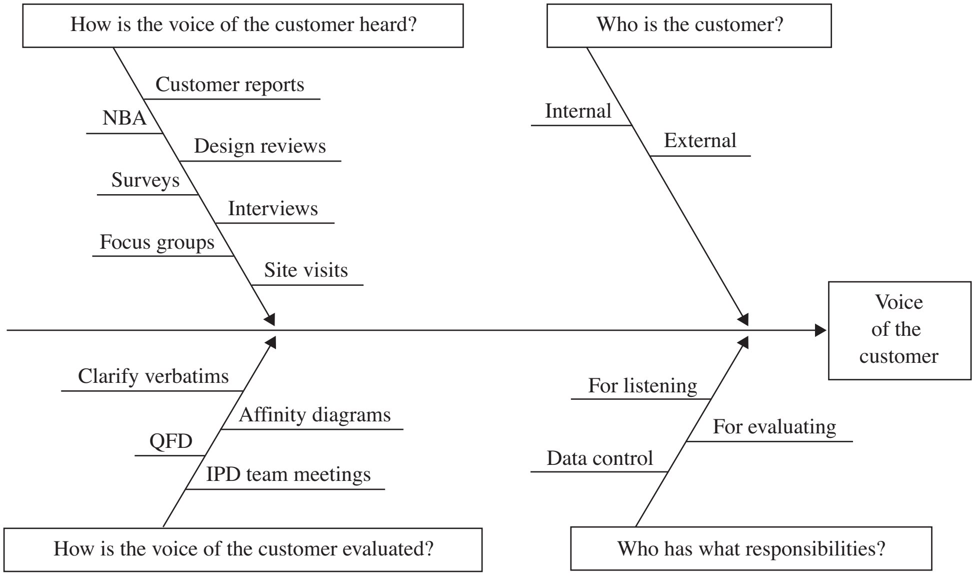

Figure 3-9 Voice of the Customer
Adapted from *Voice of the Customer* (St. Louis, Mo.: McDonnell-Douglas Corporation, 1993).

actually improves the bottom line. Customer satisfaction surveys, focus groups, interviews, and observations can help determine what customers think of a service or a product. However, what people say and think is often different from what they do. Customers may be delighted with the tropical oils and aromas in a high-priced, well-advertised hair-care product but still end up buying the generic equivalent. Therefore customer satisfaction should also be measured by using the hard measures of cash register receipts, market share, the level of customer retention, and the number of referrals from customers. The better companies have established a link between customer satisfaction and the bottom line. The analysis identifies the number of customers and the revenue at risk.[36]

Customer retention moves customer satisfaction to the next level by determining what is truly important to the customers and making sure that the customer satisfaction system focuses valuable resources on things that really matter to the customer. Customer retention is the connection between customer satisfaction and the bottom line.

Likewise, high employee retention has a significant impact on high customer retention. One way companies can manage customer retention is to pay attention to their present employees and to who they are hiring.[37]

Additional Comments

Improved service frequently carries a cost, so an organization must determine its return on the service investment by determining those elements of service that significantly improve revenues and market share. Diligent

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[36] A. Blanton Godfrey, "Beyond Satisfaction," *Quality Digest* (January 1996): 15.

[37] John Goodman, David DePalma, and Scott Broetzmann, "Maximizing the Value of Customer Feedback," *Quality Progress* (December 1996): 35–39.

use of information-collecting tools and market research will enable an organization to identify those elements most critical to customer satisfaction.

An organization should benchmark (see Chapter 8) the most successful corporations in the industry to determine where it stands relative to its own competitors. Benchmarking will provide information to improve processes and establish realistic goals.

The organization must continually improve the methods of obtaining information concerning the customer's needs and expectations. It is the quality council's responsibility to periodically review the methods.

World-class competitors tend to continually fine-tune their operations to achieve incremental improvements. They know that continuous improvement and customer satisfaction go hand-in-hand. Maximize customer satisfaction and retention, and the financial results will follow.

TQM Exemplary Organization[38]

Merrill Lynch Credit Corporation (MLCC) offers real estate and securities-based consumer credit products—including home financing, personal credit, investment financing, and commercial real-estate financing—to primarily affluent individuals. About 90 percent of its approximately 830 employees, known as partners, are located in MLCC's Jacksonville, FL headquarters.

As part of the Business Planning Process, each July senior managers translate the strategic imperatives into the company's Critical Few Objectives, key performance mea-sures for their CFOs, and specific targets for the next one and three years. For example, a CFO to increase process productivity with an aim of increasing shareholder value is measured by the number of days to approve applications, with specific, ambitious, and measurable goals. In turn, these CFOs provide the basis for determining partner perfor-mance management plans. By involving all of the firm's partners in providing information for the business planning process, and in regular refinements and progress reviews, MLCC ensures that its plans are fact-based and linked to individual goals and objectives.

MLCC segments its market into several categories of current and potential customers, stratified by their asset levels and age. Working with its parent company, MLCC uses in-depth research to target and deliver appropriate products and services. Its "Voice of the Client" process states customer satisfaction drivers for each client segment and for each of its credit categories. These priority requirements provide the basis for aligning the company's processes and work groups and for identifying indicators and key performance measures for each of its eight core processes. In turn, each of those indicators are tracked and used to identify and put in place improvements in areas having the greatest impact on customer needs and satisfaction.

Information about the customer is truly paramount for MLCC. To ensure that its market research is always current, MLCC continuously evaluates and improves its data on what its clients need and what they might want in the future.

The client data come from an array of sources, ranging from surveys of clients and financial consultants in the field to written or telephone feedback, internal audits, syndicated research, and benchmarking studies. Satisfaction levels of competitors' clients also are used in analyzing client needs. Customer complaints are analyzed in depth, reviewed monthly, and reported back to MLCC regions to identify any sudden changes and to share lessons learned. Negative trends and recurring problems trigger process improvement teams to develop countermeasures and to prevent recurrences. Clients receive acknowledgment of any complaint within two business days, and resolution is received in no more than five business days.

MLCC has impressive results to show that its focus on quality management and performance excellence is a wise investment. Net income rose 100% from 1994 to 1996 and exceeds the industry's average. Return

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[38] Malcolm Baldrige National Quality Award, 1997 Service Category Recipient, NIST/Baldrige Homepage, Internet.

on equity increased approximately 74 percent and its return on assets improved approximately 36 percent in that same period. Key indicators for loan delinquency rates and writeoffs compare favorably with the rest of the industry and are clearly improving—as are the firm's total loan originations, market share in originations, wholesale volume as a percentage of first mortgages, and size of servicing portfolio.

Summary

An organization exists because of its customers. Customer satisfaction is a proof of successful TQM implementation and therefore finds high importance in the Malcolm Baldrige National Quality Award criteria and Quality System Certification Standards. Quality is defined from customer's perspective. TQM requires focus or both, external as well as internal customers.

Customer perception of quality depends on many aspects, such as performance, service, warranty price and reputation. Organizations need to set up a feedback mechanism for measuring level of customer satisfaction. This could be done using comment cards, questionnaires, focus group surveys, customer visits, report cards and internet reviews or comments. Another essential mechanism is employee feedback.

American Customer Satisfaction Index quantifies customer satisfaction level in the U.S. and relates it to the financial performance of firms.

Most dissatisfied customers do not complain to the manufacturer of service provider of the company. Many of the customers are likely to buy the product or service again if their complaint is heard and then resolved. Thus, organizations must listen to each compliant, analyze root causes and take corrective and preventive action to resolve the same.

Assuring service quality requires communication across the organization. Sometimes, entire process change may be required to serve customers better. It is also essential that the front line people are carefully selected and properly trained as they represent the company for the customers.

The Kano model is useful in conceptualizing the customer requirements into dissatisfiers, satisfiers and delighters.

Exercises

1. Define the terms *internal customer* and *external customer*.
2. Is the main concern of most consumers the price of the product or service? Explain.
3. List and explain the six most important factors that influence consumer purchases.
4. What is the best way to improve market share for a product or service?
5. Design a customer satisfaction questionnaire for the following service industries:
   (a) Bank
   (b) Telephone company
   (c) Hospital
   (d) Accounting firm
   (e) Law firm
   (f) Hotel
6. As a manager of a small sporting goods store, describe how you would train front-line employees to handle customer complaints.

7. How does employee satisfaction relate to customer satisfaction?

8. Define quality in two words.

9. Mechanical products, such as cars, break down. Cars often are serviced by the car dealer. How can a car dealer use the service department to encourage future car sales?

10. To find out dissatisfiers, the best starting point is

    (a) Market research
    (b) Benchmarking
    (c) Brainstorming
    (d) Customer complaints

11. Which of the following are important for front line people:

    I Develop the best employees into professionals.
    II Recruit freshers as they have an open mind.
    III Hire the best.
    IV Motivate the professionals to stay and excel.

    (a) I and II Only
    (b) I, III and IV only
    (c) I, II, III and IV
    (d) III and IV only

12. Which of the following is most appropriate choice for finding delighters?

    (a) Customer surveys
    (b) Market research
    (c) Customer complaints database
    (d) Observing how customer uses a product

13. Which of the following is correct?

    (a) Satisfiers become dissatisfiers over time
    (b) satisfiers become delighters over time
    (c) Dissatisfiers become satisfiers over time
    (d) dissatisfiers become delighters over time

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4

Employee Involvement

Chapter Objectives

- Understanding motivation
- Empowering employees
  - Assessing current levels through surveys
  - Basics of Empowerment
- Understanding functioning and effectiveness of teams
- Encouraging employee participation through suggestion systems
- Understanding the concept of Gain sharing
- Brief overview of performance appraisals
- Overview of unions and employee involvement

Introduction

Employee involvement is one approach to improving quality and productivity. Its use is credited for contributing to the success enjoyed by the Japanese in the world marketplace. Employee involvement is not a replacement for management nor is it the final word in quality improvement. It is a means to better meet the organization's goals for quality and productivity at all levels of an organization.

Motivation

Knowledge of motivation helps us to understand the utilization of employee involvement to achieve process improvement.

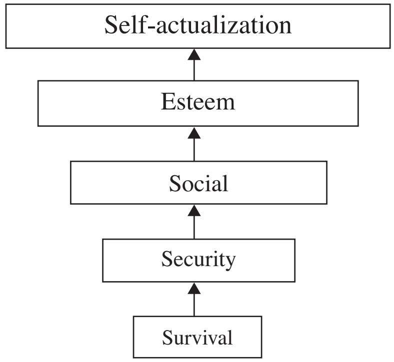

Figure 4-1 Maslow's Hierarchy of Needs

Maslow's Hierarchy of Needs

One of the first and most popular motivational theories was developed by Abraham Maslow. He stated that motivation could best be explained in terms of a hierarchy of needs and that there were five levels. These levels are survival, security, social, esteem, and self-actualization. They are shown in Figure 4-1. Once a given level is satisfied, it can no longer motivate a person.

Relating these needs to motivation, we know that Level 1 (survival) means food, clothing, and shelter, which is usually provided by a job. In the workplace, Level 1 needs include proper lighting, heating/air conditioning, ventilation, phone system, data/voice access, and computer information system.[1] Level 2 (security) can mean a safe place to work and job security, which are very important to employees. When the organization demonstrates an interest in the personal well-being of employees, it is a motivating factor. A threat of losing one's job certainly does not enhance motivation. Level 2 is not limited to job security. It also includes having privacy on the job such as being able to lock one's office door or having lockable storage for personal items, as well as having a safe work environment that may include ergonomic adjustable furniture.[2]

Because we are social animals, Level 3 (social) relates to our need to belong. It has been said that cutting someone out of the group is devastating to that individual. Isolation is an effective punishment. Conversely, giving an individual the opportunity to be part of the group by feeling important and needed will motivate that person. If possible, employees should be provided with both formal social areas such as a cafeteria and conference rooms and informal areas such as water coolers and bulletin boards.[3] Being a member of a team is a good way to bring employees into the group. Level 4 (esteem) relates to pride and self-worth. Everyone, regardless of position or job assignment, wants to be recognized as a person of value to the organization. Where possible, employees should be given offices or personal spaces with aesthetics. Business cards, workspace size, and office protocols also provide employees with a certain level of self-esteem within an organization.[4] Seeking advice or input into business or production processes is a good way of telling employees that they are of value. This activity requires giving employees control and freedom of their jobs by providing trust.[5] Level 5 (self-actualization) says that individuals must be given the opportunity to go as far as their abilities will take

[1] Brenner, Pamela M., "Motivating Knowledge Workers: The Role of the Workplace," *Quality Progress* (January 1999): 33–37.

[2] Brenner.

[3] Brenner.

[4] Brenner.

[5] Brenner.

them. Many organizations have a policy of promoting from within. It is true that some employees do not want to move up the corporate ladder, which is understandable. However, those who do want to move up must know that it is possible.

It is important to note that as employees move up the hierarchy, they will immediately revert back to the previous level if they feel threatened. For example, if an employee is satisfied in Level 3, a rumor of downsizing may cause an immediate return to Level 2.[6]

Herzberg's Two-Factor Theory

Frederick Herzberg extended the general work of Maslow by using empirical research to develop his theory on employee motivation. He found that people were motivated by recognition, responsibility, achievement, advancement, and the work itself. These factors were labeled *motivators*. In addition, his research showed that bad feelings were associated with low salary, minimal fringe benefits, poor working conditions, ill-defined organizational policies, and mediocre technical supervision. These job-related factors were labeled *dissatisfiers* or *hygiene factors*, which implies they are preventable. It is important to realize that dissatisfiers are often extrinsic in nature and motivators are intrinsic. The presence of the extrinsic conditions does not necessarily motivate employees; however, their absence results in dissatisfaction among employees. Absence of motivating factors does not make employees dissatisfied, but when there are motivating factors present, they do provide strong levels of motivation that result in good job performance for the individual and the organization. In general, dissatisfiers must be taken care of before motivators can be actuated. Herzberg's dissatisfiers are roughly equivalent to Maslow's lower levels, and the motivators are similar to the upper levels.[7]

Employee Wants

While management thinks that good pay is the number one want of the employee, survey results show that this factor is usually in the middle of the ranking. Table 4-1 shows employee wants and manager perceptions of employee wants. Employee wants tend to follow the theories of Maslow and Herzberg. It is interesting to note that the managers' perceptions are much different. By involving employees through the use of teams in meaningful work and by providing the proper reward and recognition, managers can reap the advantages of greater quality and productivity along with employee satisfaction. This chapter describes how managers can develop employee motivation and how they can involve their employees through empowerment. If managers are to effectively motivate employees, they must align their actions closer to the motivators.

Achieving a Motivated Work Force[8]

The building of a motivated work force is for the most part an indirect process. Managers at all levels cannot cause an employee to become motivated; they must create the environment for individuals to motivate themselves. Concepts to achieve a motivated work force are as follows:

1. *Know thyself*. Managers must understand their own motivations, strengths, and weaknesses. This understanding can best be obtained by having peers and employees anonymously appraise the manager's performance. Some organizations like Cummins India Ltd. have implemented 360 degree feedback system for the managers. Motivating managers know that the most valuable resource is people and that their success largely depends on employees achieving their goals.

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[6] Ann S. Daughtrey and Betty R. Hicks, *Contemporary Supervision* (New York: McGraw-Hill, 1989).

[7] Fred Luthans and Mark J. Martinko, *The Practice of Supervision and Management*, McGraw-Hill Book Company, New York, 1979.

[8] This section adapted, with permission, from Theodore B. Kinni, "Motivating the Unmotivated," *Quality Digest* (March 1993).

TABLE 4-1
What Employees Want

Factor	*Employee Rating*	*Manager Rating*
Interesting work	1	5
Appreciation	2	8
Involvement	3	10
Job security	4	2
Good pay	5	1
Promotion/growth	6	3
Good working conditions	7	4
Loyalty to employees	8	7
Help with personal problems	9	9
Tactful discipline	10	6

Source: Study by K. Kovich, *Advanced Management Journal*, as reported in the article by Theodore B. Kinni, "Motivating the Unmotivated," *Quality Digest*, March 1993.

2. *Know your employees*. Most people like to talk about themselves; therefore, the motivating manager will ask questions and listen to answers. With a knowledge of the employees' interests, the manager can help achieve them within the business context. As the manager learns more about the employee, he/she can assist the employee in directing their efforts toward satisfying their goals and well-being. This knowledge will also enable the manager to utilize their strengths.

3. *Establish a positive attitude*. A positive action-oriented attitude permeates the work unit. Managers are responsible for generating attitudes that lead to positive actions. Feedback should, for the most part (say, 87%), be positive and constructive. Respect and sensitivity toward others is essential to the development of positive attitudes. Asking employees for their opinions concerning job-related problems is an effective way to build a cooperative atmosphere. Managers should treat ideas and suggestions as price-less treasures and implement them immediately whenever possible.

4. *Share the goals*. A motivated work force needs well-defined goals that address both individual and organizational needs. Information on goal setting is given in Chapter 2.

5. *Monitor progress*. The process of goal-setting should include a road map detailing the journey with periodic milestones and individual assignments. Managers should periodically review performance.

6. *Develop interesting work*. Managers should consider altering the employees' assignments by means of job rotation, job enlargement, and job enrichment.

Job rotation permits employees to switch jobs within a work unit for a prescribed period of time. This activity reduces boredom and provides knowledge of the entire process and the affect of the sub-process. Thus, quality consciousness is raised, which may lead to process improvement.

Job enlargement combines tasks horizontally so that the employee performs a number of jobs sequentially. Thus, the employee is responsible for a greater portion of the product or service, which may also lead to process improvement.

Job enrichment combines tasks vertically by adding managerial elements such as planning, scheduling, and inspection. This contributes to the employees' sense of autonomy and control over their work, which may lead to process improvement.

7. *Communicate effectively*. Effective communication provides employees with knowledge about their work unit and the organization rather than "grapevine" information. Communication is covered in greater detail in Chapter 2.

8. *Celebrate success*. Recognizing employee achievements is the most powerful tool in the manager's toolbox. Additional information is given in the recognition and reward section of this chapter.

These eight concepts can be used at all managerial levels of the organization.

Employee Surveys[9]

As described in the previous section, an initial step a manager should take in initiating employee empowerment is to survey their employees to determine their current level of perceived empowerment. Employee surveys help managers assess the current state of employee relations, identify trends, measure the effectiveness of program implementation, identify needed improvements, and increase communication effectiveness. The success of the survey is directly related to the quality of the planning. An organization should not plan, develop, and administer the survey unless managers are willing to use the results and work towards empowering their employees.

The first step is for the quality council to create a multifunctional team with responsibilities as previously described. In addition, the team will determine the objective and develop a plan to communicate results, encourage root cause analysis, and encourage corrective action.

Next, the team will develop the survey instrument using in-house and external expertise. Identifiers such as location, sex, age, seniority, and work unit are absolutely essential to analyze the results. If the entire population is not surveyed, then the sampling procedure should be determined for the initial and subsequent ones. The survey is pilot tested and revised as needed.

Other constructs to address in the survey include personality characteristics, management styles, job attitudes, and the work.[10] Examples of each include:

- Personality characteristics—anxiety, self-esteem in the organization, and ability to participate in the organization.
- Management styles—consideration of subordinates, initiating structure, commitment to quality.
- Job attitudes—job satisfaction, social support at work and co-worker's commitment to quality.
- The work—task variety, autonomy and importance.

Several employee empowerment questionnaires exist in the literature.[10,11]

The third step is to administer the survey. This activity begins by communicating to the employees the purpose, schedule of events, and employee expectations. The survey should be administered by an outside group to maintain anonymity. Written comments should be typed with names disguised. Employees should be given time to complete the questionnaire, preferably during normal work hours in a large area such as the cafeteria. Surveys are administered every 12 to 18 months.

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[9] This section is adapted from Ronald D. Snee, "Listening to the Voice of the Employee," *Quality Progress* (January 1995): 91–95: and Roger E. Breisch, "Are You Listening," *Quality Progress* (January 1995): 59–62.

[10] Hayes, Bob E., "How to Measure Empowerment," *Quality Progress* (February 1994): 41–46.

[11] Kontoghiorghes, Constantine and Doborah Dembeck, "Prioritizing Quality Management and Sociotechnical Variables in Terms of Quality Performance," *Quality Management Journal*, Vol. 8, No. 3: 36–48.

Next, the results are compiled and analyzed, and a report is prepared for the quality council in a timely manner. This report is shared with the entire organization, including a mechanism for input of reactions and suggestions.

The last step is to determine areas for improvement. Such areas for improvement will occur at the work unit level, cross boundaries among work groups such as between engineering design and marketing, and cover the entire organization.

By listening to the voice of the employee, the organization can receive feedback to help ensure a thriving TQM effort.

Empowerment

The Manufacturers' Alliance for Productivity and Innovation stated that "[o]rganizations that empower employees as part of their total management effort are twice as likely as other firms to report significant product or service improvement."[12]

The dictionary definition of empowerment is to invest people with authority. Its purpose is to tap the enormous reservoir of potential contribution that lies within every worker. An operational definition follows:

> Empowerment is an environment in which people have the ability, the confidence, and the commitment to take the responsibility and ownership to improve the process and initiate the necessary steps to satisfy customer requirements within well-defined boundaries in order to achieve organizational values and goals.

Empowerment should not be confused with delegation or job enrichment. Delegation refers to distributing and entrusting work to others. Employee empowerment requires that the individual is held responsible for accomplishing a whole task. The employee becomes the process owner—thus, the individual is not only responsible but also accountable. Job enrichment is aimed at expanding the content of an individual's job, whereas empowerment focuses on expanding on the context of the job such as its interactions and interdependencies to other functions of the organization.[13]

In order to create the empowered environment, three conditions are necessary.

1. *Everyone must understand the need for change*. People fear change. The effective communication of why the organization needs to change is critical to success. In addition, people need to understand the role they will play in the change process. Senior management must understand that people change for their own reasons, not for reasons of the organization. People who are older, well educated, highly skilled, and experienced are more likely to accept increased demands and expectations associated with empowerment. In addition, one's perceived internal control (locus of control) contributes to whether or not an employee is receptive to an empowered environment.[14]

2. *The system needs to change to the new paradigm*. The system needs to change to reinforce and motivate individual and group accomplishments. Individuals and groups must understand that freedom to act and (sometimes to fail) is not only OK but is encouraged. Other contextual factors need to be considered if empowerment is to be successful, such as the role of unions and the type of industry (service or manufacturing). If the union environment is not willing to engage employees in an empowerment culture, success will be difficult.[15]

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[12] "News—Employee Involvement Linked to Quality Gains," *Quality Progress* (December 1993): 14.

[13] Dimitriades, Zoe S., "Empowerment in Total Quality: Designing and Implementing Effective Employee Decision-Making Strategies," *Quality Management Journal*, Vol. 8, No. 2 (2001): 19–28.

[14] Dimitriades.

[15] Dimitriades.

3. *The organization must enable its employees*. Enablement means providing information, education, and skill. To ask people to change work habits without providing them with the tools for change only increases resistance to the change process. Additional factors that should be considered before determining if organization can enable its employees are strategy and technology.[16] Companies that have a business strategy and technology focus of customization are more likely to embrace empowerment compared to companies whose strategy is that of low-cost and high volume.

There is nothing mystical about empowerment. People generally want to be more in charge of their jobs and careers. After all, they do that successfully in their personal lives every day. Most people appreciate and value the trust and responsibility inherent in an environment that supports empowered people and their actions. When people have the information, education, and skills required to perform in a changed environment, understand their boundaries of empowerment, and realize the necessity for change, their resistance to that change decreases greatly.[17]

A 1993 ASQ/Gallup survey showed that employees feel empowered to:

Stop work in progress 83%
Intervene on customer's behalf 81%
Make exception to procedures 61%
Rework product or service 61%
Replace merchandise 37%
Refund money/authorize credit 26%

Teams

Employee involvement is optimized by the use of teams. Teams, however, are not a panacea for solving all quality and productivity problems, but in most instances, they are effective.

Definition

A *team* is defined as a group of people working together to achieve common objectives or goals. *Teamwork* is the cumulative actions of the team during which each member of the team subordinates his individual interests and opinions to fulfill the objectives or goals of the group. The objective or goal is a need to accomplish something such as solve a problem, improve a process, design a refrigerator, plan a conference, audit a process, or please a customer. It needs to be clearly defined, have milestones set, have resources provided, and use a systematic approach. Members of the team will need to focus on how they relate to each other, listen to the suggestions of others, build on previous information, and use conflict creatively. They will need to set standards, maintain discipline, build team spirit, and motivate each other. Each member of the team has their own history of experience to help achieve the objective. They should have a need to see the task completed, but also the needs of companionship, fulfillment of personal growth, and self-respect.

Why Teams Work

Teams work because many heads are more knowledgeable than one. Each member of the team has special abilities that can be used to solve problems. Many processes are so complex that one person cannot be

[16] Dimitriades.

[17] Bob Mann, "Empowerment: An Enabling Process," *Quality Digest* (January 1994): 39–44.

knowledgeable concerning the entire process. Second, the whole is greater than the sum of its members. The interaction within the team produces results that exceed the contributions of each member. Third, team members develop a rapport with each other that allows them to do a better job. Finally, teams provide the vehicle for improved communication, thereby increasing the likelihood of a successful solution.

Types of Teams

The early history suggests that work simplification efforts by management and labor were most likely the first production-oriented teams. However, the development of quality control circles by the Japanese in 1961 is considered to be the beginning of the use of teams to improve quality. Quality control circles are groups of people from one work unit who voluntarily meet together on a regular basis to identify, analyze, and solve quality and other problems within their area. They choose their own problems and focus on quality-of-work-life and health/safety issues rather than on improving work processes. Often they remain in existence over a long period of time, working on project after project. Quality control circles have been quite successful in Japan and enjoyed some initial success in other countries but not as extensive. A major drawback was a lack of middle management support. Without managers on teams or directly overseeing the teams as a quality council might, members frequently were not able to persuade management to implement their recommendations.

Outside Japan, the popularity of quality control circles has declined; however, this type of team is the progenitor of our present teams. The current types of teams can be divided into four main groups. They may be called by different names and have slightly different characteristics to accommodate a particular organization.

1. *Process improvement team*. The members of a process improvement team represent each operation of the process or sub-process. Usually the scope of the team's activity is limited to the work unit. A team of about six to ten members will come from the work unit and, depending on the location of the sub-process, an external or internal supplier and external or internal customer would be included on the team. During the course of the team's life, additional expertise from other work areas may be added on a permanent or temporary as-needed basis. The life cycle of this type of team is usually temporary—it is disbanded when the objective has been obtained. When the targeted process includes many work units or the entire organization, a cross-functional team may be more appropriate with work unit teams as sub-teams.

2. *Cross-functional team*. A team of about six to ten members will represent a number of different functional areas such as engineering, marketing, accounting, production, quality, and human resources. It may also include the customer and supplier. A design review team is a good example of a cross-functional team. This type of team is usually temporary. An exception would be a product support team, which would be permanent and have as an objective to serve a particular product line, service activity, or a particular customer. This type of team breaks down functional area boundaries.

3. *Natural work teams*. This type of team is not voluntary–it is composed of all the members of the work unit. It differs from quality control circles because a manager is part of the team and the projects to be improved are selected by management. Some employees may opt not to work in teams for a variety of reasons, and managers should anticipate this action and be prepared to help employees become comfortable in the team environment or, alternatively, find work in another unit that still performs work as individuals. Even though "team work" is technically feasible, there may be such resistance that its introduction should be delayed until there has been substantial turnover.

4. *Self-directed/self-managed work teams*. They are an extension of natural work teams without the supervisor. Thus, they are the epitome of the empowered organization—they not only do the work but also manage it. There is wide discretion to organize their work subject to organizational work flow requirements. There is a team coordinator to liaison with senior management, that may rotate among members. The team meets daily to plan their activities, and decisions are usually by consensus. Additional responsibilities may include:

hiring/dismissal, performance evaluation, customer relations, supplier relations, recognition/reward, and training. The team must have access to business information in order to plan, control, and improve their processes.

Self-managed teams are empowered to take all decisions about the work which they do. For example, Federal Express claims productivity up to 40% with self-managed teams. According to a survey of *Fortune* 1000 companies, 68% of the companies use self-directed work teams; however, only 10% of the workers are involved in such teams.[18] Developing these types of teams requires not only careful planning and substantial training of the individuals, but also several organizational changes. As a result, many companies begin with a few pilot teams that are implemented slowly to full development over several years.

The growth of *Shri Mahila Griha Udyog Lijjat Papad* (popularly known as just "Lijjat") over last 5 decades is spectacular. Lijjat is managed solely by women. The members believed and practised principles of cooperation and collective ownership. Seven women initiated the venture in 1957 to make household papads. As the demand increased, more and more women entered the production process. The paucity of space forced the Lijjat sisters to decentralize production to the homes of their members.

From the initial membership of 7 women in Mumbai, it has now scaled up to over 50,000 women across the country. From a one shop organization, it has now over 65 branches and 50 divisions.[19]

Of course, there is some overlap between these four main types of teams. Also, organizations will modify them to accommodate their culture.

Recognize that the use of teams to empower employees should be done gradually so that acceptance by both management and employees is built on successful results of teamwork. As an organization becomes more comfortable with the use of teams for empowerment, teams will form both laterally and vertically throughout the organization. As Figure 4-2 indicates, a permanent process improvement team (here, a business improvement team) that is directed by the quality council may address overall cross-functional improvements for the organization. By direction of the quality council, several cross-functional teams may be established to address specific improvement problems that span several functional areas. Within functional areas, one or more process improvement teams may be engaged. Finally, one or more

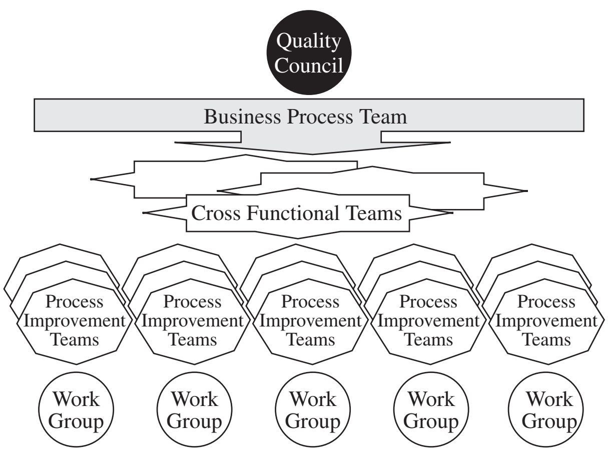

Figure 4-2 The Use of Teams Throughout an Organization

[18] Dumaine, B., "The Trouble with Teams," *Fortune*, Vol. 130, No. 5 (1994): 86–87.

[19] 2006 Report by UN-World Food Program.

functional areas may establish a work group or quality control circle to address overall improvements to the particular functional area.

Characteristics of Successful Teams

In order for a team to be effective, it should have certain characteristics, listed below.

1. *Sponsor*. In order to have effective liaison with the quality council, there should be a sponsor. Preferably the sponsor is a member of the quality council, thereby providing organizational support.

2. *Team charter*. A team charter is a document that defines the team's mission, boundaries, the background of the problem, the team's authority and duties, and resources. It also identifies the members and their assigned roles–leader, recorder, timekeeper, and facilitator (optional). Detailed information on roles is given in a later section. The sponsor and the team negotiate the charter.

3. *Team composition*. The size of the team should rarely exceed ten people except in the case of natural work teams or self-directed teams. Larger teams have difficulty maintaining commitment, and interpersonal aspects become difficult to control. Teams should be diverse by having members with different skills, perspectives, and potential. Where appropriate, internal and external customers and suppliers should be included.

4. *Training*. As the need arises, members should be trained in problem-solving techniques, team dynamics, and communication skills. A later section discusses training in detail.

5. *Ground rules*. The team must develop its rules of operation and conduct. There should be open discussion on what will and will not be tolerated. Periodically the ground rules should be reviewed and revised when appropriate.

6. *Clear objectives*. Without clear objectives and goals, the team will have difficulty. In addition, the criteria for success should be agreed on with management. Detailed information on objectives and goals is given in Chapter 2.

7. *Accountability*. The team is accountable to perform. Periodic status reports should be given to the quality council. In addition, the team should review its performance to determine possible team process weaknesses and make improvements.

8. *Well-defined decision procedures*. Effective, acceptable, and timely decisions have to be made by the team. Detailed information on decisions is given later in the chapter.

9. *Resources*. Not only is funding and employee release time for the project important, but also important is access to information. The team cannot be expected to perform successfully without the necessary tools.

10. *Trust*. Management must trust the team to perform the task effectively. There must also be trust among the members and a belief in each other.

11. *Effective problem solving*. Decisions are based on the problem-solving method given in Chapter 5. They are not made on hunches or quick fixes.

12. *Open communication*. Members actively listen, without interruption, to other members, speak with clarity and directness, ask questions, and say what they mean.

13. *Appropriate leadership*. All teams need leadership—whether imposed by the quality council, or whether someone emerges as a leader figure as the life of the team progresses, or whether the leadership changes as the team matures. Detailed information on leadership is given in Chapter 2.

14. *Balanced participation*. All members must become involved in the team's activities by voicing their opinions, lending their knowledge, and encouraging other members to take part.

15. *Cohesiveness*. Members should be comfortable working with each other and act as a single unit, not as individuals or sub-groups.

Team Member Roles

Teams are usually selected or authorized by the quality council. A team will consist of a team leader, facilitator, recorder, timekeeper, and members. All team members have clearly defined roles and responsibilities.

The *team leader*, who is selected by the quality council, sponsor, or the team itself, has the following roles.[20]

- Ensures the smooth and effective operation of the team, handling and assigning record keeping, orchestrating activities, and overseeing preparation of reports and presentations.
- Facilitates the team process, ensures that all members participate during the meetings, prevents other members from dominating, actively participates when appropriate, guides without domineering, and uses positive interpersonal behavior.
- Serves as a contact point between the team and the sponsor or quality council.
- Orchestrates the implementation of the changes recommended by the team within organizational constraints and team boundaries.
- Monitors the status and accomplishments of members, assuring timely completion of assignments.
- Prepares the meeting agenda, including time, date, and location; sticks to the agenda or modifies it where appropriate; and ensures the necessary resources are available for the meeting.
- Ensures that team decisions are made by consensus where appropriate, rather than by unilateral decision, handclasp decision, majority-rule decision, or minority-rule decision.

The *facilitator* is not a member of the team; he/she is a neutral assistant and may not be needed with a mature team. This person does not get involved in the meeting content or evaluation of the team's ideas. Roles are as follows:

- Supports the leader in facilitating the team during the initial stages of the team.
- Focuses on the team process; is concerned more with how decisions are made rather than the decision itself.
- Acts as resource to the team by intervening when necessary to keep the team on track.
- Does not perform activities that the team can do.
- Provides feedback to the team concerning the effectiveness of the team process.

The team *recorder*, who is selected by the leader or by the team and may be rotated on a periodic basis, has the following roles:

- Documents the main ideas of the team's discussion, the issues raised, decisions made, action items, and future agenda items.
- Presents the documents for the team to review during the meeting and distributes them as minutes after the meeting in a timely manner.
- Participates as a team member.

The *timekeeper*, who is selected by the leader or by the team and may be rotated on a periodic basis, has the following roles:

- Monitors the time to ensure that the team maintains the schedule as determined by the agenda.
- Participates as a team member.

[20] Jane E. Henry, "Lessons From Team Leaders," *Quality Progress* (March 1998): 57–59.

The *team member*, who is selected by the leader, sponsor, or quality council or is a member of a natural work team, has the following responsibilities:[21]

- Contributes best, without reservation, by actively participating in meetings and sharing knowledge, expertise, ideas, and information.
- Respects other people's contributions—doesn't criticize, complain, or condemn.
- Listens carefully and asks questions.
- Is enthusiastic—it's contagious and helps galvanize the entire team.
- Works for consensus on decisions and is prepared to negotiate important points.
- Supports the decisions of the team—badmouthing a decision or a member reduces the effectiveness of the team.
- Trusts, supports, and has genuine concern for other team members.
- Understands and is committed to team objectives.
- Respects and is tolerant of individual differences.
- Encourages feedback on own behavior.
- Acknowledges and works through conflict openly.
- Carries out assignments between meetings such as collecting data, observing processes, charting data, and writing reports.
- Gives honest, sincere appreciation.

Effective Team Meetings

If the participants know their roles and utilize the characteristics of successful teams, the probability of effective team meetings is enhanced. There are, however, a few items that can help improve the process:

- Meetings should be regularly scheduled; have a fixed time limit, and start on time. Participants should be notified ahead of time with the location, time, and objective. Avoid unnecessary meetings through e-mail, voice mail and telephone calls; however, also avoid accumulated issues.[22]
- An agenda should be developed, either at the end of the previous meeting or prior to the beginning of the next meeting. It should be sent to the participants prior to the meeting. Each agenda item includes a process, such as brainstorming, affinity diagram, discussion, and so forth; the presenters; and time guidelines.
- Agendas usually list: opening focus, previous meeting feedback, agenda review, agenda items, summary, and action items.
- Periodically, the meetings should be evaluated by the participants.

A simple evaluation survey can be developed and completed by team members, such as the example provided in Figure 4-3.[23] Once the team has completed their evaluations individually, specific areas of improvement can be readily identified and addressed.

Successful team meetings require planning, training, and evaluation, as well as excellent leadership. Meetings should give workers direction and allow them to take action. Meetings should not be used to learn what

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[21] Karen A. Eichelberger, "Leading Change Through Projects," *Quality Progress* (January 1994): 87–90.

[22] Eckberg, John, "Fewer Meetings Can Reduce Inefficiency," *Business Monday* (July 31, 2000): 3.

[23] *Coaching and Teambuilding Skills for Managers and Supervisors*, SkillPath, Inc. 1992.

	Agree	Disagree
1. The purpose of our meeting was well-defined.	0	0
2. We decided what we wanted to achieve by the end of the meeting.	0	0
3. We were sufficiently prepared for the meeting.	0	0
4. We reviewed our progress during the meeting.	0	0
5. We allocated the meeting time well.	0	0
6. We captured and developed spontaneous ideas.	0	0
7. We listened to all views for understanding.	0	0
8. We kept on track.	0	0
9. We kept our attention and concentration focused.	0	0
10. The meeting did not break up into small group discussions.	0	0
11. We reviewed and confirmed what had been agreed upon and how those decisions would be activated.	0	0
12. We had fun.	0	0

Figure 4-3 Example Meeting Evaluation Survey

action they should take.[24] Once at the meeting, stick to the agenda. Agendas keep the discussion moving and allow the meeting to run on time.

Stages of Team Development[25]

Organizations can dramatically improve team performance by understanding and recognizing the stages in the life cycle of teams. Knowing a team's location in the life cycle helps management understand team performance and avoid setting unrealistic objectives that limit a team's success. Bruce Tuckerman found that there were four stages to a team's development. These stages are forming, storming, norming, and performing.[26]

Forming is the beginning stage where members become aware of the boundaries of acceptable behavior. Members are often not familiar with each other's skills, and each prefers to do the work on their own as there is a lack of trust. Members are cautious with their communication and tend to be formal. In general, the mission and goals of the team are still questionable, and the problems seem too large to solve.[27] It is a stage of transition from individual to member status and of testing the leader's guidance. Considerable time is spent in organizing and training. The team accomplishes little in regard to its objectives. To expedite the forming stage, an individual should be tasked with chartering the team.[28] In chartering a team, a facilitator commonly meets with the upper management to discuss the specific problem; he/she then develops a macro flowchart of

[24] Eckberg.

[25] Adapted, with permission, from Peter R. Scholtes, *The Team Handbook* (Madison, WI: Jointer Associates Inc., 1988).

[26] "Development Sequence in Small Groups," *Psychological Bulletin* (1965).

[27] Hoye, J. and T. Tupper, "Empowering Self-Managing Work Teams," *Quality Digest* (March 1994): 34–51.

[28] Cupello, James M., "The Gentle Art of Chartering a Team," *Quality Progress* (September 1995): 83–87.

the major processes associated with the product, service or process. From this information, the facilitator can better determine the team members that should be selected based on their skills and knowledge. The facilitator can then have the team meet to evaluate the problem posed by management, determine the type of training team members may need, and identify the appropriate team leader.

Storming is the most difficult stage as members start to realize the amount of work that lies ahead. There is a tendency to panic. Members rely almost solely on their personal and professional experience and resist working with other team members. There is a great deal of conflict, and the leader needs to be patient and flexible in working with the team. However, not all conflict is bad. If a team does not have any conflict, chances are the level of organizational performance is low.[29] Such teams adapt slowly to change, show apathy, or are stagnant. On the other hand, when conflict becomes disruptive, interferes with activities and makes coordination difficult, the team is dysfunctional. Owen indicates that good teams fight more than bad teams, at least at first.[30] Each individual, particularly those on cross-functional teams, brings with them both hierarchical and functional baggage, differences in goals, differences in perceptions, as well as different levels of work ethics, sense of time, career-family priorities, and attitudes toward authority. Team leaders and facilitators need to know how to manage team conflict so that it is productive and not destructive. Below are tips to help team members handle conflict.

- Ask those who disagree to paraphrase one another's comments. This may help them learn if they really understand one another.
- Work out a compromise. Agree on the underlying source of conflict, engage in a give and take, and finally agree on a solution.
- Ask each member to list what the other side should do. Exchange lists, select compromises all are willing to accept, and test the compromise to see if it meshes with team goals.
- Have the sides each write ten questions for their "opponents." This will allow them to signal their major concerns about the other side's position. The answers often lead to compromise.
- Convince team members they sometimes may have to admit they are wrong. Help them save face by convincing them that changing a position shows strength.
- Respect the experts on the team. Give their opinions more weight when the conflict involves their expertise, but don't rule out conflicting opinions.

If managed properly, functional conflict leads to positive movement toward goals, innovation and creativity, and solutions to problems.

Norming is the stage where members begin to work together. Emotional conflict is reduced as cooperation, cohesion, and constructive criticism start to become the normal behavior. Because there is more time and energy to focus on the objectives, significant progress begins to occur.

Performing is the stage where the team members have settled their relationships and expectations. They better understand the project and begin performing by diagnosing and solving problems and choosing and implementing changes. Members understand their roles and work in concert to achieve their objective(s) effectively and efficiently.

Adjourning is a stage that is reserved for temporary teams. The team needs to evaluate its performance and determine lessons learned. This information can be transferred by members when they participate on future teams. There also needs to be a celebration to recognize the team's contribution to the organization.

As a result of proper training and effective leadership, some teams arrive at the performing stage so quickly that it may be difficult for an organization to observe the first three stages.

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[29] Chester, Raymond, "When Teams Go to War—Against Each Other," *Quality Progress* (June 1999): 25–28.

[30] Owen, Jean V., "Why Teams Fail," *Manufacturing Engineering* (September 1995): 63–69.

Ten Common People Problems and Their Solutions[31]

One way to deal with group problems is to talk about them as soon as they occur. Most problems require a more structured approach. Common team problems and their solutions are given below.

1. *Floundering* occurs when the team has trouble starting or ending a project or different stages of the project. Solutions to this state are to look critically at the improvement plan, review the mission statement, determine the cause of the holdup, and have each member write down reasons and discuss them at the next meeting.

2. *Overbearing participants* have an unusual amount of influence in the team. They usually have a position of authority or a particular expertise. Teams need these abilities; however, it becomes detrimental when they discourage discussion on their expertise and discount other members' ideas. Solutions are to reinforce the ground rules, talk to the person off-line and ask for cooperation, and enforce the importance of data and the problem-solving method.

3. *Dominating participants* like to hear themselves talk, use overlong anecdotes, and dominate the meeting. Members get discouraged and find excuses for missing meetings. Solutions are to structure discussion on key issues for equal participation, talk to the offending person off-line, and have the team agree on the need for limits and a balanced participation. In addition, the leader may act as a gatekeeper by asking questions such as "Gupta, we heard from you; what do the others think?"

4. *Reluctant participants* feel shy or unsure of themselves and must be encouraged to contribute. Problems develop when there are no built-in activities that encourage introverts to participate and extroverts to listen. In addition to structured activities, solutions include dividing the task into individual assignments and acting as a gatekeeper by asking questions such as, "Sanjeev, what is your experience in this area?"

5. *Unquestioned acceptance of opinions as facts* occurs when members assert personal beliefs with such confidence that other members think they are facts. Solutions are to request data and to follow the problem-solving method.

6. *Rush to accomplish* is common to teams being pushed by one or more members who are impatient for results. Teams must realize that improvements do not come easily and rarely overnight. Solutions are to remind members that the ground rules call for the problem-solving method or to confront the rusher off-line and explain the effects of impatience.

7. *Attribution* is the activity of guessing at a person's motives when we disagree or don't understand his or her opinion or behavior. Solutions are to reaffirm the importance of the problem-solving method, question whether this opinion is based on data, and find out the real meaning of the problem.

8. *Discounts and "plops"* arise when members fail to give credit to another's opinions or no one responds to a statement that "plops." Every member deserves the respect and attention from the team. Solutions are to reinforce active listening as a team behavior, support the discounted member, or talk off-line with members who frequently discount, put down, or ignore.

9. *Wanderlust: digression and tangents* happen when members lose track of the meeting's purpose or want to avoid a sensitive topic. Discussions then wander off in many directions at once. Solutions are to use a written agenda with time estimates, write meeting topics on flip charts, or redirect the conversation back to the agenda.

10. *Feuding team members* can disrupt an entire team with their disagreements. Usually these feuds predate the team and are best dealt with outside the team meetings. Solutions are to get the adversaries to discuss the issues off-line, offer to facilitate the discussion, and encourage them to form some contract about their behavior.

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[31] Adapted, with permission, from Peter R. Scholtes, *The Team Handbook*, (Madison, WI: Jointer Associates Inc., 1988).

When people work together on a team, some of their energies are expended on "people issues." Mastery of these "people issues" leads to team success.

Common Barriers to Team Progress[32]

Evidence shows that the barriers given below are due primarily to the system rather than to the team.

- *Insufficient training*. Teams cannot be expected to perform unless they are trained in problem-solving techniques, group dynamics, and communication skills.
- *Incompatible rewards and compensation*. In general, organizations make little effort to reward team performance. Because of a strong focus on individual rewards it is difficult for individuals to buy into the team concept. Similarly, performance appraisals do not accept input from peers or team members.
- *First-line supervisor resistance*. Supervisors are reluctant to give up power, confident that they can do the work better and faster, are concerned about job security, and are ultimately held responsible.
- *Lack of planning*. A lack of common direction or alignment on the use of collaborative efforts, internal competition, redundancy, and fragmented work processes all prevent team progress.
- *Lack of management support*. Management must provide the resources and "buy into" the quality council/sponsor system.
- *Access to information systems*. Teams need access to organizational information such as business performance, competitive performance, financial data, and so forth.
- *Lack of union support*. Organizations need union support for the team to be successful.
- *Project scope too large*. The team and organization are not clear on what is reasonable, or management is abdicating its responsibility to guide the team.
- *Project objectives are not significant*. Management has not defined what role the team will play in the organization.
- *No clear measures of success*. The team is not clear about its charter and goals.
- *No time to do improvement work*. Values and beliefs of the organization are not compatible with the team's work. Individual departmental politics interfere with the team's progress. Management has not given the team proper resources.
- *Team is too large*. The organization lacks methods for involving people in ways other than team membership.
- *Trapped in groupthink*. Team members all have a mind-set that no actions are taken until everyone agrees with every decision.

With a knowledge of these barriers, management can evaluate their own performance and take the necessary corrective action to support team progress.

Training

Training is essential for an effective team. The quality council must take an active role in establishing training programs. Large organizations spend lakhs of rupees in team training. Maruti Suzuki's annual expendi-

[32] Information for this section comes from two surveys: Association for Quality and Participation, "Self-Directed Teams: A Study of Current Practice," Development Dimensions International and *Industry Week*, 1990, as reported in *Quality Digest* (October 1993): 42; and Wilson Learning Corporation, "Meeting the Collaborative Challenge: A Study of Supports and Barriers to Team Effectiveness," as reported in *Quality Digest* (April 1994): 8. And from two articles: Snee, Ronald D., K. H. Kelleher, J. G. Myers, and S. Reynard, "Improving Team Effectiveness," *Quality Progress* (May 1998): 43–48; and Beck, John D. W., and Neil M. Yeager, "How to Prevent Teams from Failing," *Quality Progress* (March 1996): 27–31.

ture on employee training was Rs. 13 crore during the year 2008. This large investment has its payoffs. Motorola, Inc. estimates that it earns $30 for every dollar invested in employee training. A recent study of small to mid-sized manufacturing firms found a significant positive relationship between company performance, as measured by profitability, and quality management training.[33]

The training must be experimental, because the trainees will retain 20% of what they hear and about 90% of what they do. Training should be practical and given on an as-needed basis. When possible, role-playing and case studies should be used. Trainers should be carefully selected for their knowledge, enthusiasm, and respect from the trainees.

Credibility must be established early. The team members should feel comfortable with the trainer and the program that has been developed. A clear picture of the objectives and how each member will benefit must be in place. The trainees should be encouraged to express their thoughts about the training program. Team leaders should be receptive to suggestions and make changes where warranted. Employees are much more likely to support a program that they helped develop.

The first step in the training process is to make everyone aware of what the training is all about. Thoughts, suggestions, and feedback should be gathered. The second step is to get acceptance. Trainees must feel that the training will be of value to them. The third step is to adapt the program. Is everyone ready to buy into it? Does everyone feel they are a part of what is going to take place? The fourth step is to adapt to what has been agreed upon. What changes must be made in behavior and attitudes?

In addition to team training covering group dynamics and communication skills, all members must receive training in quality awareness (TQM), specific problem solving techniques such as SPC, safety, and technical aspects of the job. The only difference among the types of training is that some may be required more often and for greater lengths of time than others. Training programs fail for many different reasons, but they primarily fail because the focus is usually on the training itself and not on helping the organization improve in a real and measurable way.[34] To be efficient for the team members and the organization, training should be action oriented so that results can be obtained right away. Depending on an individual's position in the organization, Juran suggests different types of training in quality, as Table 4-2 suggests.

Team leaders play an important role in team building. There is a difference between being a supervisor and a team leader. Supervisors who become team leaders will experience a different situation than what they were accustomed to as supervisors. Team leaders share their responsibilities with other team members. They give team members a chance to succeed on their own. The team leader must be aware of the 85/15 rule, which means that 85% of the problems are part of the system. To be a good team leader requires specific training. Courses from local colleges in human relations, motivation, conflict resolution, communications, and related matters are recommended. Some organizations provide on-site training in these areas. Consultants are also available for this type of training. A well-trained team leader can help ineffective team members improve, but team members usually cannot help an ineffective team leader.

Suggestion System[35]

Suggestion systems are designed to provide the individual with the opportunity to be involved by contributing to the organization. Most of the ideas for continuous improvement will come from the team

[33] Ryan, Chuck, Richard H. Deane, and Ned P. Ellington, "Quality Management Training in Small to Midsized Manufacturing Firms," *Quality Management Journal*, Vol. 8, No. 2 (2001): 44–52.

[34] Snee, Ronald D., "Make the View Worth the Climb," *Quality Progress* (November 2001): 58–61.

[35] James A. Heath, "A Few Good Ideas for a Good Idea Program," *Quality Progress* (January 1994): 35–38.

TABLE 4-2
Who Needs to Receive Quality Training

Subject Matter	*Top Management*	*Quality Managers*	*Other Middle Managers*	*Specialists*	*Facilitators*	*Work Force*
Quality Awareness	X		X	X	X	X
Basic Concepts	X	X	X	X	X	X
Strategic quality management	X	X				
Personal Roles	X	X	X	X	X	X
Quality Processes	X	X	X	X	X	X
Problem Solving Methods		X	X	X	X	X
Basic Statistics	X	X	X	X	X	X
Advanced Statistics		X		X		
Quality in Functional Areas		X	X	X		
Motivation for Quality	X	X	X		X	

Reproduced, with permission, from J. M. Juran ed., *Quality Control Handbook*, 4th ed., (New York: McGraw-Hill, 1988).

approach. However, once the foundation for a TQM organization has been established, a suggestion system can operate effectively and in parallel to the team approach. The key to an effective system is management commitment. Management must make it easy for employees to suggest improvements. Management should then review them promptly and if feasible, implement them.

Stimulating and encouraging employee participation starts the creative process. There are five ground rules:

1. *Be progressive* by regularly asking your employees for suggestions. Merely putting up a suggestion box will not create the necessary motivation.
2. *Remove fear* by focusing on the process and not on the person. When employees know that punitive actions will not occur, they are more likely to respond.
3. *Simplify the process* so it is easy to participate. Stamp out superfluous paperwork, review, and procedures.
4. *Respond quickly* to suggestions and within a specific period of time. The evaluation process must be simple and effective. The response, in writing, has three possible responses—acceptance, rejection, or referral to a committee for further evaluation. If accepted, a time frame for implementation should be given; if rejected, the reason for the rejection should be stated; and if referred to a committee, the evaluation time should be stated.
5. *Reward the idea* with published recognition so that everyone knows the value of the contribution.

Individual ideas are a vast untapped resource. The five-step approach helps to create an environment that opens communication between employees and managers. Idea generation is a skill that requires practice. It supplements the team process.

Recognition and Reward

Recognition is a form of employee motivation in which the organization publicly acknowledges the positive contributions an individual or team has made to the success of the organization. This acknowledgment is delivered using verbal and written praise and may include symbolic items such as certificates and plaques. Reward is something tangible such as theater tickets, dinner for two, or a cash award to promote desirable behavior. Recognition and reward go together to form a system for letting people know they are valuable members of the organization.

Employees should be involved in the planning and implementation of the recognition and reward program. This activity should be performed by a cross-functional team that represents all areas of the organization. Systems that are developed with employee involvement will most likely succeed. It should be fully understood by the employees and reviewed periodically in order to continuously improve the system and because priorities—either the employee's or the organization's—may change. In addition, the system should be simple. Employees should be involved with the manager and sometimes the customer and supplier in the nomination and selection of the individuals and teams to be recognized and rewarded. Criteria for selection can utilize some of the information discussed in the section on appraisal.

The system that is developed by the team must have clear recognition criteria. Policies and procedures must be consistently and fairly applied throughout the organization. The system should be structured to avoid ranking individuals, because ranking fosters the counterproductive notion that there are winners and losers. Recognition should be valid, genuine, and meaningful for the giver and the recipient; it should not be used to manipulate people. The organization should recognize effort as well as easy-to-measure results. Recognition should not be based primarily on chance, which frequently occurs in employee-of-the-month programs.

The system should be so developed that monetary reward is not a substitute for compensation. While the reward may be delayed until an appropriate time, the recognition should be on a timely basis. Rewards should be appropriate to the improvement level—the greater the improvement, the greater the reward. They should be of value—a coffee cup does not provide much incentive to improve performance, especially when this is the third cup awarded to the employee and everyone else has two. It is also desirable for the employee to select the form of the reward from various alternatives.[36]

People like to be recognized, either as a team or individually. A person's feeling of achievement, value to the organization, knowing the organization cares, and having peer recognition may be more important than any reward. In addition to the plaque or framed certificate given at a formal banquet or informal pizza party, there are other forms of individual and team recognition. Other forms of recognition include pictures on the bulletin board, articles in newsletters or newspapers, letters to families, making a presentation to management, passing along compliments from others, personal phone calls or notes, placing positive notes in folders, and increased responsibility. Supervisors can also informally use the power of recognition by giving on-the-spot praise for a job well done whenever it is earned.

There are many different forms of individual and team rewards. Individual rewards include a better parking space, dinner out, gift certificates, gift to charity in the name of the recipient, washing an employee's car during the lunch hour, trips, and event tickets, to name a few. Group rewards are similar and can also include an outing such as a ball game, bowling, and movies; group lunch or dinner; allowing the team to make some decisions affecting their work or allowing the team to spend their reward "earnings" to improve their work

[36] Gene H. Milas, "How to Develop a Meaningful Employee Recognition Program," *Quality Digest* (May 1995): 139–141.

environment. Cash awards are also effective motivators for individual and team awards. Gainsharing is discussed next in this chapter. A survey of 100 organizations found the following intrinsic (those related to feelings of accomplishment or self-worth) and extrinsic (those related to pay or compensation issues) reward practices to be effective in their companies in supporting their TQM practices, as described in Table 4-3. Many organizations have periodic celebration banquets where awards are presented to individuals or teams.[37]

To summarize, an effective recognition and reward system:

1. Serves as a continual reminder that the organization regards quality and productivity as important.
2. Offers the organization a visible technique to thank high achievers for outstanding performance.
3. Provides employees a specific goal to work toward. It motivates them to improve the process.
4. Boosts morale in the work environment by creating a healthy sense of competition among individuals and teams seeking recognition.

Gainsharing

Gainsharing is a financial reward and recognition system that results from improved organizational performance. It is different than profitsharing, in which the stockholders share a portion of the year-end profits

TABLE 4-3
Effective Reward Practices

Intrinsic Rewards	*Extrinsic Rewards*
• Non-monetary forms of recognition to acknowledge achievement of quality improvement goals	• Profit sharing
• Celebrations to acknowledge achievement of quality improvement goals	• Gainsharing
• Regular expressions of appreciation by managers and leaders to employees to acknowledge achievement of quality improvement goals	• Employment security
• 360 degree performance appraisals—feedback from co-workers (other than the immediate supervisor), subordinates or customers is incorporated into performance appraisals	• Compensation time
• Formal suggestion system available for individuals to make quality improvement suggestions	• Individual based performance systems
• Developmental based performance appraisals	• Quality based performance appraisals
• Quality based promotions	

Reproduced, with permission, from Richard S. Allen and Ralph H. Kilmann, "How Well Does Your Reward System Support TQM?" *Quality Progress* (December 1998): 47–51.

[37] *1001 Ways to Reward Employees* (New York: Workman Publishing Co. Inc., 1994).

with salaried and occasionally hourly employees. Gainsharing is based on the philosophy that people and teamwork are the keys to success. Because organizational success is dependent on team effort, the team shares in the rewards of success. Thus, gainsharing is a measurement of organizational productivity and a method to share productivity gains.

There are many different variations to the technique. We will illustrate the basic approach. This particular method utilizes labor costs and potential sales income for the calculations and is based on four-week periods; however, calculations are made on a weekly basis. At the end of the week, the team performance is calculated based on potential sales income from the week's production less rejections and outsourcing costs. Financial data shows that labor costs are a certain percentage of sales income, and this value multiplied by the income gives the *team goal*. *Team cost* is the sum of all labor costs for the week including fringe benefits. The *gain* or loss is the difference between the team cost and the team goal. For example:

Potential income = \$ 535,000

Labor cost as a percent of sales = 27%

Team goal = \$ 5,35000 × 0.27 = \$ 144,450

Actual team cost = \$ 138,365

Gain = \$ 144,450 – 138,365 = \$ 6,085

Payments are usually made every four weeks, thereby providing motivational reinforcement. They are separate from the regular paycheck. Every four weeks gainsharing meetings are held to review the calculations, evaluate the performance, and discuss ways to make additional gains. Distribution of the gain can be to hourly personnel or to both salary and hourly personnel. It should be prorated by the employees' regular weekly earnings for four weeks. In other words, the gainsharing amount for an employee is the ratio of his four weeks earnings divided by the four weeks earnings of all employees in the plan. This ratio is multiplied by the gain. There are two types of performance strategies—financial performance measure as illustrated by the example or physical performance measure such as pieces, weight, or volume.

One of the key issues is the amount of the gains. Organizations distribute between 30% and 100%, with 50% appearing to be equitable.

Another issue is the baseline determination, which in the example was 27%. The baseline can be based on historical information or, if unavailable, targeted information. It should be changed several times a year, using a weighted average, so that gains are for recent improvements rather than old ones. The baseline may also need to be adjusted for capital improvements or changes in mix.

Gain sharing is a widely used policy in software and engineering service industry in India.

Technology service firms in India are moving to a revenue/gain share model where they get a chunk of the client's revenues or gains made due to increased productivity or reduction in processing time.

For HCL Technologies, which adopted the revenue/gain share model in 2005, less than 5% of revenue currently comes from such contracts. While engineering services and infrastructure management services clients have more readily adopted this model, those in the applications space are yet to adopt. HCL has a revenue sharing arrangement with Cisco.

Gainsharing is an excellent motivational tool that improves quality, productivity, and, of course, the bottom line.

Performance Appraisal

The purpose of performance appraisals is to let employees know how they are doing, and provide a basis for promotions, salary increases, counseling, and other purposes related to an employee's future. There should be a good relationship between the employee and the appraiser. Employees should be made aware of the appraisal

TABLE 4-4
Appraisal Formats

Type	*Description*
Ranking	Compares employees by ranking from highest to lowest.
Narrative	Gives a written description of employee's strengths and weaknesses.
Graphic	Indicates the major duties performed by the employee and rates each duty with a scale, which is usually from 1 (poor) to 5 (excellent).
Forced choice	Places each employee in a category with a predetermined percentage—for example, excellent (10%), very good (25%), good (30%), fair (25%), and poor (10%).

process, what is evaluated, and how often. Employees should be told how they are doing on a continuous basis, not just at appraisal time. The appraisal should point out strengths and weaknesses as well as how performance can be improved. Common appraisal formats are shown in Table 4-4.

Performance appraisals may be for the team or individuals. Regardless of the system, a key factor in a successful performance appraisal is employee involvement. An employee should always be given the opportunity to comment on the evaluation, to include protesting, if desired. Performance must be based on standards that are developed and agreed upon by the appraisor and employee. Standards normally contain an ideal level and an acceptable level. Standards should change when the situation changes, such as when equipment changes or new production techniques are developed.

Performance appraisals should be viewed as a positive way to get employees involved. Many supervisors look at appraisals as one of the unpleasant duties they must perform. Yet, if employees have been adequately interviewed as a part of the hiring process, properly trained, given help when needed, and counseled, then their performance will be a reflection on how well those tasks were performed. Performance appraisals also can be a pleasant duty for supervisors and can reveal how effective the employee is in contributing to the success of the organization.

Every effort should be made to avoid errors in performance evaluations. Culture, ethics, education level, and predetermined opinions can affect evaluations. It would be unfair indeed to render a poor rating based on bias or anything except how the employee has performed based on established standards. An unfair evaluation could cost the organization a valuable employee.

The traditional performance appraisal system has been criticized as being counter-productive and unnecessary by such quality experts as Deming and Scholtes. There are a number of arguments to support their opinion.

Appraisals nourish short-term performance and destroy long-term planning. Frequently, long-term gains are sacrificed by making the individual look good in the short term. This outlook is especially prevalent when we look at the emphasis on the quarterly profit and loss statement. Another criticism states that individual appraisal destroys teamwork. If teams are to become a cohesive unit of "all for one and one for all," then individual ranking would undermine the entire concept. The end result would be a team that performs poorer, not better. A third concern is the assumption that an individual is responsible for all results. In reality, the results are frequently beyond an individual's control, such as processes and equipment. Deming has stated that 85% of the problems are the result of the system. Last, there is a concern that appraisals are frequently based on subjectivity and immeasurables. They should be based on objectivity; however, it is difficult to measure some attributes such as customer satisfaction and leadership.[38]

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[38] George Eckes, "Practical Alternatives to Performance Alternatives," *Quality Progress* (November 1994): 57–60.

Rather than scrap performance appraisals, a number of practitioners have suggested that the performance appraisal system be improved. Some improvement suggestions are:

1. *Use rating scales that have few rating categories*. It is difficult to differentiate the middle range of performers (approximately 67%), whereas it is relatively easy to rate the 10 to 20% at each end. Therefore, scales should be limited to between 3 and 5.

2. *Require work team or group evaluations that are at least equal in emphasis to individual-focused evaluations*. The increased interdependence of tasks associated with TQM in the workplace dictates that team performance be utilized. This action will encourage team members to help, support, and cooperate with each other.

3. *Require more frequent performance reviews where such reviews will have a dominant emphasis on future performance planning*. Work team and individual performance data should be collected and reviewed with an evaluation of results and lessons learned. It may be necessary to have two reviews—one immediately after completion of the task and one when the performance cycle of the task allows evaluation of results. More frequent reviews with emphasis on improvement is much less threatening than the annual appraisal.

4. *Promotion decisions should be made by an independent administrative process that draws on current-job information and potential for the new job*. Placing too much weight on current performance in the selection process can force well-intentioned appraisers to make a poor decision. For example, the highest performing teller in a bank may not be the best person to be promoted to loan officer.[39]

5. *Include indexes of external customer satisfaction in the appraisal process*. In order to accomplish this process, the customers and their requirements will need to be identified, performance metrics determined using a rating scale, and the improvement process initiated. Evaluation will be based on the change in the metrics once the baseline has been established.

6. *Use peer and subordinate feedback as an index of internal customer satisfaction*. Initiation of this activity would be similar to the previous item.

7. *Include evaluation for process improvement in addition to results*. Process behavior tends to be more within the person's control. One of the basic concepts of TQM is continuous process improvement; therefore, if this concept is to be achieved, it must be appraised. There is frequently a lag between process improvement and the results from that improvement.[40]

Despite Deming's reservations, performance appraisals can reinforce TQM concepts provided these suggestions are implemented where appropriate.

Unions and Employee Involvement

In general, unions support quality improvement programs but express concern regarding management exercising too much control over employees. Union representatives must be involved in any program involving employees. Although employee involvement has been widely accepted, it could be a problem if not properly addressed. In some instances where management takes too much control over employee involvement, it could be a violation of the National Labor Laws. Some have argued that a law passed to serve a good purpose in 1935 may not be appropriate for today's problems. However, unless the National Labor Law is amended, it is in the best interest of management to be sure actions taken will not violate the National Labor Law.

[39] J. Bruce Prince, "Performance Appraisal and Reward Practices for Total Quality Organizations," *Quality Management Journal* (January 1994): 36–46.

[40] Allan J. Weber, "Making Performance Appraisals Consistent With a Quality Environment," *Quality Digest* (June 1995): 65–69.

Teams should not discuss wages, rates of pay, hours of employment, or conditions of work. In some cases, these limitations will adversely effect the team's objective.[41]

Both management and unions must examine long-held views of what constitutes proper union-management relationships. Desire for unilateral power must be changed to shared power for the benefit of employees and the organization. A joint process of determining how best to proceed to effectively meet the competition, especially from foreign organizations, is the only sensible solution. Management must recognize and respect the unique role unions play in employee involvement. A feeling of trust must be established and a partnership developed between management and the union.

There are two ways in which unions and management have chosen to deal with the implementation of employee involvement in an organization. Some have chosen to work cooperatively, giving unions membership on quality councils and having them participate fully in planning, implementation, and evaluation of the entire effort. Others have adopted the more "traditional" mode of bargaining the impact and implementation actions affecting those in the improvement team. Each approach presents benefits and potential risks. Union involvement improves the continuous improvement process; however, union leadership runs the risk of criticism from other members if it is perceived as working too closely with management. The nature of the relationship will be determined by the background and history or the labor-management relations in the organization and the willingness of the union to participate. Ideally, the leadership of the organization will seek early involvement of the union and make the nature of the involvement as specific as possible.[42]

An example of union-management cooperation is illustrated by the collective bargaining agreement between the United Auto Workers and Ford Motor Company. It provides for joint leadership in the quality improvement effort by joint committees at the corporate, division, and facility levels. These committees have the authority of the contract to plan, implement, evaluate, and expand quality systems as needed. Many orga-nizations can provide evidence that their successful quality systems can be attributed to the unions. Unions will grow if they are seen as a superior way to support democracy in the workplace and improve the performance of the organization.[43]

Benefits of Employee Involvement

Involving employees, empowering them, and bringing them into the decision-making process provides the opportunity for continuous process improvement. The untapped ideas, innovations, and creative thoughts of employees can make the difference between success and failure. Competition is so fierce that it would be unwise not to use every available tool.

Employee involvement improves quality and increases productivity, because

- Employees make better decisions using their expert knowledge of the process.
- Employees are more likely to implement and support decisions they had a part in making.
- Employees are better able to spot and pinpoint areas for improvement.
- Employees are better able to take immediate corrective action.
- Employee involvement reduces labor/management friction by encouraging more effective communication and cooperation.
- Employee involvement increases morale by creating a feeling of belonging to the organization.

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[41] Donald L. Dewar, "National Labor vs. Teams: What You Should Know," *Quality Digest* (May 1993): 60–62.

[42] Federal Quality Institute, *Employee Involvement and Quality Management in the Federal Government*, July 1993.

[43] Sidney P. Rubinstein, "Democracy and Quality as an Integrated System," *Quality Progress* (September 1993): 51–55.

- Employees are better able to accept change because they control the work environment.
- Employees have an increased commitment to unit goals because they are involved.

Additional Comments

Employee involvement should not be looked at as a fad that will go away soon. It is a way of life, crucial to TQM, and it can mean the difference between being competitive and going out of business. Employees, not senior management, hold the future in their hands. The sign over the plant entrance that says, "Through these doors pass our most important asset, our employees" does not ring true when employees have a feeling that no one really cares. More involvement might be encouraged by the sign "No one of us knows as much as all of us."

As the organizational culture begins the process of change, resistance to this change will certainly be present. Keeping people informed will reduce resistance, especially when they see the benefits. Change is an ongoing process that must occur if an organization is to continue to exist in the competitive world. People do not necessarily resist change; they resist being changed, and problems arise when a person's comfort zone is disturbed.

Much of the information in this chapter has related to the role of management. However, we must not overlook the role of the work force. Workers must become knowledgeable about the needs of the customer and nominate quality problems for solution. In addition, workers must know what they are supposed to do and how they are doing and have a commitment to improving their job.

TQM Exemplary Organization[44]

Infosys Technologies Ltd was started in 1981 by 7 people. Today, Infosys is the biggest IT venture in India. It is a leader in the "next generation" of IT and consulting services with revenue of over US$ 4 billion. The services provided include business and technology consulting, application services, systems integration, product engineering, custom software development, maintenance, re-engineering, independent testing and validation services, IT infrastructure services and business process outsourcing.

Infosys pioneered the Global Delivery Model (GDM), which emerged as a disruptive force in the industry leading to the rise of offshore outsourcing. The GDM is based on the principle of taking work to the location where the best talent is available making the best economic sense with the least amount of acceptable risk.

Infosys has a global presence with over 50 offices and development centers in India, China, Australia, the Czech Republic, Poland, the UK, Canada and Japan. Infosys and its subsidiaries have over 10 lakh employees.

In recent years, Infosys has been noted as the best employer in the country by many HR surveys. The company is well known for its employee-friendly HR practices. Though, Infosys grew to become a US$ 2 billion company by the year 2006, it still retained the culture of a small company. Infosys attracted the best talent from across the world and recruited candidates by conducting one of the toughest selection process. All the selected candidates were required undergo an intensive 14 week training program. All the employees were also required to undergo training every year and some of the chosen employees were trained at the Infosys Leadership Institute to take on higher responsibilities in the company. Infosys was one of the first companies to offer Employee Stock Ownership Plans (ESOPs) to its employees. According to, Mr. Narayan Murthy, non-executive Chairman of Infosys Technologies Ltd. "We always felt that the leader cannot operate in a vacuum. For a leader to succeed you need to have thousands of people who will work with him/her. Those people are adding value towards creating a wonderful company and its only fair that we share our wealth with these people too."

[44] Malcolm Baldrige National Quality Award, 2001 Manufacturing Category Recipient, NIST/Baldrige Homepage.

The company followed variable compensation structure where the compensation of the employees depended on the performance of the individual, the team and the company.[45,46]

Summary

Employee Involvement is an important approach to improve quality and productivity. Involvement of employees is a crucial factor in achieving higher quality collective business growth. Mature organizations should demonstrate increasing participation of employees at various levels of business operations.

There are several levels of motivation and its knowledge helps the organization understand its workforce. Management should create an environment of trust among the employees and nurture the ability of their workforce, their confidence and ownership of their processes. Employee involvement is also optimized by the use of teams.

Organization must also encourage individual efforts and ideas. Suggestion and schemes provide an individual with an opportunity to get involved by contributing to the organization.

Recognition of efforts should be done publicly acknowledging the positive contributions of an individual or a team.

Gain sharing is a financial reward and recognition system that results from improved organizational performance. It is a measurement of an organization's productivity and a method to share the productivity gains.

Performance appraisals of the individuals or teams should be done to let the employees know that their performance is evaluated and should provide basis for promotions, counseling and several other purposes.

Exercises

1. As a supervisor, list ways to improve morale.
2. List the five levels in Maslow's hierarchy of needs and describe each level.
3. How do recognition and reward affect motivation?
4. List at least five reasons given by supervisors when resisting change.
5. Discuss the advantages of an empowered team.
6. You recently completed a performance appraisal for one of your employees. The employee is not happy with the evaluation and has asked for an appointment to discuss the evaluation process. Discuss the following:
   (a) The purpose of the performance evaluation.
   (b) The evaluation criteria.
   (c) The employee's options regarding the evaluation.
7. You have been asked to develop an employee involvement policy for your organization. Respond to the following:
   (a) Why do you need union involvement?
   (b) How will you get the union involved?
   (c) What resistance should you expect?

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[45] Public domain information derived from the Website of Infosys Technologies Limited, www.infosys.com.

[46] Article "The Renaissance Man" by Yasmin Taj. Published on 14th October 2009 in "*Ascent*" Supplement of Time of India, Pune.

8. Describe the role of employees' involvement in TQM by responding to the following:
   (a) Why is employee involvement important to TQM?
   (b) Why do we need involved employees? We haven't before.
   (c) Employee time is valuable. How will it pay reasonable dividends?

9. Define the following:
   (a) teams
   (b) performance
   (c) reward
   (d) motivation
   (e) recognition
   (f) empowerment
   (g) gainsharing

10. Describe and analyze an incident where you wished you had the authority (empowerment) to make a decision but had a concern about whether or not you should make the decision on your own.

11. Conduct an employee opinion survey for a work unit and analyze the results. This may be done as an individual assignment or as a team effort.

12. Describe Herzberg's dissatisfiers and motivators.

13. What conditions are necessary for empowerment?

14. What are the different types of teams?

15. Why do teams work?

16. List five common barriers to team progress.

17. Evaluate an organization's
   (a) suggestion system
   (b) performance appraisal system
   (c) recognition and reward system
   (d) decision-making methods

   This may be done as an individual assignment or as a team effort.

18. Which of the following is correct hierarchy of needs?
   (a) survival, security, esteem, social, self actualization
   (b) survival, security, social, esteem, self actualization
   (c) security, survival, social, esteem, self actualization
   (d) security, survival, esteem, social, self actualization

19. Which of the following are motivators?
   I salary
   II certificate from the President
   III appreciation from customer
   IV air-conditioned office

   (a) I and IV only
   (b) II and III only

(c) I, II, III and IV
(d) I, II and III only

20. Which of the following is correct sequence?

(a) forming-norming-storming-performing-adjourning
(b) forming-storming-performing-norming-adjourning
(c) forming-norming-storming-adjourning-performing
(d) forming-storming-norming-performing-adjourning

21. Which of the following should be the key aspect of any performance appraisal system?

(a) opportunity for employee to comment on evaluation
(b) opportunity for peers to comment on evaluation
(c) opportunity for the customers to comment on evaluation
(d) opportunity for the HR manager to comment on the evaluation

22. At which of the team stages a team leader would generally get selected?

(a) forming
(b) norming
(c) performing
(d) storming

5

Continuous Process Improvement

Chapter Objectives

- Brief overview: perfection versus continuous improvement
- Defining and mapping a process: learning from Juran Trilogy
- Overview of approaches for process improvement
- Choosing and integrating right improvement strategies
- Understanding the types of problems
- Understanding the concept of the PDSA cycle and problem solving method
- Studying the TQM approaches: Kaizen, Reengineering and Six Sigma

Introduction

Quality-based organizations should strive to achieve perfection by continuously improving the business and production processes. Of course, perfection is impossible because the race is never over; however, we must continually strive for its attainment.

Improvement is made by

- Viewing all work as a process, whether it is associated with production or business activities.
- Making all processes effective, efficient, and adaptable.
- Anticipating changing customer needs.
- Controlling in-process performance using measures such as scrap reduction, cycle time, control charts, and so forth.
- Maintaining constructive dissatisfaction with the present level of performance.

- Eliminating waste and rework wherever it occurs.
- Investigating activities that do not add value to the product or service, with the aim of eliminating those activities.
- Eliminating nonconformities in all phases of everyone's work, even if the increment of improvement is small.
- Using benchmarking to improve competitive advantage.
- Innovating to achieve breakthroughs.
- Incorporating lessons learned into future activities.
- Using technical tools such as statistical process control (SPC), experimental design, benchmarking, quality function deployment (QFD), and so forth.

Continuous process improvement is designed to utilize the resources of the organization to achieve a quality-driven culture. Individuals must think, act, and speak quality. An organization attempts to reach a single-minded link between quality and work execution by educating its constituents to "continuously" analyze and improve their own work, the processes, and their work group.[1]

Process

Process refers to business and production activities of an organization. Business processes such as purchasing, engineering, accounting, and marketing are areas where nonconformance can represent an opportunity for substantial improvement. Figure 5-1 shows a process model.

Inputs may be materials, money, information, data, etc. *Outputs* may be information, data, products, service, etc. The output of one process also can be the input to another process. Outputs usually require performance

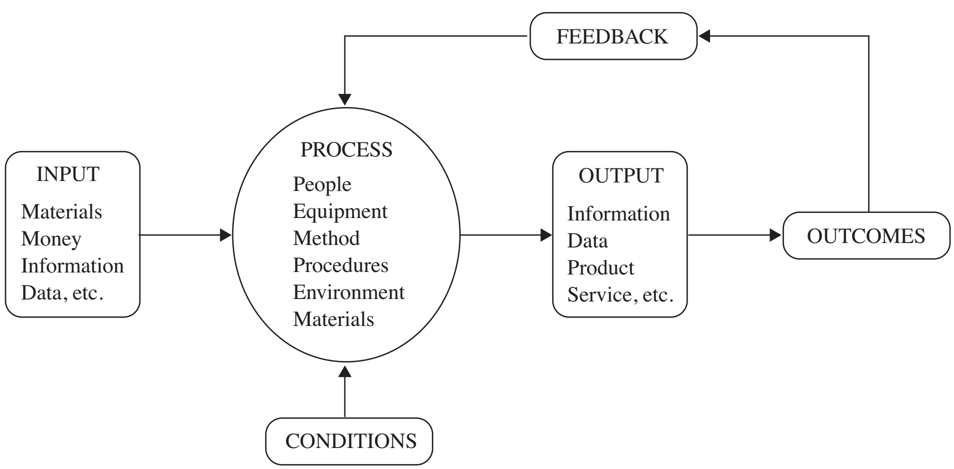

Figure 5-1 Input/Output Process Model

[1] Danny G. Langdon, "A New Language of Work," *Quality Digest* (October 1994): 44–48.

measures. They are designed to achieve certain desirable *outcomes* such as customer satisfaction. *Feedback* is provided in order to improve the process.

The *process* is the interaction of some combination of people, materials, equipment, method, measurement, and the environment to produce an outcome such as a product, a service, or an input to another process. In addition to having measurable input and output, a process must have value-added activities and repeatability. It must be effective, efficient, under control, and adaptable. In addition, it must adhere to certain *conditions* imposed by policies and constraints or regulations. Examples of such conditions may include constraints related to union-based job descriptions of employees, state and federal regulations related to storage of environmental waste, or bio-ethical policies related to patient care.

Process definition begins with defining the internal and/or external customers. The customer defines the purpose of the organization and every process within it. Because the organization exists to serve the customer, process improvements must be defined in terms of increased customer satisfaction as a result of higher quality products and services.

All processes have at least one owner. In some cases, the owner is obvious, because there is only one person performing the activity. However, frequently the process will cross multiple organizational boundaries, and supporting sub-processes will be owned by individuals within each of the organizations. Thus, ownership should be part of the process improvement initiatives.

At this point it is important to define an improvement. There are five basic ways to improve: (1) reduce resources, (2) reduce errors, (3) meet or exceed expectations of downstream customers, (4) make the process safer, and (5) make the process more satisfying to the person doing it.

First, a process that uses more resources than necessary is wasteful. Reports that are distributed to more people than necessary wastes copying and distribution time, material, user read time, and, eventually, file space.

Second, for the most part, errors are a sign of poor workmanship and require rework. Typing errors that are detected after the computer printout require opening the file, making the correction, and printing the revised document.

Third, by meeting or exceeding expectations of downstream customers, the process is improved. For example, the better the weld, the less grinding required, making the appearance of a finish paint more pleasing.

The fourth way a process can be improved is by making it safer. A safer workplace is a more productive one with fewer lost-time accidents and less workers' compensation claims.

The fifth way to improve a process is to increase the satisfaction of the individual performing the process. Sometimes a little change, such as an ergonomically correct chair, can make a substantial change in a person's attitude toward their work.

This chapter presents several different approaches towards continuous process improvement. The first, Juran's Trilogy, approaches quality improvement from a cost-oriented perspective. The second is Shewhart's Plan-Do-Study-Act cycle. This approach is basically the engineering scientific method applied to continuous improvement and quality. A more in-depth description of the problem solving method is provided to further explain how to carry out the approach. The third is Kaizen, the Japanese approach to improvement. The Kaizen approach focuses on making small incremental improvements to the individual and the organization. It is actually more behavioral in nature than the other two approaches describe, as it often focuses on improving the individual and their individual job; thus, improvements to the organization as a whole are realized. The chapter concludes with a short discussion of reengineering and six-sigma concepts. These two approaches are becoming more popular in business, and they provide many of the basic concepts presented in the chapter.

The Juran Trilogy[2]

Process improvement involves planning. One of the best approaches is the one developed by Dr. Joseph Juran. It has three components: planning, control, and improvement, and is referred to as the Juran Trilogy. It is based loosely on financial processes such as bud-geting (planning), expense measurement (control), and cost reduction (improvement).

Planning

The planning component begins with external customers. Once quality goals are established, marketing determines the external customers, and all organizational personnel (managers, members of multifunctional teams, or work groups) determine the internal customers. External customers may be quite numerous, as is the case of a bank supply organization, where they include tellers, financial planners, loan officers, auditors, managers, and the bank's customers. Where there are numerous customers, a Pareto diagram (see Chapter 15) might be useful to determine the vital few.

Once the customers are determined, their needs are discovered. This activity requires the customers to state needs in their own words and from their own viewpoint; however, real needs may differ from stated needs. For example, a stated need may be an automobile, whereas the real need is transportation or a status symbol. In addition, internal customers may not wish to voice real needs out of fear of the consequences. One might discover these needs by (1) being a user of the product or service, (2) communicating with customers through product or service satisfaction and dissatisfaction information, or (3) simulation in the laboratory. Because customer needs are stated from their viewpoint, they should be translated to requirements that are understandable to the organization and its suppliers.

The next step in the planning process is to develop product and/or service features that respond to customer needs, meet the needs of the organization and its suppliers, are competitive, and optimize the costs of all stakeholders. This step typically is performed by a multifunctional team. Quality function deployment (Chapter 10), Taguchi's quality engineering (Chapter 16), and quality by design (Chapter 11) are some of the approaches that can be used. It is important that the design team, rather than a single department, approve the final design and that the team be composed of all functional areas within an organization as well as customers and suppliers.

The fourth step is to develop the processes able to produce the product and/or ser-vice features. Some of this planning would have occurred during the previous step. This step is also performed by a multifunctional team with a liaison to the design team. Activities include determining the necessary facilities, training, and operation, control, and maintenance of the facilities. Of particular concern will be the "scaling up" from the laboratory or prototype environment to the real process environment. Additional activities include process capability evaluation and process control type and location.

Transferring plans to operations is the final step of the planning process. Once again, a multifunctional team with a liaison to the other teams is used. When training is necessary, it should be performed by members of the process planning team. Process validation is necessary to ensure, with a high degree of assurance, that a process will consistently produce a product or service meeting requirements. Positrol and process certification, discussed later in the chapter, are excellent techniques to use to help validate the process.

[2] Adapted, with permission, from J. M. Juran, ed., *Quality Control Handbook*, 4th ed. (New York: McGraw-Hill, 1988).

Control

Control is used by operating forces to help meet the product, process, and service requirements. It uses the feedback loop and consists of the following steps:

1. Determine items/subjects to be controlled and their units of measure.
2. Set goals for the controls and determine what sensors need to be put in place to measure the product, process, or service.
3. Measure actual performance.
4. Compare actual performance to goals.
5. Act on the difference.

Statistical process control (see Chapter 15) is the primary technique for achieving control. The basic statistical process control (SPC) tools are Pareto diagrams, flow diagrams, cause-and-effect diagrams, check sheets, histograms, control charts, and scatter diagrams. In addition, process capability information such as C_p and C_{pk} are used to determine if the process is capable and is centered.

Improvement

The third part of the trilogy aims to attain levels of performance that are significantly higher than current levels. Process improvements begin with the establishment of an effective infrastructure such as the quality council (see Chapter 2). Two of the duties of the council are to identify the improvement projects and establish the project teams with a project owner. In addition, the quality council needs to provide the teams with the resources to determine the causes, create solutions, and establish controls to hold the gains (see Chapter 4). The problem-solving method described in a later section may be applied to improve the process, while the quality council is the driver that ensures that improvement is continuous and neverending. Process improvement can be incremental or breakthrough.

Figure 5-2 provides an example of how the three continuous improvement processes interrelate.[3] In the figure, Juran provides a distinction between sporadic waste and chronic waste. The sporadic waste can be identified and corrected through quality control. The chronic waste requires an improvement process. As a solution is found through the improvement process, lessons learned are brought back to the quality planning process so that new goals for the organization may be established.

Improvement Strategies[4]

There are four primary improvement strategies—repair, refinement, renovation, and reinvention. Choosing the right strategy for the right situation is critical. It is also true that proper integration of the strategies will produce never-ending improvement.

Repair

This strategy is simple—anything broken must be fixed so that it functions as designed. There are two levels to this strategy. If a customer receives a damaged product, a quick fix is required. This level is a temporary or short-term measure. Although short-term measures shore up the problem, they should not become permanent.

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[3] Juran, J.M., "The Quality Trilogy," *Quality Progress* (August 1986): 19–24.

[4] This section adapted from Jack L. Huffman, "The Four R's of Total Improvement," *Quality Progress* (January 1997): 83–88. © American Society for Quality. Reprinted with permission.

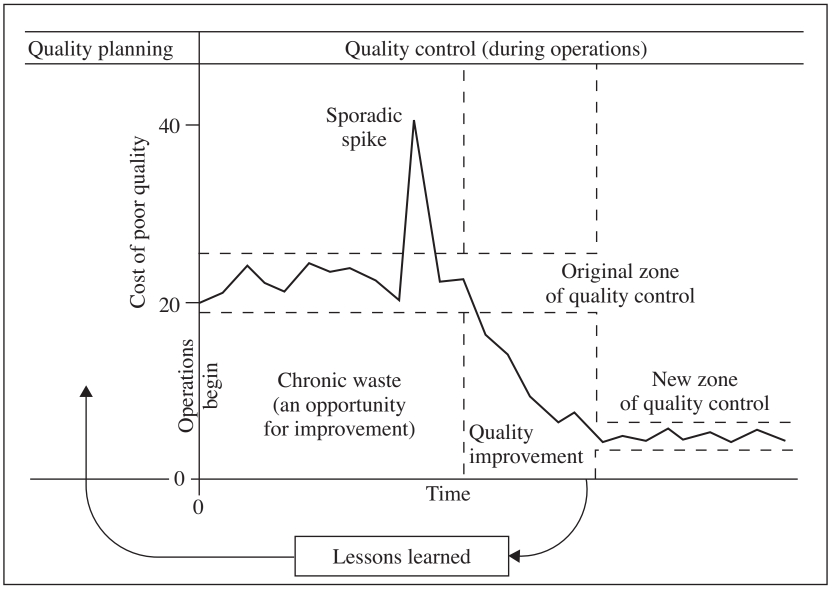

Figure 5-2 The Juran Trilogy Diagram
Adapted, with permission, from J. M. Juran, ed., *Quality Control Handbook,* 4th ed. (New York: McGraw-Hill, 1988).

The second level occurs when an individual or team identifies and eliminates the root cause(s) of the problem and effects a permanent solution. It is important to note that the repair strategy does not make the process better than the original design.

Refinement

This strategy involves activities that continually improve a process that is not broken. Improvements to processes, products, and services are accomplished on an incremental basis. Refinement improves efficiency and effectiveness. It should become an integral part of every employee's job. Both individuals and teams can use this strategy. Typically it relies on doing things just a bit quicker, better, easier, or with less waste. This is the concept behind Kaizen to be discussed later in the chapter. The change may be so gradual that there is no appearance of change. The primary benefit of gradual change is that it produces little resistance from employees. However, because the change is so gradual, management may not recognize and reward the affected employees. Also, minor changes may not be documented or properly communicated.

Organizational programs—such as process improvement teams, suggestion systems, and empowerment—are combinations of repair and refinement. They provide the mechanisms for activities aimed at making these two strategies a part of the daily work life.

Renovation

This strategy results in major or breakthrough improvements. Although the resulting product, service, process, or activity might often appear to be different from the original, it is basically the same. Innovation and technological advancements are key factors in this approach. For example, the process of drilling a hole was originally done by hand with a cranking mechanism; however, with the advent of the electric motor, the electric drill was born. The electric drill has been continually refined by improved bits, chucks, and materials.

More recently, another renovation occurred that was brought about by the development of rechargeable batteries. The rechargeable electric drill is basically the same as the old hand drill. Renovation is more costly than the previous strategies and is usually undertaken by teams rather than individuals.

Reinvention

Reinvention is the most demanding improvement strategy. It is preceded by the feeling that the current approach will never satisfy customer requirements. A new product, ser-vice, process, or activity is developed using teams based on a complete understanding of the customer's requirements and expectations. Reinvention or reengineering begins by imagining that the previous condition does not exist—in other words, a clean sheet of paper. Then the team uses in-depth knowledge of the customer's requirements and expectations and invents a new product, service, process, or activity. For example, the process of drilling holes using lasers or water jets was a reinvention.

Reinvention might also be desirable to maintain organization vitality or competitive advantage. An organization should use this strategy sparingly because of resistance to change and the fact that any new product, service, process, or activity will probably need to have the "bugs" removed by repair, refinement, and renovation.

Additional Comments

The repair and refinement strategies require that all employees have the freedom to solve problems and make incremental improvements in their jobs. Repair and refinement improvements are almost immediate with very little cost.

As previously stated, renovation and reinvention are effective in making break-through improvements; however, they usually are more costly, take longer to accomplish, and have a greater risk of failure.

Types of Problems[5]

There are five types of problems: compliance, unstructured, efficiency, process design, and product design. The first three are performance problems where an existing system is not performing satisfactorily, and the last two are design problems that require a new or improved design.

Compliance

Compliance problems occur when a structured system having standardized inputs, processes, and outputs is performing unacceptably from the user's viewpoint. These problems are identified by comparing with standards or by feedback from the internal or external customer. The major challenge is to determine the root cause of the nonconformity and then take corrective action. Diagnosis can be difficult, because products and processes are quite complex. Standards cannot address all of the potential problems due to the interaction of individually-acceptable characteristics.

Unstructured

Unstructured problems resemble compliance problems except that they are not specified by standards. The absence of standards may be due to system immaturity or to the need for flexibility in system performance. For example, an expert woodworker adjusts her activities to the grain and moisture content of the wood, and

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[5] This section adapted from Gerald F. Smith, "Quality Problem Solving: Scope and Prospects," *Quality Management Journal* (Fall 1994): 25–40. © American Society for Quality. Reprinted with permission.

customer service workers adapt their behavior to individual customers. Identification of unstructured problems is usually brought about by negative customer feedback. The major challenges are to determine customer needs and to diagnose the causes of poor performance. Because of customer variability, it is difficult to determine why a product or service was unacceptable. Organizations need to treat each customer as an individual and maintain a database on acceptable and unacceptable behavior.

Efficiency

Efficiency problems occur when the system is performing unacceptably from the viewpoint of its owners or operators. In other words, the end user is satisfied; however, the process is more costly than desired, or working conditions are not acceptable. Problem solving is directed towards reducing cost and providing safe working conditions. Identification of such problems occurs from benchmarking and operator suggestions.

Process Design

Process-design problems involve the development of new processes and revision of existing processes. Many business and production processes have not been well designed or have become obsolete with advances in technology. Identification of problems is prompted by poor performance, the knowledge that we can do better (benchmarking), or the introduction of new products. It requires that user needs and relevant constraints be identified.

Product Design

Product-design problems involve the development of new products and the improvement of existing products. A major focus is to prevent process and end user problems by relying on customer needs. Although design work can be initiated as a result of poor product performance, problem solving usually occurs as a natural part of a competitive environment. A major challenge is translating, in a timely manner, user needs and constraints into product attributes and specifications, usually using quality function deployment (QFD).

The PDSA Cycle

The basic Plan-Do-Study-Act (PDSA) cycle was first developed by Shewhart and then modified by Deming.[6] It is an effective improvement technique. Figure 5-3 illustrates the cycle.

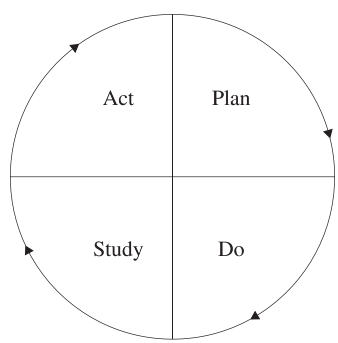

Figure 5-3 The PDSA Cycle

[6] Shewhart's cycle was called Plan-Do-Check-Act (PDCA).

The four steps in the cycle are exactly as stated. First, *plan* carefully what is to be done. Next, carry out the plan (*do* it). Third, *study* the results—did the plan work as intended, or were the results different? Finally, *act* on the results by identifying what worked as planned and what didn't. Using the knowledge learned, develop an improved plan and repeat the cycle. The PDSA cycle is a simple adaptation of the more elaborate problem-solving method discussed in the next section.

Problem-Solving Method

Process improvement achieves the greatest results when it operates within the framework of the problem-solving method. In the initial stages of a program, quick results are frequently obtained because the solutions are obvious or an individual has a brilliant idea. However, in the long term, a systematic approach will yield the greatest benefits.

The problem-solving method (also called the scientific method) has many variations depending, to some extent, on the use; however, they are all similar. There are seven phases, as shown in Figure 5-4. Also shown is the relationship to the PDSA cycle.

The phases are integrated because each phase is dependent upon the previous phase. Continuous process improvement is the objective, and these phases are the framework to achieve that objective.

Phase 1: Identify the Opportunity

The objective of this phase is to identify and prioritize opportunities for improvement. It consists of three parts: identify the problem, form the team (if one is not in existence) and define the scope.

Problem identification answers the question, "What are the problems?" The answer leads to those problems that have the greatest potential for improvement and have the greatest need for solution. Problems can be identified from a variety of inputs, such as the following:

- Pareto analysis of repetitive external alarm signals, such as field failures, complaints, returns, and others (see Chapter 15).
- Pareto analysis of repetitive internal alarm signals (for example, scrap, rework, sorting, and the 100% test).

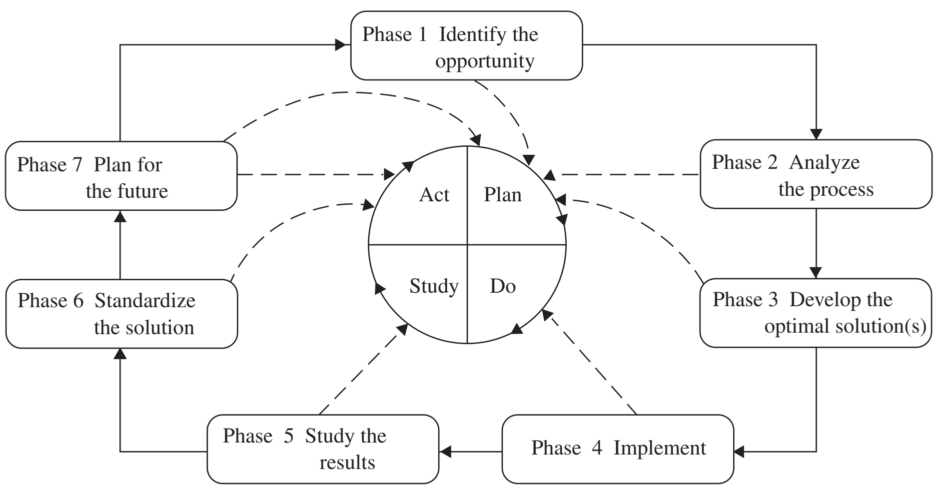

Figure 5-4 Continuous Process Improvement Cycle

- Proposals from key insiders (managers, supervisors, professionals, and union stewards).
- Proposals from suggestion schemes.
- Field study of users' needs.
- Data on performance of competitors (from users and from laboratory tests).
- Comments of key people outside the organization (customers, suppliers, journalists, and critics).
- Findings and comments of government regulators and independent laboratories.
- Customer surveys.
- Employee surveys.
- Brainstorming by work groups.

Problems identified provide opportunities for improvement. For a condition to qualify as a problem, it must meet the following three criteria:

- Performance varies from an established standard.
- Deviation from the perception and the facts.
- The cause is unknown; if we know the cause, there is no problem.

Identifying problems for improvement is not difficult, as there are many more problems than can be analyzed. The quality council or work group must prioritize problems using the following selection criteria:

1. Is the problem important and not superficial and why?
2. Will problem solution contribute to the attainment of goals?
3. Can the problem be defined clearly using objective measures?

In selecting its initial improvement opportunity, a work group should find a problem that, if solved, gives the maximum benefit for the minimum amount of effort.

The second part of Phase 1 is to form a team. If the team is a natural work group or one where members already work together, then this part is complete. If the problem is of a multifunctional nature, as most are, then the team should be selected and tasked by the quality council to address the improvement of a specific process. Goals and milestones are established. More information on teams is given in Chapter 4.

If the improvement strategy is repair or refinement, an individual, rather than a team, may be assigned to work on the problem.

The third part of Phase 1 is to define the scope. Failure in problem solving is frequently caused by poor definition of the problem. A problem well stated is half solved. Criteria for a good problem statement are as follows:

- It clearly describes the problem as it currently exists and is easily understood.
- It states the effect—what is wrong, when it happens, and where it is occurring, not why it is wrong or who is responsible.
- It focuses on what is known, what is unknown, and what needs to be done.
- It uses facts and is free of judgment.
- It emphasizes the impact on the customer.

An example of a well-written problem statement is:

> As a result of a customer satisfaction survey, a sample of 150 billing invoices showed that 18 had errors that required one hour to correct.

The above statement describes the current state. We might also wish to describe the desired state, such as "Reduce billing errors by 75%."

In addition to the problem statement, this phase requires a comprehensive charter for the team. The charter specifies the following:

1. *Authority*. Who authorized the team?
2. *Objective and Scope*. What are the expected outputs and specific areas to be improved?
3. *Composition*. Who are the team members and process and sub-process owners?
4. *Direction and Control*. What are the guidelines for the internal operation of the team?
5. *General*. What are the methods to be used, the resources, and the specific milestones?

Phase 2: Analyze the Current Process

The objective of this phase is to understand the process and how it is currently performed. Key activities are to define process boundaries, outputs and customers, inputs and suppliers, and process flow; determine levels of customer satisfaction and measurements needed; gather data; and identify root causes.

The first step is for the team to develop a process flow diagram (see Chapter 15). A flow diagram translates complex work into an easily-understood graphic description. This activity is an "eye-opening" experience for the team, because it is rare that all members of the team understand the entire process.

Next, the target performance measures (see Chapter 6) are defined. Measurement is fundamental to meaningful process improvements. If something cannot be measured, it cannot be improved. There is an old saying that what gets measured gets done. The team will determine if the measurements needed to understand and improve the process are presently being used; if new ones are needed, the team will:

- Establish performance measures with respect to customer requirements.
- Determine data needed to manage the process.
- Establish regular feedback with customers and suppliers.
- Establish measures for quality/cost/timelines of inputs and outputs.

Once the target performance measures are established, the team can collect all available data and information. If these data are not enough, then additional new information is obtained. Gathering data (1) helps confirm that a problem exists, (2) enables the team to work with facts, (3) makes it possible to establish measurement criteria for baseline, and (4) enables the team to measure the effectiveness of an implemented solution. It is important to collect only needed data and to get the right data for the problem. The team should develop a plan that includes input from internal and external customers and ensures the plan answers the following questions:

1. What problem or operation do we want to learn about?
2. What are the data used for?
3. How many data are needed?
4. What conclusions can be drawn from the collected data?
5. What action should be taken as a result of the conclusion?

Data can be collected by a number of different methods, such as check sheets (see Chapter 15), computers with application software, data-collection devices like hand-held gauges, or an online system.

The team will identify the customers and their requirements and expectations as well as their inputs, outputs, and interfaces of the process. Also, they will systematically review the procedures currently being used.

Common items of data and information are:

- Customer information, such as complaints and surveys.
- Design information, such as specifications, drawings, function, bills of materials, costs design reviews, field data, service, and maintainability.
- Process information, such as routing, equipment, operators, raw material, and component parts and supplies.
- Statistical information, such as average, median, range, standard deviation, skewness, kurtosis, and frequency distribution.
- Quality information, such as Pareto diagrams, cause-and-effect diagrams, check sheets, scatter diagrams, control charts, histograms, process capability, acceptance sampling, run charts, life testing, inspection steps, and operator and equipment matrix analysis.
- Supplier information, such as process variation, on-time delivery, and technical competency.

The cause-and-effect diagram is particularly effective in this phase. Determining all of the causes requires experience, brainstorming, and a thorough knowledge of the process. It is an excellent starting point for the project team. One word of caution—the object is to seek causes, not solutions. Therefore, only possible causes, no matter how trivial, should be listed. Where data is not readily available for the process, many companies are turning to the use of simulation modeling to identify possible causes.[7,8]

It is important to identify the root cause. This activity can sometimes be determined by voting (see Chapter 15). It is a good idea to verify the most likely cause, because a mistake here can lead to the unnecessary waste of time and money by investigating possible solutions to the wrong cause. Some verification techniques are the following:

1. Examine the most likely cause against the problem statement.
2. Recheck all data that support the most likely cause.
3. Check the process when it is performing satisfactorily against when it is not by using the who, where, when, how, what, and why approach.
4. Utilize an outside authority who plays "devil's advocate" with the data, information, and reasoning.
5. Use experimental design, Taguchi's quality engineering, and other advanced techniques to determine the critical factors and their levels.
6. Save a portion of the data used in the analysis to confirm during verification.

Once the root cause is determined, the next phase can begin.

Phase 3: Develop the Optimal Solution(s)

This phase has the objective of establishing potential and feasible solutions and recommending the best solution to improve the process. Once all the information is available, the project team begins its search for possible solutions. More than one solution is frequently required to remedy a situation. Sometimes the solutions are quite evident from a cursory analysis of the data.

In this phase, creativity plays the major role, and brainstorming (see Chapter 15) is the principal technique. Brainstorming on possible solutions requires not only a knowledge of the problem but also innovation and creativity.

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7 Czarnecki, Hank, Bernard J. Schroer, Mel Adams, and Mary Spann, "Continuous Process Improvement Which It Counts Most: The Role of Simulation in Process Design," *Quality Progress* (May 2000): 74–80.

8 Peterman, Mike, "Simulation Nation," *Quality Digest* (May 2001): 39–42.

There are three types of creativity: (1) create new processes, (2) combine different processes, or (3) modify the existing process. The first type is innovation in its highest form, such as the invention of the transistor. Combining two or more processes is a synthesis activity to create a better process. It is a unique combination of what already exists. This type of creativity relies heavily on benchmarking (see Chapter 7). Modification involves altering a process that already exists so that it does a better job. It succeeds when managers utilize the experience, education, and energy of empowered work groups or project teams. There is not a distinct line between the three types—they overlap.[9]

Creativity is the unique quality that separates mankind from the rest of the animal kingdom. Most of the problems that cause inefficiency and ineffectiveness in organizations are simple problems. There is a vast pool of creative potential available to solve these problems. Quality is greatly improved because of the finding and fixing of a large number of problems, and morale is greatly increased because it is enormously satisfying to be allowed to create.[10]

Areas for possible change are the number and length of delays, bottlenecks, equipment, timing and number of inspections, rework, cycle time, and materials handling. Consideration should be given to combining, eliminating, rearranging, and executing simultaneously the process steps. In particular, reducing cycle times, lowering inventory levels, and searching for non-value-added activities are excellent sources for change, as these typically have many hidden costs that, if minimized or eliminated, affect a number of processes in the organization. For example, lowering inventory levels allows there to be less WIP to be transported, frees floor space, and lessens the management and accounting of the WIP, particularly if the inventory is time-dated material.

Once possible solutions have been determined, evaluation or testing of the solutions comes next. As mentioned, more than one solution can contribute to the situation. Evaluation and/or testing determines which of the possible solutions have the greatest potential for success and the advantages and disadvantages of these solutions. Criteria for judging the possible solutions include such things as cost, feasibility, effect, resistance to change, consequences, and training. Solutions also may be categorized as short range and long range. At a minimum, the solution must prevent recurrence.

One of the features of control charts is the ability to evaluate possible solutions. Whether the idea is good, poor, or has no effect is evident from the chart.

Phase 4: Implement Changes

Once the best solution is selected, it can be implemented. This phase has the objective of preparing the implementation plan, obtaining approval, and implementing the process improvements.

Although the project team usually has some authority to institute remedial action, more often than not the approval of the quality council or other appropriate authority is required. If such approval is needed, a written and/or oral report is given.

The contents of the implementation plan report must fully describe

- Why will it be done?
- How will it be done?
- When will it be done?
- Who will do it?
- Where will it be done?

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9 Paul Mallette, "Improving Through Creativity," *Quality Digest* (May 1993): 81–85.

10 George Box, "When Murphy Speaks—Listen," *Quality Progress* (October 1989): 79–84.

Answers to these questions will designate required actions, assign responsibility, and establish implementation milestones. The length of the report is determined by the complexity of the change. Simple changes may require only an oral report, whereas other changes require a detailed, written report.

After approval by the quality council, it is desirable to obtain the advice and consent of departments, functional areas, teams, and individuals that may be affected by the change. A presentation to these groups will help gain support from those involved in the process and provide an opportunity for feedback with improvement suggestions.

The final element of the implementation plan is the monitoring activity that answers the following:

- What information will be monitored or observed, and what resources are required?
- Who will be responsible for taking the measurements?
- Where will the measurements be taken?
- How will the measurements be taken?
- When will the measurements be taken?

Measurement tools such as run charts, control charts, Pareto diagrams, histograms, check sheets, and questionnaires are used to monitor and evaluate the process change.

Pylipow provides a combination map to help formulate an action plan to help mea-sure the results of an improvement. The map, shown in Table 5-1 provides the dimensions of: what is being inspected, the type of data, timing of data collection, by whom, how the results will be recorded, the necessary action that needs to be taken based on the results, and who is to take the action.

Phase 5: Study the Results

This phase has the objective of monitoring and evaluating the change by tracking and studying the effectiveness of the improvement efforts through data collection and review of progress. It is vital to institutionalize meaningful change and ensure ongoing mea-surement and evaluation efforts to achieve continuous improvement.

The team should meet periodically during this phase to evaluate the results to see that the problem has been solved or if fine-tuning is required. In addition, the team will want to see if any unforeseen problems have developed as a result of the changes. If the team is not satisfied, then some of the phases will need to be repeated.

Phase 6: Standardize the Solution

Once the team is satisfied with the change, it must be institutionalized by positive control of the process, process certification, and operator certification. Positrol (positive control) assures that important variables are kept under control. It specifies the what, who, how, where, and when of the process and is an updating of the monitoring activity. Standardizing the solution prevents "backsliding." Table 5-2 gives an illustration of a few variables of a wave soldering process.

In addition, the quality peripherals—the system, environment, and supervision—must be certified. The partial checklist in Table 5-3 provides the means to initially evaluate the peripherals and periodically audit them to ensure the process will meet or exceed customer requirements for the product or service.

Finally, operators must be certified to know what to do and how to do it for a particular process. Also needed is cross-training in other jobs within the process to ensure next-customer knowledge and job rotation. Total product knowledge is also desirable. Operator certification is an ongoing process that must occur periodically.

TABLE 5-1
Combination Map of Dimensions for Process Control

What's Inspected	*Type of Data*	*Timing*	*By Whom?*	*Type of Record*	*Action*	*By Whom?*
Process variable: continuous	Variable	During run: on-line	Device	Electronic control chart	Process Improved	Automated equipment
Process variable: sample				Paper control chart		
		During run: off-line	Process Operator	Electronic trend chart	Process adjusted	Operator
Product Sample	Attribute			Paper trend chart	Lot sorted	
		After lot: complete	Inspector	Electronic list	Sample repaired or discarded	Inspector or mechanic
100% of product				Paper list		
				None		

Reproduced, with permission, from Peter E. Pylipow, "Understanding the Hierarchy of Process Control: Using a Combination Map to Formulate an Action Plan," *Quality Progress* (October 2000): 63–66.

TABLE 5-2
Positrol of a Wave Soldering Process

What	*Specs.*	*Who*	*How*	*Where*	*When*
An 880 flux	0.864 g ± 0.008	Lab technician	Sp. gravity meter	Lab	Daily
Belt speed	ft/min ± 10%	Process technician	Counter	Board feed	Each change
Preheat temperature	220° ± 5°	Automatic	Thermo-couple	Chamber entrance	Continuous

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Phase 7: Plan for the Future

This phase has the objective of achieving improved levels of process performance. Regardless of how successful initial improvement efforts are, the improvement process continues. It is important to remember that TQM addresses the quality of management as well as the management of quality. Everyone in the organization

TABLE 5-3
Checklist for Process Certification

Quality System	*Environment*	*Supervision*
Authority to shut down line	Water/air purity	Coach, not boss
Preventive maintenance	Dust/chemical control	Clear instructions
Visible, audible alarm signals	Temp/humidity control	Combe tasks
Foolproof inspection	Electrostatic discharge	Encourage suggestions
Neighbor and self-inspection	Storage/inventory control	Feedback of results

is involved in a systematic, long-term endeavor to constantly improve quality by developing processes that are customer oriented, flexible, and responsive.

A key activity is to conduct regularly scheduled reviews of progress by the quality council and/or work group. Management must establish the systems to identify areas for future improvement and to track performance with respect to internal and external customers. They must also track changing customer requirements.

Continuous improvement means not only being satisfied with doing a good job or process but also striving to improve that job or process. It is accomplished by incorporating process measurement and team problem solving in all work activities. TQM tools and techniques are used to improve quality, delivery, and cost. Organizations must continuously strive for excellence by reducing complexity, variation, and out-of-control processes.

Lessons learned in problem solving, communications, and group dynamics, as well as technical know-how, must be transferred to appropriate activities within the organization.

Although the problem-solving method is no guarantee of success, experience has indicated that an orderly approach will yield the highest probability of success. Problem solving concentrates on improvement rather than control.

Note that there are many similar approaches to problem solving that deviate slightly from the one presented here; however, all such approaches provide similar features. A similar problem-solving approach was used by the Federal Communications Commission (FCC) when it began its quality effort in 1990. Their seven-step approach to continuous improvement included identifying improvement opportunities, prioritizing and selecting potential improvements, analyzing root causes, developing alternatives and selecting choice solutions, testing of solutions, implementing them, and tracking the effectiveness of the solutions. When it began its quality effort in 1991, the FCC was receiving roughly 900 license applications per year and had a nine-month backlog of 600 applications. During the first step, the quality improvement team brainstormed on 20 possible improvement ideas, which were then narrowed to five. Next, they prioritized the opportunities based on an estimate of the cost of poor quality. Upon collection of data, it was found that over half of the licensing applications received contained errors that doubled the processing time. Once the team identified this information, they developed an "opportunity statement" to "increase the percentage of error-free license applications from 40% to 70%." To analyze the root causes, the team flow-charted the licensing process and constructed a cause-and-effect diagram. Through a data collection effort, it was found that 50% of the errors were due to unqualified persons completing the license application, and that the license form and instructions were unclear. As a result, the team redesigned the application process so that the instructions were clearer and processing guidelines were understandable by the applicants. Before implementing the final solution, the form was pilot tested to a sample group. A little over a year, the team implemented the new form. Nine months after implementing their new solution, the percentage of applications received without errors increased from 40% to 80%, the backlog was reduced to 16 applications without staff increases, the speed of service improved 47%, and the cost of poor quality was reduced by 67%.[11]

Technology is also playing an important part in the management of continuous improvement. Many problem-solving approaches have been incorporated into software to help facilitate the continuous improvement process for organizations. According to a recent *Quality Progress* survey, 88% of the respondents indicated that their organization used software or similar technology to aid in the improvement process.[12]

Kaizen

Kaizen is a Japanese word for the philosophy that defines management's role in continuously encouraging and implementing small improvements involving everyone. It is the process of continuous improvement in small increments that make the process more—efficient, effective, under control, and adaptable. Improvements are usually accomplished at little or no expense, without sophisticated techniques or expensive equipment. It focuses on simplification by breaking down complex processes into their sub-processes and then improving them.

The Kaizen improvement focuses on the use of:[13]

1. Value-added and non-value-added work activities.
2. *Muda*, which refers to the seven classes of waste—over-production, delay, transportation, processing, inventory, wasted motion, and defective parts.
3. Principles of motion study and the use of cell technology.
4. Principles of materials handling and use of one-piece flow.
5. Documentation of standard operating procedures.
6. The five S's for workplace organization, which are five Japanese words that mean proper arrangement (*seiko*), orderliness (*seiton*), personal cleanliness (*seiketso*), cleanup (*seiso*), and discipline (*shitsuke*).
7. Visual management by means of visual displays that everyone in the plant can use for better communications.
8. Just-in-time principles to produce only the units in the right quantities, at the right time, and with the right resources.
9. *Poka-yoke* to prevent or detect errors.
10. Team dynamics, which include problem solving, communication skills, and conflict resolution.

Kaizen relies heavily on a culture that encourages suggestions by operators who continually try to incrementally improve their job or process. An example of a Kaizen-type improvement would be the change in color of a welding booth from black to white to improve operator visibility. This change results in a small improvement in weld quality and a substantial improvement in operator satisfaction. The PDSA cycle described earlier may be used to help implement Kaizen concepts.

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[11] Fontaine, Daniel J. and Diane B. Robinette, "FCC Makes Dramatic Quality Improvements," *Quality Progress* (November 1994): 87–91.

[12] Brown, Paula, "Technology and Performance Improvement: Intellectual Partners?" *Quality Progress* (April 1998): 69–71.

[13] Glenn Gee, Phil McGrath, and Mahyar Izadi, "A Team Approach to Kaizen," *Journal of Industrial Technology* (Fall 1996): 45–48.

Kaizen traditionally involves slow incremental improvements; however, with the influence of Toyota and the now-infamous Toyota Production System that incorporates lean manufacturing principles, many of the concepts of Kaizen can be implemented in a more rapid fashion. An example, of such concepts being implemented is Zydus Cadila India, which is a pharmaceutical company with its headquarters at Ahmedabad. The company with the help of their Kaizen consultants identified "muda" in the forms of overproduction, unnecessary transportation, excess inventory, waiting for parts or machines, overprocessing, rework and failure to fully utilize the time and talents of the people. Their new plant was planned and based on the Kaizen principles to minimize wastes involving the shop-floor managers and workers. The new plant was based on cellular flow concepts, continuous material movement and no in-process storage with full visibility of operations from the same floor. Each process was based on pull system instead of the conventional push system. With the Kaizen overhaul of the plant,

- the capacity improved five times
- cycle time improved to 80 from 600 i.e. 1/5th of original and
- the distance travelled by the batch of tablets reduced to 73 from 220 meters.

Later, the Kaizen initiative was extended further to the vaccine packing and injectables manufacturing units. The new practice resulted in 30% productivity improvement in vaccine division and 50% reduction in cycle time in the injectables unit.[14]

Reengineering

According to Hammer and Champy, reengineering is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical measures of performance.[15] Many practitioners believe that TQM is associated with only incremental improvements. Nothing could be further from the truth—for many years, the Malcolm Baldrige National Quality Award has defined continuous improvement as referring to both incremental and "breakthrough" improvement. The Japanese have not only relied on *kaizen* but have developed policy management (*hoshin kanri*) and policy deployment (*hoshin tenkai*) in large part to produce the kind of large-scale breakthroughs that Hammer and Champy promote. Nor is this concept uniquely Japa-nese. Joseph Juran has had a long-standing emphasis on breakthrough efforts aimed at achieving unprecedented levels of performance.[16]

In 1997, EM Jorgensen Company applied reengineering using a five-phased problem solving approach that ultimately reduced operating costs by 12%. The focus of the project was to identify and eliminate non-value-added work and reduce corresponding costs while maintaining quality.[17]

Six-Sigma

In 1999, M. Harry and R. Schroeder published *Six Sigma: The Breakthrough Management Strategy Revolutionizing the World's Top Corporations*. Since that time, there has been considerable interest in the subject; therefore, the authors have devoted much space to a review of the concept.

[14] Business India May 3, 2009.

[15] Michael Hammer and James Champy, *Reengineering the Corporation, A Manifesto for Business Revolution* (New York, NY: HarperCollins, 1993).

[16] Robert E. Cole, "Reengineering the Corporation: A Review Essay," *Quality Management Journal* (July 1994): 77–85.

[17] Dagestino, Kathryn, Wendy L. Moore, and Jorn Teutloff, "Hustle, That's All," *Quality Progress* (September 2000): 73–79.

Statistical Aspects

According to James Harrington, "Six sigma was simply a TQM process that uses process capability analysis (see Chapter 15) as a way of measuring progress."[18] Sigma, σ, is the Greek symbol for the statistical measurement of dispersion called standard deviation. It is the best measurement of process variability, because the smaller the deviation value, the less variability in the process. Figure 5-5 shows a process that is normally distributed and centered with the upper and lower specification limits (USL and LSL) established at $\pm$ 6 σ. For this situation, 99.9999998% of the product or service will be between specifications, and the nonconformance rate will be 0.002 parts per million, or 2.0 per billion. The situation diagrammed represents a process capability index (C_p) of 2.0. A C_p of 1.33 has been a defacto standard. Table 5-4 shows the percent between specifications, the nonconformance rate, and process capability for different specification limit locations.

According to the six-sigma philosophy, processes rarely stay centered—the center tends to "shift" above and below the target, μ. Figure 5-6 shows a process that is normally distributed, but has shifted within a range of 1.5σ above and 1.5σ below the target. For the diagrammed situation, 99.9996600% of the product or service will be between specifications and the nonconformance rate will be 3.4 ppm. This off-center situation gives a process capability index (C_{pk}) of 1.5 with 1.0 being the defacto standard. Note that the

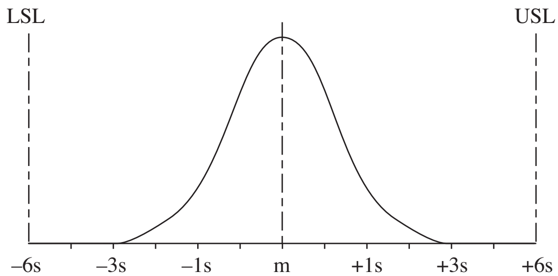

Figure 5-5 Nonconformance Rate When Process is Centered

TABLE 5-4
Nonconformance Rate and Process Capability When the Process is Centered

Specification Limit	*Percent Conformance*	*Nonconformance Rate (ppm)*	*Process Capability (C_p)*
$\pm1\sigma$	68.7	317300	0.33
$\pm2\sigma$	95.45	485500	0.67
$\pm3\sigma$	99.73	2700	1.00
$\pm4\sigma$	99.9937	63	1.33
$\pm5\sigma$	99.999943	0.57	1.67
$\pm6\sigma$	99.9999998	0.002	2.00

[18] H. James Harrington, "Six Sigma's Long-Term Impact," *Quality Digest* (June 2001): 16.

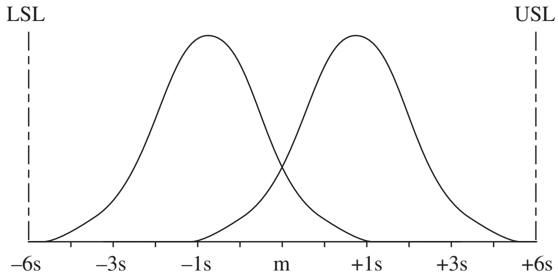

Figure 5-6 Nonconformance Rate When Process is Off-Center ± 1.5σ.

TABLE 5-5
Nonconformance Rate and Process Capability When the Process is Off-Center ±1.5σ.

Specification Limit	*Percent Conformance*	*Nonconformance Rate (ppm)*	*Process Capability (C_{pk})*
±1σ	30.23	697700	− 0.167
±2σ	69.13	308700	0.167
±3σ	93.32	66810	0.500
±4σ	99.3790	6210	0.834
±5σ	99.97670	2330	1.167
±6σ	99.9996600	3.4	1.500

index is calculated differently and, therefore, has a different symbol (C_p vs. C_{pk}). See Chapter 15 for a detailed analysis of the differences. Table 5-5 shows the percent between specifications, the nonconformance rate, and process capability for different specification limit locations. The magnitude and type of shift is a matter of discovery and should not be assumed ahead of time. None of the case studies in the literature have indicated a shift as great as 1.5σ. The automotive industry recognized the concept in the mid-1980's, evaluated it and deemed it unacceptable.[19] In fact, the original work of six sigma was based on only a few empirical studies of a single process.[20]

The statistical aspects of six-sigma tell us that we should reduce the process variability, σ, and try to keep the process centered on the target, μ;. These concepts are not new. They have been long advocated by Shewhart, Deming, and Taguchi and are covered in Chapter 15.

Other Aspects

Harry and Schroeder use a methodology called DMAIC, which stands for define, mea-sure, analyze, improve, and control. This approach is somewhat similar but not as comprehensive as the seven phases of the problem-solving method discussed in this chapter. Their methodology features a breakthrough strategy using the project approach, which is similar to the same strategy advocated by Juran. Projects are identified by the amount

[19] D.H. Stamatis, "Who Needs Six Sigma, Anyway?" *Quality Digest* (May 2000): 33–38.

[20] Bender, Arthur, "6 × 2.5 = 9, Benderizing Tolerances—A Simple Practical Probability Method for Handling Tolerances for Limit-Stack-Ups," *Graphic Science* (December 1962): 17–21.

of savings they can generate, which is simply good business sense and is one of the duties of the quality council as given in Chapter 2. The body of knowledge is not as comprehensive as that for a Certified Quality Engineer or the information in this textbook. Harry and Schroeder and others emphasized the need for management commitment and involvement, but these factors are necessary for any successful program and have been emphasized in this textbook. Except for the information in the next paragraph, six sigma has little to offer that isn't already available through other approaches.[21]

The Harry and Schroeder approach, however, does introduce an infrastructure of trained personnel to ensure that projects have the necessary resources to make improvements. A small group of individuals in the organization have the full-time job of making improvements. Competency levels of these individuals use the Karate designations of Green Belts, Black Belts, and Master Black Belts. Green Belts are the project leaders and have five days of classroom training. Black Belts help Green Belts define their projects, attend training with their Green Belts, and assist them with their projects after the training. Black Belts receive 160 hours of classroom instruction and one-on-one project coaching from Master Belts. Master Black Belts provide the technical leadership and much of the training for the program.[22]

Problems

There are a number of problems associated with the six-sigma methodology. It would be very difficult and not very cost effective for a small business to develop the required infrastructure. Even a medium-sized business would have difficulty paying for the high cost of the training. General Electric has spent over two billion dollars to develop their infrastructure.

In large companies, there is a great danger that the infrastructure will become a bureaucracy. At one flagship six-sigma company, a technical employee was admonished by a Black Belt for fixing several processes rather than turn them into six-sigma projects.[23] It is possible that operating personnel who know the most about the process will be outside the improvement loop. Certainly the concept of Kaizen is not compatible with having projects that average $175,000 in savings.

According to Stamatis, "Six sigma presents absolutely nothing new to the quality field of defect prevention. It's little more than an old appraisal methodology that focuses on problems after they've already occurred."

Iomega, maker of Zip drives, began the implementation of its six-sigma program in 1998. The infrastructure of over 400 Master Black Belts, Black Belts, and Green Belts out of 3400 employees made impressive improvements. However, by May, 2001 the company was losing money, the share price went from $4.00 to $1.75 and the CEO, a former General Electric manager, was fired along with many employees.[24] It should also be pointed out that Motorola, where the six-sigma concept originated, has lost a considerable amount of market share of its wireless business and did not show a profit in 2001 for the first time in many years.

TQM Exemplary Organization[25]

Cummins India Ltd. (CIL) is a company that designs, develops and manufactures diesel and dual fuel engines and generating sets. CIL is a unit of Cummins Inc. (USA). In the 1980s, Cummins formulated a comprehensive set of procedures with help from Dr. Armand Feigenbaum. This was called total quality system (TQS). TQS has procedures right from new product development to customer complaint handling. Based on the extent

[21] Stamatis.

[22] Thomas Pyzdek, "The Six Sigma Infrastructure," *Quality Digest* (August 2001): 54.

[23] Anonymous, "The Emperor's New Woes, Revisited," *Quality Digest* (August 2001): 80.

[24] Louis F. Hannigan, "Letters," *Quality Digest* (October 2001): 8–9.

[25] Malcolm Baldrige National Quality Award, 2001 Education Category Recipient, NIST/Baldrige Homepage, Internet.

of deployment and results, plants were rated as A, AA, AAA and Total Quality Excellence (TQE). Later, during the early nineties, Cummins globally initiated the TQM approach which was internally called "Common Approach to Continuous Improvement" (CACI). This was a seven step approach, which started with customers and included comprehensive set of tools and techniques for structured problem solving. A set of performance metrics and measurement system was an integrated part of CACI. It was additionally supported by functional excellence programs in leadership, product development, quality, shop operations, manufacturing, Engineering and finance. These programs were focussed to improve functional capabilities and performance.

In 1991–92, CIL became the first company to receive the Best among the winners of Rajiv Gandhi National Quality Award for business excellence in India. CIL was one of the first few companies from India, which received ISO 9001 certification in 1991. In the year 1998, its service wing won the Rajiv Gandhi National Quality Award – for service excellence.

In 2000, Tim Solso, CEO of Cummins Inc. announced launching of Six Sigma initiative worldwide. Benchmarking GE and Allied Signal, Tim along with his leadership team attended the Six Sigma training. In 2009, with a strong team of 12 master black belts (MBB), 34 black belts and 1500 green belts, CIL had completed 248 projects with an annualized savings of INR 760 million (approximately 16 million US $). Apart from the financial savings, 35 out of 248 projects were customer-led and were being actually led by CIL customers' employees! Cummins calls these as "Customer Focussed Six Sigma" (CFSS). Also, more than 50 projects were "Supplier Focused Six Sigma Projects" (SFSS). Six Sigma is considered as a strategic tool with the objectives of reducing defects, developing leadership skills and making a cultural change. The change is from "biases and opinions" to "analysis and data-based decisions".[26]

Summary

Continuous improvement is an essential aspect of TQM philosophy and implementation. The Juran Trilogy of Quality Planning, Quality Control and Quality Improvement provides a conceptual framework for continuous improvement.

There are four improvement strategies: repair, refinement, renovation and reinvention. Choice of the appropriate strategy for various situations is critical.

The PDSA cycle developed by Shewhart and then modified by Deming provides a roadmap to continuous improvement. Structured problem-solving method can be easily blended with the PDSA cycle.

Important philosophies deployed by various organizations include Kaizen, Reengineering and Six Sigma. Kaizen relies heavily on involvement of all employees while Six Sigma relies more on fewer project leaders called black and green belts. Success of any approach requires fully committed management.

Exercises

1. List various techniques to sustain continuous improvement.

2. Working as an individual or in a team of three or more people, evaluate one or more of the following organizations concerning their use of the Juran Trilogy.

   (a) Large bank
   (b) Health-care facility

[26] *CIL Annual Report for 2008–09*, CIL web site http:// cumminsindia.com: 8080/xsql/cumminsIndia/CIL/milestones.html)

(c) University academic department
(d) University nonacademic department
(e) Large department store
(f) Grade school
(g) Manufacturing facility
(h) Large grocery store

3. Using a product such as a house, machine, or car, give an example of the four improvement strategies.

4. Give an example of the use of the PDSA cycle in your personal life and in your work experiences.

5. Select a problem in one of the processes of your daily life and use the seven phases to solve it.

6. Working as an individual or in a team of six or more people, implement the seven phases of the problem-solving method in one or more of the organizations listed in Exercise 2.

7. Describe how empowerment, work groups, and multifunctional teams would or would not affect the five types of problems.

8. A Pareto chart for the number of defects in a foundry is shown in the following table. The data of four categories of defects was recorded.

Crack	71
Leak	12
Rusty	30
Others	38

The correct conventional listing for the Pareto chart categories from left to right would be:

(a) crack, leak, rusty, others
(b) crack, rusty, others and leak
(c) crack, rusty, leak and others
(d) crack, leak, rusty and others

9. Elements and sequence of Juran Trilogy are:

(a) analyze, improve, control
(b) plan-do-study-act
(c) plan-control-improve
(d) measure-analyze-improve-control

10. A popular roadmap of Six Sigma is:

(a) Define-Measure-Analyze-Improve-Control
(b) Define-Analyze-Measure-Improve-Control
(c) plan-control-improve
(d) measure-analyze-improve-control

11. Capability Index Cp and Cpk for a process at Six Sigma level of performance is:
    (a) 1.5, 2
    (b) 2, 2
    (c) 1.5, 1.5
    (d) 2, 1.5

12. Which of the statements is most appropriate for Kaizen?
    (a) small projects, no investment, elimination of waste
    (b) small projects, no investment, statistical tools
    (c) large projects, no investment, elimination of waste
    (d) large projects, large investment, statistical tools

6

Performance Measures

Chapter Objectives

- Learning how to manage by facts
- Understanding the basic concepts of performance measurement
- Establishing strategic measurement system
- Learning basic techniques for performance presentation:
  - Time series plots
  - Control charts
  - Capability indices
  - Taguchi loss function
  - Use of criteria in national/international quality awards
  - Balanced score card
- Brief overview of the estimation and representation in quality costs
- Overview of quality cost programs and their implementation
- Detailing of Malcolm Baldrige National Quality Award
  - Criteria
  - Scoring system
  - Self appraisal
  - Journey towards excellence

Introduction

The sixth and final concept of Total Quality Measurement (TQM) is performance measures. One of the Malcolm Baldrige National Quality Award core values is managing by fact rather than by gut feeling. Managing an organization without performance measures is like a captain of a ship navigating without instrumentation.

The ship would most likely end up traveling in circles, as would an organization. Measures play a vital part in the success or failure of an organization.

Basic Concepts[1]

Objectives

Performance measures are used to achieve one or more of the following seven objectives:

1. Establish baseline measures and reveal trends.
2. Determine which processes need to be improved.
3. Indicate process gains and losses.
4. Compare goals with actual performance.
5. Provide information for individual and team evaluation.
6. Provide information to make informed decisions.
7. Determine the overall performance of the organization.

Typical Measurements

What should be measured is frequently asked by managers and teams. The information below suggests some items that can be measured.

Human Resources:
Lost time due to accidents, absenteeism, turnover, employee satisfaction index, number of suggestions for improvement, number of suggestions implemented, number of training hours per employee, training cost per employee, number of active teams, number of grievances.

Customers:
Number of complaints, number of on-time deliveries, warranty data such as parts replacement, customer satisfaction index, time to resolve complaints, telephone data such as response time, mean time to repair, dealer satisfaction, report cards.

Production:
Inventory turns, SPC charts, C_p/C_{pk}, amount of scrap/rework, nonconformities per million units, software errors per 1000 lines of code, percent of flights that arrive on time, process yield, machine downtime, actual performance to goal, number of products returned, cost per unit.

Research and Development:
New product time to market, design change orders, R & D spending to sales, average time to process proposal, recall data, cost estimating errors.

[1] This section adapted, with permission, from Ray F. Boedecker, *Eleven Conditions for Excellence: The IBM Total Quality Improvement Process* (Quincy, Mass.: American Institute of Management, 1987).

Suppliers:
SPC charts, C_p/C_{pk}, on-time delivery, service rating, quality performance, billing accuracy, average lead time, percent of suppliers that are error free, just-in-time delivery target.

Marketing/Sales:
Sales expense to revenue, order accuracy, introduction cost to development cost, new product sales to total sales, new customers, gained or lost accounts, sales income to number of salespeople, number of successful calls per week.

Administration:
Revenue per employee, expense to revenue, cost of poor quality, percent of payroll distributed on time, number of days accounts receivable past due, number of accounts payable past due, office equipment up-time, purchase order errors, vehicle fleet data, order entry/billing accuracy.

A good metric compares the measurement of interest to the total possible outcomes, such as rework hours to total hours.

Criteria

All organizations have some measurements in place that can be adapted for TQM. However, some measurements may need to be added. In order to evaluate the existing measures or add new ones, the following ten criteria are recommended:

1. *Simple*: Measures should be understandable by those who will use them.
2. *Few in number*: The important measures must be distinguished from the unimportant ones so that users can concentrate on just a few. Two or three measures should be sufficient for any work group, with the number increasing for departments, functional areas, plants, and corporations. Quality councils may wish to use composite measures such as a customer satisfaction index. It is composed of several weighted metrics such as on-time delivery, cost, product or service quality, and complaints.
3. *Developed by users*: In order to ensure ownership of the measures, they must be developed by the user. Measures dictated by a higher authority will usually not receive support from downstream units. However, in some cases, measures are mandated by the customer.
4. *Relevance to customer*: Measures must be relevant to the needs of internal or external customers. Control over important changes should be vested in the people who are held responsible for the performance measure. They also decide what measures to use and set target goals.
5. *Improvement*: Although correcting nonconformances and making current decisions are important, the focus should be on improvement, prevention, and strategic long-term planning and goal setting. Measures are used to promote improvement, not to identify poor performance and penalize the low performers. They should be sensitive to the improvements made.
6. *Cost*: Of course, the bottom line is that cost and profit must reflect an improved financial picture, as shown by the cost of poor quality system and other financial data. In addition, the cost of measurement should be considered.
7. *Visible*: Facility-wide measures should be posted in a central location, such as the lunch or break room, where everyone can see them. Likewise, unit measures should be posted at the machine or work center.
8. *Timely*: Financial and accounting data are often presented too late to be actionable. This may require that measurements are taken hourly, daily, or weekly rather than monthly or quarterly as in traditional

accounting systems. A significant portion of measurements need to be operational rather than financial.[2] Data needs to be measured, analyzed, and evaluated with respect to the desired goals so that the information can be used effectively in decision making.

9. *Aligned*: A comprehensive set of measures and indicators tied to customer and organizational performance requirements provides a way to align all activities with organizational goals.

10. *Results*: Key result measures need to be guided and balanced by the interests of all stakeholders—customers, employees, stockholders, suppliers, the public, and the community.

Use of these criteria will improve the suitability of the selected measures.

Strategy

The quality council has the overall responsibility for the performance measures. It ensures that all the measures are integrated into a total system of measures. To develop the system, the quality council will obtain appropriate information from all of the stake-holders. They will utilize the core values, goals, mission, and vision statements (see Chapter 2) as well as the objectives and criteria given above. With this information, the strategic measurement system is created.

An example of a system that emphasizes percent improvement might contain the functions and metrics as given below:

Quality

- Percent reduction in cost of poor quality
- Percent reduction in nonconformities
- Percent of certified suppliers
- Percent reduction in supplier base
- Percent reduction in corrective action cycle time

Cost

- Percent increase in inventory turnover
- Percent reduction in data transactions
- Percent increase in materials shipped direct to work-in-process by the supplier
- Percent increase in output dollars per employee
- Percent reduction in floor space utilization

Flexibility

- Percent reduction in cycle time
- Percent reduction in setup time
- Percent reduction in lot/batch size
- Percent increase in number of jobs mastered per employee
- Percent increase in common materials used per product

Reliability

- Percent of processes capable of $C_p = 2.0$
- Percent reduction in down time

[2] James W. Cortada, "Balancing Performance Measurements and Quality," *Quality Digest* (December 1994): 48–54.

- Percent reduction in warranty costs
- Percent reduction in design changes
- Percent increase in on-time delivery

Innovation

- Percent reduction in new product introduction time
- Percent increase in new product sales revenue as a percent of total sales revenue
- Percent increase in new patents granted
- Customer perception as a leader in innovation
- Percent of management time spent on or leading innovation

The above metrics are tracked monthly to show trends, identify problem areas, and allocate resources.[3]

Once the strategic measurement system is developed, the functional areas can develop their systems by involving their departments and work groups. The first step is to determine which processes or sub-processes are critical to providing input for the strategic system. Next, the critical metric(s) are determined using the information given above under Basic Concepts. This activity is followed by assigning responsibility for the collection, analysis, and dissemination of the data. The last step is the development of improvement procedures.

Each month the quality council should meet to monitor current activities and plan future ones. To assist them, a report package is prepared consisting of (1) performance measures; (2) narrative reports on competition, opportunities, and pertinent events; and (3) system audits.

Performance Measure Presentation

There are six basic techniques for presenting performance measures. The simplest and most common is the time series graph shown in Figure 6-1. Time as measured by days, weeks, months, and so forth, is shown on the horizontal axis, and the performance measure is shown on the vertical axis. This type of graph benchmarks the process and shows favorable and unfavorable trends in the measure.

A second form of presentation is the control chart (see Chapter 15). A control chart for percent nonconforming is shown in Figure 6-2.

A third presentation technique is the capability index, which is the ratio of the tolerance to the capability. There are two measures: one indicates the ability of the process to meet specifications, and the other indicates the centering of the process on the target (see Chapter 15).

Another way of measuring quality is Taguchi's loss function. This technique combines target, cost, and specifications into one measurement. Figure 6-3 illustrates the concept (see Chapter 16).

The fifth method of presenting performance measures is the cost of poor quality. Money attracts the attention of senior management; quality costs are described in the next section of this chapter.

The last method includes the performance measurement based on the criteria of national/international quality awards such as Malcolm Baldrige National Quality Award (U.S.), Deming Prize (Japan) or Rajiv Gandhi National Quality Award (India). The criteria for such awards quite effectively measure the performance of TQM effort, on an annual basis. The details are described in the last section of this chapter.

Another approach adopted by many modern organizations is the Balanced Score Card (BSC), which is aimed at the assessment of an organization's financial performance in "balance" with the other business aspects. This approach is also described in the last section.

[3] Michael G. Tincher and Michael J. Stickler, "Measuring Continuous Improvement," *Actionline* (November 1994): 36–39.

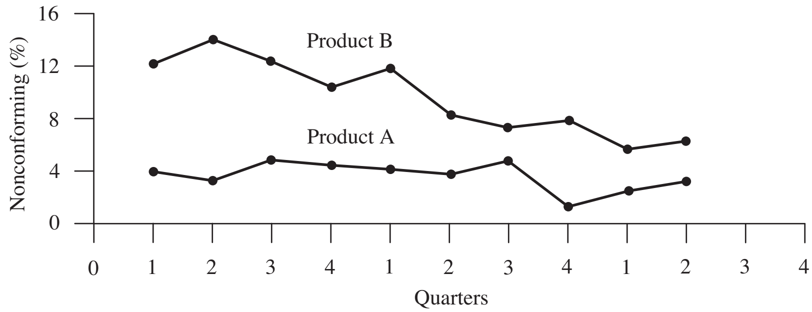

Figure 6-1 **Time Series Graph for Percent Nonconforming**

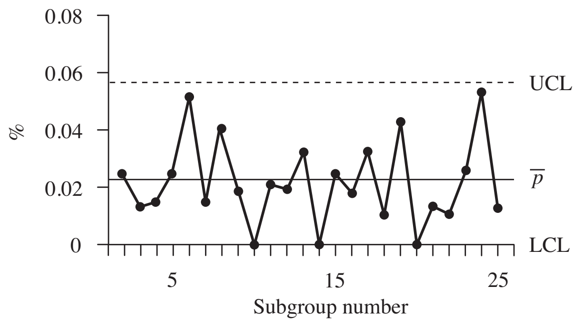

Figure 6-2 **Control Chart for Percent Nonconforming**

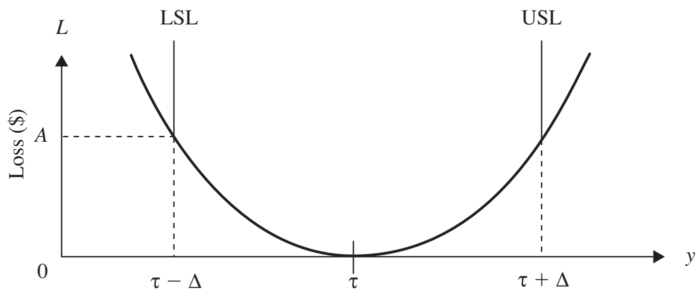

Figure 6-3 **Taguchi's Quadratic Loss Function for Nominal-the-Best**

Cost of Quality

"Cost of quality" is an approach to measure and track financial impact of various quality activities. Until 1950s, the concept did not explicitly extend to the quality function and the activities related to inspection, testing and audits were merely categorized as "overheads". In the 1950s, Dr. Armand Feigenbaum suggested to consider reporting systems focusing on quality costs. Dr. Joseph Juran also started emphasizing the need to speak of the language of upper management which is money. As the upper management best understands the language of money, reporting cost of quality can help in prioritizing appropriate improvement activities to minimize overall costs.

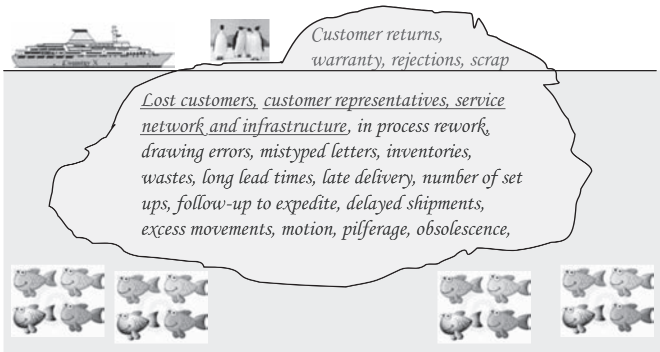

Figure 6-4 Iceberg of Cost of Poor Quality
(Reproduced with permission from the Institute of Quality and Reliability, Pune, www.world-class-quality.com)

With the increasing efforts towards quality control, more and more resources were allocated to the quality function and it became necessary to account for them separately. The heads of quality departments also had to sell their activities to the top management. Since the management understands only one language, money, there was the emergence of the concept of studying quality related costs.

Such studies were undertaken and they led to many surprising results. The quality related costs were much more than those shown in accounting statements. These costs were not only limited to factory operations but also extended to support functions. Big chunk of the cost was on account of poor quality. Cost of poor quality is often compared with the tip of an iceberg. Figure 6-4 shows that the warranty costs and scrap costs are clearly visible but significant portion of the financial impact of poor quality is hidden like an iceberg.

The term "Quality Cost" means different to different people. Some perceive it as the cost involved in attaining the quality, whereas some equate it with the cost of running Quality Department. The interpretation of quality specialists has been to equate the "quality cost" with the cost of poor quality.

What is the Need for Evaluation?

The language of money is well understood across an organization. Quality problems, when manifested on monetary scale, have better appeal.

Cost of quality is a result of many specific segments, each one linked with a specific (or linked) root cause. Estimation of quality cost leads to identification of improvement plans and also sensitizes the managers to take actions in order to reduce the costs. Reduction in quality cost has a direct bearing on the increase in profitability, without increasing sales or without deploying more resources.

Some components of poor quality are the result of product failure, which takes place after sales. Quality costing and its associated analysis exercise leads to identification of opportunities for reducing customer dissatisfaction.

Most companies have financial controls on the basis of departments. For costs like scrap, rework and field failures, which cut across the departmental lines, quality costing helps in bringing the right focus and financial allotments.

Categories of Quality Cost

INTERNAL FAILURE COSTS

These are costs which are associated with the defects or non-conforming situations that are found prior to shipment of the product to customer. These costs can be reduced to zero if no defect existed prior to shipment. Whenever quality appraisals are carried out, there exists a possibility of discovering non-conforming situations. Such situations are salvaged by either rework, complete replacement or scrapping. The total cost of carrying out re-inspection/re-tests, failure analysis, evaluation, disposition and subsequent actions are included in the internal failure cost. In summary, this includes all material, labor, energy and overhead expenses that are wasted on account of non-conforming or defective product or service.

Examples of internal failure costs are:

- Rework, fixing of bugs detected in internal testing of software
- Premium freight due to late delivery
- Internal scrap
- Engineering and drawing changes to correct errors
- Energy cost for remelting of rejected castings

EXTERNAL FAILURE COSTS

Often the defects are found only after the product reaches the dealer or customer. Such costs are included in the external failure costs. This component of quality cost also disappears if there are no defects. Some examples of external failure cost are:

- **Complaints:** Complaints from customer are analyzed, resolved and communication is sent to customer. Sometimes it may also involve field service or adjustments.
- **Warranty claims:** Recall of vehicles for defects, costs involved in repairs or replacement of product during warranty period, the cost associated with receipt, evaluation and replacement of defective product from field.
- **Retrofit and recall costs:** It is often required to modify or update the product in order to incorporate new design changes in order to overcome design deficiencies. There are several cases in recent past, where automobiles were recalled due to failure investigation reports on the steel used in the manufacturing.
- **Liabilities and penalties:** Insurance claims and contractual obligatory claims are included in such types of costs.
- **Allowances and customer goodwill:** The cost of concessions offered to the customer due to substandard product, poor quality or costs incurred because the customer is not completely satisfied with the quality because his expectations were higher than those delivered to him by the product.
- External failure costs will also include lost sales and loss of goodwill although these are difficult to measure

APPRAISAL COSTS

These are the costs incurred while conducting inspection, tests, and several other planned evaluations with the purpose of determining whether the product (or service) confirms to its stated requirements. Appraisal cost also includes various activities related to quality system audit, cost of legal compliance, supplier surveillance, product quality audits, costs for calibration of testing equipment, etc. Thus, cost of maintaining the inspection and test equipment is a part of appraisal cost. Examples include:

- Design reviews
- Software testing
- Set-up inspection
- Performance testing by customer
- Calibration of gauges
- Calibration of testing facility
- Receiving inspection of purchased parts

PREVENTION COSTS

These are the costs of all such activities undertaken to prevent defects in design, development, purchase, labor and other aspects of creation of the product/service. Prevention costs lower the other costs (failure cost and appraisal cost). Prevention is achieved by examining previous failure data and developing action plans for incorporating into the basic system so that the same failures/ defects do not occur again. Examples of prevention costs include:

- Staff training
- Product Quality Planning
- Design and Process FMEA
- Tolerance analysis before design release
- Computer aided design and analysis
- Process capability study for process qualification
- Part selection for better reliability
- Designed experiment for optimum settings of the product

Cost of quality is the addition of all the four categories and is often expressed as percent sales.

Figure 6-5 shows a broad-level relationship between cost of prevention + appraisal and failure costs. There is a quality level at which the total cost of quality is minimum. The quality level for minimum cost has been challenged by Six Sigma professionals. They argue that the achieving the five or six sigma level of performance dramatically reduce cost of appraisal and prevention (reference: Six Sigma Breakthrough Management Strategy Revolutionizing World's Top Corporations' by Michael Harry and Richard Schroeder published by Doubleday, New York in 2000).

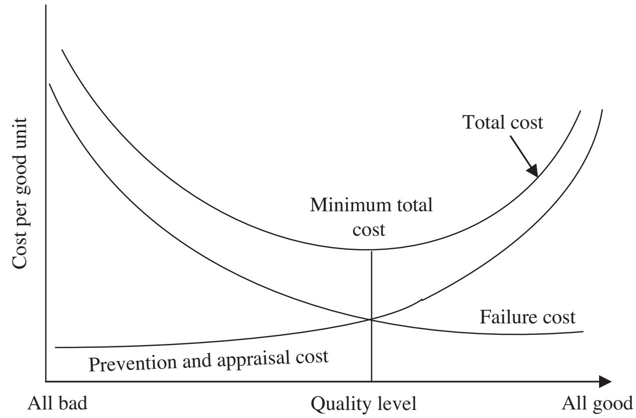

Figure 6-5 Relation Between Prevention + Appraisal and Failure Costs

Data Collection and Reporting

It may sound logical that study on cost of poor quality is performed by the accountant but it is often seen that necessary skills and understanding may rest with the quality manager. Often the book of accounts does not contain the data in the requisite details. For example, it does not provide numbers related to scrap, rework, etc. Under this situation, quality manager should work closely with the accountant. As a step by step approach, quality manager should initially collect the quality related information in the existing accounting format. This initial information should be then presented to the management in order to flag out the quality issues. This information will make maximum impact if it is in the language of money.

Next step is to appoint a task force to measure cost of quality. The task force should propose a list of categories, identify responsibilities and propose schedule for data collection. Management should ensure that the activity is carried out by involvement of the all such functions that are identified by the initial information by the quality manager.

Actual data collection can be performed on either estimation basis or on detailed and more accurate basis. Often the estimation study is completed within a few days and it reveals whether there is major cost reduction opportunity or not. In the initial study, data can be obtained from:

1. **Established accounts:** Examples are appraisal activities and audit expenses, warrantee expenses during the year, etc
2. **Analysis of different expenditure ingredients:** For example, accounts statement may include "customer return" and report all the returned goods. A separate break up may be necessary

The second approach often involves altering the existing accounting system and it usually takes more time and efforts from accounting and quality departments. For early stages of quality improvement, estimated data is often adequate.

Some quality cost data crosses the departmental borders and requires a detailed study. For example, scrap and rework costs may involve many departments. On the other hand, insignificant contributors to cost of quality (like a secretary retyping a letter) can be overlooked. It should, however, be noted that significant factors are often hidden because the existing accounting system may not be designed to handle them.

Relating Quality Cost to Business Measures

While sharing the results of quality cost with the management, quality manager should relate it to the overall business measures. It will have great impact on the management if cost of quality relates to the other figures, such as total sales, total profit, etc., with which managers are familiar. For this purpose, some base line is required and the examples are:

1. **As a percentage of sales:** Most of the financial reports extensively use total sales or business value as a key performance index. When quality costs are related to total sales, its impact on top management is inevitable. It gives valuable input for decision making and arriving at annual planning.
2. **As compared to profit:** In the initial studies of quality cost, it comes as a surprise that quality costs are even higher than the company profit.
3. **As related to production:** Quality cost per unit (say dollar) of production cost is also a commonly used index. Production cost consists of material, labor and overheads and is often used in several other indices. It can be similarly indexed with design cost or purchase cost.
4. **As related to unit of production:** Quality cost per unit, such as an engine, one meter of cloth, etc. is a very simple index and effective for comparison when production lines are similar. In case of dissimilar production lines, the comparison is rather difficult.

Accounting departments normally issue quality cost reports. The report contains quality costs per month (or any suitable period) for each element and also data of the previous year. Comparison of current costs and historical data enables the management to arrive at budgets for next period and strategy for control.

Figure 6-6 shows cost of quality as percentage sales. While the absolute value of cost does not show specific trend, the percentage shows some reduction due to increase in sales.

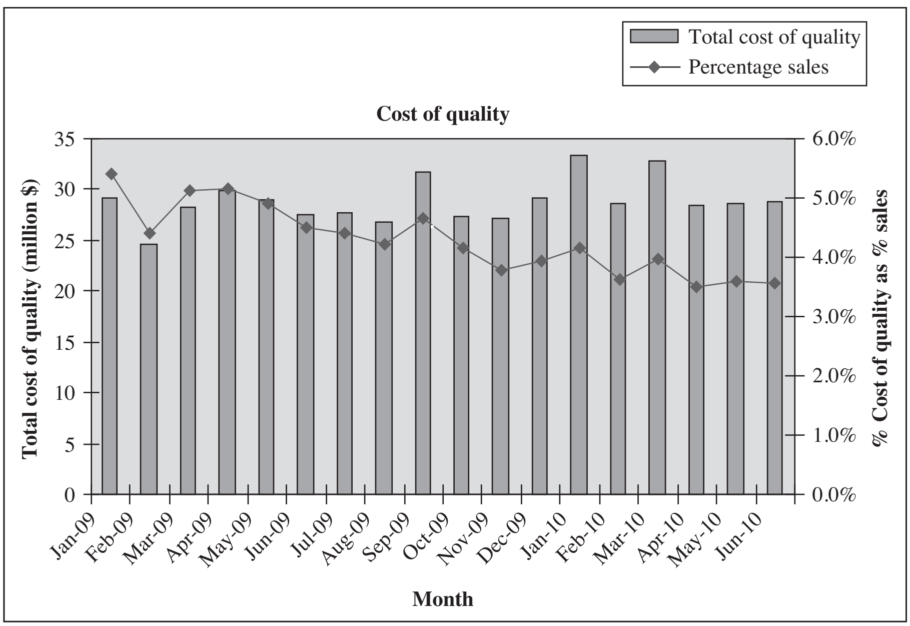

Figure 6-6 Cost of Poor Quality Tracked as Percentage of Sales (Sample Report)

Analysis

Analysis of how quality costs are distributes amongst various categories indicates focus areas. Most common tools are trend and Pareto analysis. Trend analysis over a long time period helps in monitoring the progress of improvement actions. It is often seen that in initial stages, share of failure costs in the total cost of quality is predominant. The trend slowly shifts as improvement actions are initiated. Total cost of quality is expected to reduce with advent of time.

Pareto analysis helps in identifying the vital few contributors for initiating improvement actions.

Note: Detailed study on economic model of distribution of quality costs for 4 major categories is available in *Juran's Quality Control Handbook,* published by McGraw-Hill Book Company.

Improvement Action Strategy and Plan

Cost of Quality is a powerful management tool for the purpose of focusing attention on quality management. The basis of action plan is that failures have a root cause and these causes are preventable. Once the management is convinced about the focus on reducing the cost of quality, the next question is "what action must be taken to reduce the cost of quality?"

The most evident step is to control the number of defects. On this path, companies invariably increase the inspection. This approach fails because it does not eliminate root cause. In another words, more inspection results in more detection but not in prevention. To attach the root causes and to achieve significant and lasting reduction in cost, management should take a structured approach. It should lead to undertaking several improvement projects. Management techniques like structured problem solving, Kaizen, Six Sigma are often used. Many of these are discussed in chapter 5 on Continuous Improvement. According to Deming, about 85% of quality problems cross departmental boundaries and functional lines! Project teams should be therefore selected in such a manner that key persons form related departments, quality, design; production, marketing, etc. are involved.

Limitations of Quality Cost

Quality cost analysis is useful for setting priority for upper management but usually does not suggest specific actions. It provides a broad direction but requires further detailed analysis of data such as item-wise analysis of rejections, warranty, customer complaints etc. to decide action plan. Often, Quality Cost data is not accurate and therefore is not reviewed seriously.

Malcolm Baldrige National Quality Award[4]

The Malcolm Baldrige National Quality Award (MBNQA) is an annual award to recognize U.S. organizations for performance excellence. It was created by Public Law 100–107 on August 20, 1987. The award promotes: understanding of the requirements for performance excellence and competitiveness improvement, sharing of information on successful performance strategies, and the benefits derived from using these strategies. There are five categories: manufacturing, service, small business, health care, and education. Three awards may be given each year in each category. Competition for the awards is intense, and interestingly, many organizations who are not interested in the award are, nevertheless, using the categories as a technique to measure their TQM effort on an annual assessment basis.

[4] Adapted from U.S. Department of Commerce, *Malcolm Baldrige National Quality Award Criteria*, 2009–10.

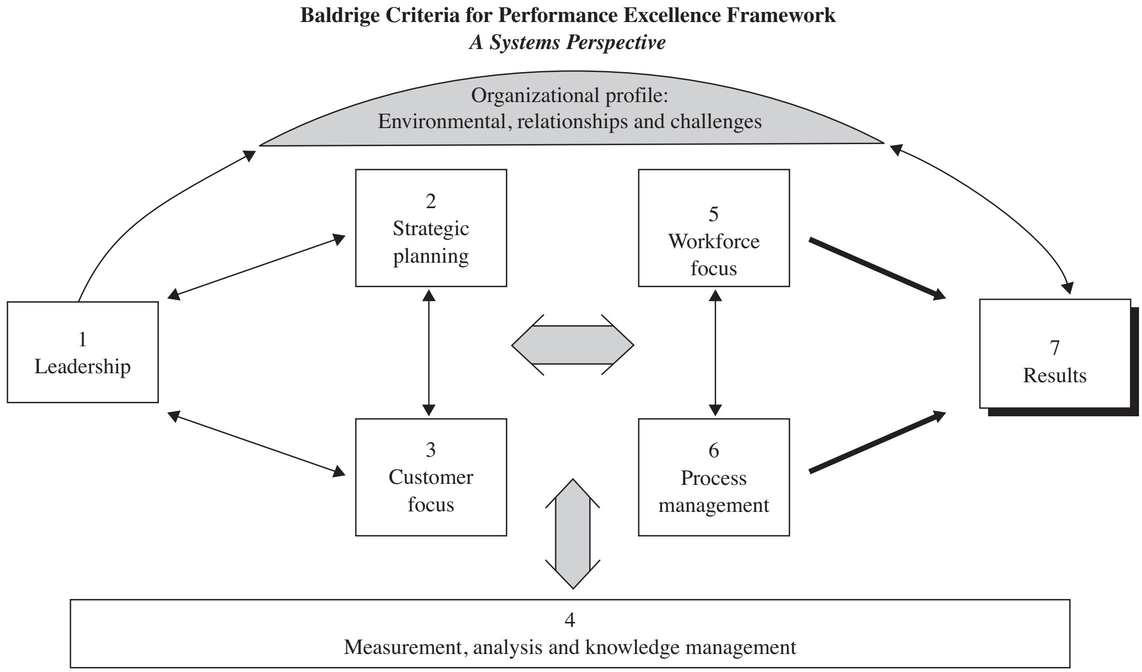

Figure 6-7 Award Criteria Framework

Criteria for Performance Excellence

The criteria for performance excellence are the basis for making awards and for giving feedback to applicants. In addition, they (1) help improve performance practices and capabilities, (2) facilitate communication and sharing of best practices information among U.S. organizations of all types, and (3) serve as a working tool for understanding and managing performance, planning, training, and assessment. The results-oriented goals are designed to deliver ever-improving value to customers, resulting in marketplace success, and to improve overall organization performance and capability. The criteria are derived from the set of core values and concepts described in Chapter 2, Leadership.

The core values and concepts are embodied in seven categories, as shown in Figure 6-7.

The seven categories shown in the figure are subdivided into 18 examination items and one or more sets of areas to address. Information is submitted by applicants in response to specific requirements of these areas.

Key Characteristics of the Criteria

1. The criteria are directed toward results. They focus principally on seven key areas of business performance. Results are a composite of

- Product
- Customer

- Market and financial
- Internal operational performance results
- Workforce
- Leadership
- Governance
- Societal responsibility

Improvements in these seven areas contribute significantly to organization performance, including financial performance. The results also recognize the importance of suppliers, the needs of communities, and the needs of the nation.

2. The criteria are nonprescriptive and adaptable because

- The focus is on results, not on procedures or tools. Organizations are encouraged to develop and demonstrate creative, adaptive, and flexible approaches, for meeting basic requirements. Nonprescriptive requirements are intended to foster incremental and major “breakthrough” improvement.
- Selection of tools, techniques, and systems usually depends upon factors such as business type and size, the organization’s stage of development, and employee capabilities and responsibilities.
- The focus is on common requirements within an organization rather than on specific procedures, which fosters better understanding, communication, sharing, and alignment while supporting diversity and creativity in approaches.

3. The criteria support a systems approach to maintaining organization-wide goal alignment. A systems approach to goal alignment, particularly when strategy and goals change over time, requires dynamic linkages among criteria items. In the criteria, action-oriented learning takes place using feedback between processes and results through cycles of learning.

The learning cycles have four clearly defined stages, similar to Shewhart’s P-D-S-A.

1. Planning, including design of processes, selection of measures, and deployment of requirements.
2. Execution of plans.
3. Assessment of progress, taking into account internal and external results.
4. Revision of plans based upon assessment findings, learning, new inputs, and new requirements.

4. The criteria support goal-based diagnosis. The criteria and the scoring guidelines make up a two-part diagnostic (assessment) system. The criteria are a set of 18 performance-oriented requirements. The scoring guidelines indicate the assessment dimensions—approach, deployment, and results—and the key factors used to assess against each dimension. An assessment thus provides a profile of strengths and opportunities for improvement relative to the 18 basic requirements. In this way, assessment leads to actions, which contribute to the results composite previously described. This diagnostic assessment is thus a useful management tool that goes beyond most performance reviews and is applicable to a wide range of strategies and management systems.

Criteria for Performance Excellence

Table 6-1 shows the award categories and the 18 items with their point values. It is important to note that 45% of the total score is based on results.

The Leadership category examines how personal actions of the senior leaders of an organization guide and sustain the organization. Also examined, are organization’s governance system and how an organization fulfills its legal, ethical and societal responsibilities and supports its key communities.

TABLE 6-1
Criteria for Performance Excellence—Item Listing

Preface: Organizational Profile
P.1 Organizational Description
P.2 Organizational Situation

Categories and Items		*Point*	*Values*
1	**Leadership**		**120**
1.1	Senior Leadership	70	
1.2	Governance and Societal Responsibilities	50	
2	**Strategic Planning**		**85**
2.1	Strategy Development	40	
2.2	Strategy Development	45	
3	**Customer Focus**		**85**
3.1	Customer Engagement	40	
3.2	Voice of the Customer	45	
4	**Measurement, Analysis and Knowledge Management**		**90**
4.1	Measurement, Analysis and Improvement of Organizational Performance	45	
4.2	Management of Information, Knowledge and Information Technology	45	
5	**Workforce Focus**		**85**
5.1	Workforce Engagement	45	
5.2	Workforce Environment	40	
6	**Process Management**		**85**
6.1	Work Systems	35	
6.2	Work Processes	50	
7	**Results**		**450**
7.1	Product Outcomes	100	
7.2	Customer-focused Outcomes	70	
7.3	Financial and Market Outcomes	70	
7.4	Workforce-focused Outcomes	70	
7.5	Process Effectiveness Outcomes	70	
7.6	Leadership Outcomes	70	
	TOTAL POINTS		**1000**

The strategic planning category examines how an organization develops strategic objectives and action plans. Also examined, are how the chosen strategic objectives and action plans are deployed and changed if circumstances require, and how progress is measured.

The customer focus category examines how an organization engages its customers for long-term marketplace success. This engagement strategy includes how an organization builds a customer-focused culture. It also examines, how an organization listens to the voice of its customers and uses this information to improve and identify opportunities for innovations.

The measurement, analysis, and knowledge management category examines how an organization selects, gathers, analyzes, manages and improves its data, information and knowledge assets and how it manages its information technology. The category also examines, how an organization reviews and uses those reviews to improve its performance.

The workforce focus category examines how an organization engages, manages and develops the workforce to utilize its full potential in alignment with its overall mission, strategy and action plans. The category examines the ability to assess workforce capability, capacity needs and, the ability to build a workforce environment conducive to high performance.

The process management category examines how an organization designs its work systems and how it designs, manages and improves its key processes for implementing those work systems, that deliver customer value and achieve organizational success and sustainability. Also, examined is an organization's readiness for emergencies.

The results category examines an organization's performance and improvement in all key areas, namely, product, customer-focused, financial and market, workforce-focused, process effectiveness and leadership outcomes. Performance levels are examined relative to those of the competitors and other organizations with similar product offerings.

Scoring System

The system for scoring applicant responses is based on three evaluation dimensions: (1) approach, (2) deployment, and (3) results.

Approach refers to how the applicant addresses the item requirements. The factors used to evaluate approaches include:

- Appropriateness of the methods to the requirements.
- Effective use of the methods.
- Degree to which the approach is systematic, integrated, and consistently applied; embodies effective evaluation/improvement/learning cycles; and is based on reliable information and data.
- Evidence of innovative and/or significant and effective adaptations of approaches used in other applications or types of businesses.

Deployment refers to the extent to which the applicant's approach is applied to all requirements of the item. The factors used to evaluate deployment include:

- Use of the approach in addressing business and item requirements.
- Use of the approach by all appropriate work units.

Results refer to outcomes in achieving the purposes given in the item. The factors used to evaluate results include:

- Current performance.
- Performance relative to appropriate comparisons and/or benchmarks.

- Rate, breadth, and importance of performance improvements.
- Demonstration of sustained improvement and/or sustained high-level performance.
- Linkage of results measures to key performance measures identified in the business overview and in approach/deployment items.

Use of the scoring system requires considerable training. Examiners receive more than three days of training, with most of the time devoted to the scoring system. A simpler system is given by the sample self-evaluation, which is shown in the next section. This approach would be more appropriate for small and medium-sized organizations.

Sample Self-Evaluation[5]

Applying for Baldrige Award is an assessment process in itself. The criteria offer opportunity for the organizations to carry out self-assessment. Often such, self-assessment/ evaluation is carried out using the worksheets, which are available as a part of award application. The format of the worksheet is also available on the website www. baldrige.nist.gov.

Applicants or aspiring organizations often initially carry out such self-assessment and arrive at the improvement action plan. One should use the subjective judgment to grade how well the organization confirms to the specific criteria by assigning numerical rating on the scale of 1 to 10 (1 being low and 10 being high). The scores on each sub-category are added and normalized. The individual and total scores are then used as a baseline to monitor the progress. Once the self-assessment indicates a satisfactory and desired level, the organization can then consider itself ready for applying for the Baldrige Award.

Rajiv Gandhi National Quality Award

Rajiv Gandhi National Quality Award (RGNQA) was instituted by the Bureau of Indian Standards in 1991, with a view to encourage Indian manufacturing and service organizations to strive for excellence and giving special recognition to those who are considered to be the leaders of quality movement in India. This award is intended to generate interest and involvement of Indian Industry in quality programs, drive the products and services to higher levels of quality and equip industry to meet the challenges, of the domestic and international markets.

The award has been christened after India's late Prime Minister Rajiv Gandhi, recognizing the new thrust he had given to the quality movement in India, which would enable India to march into 21st century with pride.

RGNQA helps Indian Industry to improve quality by

- Encouraging Indian industry to make significant improvements, in the quality for maximizing consumer satisfaction and successfully facing competition in the global market.
- Recognizing the achievements of those organizations, which have improved the quality of their products and services and thereby, set an example for others
- Establishing guidelines and criteria that can be used by the industry in evaluating their own quality improvement efforts

[5] Adapted, with permission, from G. W. Chase, *Implementing TQM in a Construction Company* (Washington, D.C.: Associated General Contractors of America, 1993).

- Providing specific guidance to other organizations that wish to learn how to achieve excellence in quality by making available detailed information on the Quality Management Approach adopted by the award winning organizations to change their culture and achieve eminence.

The award has been designed in line with similar awards like Malcolm Baldrige National Quality Award in the U.S., Deming Prize in Japan and European Quality Award.[6]

Balanced Score Card

A new approach to strategic management was developed in the early 1990s by Robert Kaplan and David Norton. They named this system as Balanced Score Card (BSC). Recognizing some of the weaknesses and vagueness of previous management approaches, this approach provides a prescription as to what companies should measure in order to "balance" the financial perspective.

The BSC is a not merely a measurement system but a management system that enables the organizations to clarify their vision and strategy and translate them into action. Financial measures tell the story of past, but the stakeholders are more concerned about the future and long-term capabilities and more so, on how to achieve the goals. BSC approach provides a mechanism to achieve feedback on internal business processes and external output such as customer satisfaction.

BSC is a medium to convert vision and objectives into a strategy and measurable objectives to provide direction to the organization. In today's world mere balance sheet is not adequate to read the performance. BSC suggests that we review the organization from four perspectives to develop metrics, collect data and analyze it relative to each of these perspectives:

- The learning and growth perspective
- The business process perspective
- The customer perspective
- The financial perspective

The most critical aspect is often to link measurements to the organizational strategy. One such approach is described in Figure 6-8.

Comments

The MBNQA provides a plan to keep improving all operations continuously and a system to measure these improvements accurately. Benchmarks are used to compare the organization's performance with the world's best and to establish stretch goals. A close partnership with suppliers and customers that feeds improvements back into the operation is required. There is a long-lasting relationship with customers, so that their wants are translated into products and services that go beyond delivery. Management from top to bottom is committed to improving quality. Preventing mistakes and looking for improvement opportunities is built into the culture. There is a major investment in human resources by means of training, motivation, and empowerment.

[6] Taken from Bureau of Indian Standards, www.bis.org.in.

Figure 6-8 Deriving Performance Measures from Organizational Strategy
(Reproduced with permission from the Institute of Quality and Reliability, Pune).

According to Dr. J. M. Juran, who studied the winners of the award, the gains have been stunning. The gains can be accomplished by large and small U.S. organizations and by U.S. workers. The gains include quality, productivity, and cycle time.

TQM Exemplary Organization[7]

Spicer Driveshaft, part of the Dana Corporation, is North America's largest independent manufacturer of automotive driveshafts and related components, supplying customers in the United States and around the world. Headquartered in Toledo, Ohio, Spicer Driveshaft has 17 plants and offices in the United States. More than two-thirds of its 3,300 employees work in five manufacturing and sub-assembly plants.

The company's quality policy—"Dedicated to total quality and continuous improvement"—guides the entire business. Its Quality Council sits at the pinnacle of Spicer Driveshaft's pyramid-like leadership system, where it is positioned to commit quality policy to organizational practice. Balancing present and future is a top concern of management, as reflected in the company's philosophy that "to have a future we must perform today, but to build a better future we must plan for it today." All of Spicer Driveshaft's senior leaders are involved in a two-phase strategic planning process that sets the company's five-year strategic business goals

[7] Malcolm Baldrige National Quality Award, 2000 Manufacturing Category Recipient, NIST/Baldrige Homepage, Internet.

along with its annual business and performance objectives. Expectations for the coming year are set during the annual Hellweek, a Dana Corporation process that results in measurable performance objectives, detailed plans for resource allocation and capital investment, customer-focus strategies, and other key elements. As a result of this systematic process, detailed 12-month plans—along with long-range performance goals and resource needs—are developed for each Spicer Driveshaft facility and department.

The organization's Total Quality Management Control Plan is its chief vehicle for aligning key business drivers, long-term strategies, annual plans, and specific performance objectives. At the heart of this plan are 17 measurable TQM indicators that provide a common focus on quality and convey the relationship between today's performance and the company's targets for improvement. For example, indicators for customer satisfaction—one of five key business drivers—are on-time delivery, customer performance ratings, aftermarket order fill, and results of the company's comprehensive annual customer survey.

The vertically-integrated measurement system enables data to be aggregated and consolidated for analyses of trends or to be broken out for a fine-grained analysis of operational performance. Considerable effort is devoted to ensuring that Spicer Driveshaft's measurement system corresponds with the company's strategic directions and that the data collected and analyzed are causally connected to performance. A cross-functional team holds quarterly measurement summits to evaluate the system, make adjustments, and decide what improvements are needed to respond to current and future business needs.

Aided by an information technology system that supports real-time communication and data exchanges with customers, dedicated teams of sales, engineering, quality, and warranty personnel are assigned to each Spicer Driveshaft customer. These Customer Platform Teams are charged with building and maintaining long-term relationships. They are responsible for capturing current customer requirements, anticipating new ones, meeting with customer personnel that install Spicer Driveshaft products, ensuring quick and effective access to key points of contact in the company, and tracking complaints and concerns. Most teams hold monthly meetings with their customers to review designs, resolve pending issues, and plan future programs.

Employees are encouraged to suggest and implement changes. On average, each employee submits three suggestions for improvement each month. In 1999, almost 80% of these ideas were implemented. Many ideas are advanced during continuous improvement "blitzes" that management encourages at all facilities—for both production and support operations. During blitzes, teams gather to brainstorm, identify opportunities for improvement, and then proceed immediately to implement their ideas. At some facilities, blitzes are held as often as every three or four weeks.

Results of the annual, 57-question Quality Culture Survey and other indicators of employee well-being indicate consistently high levels of employee morale. For example, Spicer Driveshaft's employee turnover rate is below 1%, which is better than the best competitor; and the attendance rate has topped 98% for the last six years.

The company's return on net assets has improved to more than 25% in 2000, as compared with less than 20% in 1997. Internal defect rates have decreased over 75% from 1996 to 2000 and are approaching best-in-class levels, while defect rates for key suppliers have decreased to less than one-fifth the level for the best-known competitor. From 1998 to 2000, overall customer satisfaction, as measured in a third-party survey, has averaged 80% or better, topping all competitors. Customer complaints have dropped steadily, from 6.8 per million units shipped in 1995 to about 2.8 per million units shipped in 2000, and since 1996, Spicer Driveshaft has not lost a single customer.

Summary

In order to achieve growth and progress, an organization must establish performance measures for itself. Management should track the performance and take corrective steps to steer the organization to its stated goals and objectives.

The measures should include all those aspects that it considers critical for business, such as human resource, customers and stakeholders, production, R&D efforts, suppliers, marketing/sales, administration, etc. Performance measures or metrics should be aligned with organization's core and business values and policies. Management should track the metrics on regular basis in order to identify problems and allocate resources. Several tools and techniques are available for the presentation of the measures.

An organization should establish methods to assess and control cost of poor quality. High cost of quality is an indication of management effectiveness. Quality cost programs should address all perceived, hidden and buried costs in all the functional areas.

The Malcolm Baldrige National Quality Award (MBNQA) is an annual award to recognize organizations from U.S. in the field of performance excellence. The award criteria supports a systems approach in maintaining organization-wide goal alignment and goal-based diagnosis. The system for scoring is based on three evaluation dimensions, namely, (1) approach, (2) deployment and (3) results.

Several other national awards like Deming Award and Rajiv Gandhi National Quality Award also adopt similar approaches in evaluation of organizational excellence.

Exercises

1. Working in a team of three or more people, what performance measures would you recommend for the following organizations?

   (a) Large bank
   (b) Health-care facility
   (c) University academic department
   (d) University nonacademic department
   (e) Large department store
   (f) Grade school
   (g) Manufacturing facility
   (h) Large grocery store

2. Working as an individual or in a team of three or more people, evaluate the strategy used by one of the organizations listed in Exercise 1.

3. Construct a Pareto diagram[8] for the analysis of internal failures for the following data (the numbers in parentheses refer to cost elements):

Type of Cost	*Dollars (Thousands)*
Purchasing—rejects (3.2)	205
Design—scrap (3.1)	120
Operations—rework (3.3)	355
Purchasing—rework (3.2)	25
All other	65

[8] Detailed information on the Pareto diagram is given in Chapter 15.

4. Construct a Pareto diagram for the analysis of the external failure costs for a cellular telephone manufacturer using the following data:

Type of Cost	*Dollars (Thousands)*
Customer complaints (4.1)	20
Returned goods (4.2)	30
Retrofit costs (4.3)	50
Warranty claims (4.4)	90
Liability costs (4.5)	10
Penalties (4.6)	5
Customer goodwill (4.7)	25

5. A building construction organization needs a Pareto diagram for the analysis of the following design department quality costs:

Elements	*Dollars (Thousands)*
Progress reviews (1.2)	5
Support activities (1.2)	3
Qualification tests (1.2)	2
Corrective action (3.1)	15
Rework (3.1)	50
Scrap (3.1)	25
Liaison (3.1)	2

6. Construct a Pareto diagram for the analysis of the following purchasing department quality costs of a major airline:

Element	*Dollars (Thousands)*
Supplier review (1.3)	10
Supplier rating (1.3)	5
Specification review (1.3)	2
Supplier quality planning (1.3)	5
Receiving inspection (2.1)	95
Measuring equipment (2.1)	60
Qualification of supplier product (2.1)	5
Source inspection (2.1)	15
Material reject (3.2)	120
Material replacement (3.2)	180
Supplier corrective action (3.2)	53
Rework of supplier (3.2)	5

7. Construct a trend analysis graph for the quality cost categories and the total. Quality cost data for a wheelbarrow manufacturer as a percent of net sales are as follows:

Year	*Prevention*	*Appraisal*	*Internal Failure*	*External Failure*	*Total*
1	0.2	2.6	3.7	4.7	11.2
2	0.6	2.5	3.3	3.6	10.0
3	1.2	2.8	4.0	1.8	9.8
4	1.2	1.7	3.4	1.2	7.5
5	1.0	1.3	1.8	0.9	5.0

8. For a homeowners' insurance organization, prepare graphs and analyze the internal failure costs for the past eight months using the labor index.

Month	*Cost*	*Direct Labor (Worker-hours)*
June	$74,000	18,000
July	$69,000	16,600
Aug.	$71,000	17,300
Sept.	$74,000	17,800
Oct.	$72,000	17,600
Nov.	$74,000	17,500
Dec.	$73,000	16,800
Jan.	$81,000	18,200

9. Prepare graphs and analyze the appraisal costs of a leading bank for the past eight months using the net sales index.

Month	*Cost*	*Net Sales (Thousands)*
Feb.	$45,000	$2,500
Mar.	$43,500	$2,290
April	$46,100	$2,560
May	$45,800	$2,540
June	$47,000	$2,470
July	$48,600	$2,550
Aug.	$49,900	$2,500
Sept.	$49,300	$2,580

10. For a hardware manufacturer, prepare graphs and analyze the internal failure costs for the past six months using the net sales index.

Month	*Cost*	*Net Sales (Thousands)*
Mar.	$45,300	$ 755
April	$45,800	$ 790
May	$46,100	$ 840
June	$47,000	$ 925
July	$48,600	$1,050
Aug.	$49,300	$1,232

11. For a microwave manufacturer, prepare and analyze the graph of the procurement appraisal costs as a percent of total purchased material costs using the following data:

Month	*Procurement Appraisal Costs (Thousands)*	*Purchased Material Costs (Thousands)*
June	8.5	102
July	7.9	127
Aug.	9.9	116
Sept.	7.2	115
Oct.	7.7	108
Nov.	6.2	112

12. Prepare a short-range trend chart of the operations appraisal cost/production cost ratio using the following data.

Month	*Operation Appraisal Costs (Thousands)*	*Production Costs (Thousands)*
Jan.	$10	$100
Feb.	$13	$120
Mar.	$ 9	$115
April	$11	$145
May	$ 9	$125
June	$ 8	$ 95
July	$ 8	$105

What information does the chart give? Suggest additional information that could be valuable.

13. Using the sample self-evaluation for the construction industry, design a similar instrument for one of the organizations listed in Exercise 1.

14. Working in a team of three or more people, visit one of the organizations listed in Exercise 1 and conduct an assessment of their TQM performance using the self-evaluation developed in Exercise 13.

15. Which of the following criteria are not recommended for performance measures?

    (a) simple
    (b) visible
    (c) should be developed by senior management
    (d) aligned

16. Which of the following is not a prevention cost?

    (a) design review
    (b) final inspection
    (c) purchase order review
    (d) capability study

17. Which of the following quality improvement strategies is preferred?

    (a) minimize all quality costs
    (b) minimize external and internal failure costs and improve productivity
    (c) reduce failure costs, implement right prevention activities, Reduce appraisal cost where justified
    (d) maximize appraisal and prevention cost to minimize external and internal failure costs

18. Which of the following methods is not appropriate for presentation?

    (a) pareto chart
    (b) trend chart
    (c) loss function
    (d) control chart

19. Malcolm Baldrige criteria for excellence include all of the following except:

    (a) leadership
    (b) product specifications
    (c) workforce
    (d) business results

20. State True or False:

    1. In MBNQA criteria, core values and concepts are embodied in seven categories.
    2. The approach of Balanced Score Card was developed by David Norton and Michael Harry.
    3. BSC enables the organization to convert its vision into measurable objectives.

    (a) 1-True, 2-False, 3-False
    (b) 1-False, 2-False, 3-True
    (c) 1-True, 2-True, 3-True
    (d) 1-True, 2-False, 3-True

7

Benchmarking

Chapter Objectives

- Defining benchmarking and understanding its need
- Understanding the process of benchmarking
- Identifying the critical factors to success
- Understanding the current performance
- Planning the benchmarking exercise
- Studying and analyzing the results
- Understanding limitations and pitfalls

Introduction

Benchmarking is a systematic method by which organizations can measure themselves against the best industry practices. It promotes superior performance by providing an organized framework through which organizations learn how the "best in class" do things, understand how these best practices differ from their own, and implement change to close the gap. The essence of benchmarking is the process of borrowing ideas and adapting them to gain competitive advantage. It is a tool for continuous improvement.

Benchmarking is an increasingly popular tool. It is used extensively by both manufacturing and service organizations, including Xerox, AT&T, Motorola, Ford, and Toyota. Benchmarking is a common element of quality standards, such as the Chrysler, Ford, and General Motors Quality System Requirements. These standards stipulate that quality goals and objectives be based on competitive products and benchmarking, both inside and outside the automotive industry. The Malcolm Baldrige National Quality Award similarly requires that applicants benchmark external organizations.

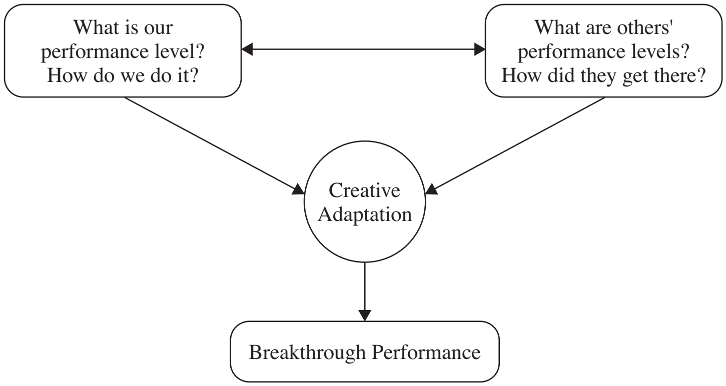

Figure 7-1 Benchmarking Concept

Benchmarking Defined

Benchmarking is the systematic search for best practices, innovative ideas, and highly effective operating procedures. Benchmarking considers the experience of others and uses it. Indeed,- it is the common-sense proposition to learn from others what they do right and then imitate it to avoid reinventing the wheel. Benchmarking is not new and indeed has been around for a long time. In fact, in the 1800s, Francis Lowell, a New England colonist, studied British textile mills and imported many ideas along with improvements he made for the burgeoning American textile mills.

As shown in Figure 7-1, benchmarking measures performance against that of best-in-class organizations, determines how the best in class achieve those performance levels, and uses the information as the basis for adaptive creativity and breakthrough performance.[1]

Implicit in the definition of benchmarking are two key elements. First, measuring performance requires some sort of units of measure. These are called metrics and are usually expressed numerically. The numbers achieved by the best-in-class benchmark are the target. An organization seeking improvement then plots its own performance against the target. Second, benchmarking requires that managers understand *why* their performance differs. Benchmarkers must develop a thorough and in-depth knowledge of both their own processes and the processes of the best-in-class organization. An understanding of the differences allows managers to organize their improvement efforts to meet the goal. Benchmarking is about setting goals and objectives and about meeting them by improving processes.

Reasons to Benchmark

Benchmarking is a tool to achieve business and competitive objectives. It is powerful and extremely effective when used for the right reasons and aligned with organization strategy. It is not a panacea that can replace all other quality efforts or management processes. Organizations must still decide which markets to serve and

[1] Christopher E. Bogan and Michael J. English, "Benchmarking for Best Practices: Winning Through Innovative Adaptations," *Quality Digest* (August 1994): 52–62.

determine the strengths that will enable them to gain competitive advantage. Benchmarking is one tool to help organizations develop those strengths and reduce weaknesses.

By definition, benchmarking requires an external orientation, which is critical in a world where the competitor can easily be on the other side of the globe. An external outlook greatly reduces the chance of being caught unaware by competition. Benchmarking can notify the organization if it has fallen behind the competition or failed to take advantage of important operating improvements developed elsewhere. In short, benchmarking can inspire managers (and organizations) to compete.

In contrast to the traditional method of extrapolating next year's goal from last year's performance, benchmarking allows goals to be set objectively, based on external information. When personnel are aware of the external information, they are usually much more motivated to attain the goals and objectives. Also, it is hard to argue that an objective is impossible when it can be shown that another organization has already achieved it.

Benchmarking is time and cost efficient because the process involves imitation and adaptation rather than pure invention. Benchmarking partners provide a working model of an improved process, which reduces some of the planning, testing, and prototyping effort. As the old saying goes, Why reinvent the wheel?

The primary weakness of benchmarking, however, is the fact that best-in-class performance is a moving target. For example, new technology can create quantum leap performance improvements, such as the use of electronic data interchange (EDI). Automobile makers no longer use paper to purchase parts from suppliers. A computer tracks inventory and transmits orders directly to a supplier's computers. The supplier delivers the goods, and payment is electronically transmitted to the supplier's bank. Big Bazar in India runs SAP ERP system for their inventory management. These applications of EDI save tens of thousands of worker hours and whole forests of trees, as well as helping to meet customer requirements.

For functions that are critical to the business mission, organizations must continue to innovate as well as imitate. Benchmarking enhances innovation by requiring organizations to constantly scan the external environment and to use the information obtained to improve the process. Potentially useful technological breakthroughs can be located and adopted early.

Process

Organizations that benchmark, adapt the process to best fit their own needs and culture. Although the number of steps in the process may vary from organization to organization, the following six steps contain the core techniques.

1. Decide what to benchmark.
2. Understand current performance.
3. Plan.
4. Study others.
5. Learn from the data.
6. Use the findings.

Table 7-1 illustrates how AT&T and Xerox have adapted benchmarking to their own needs. AT&T, in its first six steps, explicitly incorporates training and makes sure that personnel using benchmarking results to improve their processes buy into the program. The assumption is that if the process owners are not committed, they will ignore the results and the effort will have been wasted. Steps 7 through 12 represent the core benchmarking process.

Xerox, in Steps 5 through 8, devotes extra effort to integrating benchmarking results into its formal planning process. This involves justification to senior management and gaining agreement from senior management. Again, steps are added to fit the process to the organizational need, but the core activities are consistent.

TABLE 7-1
Approaches to Benchmarking

AT&T's 12-Step Process	*Xerox's 10-Step Process*
1. Determine who the clients are—who will use the information to improve their processes.	1. Identify what is to be benchmarked.
2. Advance the clients from the literacy stage to the champion stage.	2. Identify comparative organizations.
3. Test the environment. Make sure the clients can and will follow through with benchmarking findings.	3. Determine data-collection method and collect data.
4. Determine urgency. Panic or disinterest indicate little chance for success.	4. Determine current performance gap.
5. Determine scope and type of benchmarking needed.	5. Project future performance levels.
6. Select and prepare the team.	6. Communicate benchmark findings and gain acceptance.
7. Overlay the benchmarking process onto the business planning process.	7. Establish functional goals.
8. Develop the benchmarking plan.	8. Develop action plans.
9. Analyze the data.	9. Implement specific actions and monitor progress.
10. Integrate the recommended actions.	10. Recalibrate benchmarks.
11. Take action.	
12. Continue improvement.	

Deciding What to Benchmark

Benchmarking can be applied to virtually any business or production process. Improvement to best-in-class levels in some areas will contribute greatly to market and financial success, whereas improvement in other areas will have no significant impact. Most organizations have a strategy that defines how the firm wants to position itself and compete in the marketplace. This strategy is usually expressed in terms of mission and vision statements. Supporting these statements is a set of critical activities, which the organization must do successfully to realize its vision. They are often referred to as *critical success factors*. Critical processes are usually made of a number of sub-processes. In general, when deciding what to benchmark, it is best to begin by thinking about the mission and critical success factors.

For example, take the case of two insurance organizations. The chairperson of the first expresses the organization's vision as becoming the "easiest in the industry to do business with." He wants to sell customers all their insurance needs by emphasizing speed of writing policies and an outstanding level of customer service.

Critical success factors in this case could include a 24-hour, toll-free call service, fast payment of claims, database systems that can relate information on all policies held by each customer, and reduced cycle time. Benchmarking customer service processes would have a substantial impact on the vision.

The chairperson of the second organization admits that his organization is only an average performer in terms of customer service but intends to reduce the cost of insurance through excellent investment performance. Because today's premiums are invested to pay tomorrow's claims, higher earnings from investments would allow the organization to charge less. The critical success factors for this firm could include hiring and training good financial managers, using telecommunications to track and act on developments in global money markets, development of on-line, real-time information systems, and expert forecasting. Benchmarking investment processes would be appropriate in this case.[2]

Some other questions that can be raised to decide high impact areas to benchmark are:

1. Which processes are causing the most trouble?
2. Which processes contribute most to customer satisfaction and which are not performing up to expectations?
3. What are the competitive pressures impacting the organization the most?
4. What processes or functions have the most potential for differentiating our organization from the competition?[3]

In deciding what to benchmark, it is best not to choose too large a scope. A benchmarking study should be done quickly, or it may not get done at all. Teams can get very bogged down in the technicalities of benchmarking and take a year or longer to complete a study. Many circumstances can change in an organization over a year. Team members or management may change in a year's time, and that may compromise the study or even force a study to be abandoned. In order to limit the scope of a study and thereby limit the time it takes to conduct the study, it is best to choose a broad and shallow scope or a narrow and deep scope as shown in Figure 7-2. Broad and shallow studies ask, "What is done?" and span many functions and people and do not go into detail in any one area. Broad and shallow studies are useful in developing strategies, setting goals, and reorganizing functions to be more effective. Narrow and deep studies ask, "How is it done?" and delve into a few aspects of a process or function. Narrow and deep studies are useful in changing how people perform their jobs. Some benchmarking teams start with a broad-and-shallow scope and identify a few areas of particular interest to do a narrow and deep study. Other benchmarking teams identify the narrow and deep target immediately, based on existing data or experience.

Pareto analysis can be a helpful technique for deciding what processes to investigate. It is often effective to start with the process output and trace back to the inputs, asking what, how, where, when, and why questions along the way. Cause-and-effect diagrams and flow diagrams are excellent tools for tracing outputs back to inputs and for examining factors that influence the process. The bottlenecks identified become benchmarking candidates.

At this point, it is appropriate to begin thinking about metrics (measurements). Numerical measures illustrate the effects of improvement and thereby aid in deciding where to direct benchmarking activities. One quick and meaningful metric is the value added per employee. Measuring labor productivity is a fundamental indicator of efficiency that strongly correlates with profitability.

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[2] Peter G. W. Keen, *Shaping the Future: Business Design Through Information Technology* (Boston: Harvard Business School Press, 1991).

[3] Paul Adam and Richard Vandewater, "Benchmarking and the Bottom Line: Translating Business Reengineering into Bottom-line Results," *Industrial Engineering* (February 1995): 24–26.

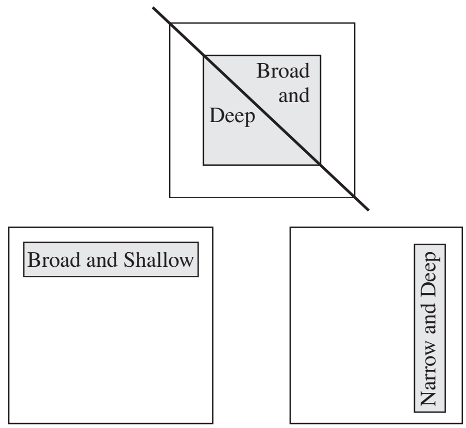

Figure 7-2 Choosing the Scope of the Benchmarking Study
Source: Sarah Lincoln and Art Price, "What Benchmarking Books Don't Tell You," *Quality Progress* (March 1996): 33–36.

Understanding Current Performance

To compare practices to outside benchmarks, it is first necessary to thoroughly understand and document the current process. It is essential that the organization's performance is well understood. Several techniques, such as flow diagrams and cause-and-effect diagrams, and understanding. Attention must be paid to inputs and outputs. Careful questioning is necessary to identify circumstances that result in exceptions to the normal routine. Exceptions commonly consume a good deal of the process resources; however, process participants may not think to mention them during interviews.

Those working in the process know the most about it and are the most capable of identifying and correcting problems. The benchmarking team should be comprised of those who own or work in the process to ensure suggested changes are actually implemented.

When documenting the process, it is important to quantify it. Units of measure must be determined. These are the key metrics that will be compared during the benchmarking investigation. Common examples include unit costs, hourly rates, asset measures, and quality measures. In some cases, important measures are not available or are unclear. Decisions will have to be made as to whether the information can be estimated or if additional data-collection efforts are necessary. Data form the baseline for benchmark comparisons.

Special care should be taken when using accounting information. Most accounting systems were developed to satisfy external reporting requirements to the tax and regulatory authorities. As a result, costs may be aggregated in a way that the activities under study are misrepresented. Benchmarkers should take the time to determine what is and what is not included in accounting information.

Planning

Once internal processes are understood and documented, it is possible to make decisions about how to conduct the study. If not already selected, a benchmarking team should be chosen. The team should decide what type of benchmarking to perform, what type of data are to be collected, and the method of collection. Organizations that are candidates to serve as the benchmark need to be identified. Finally, timetables should be agreed upon for each of the benchmarking tasks and the desired output from the study.

Benchmark planning is a learning process. In fact, the entire purpose of benchmarking is to learn. There is a tendency to want to call several organizations immediately and schedule visits. This activity is usually a waste of time. It is better first to use information in the public domain to focus the inquiry and to find appropriate benchmark partners.

There are three main types of benchmarking: internal, competitive, and process. In most large firms, similar activities are performed in different operating divisions. For example, Bell Labs trained engineers to copy the work and social habits of the best performers. Some of these habits were as simple as managing work in-baskets, accepting constructive criticism, and seeking help instead of wasting time. Engineers who went through the Bell Labs program boosted their productivity by ten percent in eight months.[4] Internal comparisons have several advantages. Data are easy to obtain because problems of confidentiality don't exist. Often, dialog with internal groups generates immediate improvement ideas or defines common problems that help to focus external inquiries.

Product competitors are an obvious choice to benchmark. Any organization's survival depends on its performance relative to the competition. In most cases, products and processes are directly comparable. Some competitors do share information. For instance, mortgage bankers compare their product types, service fees, and interest rates on a weekly basis. On the other hand, some organizations would never knowingly share proprietary information. However, there are several ways to obtain data. Particularly good sources are information in the public domain and third parties. For instance, *Consumer Reports* in the U.S. evaluates the features of various products, *Economic Times* evaluates the financial performance of various stocks, and J.D. Powers evaluates automobile customer-satisfaction levels. Buying a competitor's product to take apart and test is another common practice. McKinsey partners with its customers to obtain information about competitors. The organization observes both its products and its competitor's products in use at the customer's location and collects comparative data.[5]

Process benchmarking is sometimes known as functional or generic benchmarking. The idea is that many processes are common across industry boundaries, and innovations from other types of organizations can be applied across industries. For example, every industry has payroll and accounts receivable functions. All kinds of organizations design new products and have logistics functions. A classic example of this type of benchmarking is the case of Southwest Airlines. When Southwest was unhappy with the airplane turnaround time, it benchmarked auto-racing pit crews and implemented many new ideas. Likewise, Motorola looked to Domino's Pizza and Federal Express for the best ways to speed up delivery systems. Another example of process benchmarking is when Remington Rifle Co. used Maybelline cosmetics' shiny lipstick cartridge production process techniques to produce shinier rifle shells.[6]

Process benchmarking has several advantages. Compared with competitive benchmarking, it is much easier to get organizations to share information. It is relatively easy to find organizations with world-class operations through published information and through discussions with suppliers and consultants who specialize in the field. However, care must be taken to pick firms that are comparable. Often data must be adjusted to arrive at a meaningful metric.

Many excellent techniques are available to assist in setting project timetables. These range from simple Gant charts to project evaluation and review technique (PERT). Excellent discussions of these methods can be found in management texts. Relatively inexpensive personal computer software that automates these techniques is also widely available.

Identifying the best firms to find a benchmark is a research project. There is no pre-existing magic list of best-in-class companies. In fact, "best-in-class" depends on the organization's needs. Find organizations that are the

[4] Bogan.

[5] "Beyond Benchmarking," *European Quality* (October 1993).

[6] Bogan.

World Class
Country-wide
Industry-wide
Competitor
Internally

Figure 7-3 Hierarchy of Best Practices

best performers relative to the defined measures established by using the critical success factors. Identify a large number of possible candidates and reduce the list to come up with a short list for further research. Best practices can be found internally, in a competitor, in the industry, in another organization in the country, or in a global organization. A hierarchy of sources is given in Figure 7-3.

The search starts with publicly-available information, such as that in trade journals and on the Internet. Magazines are published for industries, occupations, and functions, from accounting to zookeeping. These feature success story articles, technical information, and regular lists of top-performing organizations. Often they are published by associations whose members and officers are additional sources. There are numerous benchmarking databases, such as the India Business Insight Database (IBID) covering over 40 industrial domains in India. There is a nominal fee for searches, and data can be sorted by industry type or question.

Using public sources of information requires a grasp of key process metrics. Researchers should look for numbers and ratios to find industry best practices. Many sources of financial information are available in the public domain. Annual reports and Securities and Exchange Commission filings can be accessed through business libraries and online services. Standard ratios are available for all publicly-traded organizations in the respective countries as well as the foreign countries. If the benchmarking team includes a skilled financial person, he or she should be able to derive additional measures from published information.

Government agencies also compile large quantities of industry information. This data can be acquired through government publications and by talking directly to government experts. Finally, business contacts, including suppliers, consultants, customers, and people within the organization, can be a gold mine of information. Often a benchmarker is referred to someone else for additional information. It is frequently worth the effort to follow these leads.

The planning process should result in a "short list" of possible benchmark partners. The scope of the study and the type of benchmarking may require examination of several outside organizations. When a process is broken into sub-processes, it is common to discover that a single organization is not best-in-class for all sub-processes. In these cases, studying multiple organizations ensures that the best practices are discovered.

Studying Others

Benchmarking studies look for two types of information: a description of how best-in-class processes are practiced and the measurable results of these practices. In seeking this information, benchmarkers can use internal sources, data in the public domain, original research, or—most likely—a combination of sources. Considerations include the cost and time involved in gathering data and the need for appropriate data quality and accuracy.

When most people think of benchmarking, they generally think of conducting original research through site visits and interviews. This is not always necessary, and some organizations find industrial tourism a waste of time. Needed information that is easier and faster to obtain may be available internally or publicly. In any case, internal and public sources should have been examined during the planning process, so benchmarkers will have a good idea as to what additional information should be collected.

Three techniques for conducting original research are questionnaires, site visits, and focus groups. Questionnaires are particularly useful to ensure respondent anonymity and confidentiality, when data are desired from many external organizations, and when using a third party to collect information. Respondents can be surveyed by mail, by telephone, or in person. Additionally, questionnaires can be developed as preparation for a site visit, as a checklist during a site visit, or as a follow-up device. As with any survey, careful design and interpretation are essential, especially when questionnaires are administered by mail or phone.

Site visits provide the opportunity to see processes in action and for face-to-face contact with best-in-class operators. Site visits usually involve a tour of the operation or plant followed by a discussion period. Because personnel of both the visiting and the host organizations devote time, it is important to prepare properly for the visit. Laying the groundwork starts with the initial contact, which should establish a basis of mutual learning and information sharing as well as rapport. The initial contact can be made through marketing representatives if a supplier/customer relationship exists, through occupational or trade groups, or simply by one professional calling another. Before visiting, the parties should agree on an itinerary so that needed staff and information will be available. As mentioned previously, internal operations should be fully understood before the visit, and relevant publicly-available information should have been acquired. As soon as possible following the trip, the visiting team should hold a debriefing to document the findings and determine follow-up activities.

Focus groups are simply panels of benchmarking partners brought together to discuss areas of mutual interest. Most often the panels are comprised of people who have some previous joint benchmarking activity. Alternatively, panels can be comprised of customers, suppliers, or members of a professional organization such as the American Society for Quality (ASQ), the Federation of Indian Chamber of Commerce and Industry (FICCI) and the Confederation of Indian Industries (CII) etc.

Learning from the Data

Learning from the data collected in a benchmarking study involves answering a series of questions:

Is there a gap between the organization's performance and the performance of the best-in-class organizations?

What is the gap? How much is it?

Why is there a gap? What does the best-in-class do differently that is better?

If best-in-class practices were adopted, what would be the resulting improvement?

Benchmarking studies can reveal three different outcomes. External processes may be significantly better than internal processes (a negative gap). Process performance may be approximately equal (parity). Or the internal process may be better than that found in external organizations (positive gap). Negative gaps call for a major improvement effort. Parity requires further investigation to determine if improvement opportunities exist. It may be that when the process is broken down into sub-processes, some aspects are superior and represent significant improvement opportunities. Finally, the finding of a positive gap should result in recognition for the internal process.

There are at least two ways to prove that one practice is superior to another. If the processes being compared are clearly understood and adequate performance measures are available, the practices can be analyzed quantitatively. Summary measures and ratios, such as activity costs, return on assets, defect rates, or customer satisfaction levels, can be calculated and compared. It is fairly simple to determine superior practices, as the numbers speak for themselves, provided relevant measures are used.

A second way to prove superiority is through market analysis. Consumers of products and services vote with their checkbooks. Does the market prefer one process over others? If so, it can be judged superior. How many more customers would we have if we delivered in 24 hours instead of five days? Another way to use market analysis is to price outside services. If we had excess capacity, could we sell this service to others? For how much? What do suppliers charge for this process?

Identifiable benchmark gaps must be described and quantified. By definition, processes have inputs, activities, and outputs. Processes determined to be superior should be described using words and graphics to the level of detail necessary so that each step can be understood and emulated. The level of detail must be sufficient to allow eventual quantification. Describing best-in-class processes in appropriate detail is the primary way to determine why there is a gap and how to close it.

Once best-in-class practices are described and understood, key process measures should be quantified. The objective is to determine in summary form the overall effect on the internal operation of adapting the best-in-class practices. In other words, what is the size of the gap and what are the appropriate benchmark metrics and objectives?

Any summary measures are likely to be synthetic or derived rather than directly measured from external processes. One reason is that when a process is broken down to its component steps, a single external operation may not be the best in all sub-processes. Numbers may come from several organizations and then be combined to arrive at a combined best-in-class projection. Second, even if a single best-in-class benchmark exists, there will almost certainly be enough situational differences to require adjustments in the measures. These include differences in industry, operation size and scale, geographic reach, and required outputs. In many cases, it is appropriate that metrics be expressed as ranges rather than single point numbers.

When best-in-class processes have been described and quantified, additional analysis is necessary to determine the root causes of the gaps. Gaps are a result of process practices themselves, general business practices, and the organizational and operational structure. Given enough time, anything can be changed. However, some judgment is needed to determine what can be done in the relevant planning period to arrive at an appropriate benchmark goal or objective.

Process practices are the methods that make up the process itself. An example is a customer-fulfillment process that consists of receiving an order, selecting it from the warehouse, packing the order, shipping it, billing it, collecting payment, and updating the customer record for each transaction. Of course, each of these sub-processes may consist of multiple steps. Business practices are more general in nature and may apply to many or all of the organization's processes. These include personnel policy and procedures, accounting practices, and measurement and reward systems. Organizational and operational structure has to do with the location of activities, the organization chart, separation of responsibilities, and information system capabilities. Process practices are generally the easiest to change. Changing general business practices and organizational and operational structure will often be long-term projects and will almost certainly affect other processes. However, objective information developed through benchmarking studies can offer compelling reasons to make changes.

Using the Findings

When a benchmarking study reveals a negative gap in performance, the objective is to change the process to close the gap. Benchmarking is a waste of time if change does not occur as a result. To effect change, the findings must be communicated to the people within the organization who can enable improvement. The findings must translate to goals and objectives, and action plans must be developed to implement new processes.

Two groups must agree on the change. The first group consists of the people who will run the process, the process owners. The second group consists of the people, usually upper management, who can enable the process by incorporating changes into the planning process and providing the necessary resources. Process owners may be inclined to disbelieve or discount the findings, particularly if the gap is large. Therefore, it is important to completely describe how the results were obtained from the external organizations studied. Of course, current practices can't generate best-in-class results, but changing the process can.

Process changes are likely to affect upstream and downstream operations as well as suppliers and customers. Therefore, senior management has to know the basis for and payoff of new goals and objectives in order to support the change. As discussed in the previous section, changes in business practices and in organizational and operational structure may be indicated. These changes have to be considered and incorporated into the strategic planning process.

Because findings are objective, the benchmarking process helps make the case to both groups. The effect of change can be predicted quantitatively and the process fully described.

When acceptance is gained, new goals and objectives are set based on the benchmark findings. Exactly how this happens depends on the individual organization's planning process. The generic steps for the development and execution of action plans are:

1. Specify tasks.
2. Sequence tasks.
3. Determine resource needs.
4. Establish task schedule.
5. Assign responsibility for each task.
6. Describe expected results.
7. Specify methods for monitoring results.

Goals and objectives should be consistent with the execution of the action plan so that the end result is process superiority. The best results are obtained when process owners fully participate in the design and execution of the plan.

The next step is to repeat the benchmarking process. Benchmarking is a continuous improvement tool. It is not to be done once to create one permanent improvement and thereby miss the opportunity for future improvements. In order to avoid complacency, benchmarking must be used continuously to pursue emerging new ideas.

Pitfalls and Criticisms of Benchmarking

The basic idea of benchmarking can be summed up quite simply. Find someone who executes a process better than you do and imitate what he or she does. The most persistent criticism of benchmarking comes from the idea of copying others. How can an organization be truly superior if it does not innovate to get ahead of competitors? It is a good question, but one can also ask the reverse: How can an organization even survive if it loses track of its external environment?

Benchmarking is not a panacea. It is not a strategy, nor is it intended to be a business philosophy. It is an improvement tool. To be effective, it must be used properly. Benchmarking isn't very helpful if it is used for processes that don't offer much opportunity for improvement. It breaks down if process owners and managers feel threatened or do not accept and act on the findings. Over time, things change, and what was state-of-the-art yesterday may not be today. Some processes may have to be benchmarked repeatedly.

Benchmarking is also not a substitute for innovation; however, it is a source of ideas from outside the organization. Business success depends on setting and achieving goals and objectives. Benchmarking forces an organization to set goals and objectives based on external reality. Consumers don't care if a process achieved a 20% year-to-year productivity gain. They care about quality, cost, and delivery, and they vote with their checkbooks for the superior organization.

TQM Exemplary Organization[7]

The Centre for the Development of Advanced Computing (C-DAC), Pune based center catapulted India to a supercomputing power. A young and a highly charged team of scientists and technocrats with an average age of 23 or so battled numerous odds including a blockade of critical components from the overseas countries through the late-1980s and the 1990s to craft Param, India's first supercomputer, many versions of which followed later.

The C-DAC Director, Vijay Bhatkar, and his team's journey in building the Param–a gigaflop range machine—was seeded in 1987, when India was denied the latest technology Cray supercomputer. The then Indian Prime Minister Rajiv Gandhi posed a challenge to the Indian technocrats, "Can you build a supercomputer?" At that time, only supercomputer applications were in the public domain; very little on its architecture was available. However, Bhatkar, after meeting the PM and the other top government officials without hesitation agreed to undertake the mission to be completed in three years with a budget of Rs 340 million. Three years, because that was the time it took to import a supercomputer then and Rs 340 million, because it was the prevailing price of the machine! *The Mission thus, started with the benchmark.*

The C-DAC with its open and non-hierarchical approach attracted the best of talent from across the country. It followed very un-conventional management style and an open organization structure, which was new at that time. The engineers and design experts Bhatkar quit permanent jobs to be on contract for three years. In fact, the first set of 20 people worked without pay for six months due to procedural delays in receiving the government funds.

CDAC decided to adopt the new concept of Parallel Processing architecture, basically an ensemble of processors to undertake a supercomputing task. The team had to source some critical components and route them through different countries to India.

Within two years after the mission started, a prototype of Param was ready, but none in India was willing to believe that it was indeed, a true blue supercomputer. Therefore, Bhatkar took a strategic decision to benchmark his machine at the 1990 Zurich supercomputing show, in which the U.S., Japan, Germany, Russia and an Anglo-French consortium were to participate. At the show, it beat Japan, Germany and Russia. It landed second in competition, only next to the U.S. Subsequently, its brilliance prompted, even countries like Russia to purchase the Indian Param. The success heralded the emergence of India as a supercomputer power.

Param's key applications are used in several significant programs in the country such as weather forecasting, remote sensing, molecular modeling and drug design.[8]

Summary

The organizations which have intentions to grow and perform well should measure themselves against the best industry practices. Benchmarking provides a systematic approach to achieve this purpose. It primarily contains two elements, first, doing comparative performance measure on the basis of well-established metrics and second, understanding why their own performance differs from the targeted values.

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7 Malcolm Baldrige National Quality Award, 2000 Manufacturing Category Award Recipient, NIST/Baldrige Homepage, Internet.

8 Naren Karunakaran, "God, Man and Machine", *Outlook*, 15 May 2009.

Benchmarking can be adapted to any business or production process. The organization must indentify critical processes or business measures, which it wants to benchmark and at the end achieve it. Several techniques are available to carry out the benchmark studies. Organizations must ensure that business ethics are maintained in obtaining such data and should avoid copying the processes blindly.

Exercises

1. Efficiency has been defined as "doing things better" and effectiveness as "doing better things." Describe how benchmarking can be used to improve both efficiency and effectiveness.
2. Explain how an organization might benefit from benchmarking organizations in a completely different industry.
3. Identify and explain the three main types of benchmarking. In what circumstances would each type be most appropriate?
4. What difficulties are typically encountered when benchmarking direct competitors? Describe several ways to work around these problems.
5. What are the advantages to using benchmarking as an improvement tool? What are the disadvantages?
6. What is a critical success factor? How is it important in benchmarking?
7. What is a metric? How are metrics used?
8. What three different outcomes can benchmarking studies reveal? What course of action is appropriate for each outcome?
9. Benchmarking studies are a search for two types of information—an understanding of best-in-class processes and the metrics that result. In your opinion, which piece of information is more important? Why?
10. Describe two ways to determine a superior process.
11. Describe several methods for conducting a benchmarking study. What are some of the considerations in choosing the method(s)?
12. Why is it important to understand internal processes before studying those of other organizations? What tools are useful in examining internal processes?
13. Which process should be selected for benchmarking?

    (a) where we have most problems
    (b) where we have good performance
    (c) process strategic to our business
    (d) most complex process

14. Which of the following is most common criticism of benchmarking?

    (a) in benchmarking, we are copying others
    (b) benchmarking is an expensive process
    (c) benchmarking exists in theory but cannot be practiced
    (d) benchmarking requires commitment of top management

15. Arrange the following steps for benchmarking in correct order:

    1. plan
    2. decide what to benchmark
    3. study others
    4. understand current performance
    5. use the findings
    6. learn from data

    (a) 4, 2, 1, 3, 6, 5
    (b) 2, 1, 4, 6, 3, 5
    (c) 1, 2, 3, 4, 5, 6
    (d) 2, 4, 1, 3, 6, 5

16. State True or False

    1. benchmarking involves development of in-depth knowledge of one's own processes and processes of the best in class organizations
    2. benchmarking cannot be applied to special processes
    3. positive gaps in benchmarking outcomes call for major improvement efforts

    (a) 1-True, 2-True, 3-False
    (b) 1-True, 2-False, 3-False
    (c) 1-True, 2-False, 3-True
    (d) 1-False, 2-False, 3-True

8

Quality Management Systems

Chapter Objectives

- Understanding the ISO 9000 series of standards, namely, ISO 9000, ISO 9001 and ISO 9004
- Brief overview of sector specific standards, namely, AS 9100, ISO/TC 16946 and TL 9000
- Understanding the ISO 9001 requirements
- Overview of ISO 9001 implementation
- Detailed analysis of registration requirements

Introduction

The International Organization for Standardization (ISO) was founded in 1946 in Geneva, Switzerland, where it is still based. Its mandate is to promote the development of international standards to facilitate the exchange of goods and services worldwide. ISO is composed of more than 90 member countries. The United States representative is the American National Standards Institute (ANSI).

The ISO Technical Committee (TC) 176 developed a series of international standards for quality systems, which were first published in 1987. The standards (ISO 9000, 9001, and 9004) were intended to be advisory and were developed for use in two-party contractual situations and internal auditing. However, with their adoption by the European Community (EC) and a worldwide emphasis on quality and economic competitiveness, the standards have become universally accepted.

The fourth edition of ISO 9001 was released in the year 2008 and it replaces the third edition (ISO 9001:2000), which had been amended to clarify the points in the text and also to enhance the compatibility with ISO 14001:2004.

Most countries have adopted the ISO 9000 series as their national standards. Likewise, thousands of organizations throughout the world have quality systems registered to the standard. In the United States, the national standards are published by the American National Institute/American Society for Quality (ANSI/ASQ) as the ANSI/ASQ Q9000 series. Government bodies throughout the world, including the United States, are also using the standards. U.S. government agencies using the series are the Department of Defense (DOD) and the Food and Drug Administration (FDA).

In India, Bureau of Indian Standards (BIS) adopts ISO certification standards under the dual numbering scheme.

In a two-party system, the supplier of a product or service would develop a quality system that conformed to the standards. The customers would then audit the system for acceptability. This two-party system results in both the supplier and customer having to participate in multiple audits, which can be extremely costly. This practice is replaced by a third-party registration system.

A quality system registration involves the assessment and periodic surveillance audit of the adequacy of a supplier's quality system by a third party, who is a registrar. When a system conforms to the registrar's interpretation of the standard, the registrar issues a certificate of registration to the supplier. This registration ensures customers or potential customers that a supplier has a quality system in place and it is being monitored.

Benefits of ISO Registration

There are various reasons for implementing a quality system that conforms to an ISO standard. The primary reason is that customers or marketing are suggesting or demanding compliance to a quality system. Other reasons are needed improvement in processes or systems and a desire for global deployment of products and services.[1] As more and more organizations become registered, they are requiring their subcontractors or suppliers to be registered, creating a snowball effect. Consequently, in order to maintain or increase market share, many organizations are finding they must be in conformance with an ISO standard. Internal benefits that can be received from developing and implementing a well-documented quality system can far outweigh the external pressures.

A study of 100 Italian manufacturing firms was undertaken to determine if there was any improvement in performance after registration. Significant improvement was noted in:

Internal quality as measured by the percent of scrap, rework, and nonconformities at final inspection.

Production reliability as measured by the number of breakdowns per month, percent of time dedicated to emergencies, and percent of downtime per shift.

External quality as measured by product accepted by customers without inspection, claims of nonconforming product, and returned product.

Time performance as measured by time to market, on-time delivery, and throughput time.

Cost of poor quality as measured by external nonconformities, scrap, and rework.

On the negative side, prevention and appraisal costs increased.[2]

Additional examples of benefits after registration are:

The American Institute of Certified Public Accountants (AICPA) now has a quality system that works, and there was a 4% improvement in gross margins, which was the largest improvement in their history.[3]

ISO 9000 Series of Standards

The ISO 9000 Series of Standards is generic in scope. By design, the series can be tailored to fit any organization's needs, whether it is large or small, a manufacturer or a service organization. It can be applied to

[1] F. C. Weston, Jr., "What Do Managers Really Think of the ISO 9000 Registration Process?" *Quality Progress* (October 1995): 67–73.

[2] Pietro Romano, "ISO 9000: What Is Its Impact On Performance?" *Quality Management Journal* (Vol. 7, No. 3, 2000): 38–55.

[3] Norman Ho, "ISO 9000: No Longer a Stranger to Service," *Quality Digest* (June 1999): 33–36.

construction, engineering, health care, legal, and other professional services as well as the manufacturing of anything from nuts and bolts to spacecraft. Its purpose is to unify quality terms and definitions used by industrialized nations and use those terms to demonstrate a supplier's capability of controlling its processes. In very simplified terms, the standards require an organization to say what it is doing to ensure quality, then do what it says, and, finally, document or prove that it has done what it said.

The three standards of the series are described briefly in the following paragraphs:

ISO 9000:2005—Quality Management Systems (QMS)—fundamentals and vocabulary discusses the fundamental concepts related to the QMS and provides the terminology used in the other two standards.

ISO 9001:2008—Quality Management Systems (QMS)—requirements is the standard used for registration by demonstrating conformity of the QMS to customers, regulatory, and the organization's own requirements.

ISO 9004:2000—Quality Management Systems (QMS)—guidelines for performance improvement provides guidelines that an organization can use to establish a QMS focused on improving performance.

Sector-specific Standards

The ISO 9000 system is designed as a simple system that could be used by any industry. Other systems have been developed that are specific to a particular industry such as automotive or aerospace. These systems use the ISO 9001 as the basic framework and modify it to their needs. There are currently three other quality systems: AS9100, ISO/TS 16949, and TL 9000.

One of the problems with sector-specific standards is the need for suppliers with customers in different industries to set up quality systems to meet each sector's requirements. For example, a packaging supplier that services the aerospace, automobile, and telecommunications industries would need to set up its system to accommodate not only ISO 9001 but three other standards. In addition, the Registration Accreditation Board (RAB) points out that sector-specific standards have created a need for specialized auditors and training courses. On the positive side, the standardization of requirements beyond ISO 9001 makes compliance by key suppliers and implementation by major customers much easier.[4]

AS9100

This aerospace industry quality system was officially released by the Society of Automotive Engineers in May 1997. Its development and release represents the first attempt to unify the requirements of NASA, DOD, and FAA, while satisfying the aerospace industry's business needs. In March 2001, the International Aerospace Quality Group (IAQG) aligned AS9100 with ISO 9001:2000. Industry-specific interpretations and methodologies are identified in italics and bold type. These additions are accepted aerospace approaches to quality practices and general requirements. Aerospace organizations in Europe, Japan, and the U.S. will certify registrars and auditors.[5]

AS 9100 Revision C is released in January 2009.

ISO/TS 16949

This standard is entitled *Quality Systems Automotive Suppliers—Particular Requirements for the Application of ISO 9001*. It harmonizes the supplier quality requirements of the U.S. big three as provided in QS 9000

[4] Leslie Norris, "The Pros and Cons of Sector-Specific Standards," *Quality Progress* (April 1999): 92–3.

[5] Dale K. Gordon, "What the Aerospace Sector is Doing," *Quality Progress* (August 2001): 80

Third Edition[6] with the French, German and Italian automakers. The standard has been approved by Asian automakers. The goal of this technical specification is the development of fundamental quality systems that provide for continuous improvement, emphasizing defect prevention, and the reduction of variation and waste in the supply chain. There are three basic levels: (1) ISO 9001, (2) sector-specific requirements, and (3) company-specific requirements, and if appropriate levels for division-specific, commodity-specific, and part-specific requirements. Registrars will need to be certified to the standard and their number will be limited.

It is assumed that this standard will show the same rate of improvement as QS 9000. GM reported that supplier parts-per-million defect rate improved about 85% for the first five years of the use of QS 9000.[7]

TL 9000

The Quality Excellence for Suppliers of Telecommunications Forum (QuEST) wrote TL 9000 to consolidate the various quality system requirements within the telecommunications industry. This forum was created to develop the standard wherein suppliers such as Motorola and Lucent, and telecom service providers such as Verizon, Southwestern Bell, and AT&T would have an equal vote in developing the new strategy. It is a specific set of requirements based on ISO 9001 that defines the design, development, production, delivery, installation, and maintenance of telecommunications products and services. Customers and suppliers receive a number of benefits including continuous improvement, enhanced customer/supplier relationships, efficient management of external audits, worldwide standards, increased competitiveness which results in overall cost reduction, industry benchmarks for performance metrics, and a platform for improvement initiatives.

Figure 8-1 shows the structure of the TL 9000 standard and its five layers. The first layer is the ISO 9000 requirements. It is followed by Book 1, called *TL9000 Quality System Requirements (QSR),* which establishes a common set of requirements applicable to hardware, software, and services. The second layer of Book 1 provides specific requirements for hardware, software, and services. In the first layer of Book 2, called *Quality System Measurements (QSM),* the common industry measurements such as billing errors are specified. In the last layer the specific measurements for hardware, software, and services are defined.

The unique feature of the standard is the use of the metrics specified in the QSM book to communicate and monitor actual results. Cost and performance-based metrics provides information to enable the industry to measure progress and evaluate results of quality system implementation. The University of Texas at Dallas (UTD) will administer the QSM. Participants will report specially coded metrics information to UTD, which stores and analyzes the data. Descriptive statistics such as mean, range, median, standard deviation, and best

ISO 9001 Requirements		
Common TL 9000 Requirements (QSR)—Book 1		
Hardware Specific Requirements	Software Specific Requirements	Services Specific Requirements
Common TL 9000 Measurements (QSM)—Book 2		
Hardware Specific Measurements	Software Specific Measurements	Services Specific Measurements

Figure 8-1 Structure of the TL 9000 Requirements

[6] This standard, which was developed in 1994 by Chrysler, Ford, and General Motors, was not updated to reflect the ISO 9001:2000 standard and, therefore, is obsolete.

[7] Susan E. Daniels, "Management System Standards Poised for Momentum Boost," *Quality Progress* (March 2000): 31–39.

in industry is calculated. This information is available to the over 200 forum members on the forum's website. A supplier's identity remains anonymous at all times. Each organization can benchmark its performance against the industry standard and determine which of their processes need improvement—thereby improving customer-supplier relations.[8]

ISO 9001 Requirements[9]

The standard has eight clauses: Scope, Normative References, Definitions, Quality Management Systems, Management Responsibility, Resource Management, Product and/or Service Realization, and Measurement, Analysis, and Improvement. The first three clauses are for information while the last five are requirements that an organization must meet. The numbering system used in the standard is followed in this section.

The application of a system of processes within an organization, together with their identification and interactions and the managing of these processes, is referred to as the process approach. This approach emphasizes the importance of:

- Understanding and fulfilling the requirements.
- The need to consider processes in terms of value added.
- Obtaining results of process performance and effectiveness.
- Continual improvement of processes based on objective measure.

For the five required clauses, the system is shown in Figure 8-2.

1. Scope

The purpose of the standard is for the organization to demonstrate its ability to provide a product[10] that meets customer and regulatory requirements and to enhance customer satisfaction. This purpose is accomplished

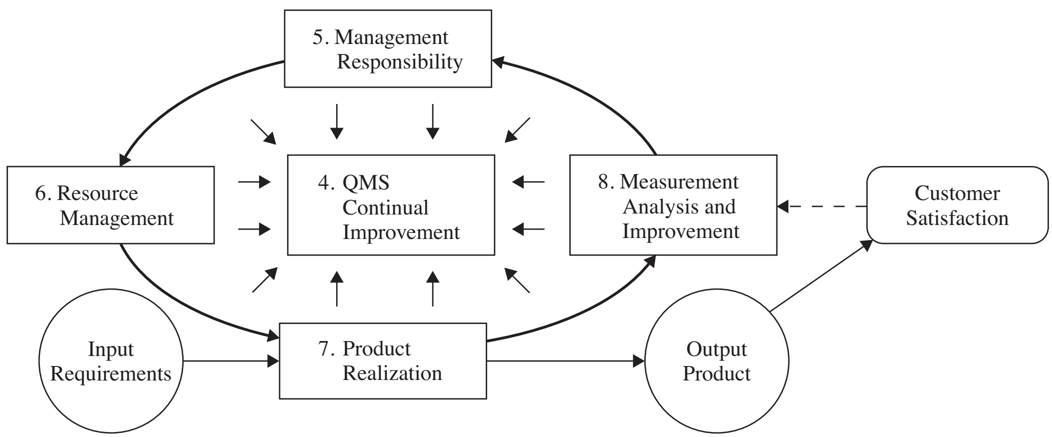

Figure 8-2 Model of a Process-Based Quality Management System

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[8] Eugene E. Hutchison, "The Road to TL 9000: From the Bell Breakup to Today," *Quality Progress* (June 2001): 33–37.

[9] Adapted, with permission, from *Quality Management Systems—Requirements,* ANSI/ISO/ASQ Q9001: 2000, © 2000 ASQ Quality Press. (Milwaukee, WI: ASQ 2000).

[10] The standard defines product as including both product and service.

by evaluating and continually improving the system, rather than the product. The requirements of the standard are intended to be applicable to all types and sizes of organizations. Requirements in Clause 7, Product Realization, that are not appropriate to the organization, can be excluded.

2. Normative Reference

ISO 9000:2005 *Quality Management Systems—Fundamentals and vocabulary* are a normative reference that provides applicable concepts and definitions.

3. Terms and Definitions

For the purposes of this standard, the terms and definitions given in ISO 9000:2000 apply. Throughout the text of this standard, the term "Product" also means "Service."

4. Quality Management System (QMS)

4.1 GENERAL REQUIREMENTS

The organization shall establish, document, implement, and maintain a QMS and continually improve its effectiveness. The organization shall (a) determine the processes needed for QMS and their applications throughout the organization, (b) determine their sequence and interaction, (c) determine criteria and methods for effective operation and control of these processes, (d) ensure the availability of resources and information necessary to support and monitor these processes, (e) monitor, measure wherever applicable, and analyze these processes, and (f) implement actions to achieve planned results and continual improvement of these processes. Outsourced processes that affect the quality of the product shall be identified and included in the system.

4.2 DOCUMENTATION

4.2.1 General Documentation shall include (a) statements of a quality policy and quality objectives, (b) a quality manual, (c) required documented procedures and records, (d) needed documents to ensure effective planning, operation, and control of processes, and records. A procedure or work instruction is needed if its absence could adversely affect the product quality. The extent of the documentation will depend on the organization's size and type of activities; the complexity of the processes and their interactions; and the competency of the employees. For example: a small organization may verbally notify a manager of an upcoming meeting, whereas a large organization would need written notification. The standard should satisfy the contractual, statutory, and regulatory requirements and the needs and expectations of customers and other interested parties. Documentation may be in any form or type of medium.

4.2.2 Quality Manual A quality manual shall be established and maintained that includes (a) the scope of the QMS with details and justification for any exclusions, (b) the documented procedures or reference to them, and (c) a description of the interaction among the QMS processes.

4.2.3 Control of Documents Documents required by the QMS shall be controlled. Records are special type of documents. A documented procedure shall be in place to define the controls needed to (a) approve documents prior to use, (b) review, update, and re-approve as necessary, (c) identify the current revision status, (d) ensure that current versions are available at the point of use, (e) ensure that documents are legible and readily identified, (f) identify and distribute documents of external origin, and (g) provide for the prompt removal of obsolete documents and suitably identify any that may be retained. Documented procedure means that the procedure is established, documented, implemented, and maintained. They are required in elements 4.2.3, 4.2.4, 8.2.2, 8.3, 8.5.2, and 8.5.3.

4.2.4 Control of Records Records which are established to provide evidence of conformity to requirements and the effective operation of QMS shall be controlled. A documented procedure shall be established to define the controls needed for the identification, storage, protection, retrieval, retention and disposition of records. Records shall remain legible, readily identifiable and retrievable. Records can be used to document traceability and to provide evidence of verification, preventive action, and corrective action. They are required in elements 5.5.6, 5.6.3, 6.2.2, 7.2.2, 7.3.4, 7.3.6, 7.3.7, 7.4.1, 7.5.2, 7.6, and 8.2.4.

5. Management Responsibility

5.1 MANAGEMENT COMMITMENT

Top management shall provide evidence of its commitment to the development, implementation, and continual improvement of the QMS by (a) communicating the need to meet customer, legal, and regulatory requirements, (b) establishing a quality policy, (c) ensuring that quality objectives are established, (d) conducting management reviews, and (e) ensuring the availability of resources. Top management is defined as the person or group of people who directs and controls an organization.

5.2 CUSTOMER FOCUS

Top management shall ensure that customer requirements are determined and met with the aim of enhancing customer satisfaction.

5.3 QUALITY POLICY

Top management shall insure that the quality policy (a) is appropriate to the organization's purpose or mission, (b) includes a commitment to comply with requirements and continually improve the effectiveness of the QMS, (c) provides a framework for establishing and reviewing the quality objectives, (d) is communicated and understood within the organization, and (e) is reviewed for continuing stability. The quality policy gives the overall intention and direction of the organization related to quality.

5.4 PLANNING

5.4.1 Quality Objectives Top management shall ensure that quality objectives are established at relevant functions and levels within the organization and include product requirements. They shall be measurable and consistent with the quality policy. In addition, they should ensure that customer expectations are met. Quality objectives are something sought or aimed for related to quality. For example, finishing department scrap will be reduced from 5.0% to 4.3% and the first line supervisor is the person responsible.

5.4.2 Quality Management System Planning Top management shall ensure that the planning of the QMS is accomplished in order to meet the requirements of the QMS as stated in the General Requirements, Element 4.1, as well as the Quality Objectives, 5.4.1. In addition, the integrity of the QMS is maintained when changes are planned and implemented.

5.5 RESPONSIBILITY, AUTHORITY, AND COMMUNICATION

5.5.1 Responsibility and Authority Top management shall ensure that responsibilities and authorities are defined and communicated within the organization. Responsibilities can be defined in job descriptions, procedures, and work instructions. Authorities and interrelationships can be defined in an organization chart.

5.5.2 Management Representative Top management shall appoint a member of organization's management, regardless of his/her other duties, that shall have the responsibility and authority that includes (a) ensuring that processes needed for the QMS system are established, implemented, and maintained, (b) reporting to top management on the performance of the QMS and any need for improvement, and (c) ensuring the promotion of awareness of customer requirements throughout the organization. Appointment of a member of top management as the representative can contribute to the effectiveness of the QMS.

5.5.3 Internal Communication Top management shall ensure that appropriate communication channels are established within the organization and that communication takes place regarding the QMS. Typical communication techniques are management workplace briefing, recognition of achievement, bulletin boards, e-mail, and in-house news brochures.

5.6 MANAGEMENT REVIEW

5.6.1 General Top management shall review the QMS at planned intervals to ensure its continuing suitability, adequacy, and effectiveness. This review shall include assessing opportunities for improvement and the need for changes to the QMS including the quality policy and quality objectives. Records from the reviews shall be maintained.

5.6.2 Review Input The input to the review shall include information on (a) results of audits, (b) customer feedback, (c) process performance and product conformity, (d) status of corrective and preventative performance, (e) follow-up actions from previous management reviews, (f) changes that could affect the QMS, and (g) recommendations for improvement.

5.6.3 Review Output The output from the review shall include any decisions and actions related to (a) improvement of the effectiveness of the QMS and its processes, (b) improvement of the product related to customer requirements, and (c) resource needs. Top management can use the outputs as inputs to improvement opportunities.

6. Resource Management

6.1 PROVISION OF RESOURCES

The organization shall determine and provide the resources needed (a) to implement and maintain the QMS and continually improve its effectiveness, and (b) to enhance customer satisfaction by meeting customer requirements. Resources may be people, infrastructure, work environment, information, suppliers, natural resources, and financial resources. Resources can be aligned with quality objectives.

6.2 HUMAN RESOURCES

6.2.1 General Personnel performing work that affects conformity to product requirements shall be competent on the basis of appropriate education, training, skills, and experience.

Conformity to product requirements can be affected directly or indirectly by personnel performing any task within the QMS.

6.2.2 Competence, Training, and Awareness The organization shall (a) determine the necessary competence for personnel performing work affecting conformity to product requirements, (b) where applicable, provide training or take other actions to achieve the necessary competence, (c) evaluate the effectiveness of the actions taken, (d) ensure that its personnel are aware of the relevance and importance of their activities and how they contribute to the achievement of the quality objectives, and (e) maintain appropriate records of education, training, skills, and experience. Competency is defined as the demonstrated ability to apply knowledge and skills. It can be contained in the job description by function, group, or specific position. Training effectiveness can be determined by before and after tests, performance, or turnover.[11] *ISO 10015 Guidelines for Training* will help organizations comply with this standard.

6.3 INFRASTRUCTURE

The organization shall determine, provide, and maintain the infrastructure needed to achieve conformity to product requirements. Infrastructure includes, as applicable (a) buildings, workspace, and associated utilities, (b) process equipment (both hardware and software), and (c) supporting services (such as transport, communication or information systems).

6.4 WORK ENVIRONMENT

The organization shall determine and manage the work environment needed to achieve conformity to product requirements. Creation of a suitable work environment can have a positive influence on employee motivation, satisfaction, and performance.

The term "work environment" relates to those conditions under which work is performed including physical, environmental and other factors (such as noise, temperature, humidity, lighting and weather).

7. Product Realization

7.1 PLANNING OF PRODUCT REALIZATION

The organization shall plan and develop the processes needed for product realization. Planning of product realization shall be consistent with the requirements of the other processes of QMS. In planning product realization, the organization shall determine the following, as appropriate: (a) quality objectives and requirements for the product; (b) the need to establish processes and documents, and to provide resources specific to the product; (c) required verification, validation, monitoring, measurement inspection, and test activities specific to the product and the criteria for product acceptance; and (d) records needed to provide evidence that the realization processes and resulting product or service meet requirements. The output of this planning shall be in a form suitable for the organization's method of operations. A document specifying the processes of the QMS (including the product realization processes) and the resources to be applied to a specific product, project or contract, can be referred to as a quality plan. The organization may also apply the requirements given in 7.3 to the development of the product realization processes.

7.2 CUSTOMER-RELATED PROCESSES

7.2.1 Determination of Requirements Related to the Product The organization shall determine (a) requirements specified by the customer, including the requirements for delivery and post-delivery activities, (b) requirements not stated by the customer but necessary for specified or intended use, where known, (c) statutory and

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[11] Jeanne Ketola and Kathy Roberts, "Demystify ISO 9001:2000," *Quality Progress* (September 2001): 65–70.

regulatory requirements applicable to the product, and (d) any additional requirements considered necessary by the organization.

Note : Post-delivery activities include, for example, actions under warranty provisions, contractual obligations such as maintenance services and supplementary services such as recycling or final disposal.

7.2.2 Review of Requirements Related to the Product The organization shall review the requirements related to the product. This review shall be conducted prior to the organization's commitment to supply a product to the customer (for example, submission of tenders, acceptance of contracts or orders, acceptance of changes to contracts or orders) and shall ensure that (a) product requirements are defined, (b) contract or order requirements differing from those previously expressed are resolved, and (c) the organization has the ability to meet the defined requirements. Records of the results of the review and actions arising from the review shall be maintained. Where the customer provides no documented statement of requirement, the customer requirements shall be confirmed by the organization before acceptance. Where product requirements are changed, the organization shall ensure that relevant documents are amended and that relevant personnel are made aware of the changed requirements. In some situations, such as Internet sales, a formal review is impractical for each order. Instead, the review can cover relevant product information such as catalogs or advertising material.

7.2.3 Customer Communication The organization shall determine and implement effective arrangements for communicating with customers in relation to (a) product information, (b) inquiries, contracts, or order handling, including amendments, and (c) customer feedback, including customer complaints.

7.3 DESIGN AND DEVELOPMENT

7.3.1 Design and Development Planning The organization shall plan and control the design and development of the product. During the design and development planning, the organization shall determine (a) the design and development stages, (b) the review, verification and validation that are appropriate to each design and development stage, and (c) the responsibilities and authorities for design and development. The organization shall manage the interfaces between different groups involved in design and development to ensure effective communication and clear assignment of responsibility. Planning output shall be updated, as appropriate, as the design and development progresses.

Design, development, review, verification and validation have district purposes. They can be conducted and recorded separately or in any combination as suitable for the product and the organization.

7.3.2 Design and Development Inputs Inputs relating to product requirements shall be determined and records maintained. These shall include (a) functional and performance requirements, (b) applicable statutory and regulatory requirements, (c) where applicable, information derived from previous similar designs, and (d) other requirements essential for design and development. The inputs shall be reviewed for adequacy. Requirements shall be complete, unambiguous and not in conflict with each other.

7.3.3 Design and Development Outputs The outputs of design and development shall be in a form suitable for verification against the design and development input and shall be approved prior to release. Design and development outputs shall (a) meet the input requirements for design and development, (b) provide appropriate information for purchasing, production, and service provision, (c) contain or reference product acceptance criteria, and (d) specify the characteristics of the product that are essential for its safe and proper use.

Note: Information for production and service provision can include details for the preservation of the product.

7.3.4 Design and Development Review At suitable stages, systematic reviews of design and development shall be performed in accordance with planned arrangements (a) to evaluate the ability of the results of design and development to meet requirements, and (b) to identify any problems and propose necessary actions. Participants in such reviews shall include representatives of functions concerned with the design and development stage(s) being reviewed. Records of the results of the reviews and any necessary actions shall be maintained. Risk assessment such as FMEA, reliability prediction, and simulation techniques can be undertaken to determine potential failures in products or processes.

7.3.5 Design and Development Verification Verification shall be performed in accordance with planned arrangements to ensure that the design and development outputs have met the design and development input requirements. Records of the results of the verification and any necessary actions shall be maintained. Verification confirms, through objective evidence, that the specified requirements have been fulfilled. Confirmation can comprise activities such as performing alternate calculations, comparing the new design specification to a similar proven design specification, undertaking tests and demonstrations, and reviewing documents prior to issue.

7.3.6 Design and Development Validation Design and development validation shall be performed in accordance with planned arrangements to ensure that the resulting product is capable of meeting the requirements for the specified application or intended use, when known. Wherever practicable, validation shall be completed prior to the delivery or implementation of the product. Records of the results of validation and any necessary actions shall be maintained. Validation confirms, through objective evidence, that the requirements for a specific intended use have been fulfilled.

7.3.7 Control of Design and Development Changes Design and development changes shall be identified and records maintained. The changes shall be reviewed, verified and validated, as appropriate, and approved before implementation. The review of design and development changes shall include evaluation of the effect of the changes on constituent parts and product already delivered. Records of the results of the review of changes and any necessary actions shall be maintained.

7.4 PURCHASING

7.4.1 Purchasing Process The organization shall ensure that purchased product conforms to specified purchase requirements. The type and extent of control applied to the supplier and the purchased product shall be dependent upon the effect of the purchased product on subsequent product realization or the final product. The organization shall evaluate and select suppliers based on their ability to supply product in accordance with the organization's requirements. Criteria for selection, evaluation, and re-evaluation shall be established. Records of the results of evaluations and any necessary actions arising from the evaluation shall be maintained. This standard does not apply to items such as office and maintenance supplies, unless they are a product.

7.4.2 Purchasing Information Purchasing information shall describe the product to be purchased, including where appropriate (a) requirements for approval of product, procedures, processes, and equipment, (b) requirements for qualification of personnel, and (c) QMS requirements. The organization shall ensure the adequacy of specified requirements prior to their communication to the supplier.

7.4.3 Verification of Purchased Product The organization shall establish and implement the inspection or other activities necessary for ensuring that purchased product meets specified purchase requirements. Where the organization or its customer intends to perform verification at the supplier's premises, the organization shall state the intended verification arrangements and method of product release in the purchasing information.

7.5 PRODUCTION AND SERVICE PROVISION

7.5.1 Control of Production and Service Provision The organization shall plan and carry out production and service provision under controlled conditions. Controlled conditions shall include, as applicable (a) the availability of information that describes the characteristics of the product, (b) the availability of work instructions, as necessary, (c) the use of suitable equipment, (d) the availability and use of monitoring and measuring equipment (e) the implementation of monitoring and measurement, and (f) the implementation of product release, delivery, and post-delivery activities.

7.5.2 Validation of Processes for Production and Service Provision The organization shall validate any processes for production and service provision where the resulting output cannot be verified by subsequent monitoring or measurement, and as a consequence, deficiencies become apparent only after the product is in use or the service has been delivered. Validation shall demonstrate the ability of these processes to achieve planned results. The organization shall establish arrangements for these processes including, as applicable (a) defined criteria for review and approval of the processes, (b) approval of equipment and qualification of personnel, (c) use of specific methods and procedures, (d) requirements for records, and (e) revalidation.

7.5.3 Identification and Traceability Where appropriate, the organization shall identify the product by suitable means throughout product realization. The organization shall identify the product status with respect to monitoring and measurement requirements throughout product realization. Where traceability is a requirement, the organization shall control and record the unique identification of the product and maintain records. In some industry sectors, configuration management is a means by which identification and traceability are maintained. Identification can frequently be accomplished with a production router or traveller.

7.5.4 Customer Property The organization shall exercise care with customer property while it is under the organization's control or being used by the organization. The organization shall identify, verify, protect and safeguard customer property provided for use or incorporation into the product. If any customer property is lost, damaged, or otherwise found to be unsuitable for use, the organization shall report this to the customer and maintain records. Customer property can include intellectual property and personal data.

*7.5.5 Preservation of Produc*t The organization shall preserve the product during internal processing and delivery to the intended destination in order to maintain conformity to the requirements. This preservation shall include identification, handling, packaging, storage, and protection. Preservation shall also apply to the constituent parts of a product.

7.6 CONTROL OF MONITORING AND MEASURING EQUIPMENT

The organization shall determine the monitoring and measurement to be undertaken and the monitoring and measuring equipment needed to provide evidence of conformity of product to determined requirements. The organization shall establish processes to ensure that monitoring and measurement can be carried out and are carried out in a manner that is consistent with the monitoring and measurement requirements. Where necessary to ensure valid results, measuring equipment shall (a) be calibrated or verified or both at specified intervals or prior to use, against measurement standards; where no such standards exist, the basis used for calibration or verification shall be recorded, (b) be adjusted or re-adjusted as necessary, (c) have identification in order to determine its calibration status (d) be safeguarded from adjustments that would invalidate the measurement result, and (e) be protected from damage and deterioration during handling, maintenance and storage. In addition, the organization shall assess and record the validity of the previous measuring results when the equipment is found not to conform to requirements. The organization shall take appropriate action on the equipment and any product affected. Records of the results of calibration and verification shall be maintained. When used in the monitoring and measurement of specified requirements, the ability of computer software to satisfy the intended application shall be confirmed. This shall be undertaken prior to initial use and reconfirmed as necessary. Confirmation of the ability of computer software to satisfy the intended application would typically include its verification and configuration management to maintain its suitability for use.

8. Measurement, Analysis, and Improvement

8.1 GENERAL

The organization shall plan and implement the monitoring, measurement, analysis, and improvement processes needed (a) to demonstrate conformity to product requirements (b) to ensure conformity of the QMS, and (c) to continually improve the effectiveness of the QMS. This shall include determination of applicable methods, including statistical techniques, and the extent of their use.

8.2 MONITORING AND MEASUREMENT

8.2.1 Customer Satisfaction As one of the measurements of the performance of the QMS, the organization shall monitor information relating to customer perception as to whether the organization has met customer requirements. The methods for obtaining and using this information shall be determined.

Monitoring customer perception can include inputs from sources such as customer satisfication surveys, customer data on delivered product quality, user opinion surveys, lost business analysis, compliments, warranty claims and dealer reports.

8.2.2 Internal Audit The organization shall conduct internal audits at planned intervals to determine whether the QMS (a) conforms to the planned arrangements (see 7.1), to the requirements of this standard, and to the requirements established by the organization, and (b) is effectively implemented and maintained. An audit program shall be planned, taking into consideration the status and importance of the processes and areas to be audited, as well as the results of previous audits. The audit criteria, scope, frequency, and methods shall be defined. The selection of auditors and conduct of audits shall ensure objectivity and impartiality of the audit process. Auditors shall not audit their own work. The responsibilities and requirements for planning and conducting audits and for reporting results and maintaining records shall be defined in a documented procedure. The management responsible for the area being audited shall ensure that any necessary corrections and corrective actions are taken without undue delay to eliminate detected nonconformities and their causes. Follow-up activities shall include the verification of the actions taken and the reporting of verification results. *ISO 19011 Guidelines on quality and/or environmental management auditing* can be used for guidance.

8.2.3 Monitoring and Measurement of Processes The organization shall apply suitable methods for monitoring and, where applicable, measurement of the QMS processes. These methods shall demonstrate the ability of the processes to achieve planned results. When planned results are not achieved, correction and corrective action shall be taken, as appropriate.

When determining suitable methods, it is adviseable that the organization considers the type and extent of monitoring or takes measures appropriate to each of its processes in relation to their impact on the conformity to product requirements and on the effectiveness of the quality management system.

8.2.4 Monitoring and Measurement of Product and Service The organization shall monitor and measure the characteristics of the product to verify that product requirements have been met. This shall be carried out at appropriate stages of the product realization process in accordance with the planned arrangements. Evidence of conformity with the acceptance criteria shall be maintained. Records shall indicate the person(s) authorizing release of product for delivery to the customer. The release of product and delivery of service to the customer shall not proceed until the planned arrangements have been satisfactorily completed, unless otherwise approved by a relevant authority and, where applicable, by the customer.

8.3 CONTROL OF NONCONFORMING PRODUCT

The organization shall ensure that product which does not conform to product requirements is identified and controlled to prevent its unintended use or delivery. A document procedure shall be established to define the controls and related responsibilities and authorities for dealing with nonconforming product. Wherever applicable, the organization shall deal with nonconforming product in one or more of the following ways: (a) by taking action to eliminate the detected nonconformity; (b) by authorizing its use, release or acceptance under concession by a relevant authority and, where applicable, by the customer; and (c) by taking action to preclude its original intended use or application, (d) by taking action appropriate to the effects of the non-conformity, when non-conforming product is detected after delivery or use has started. Records of the nature of nonconformities and any subsequent actions taken, including concessions obtained, shall be maintained. When nonconforming product is corrected, it shall be subject to re-verification to demonstrate conformity to the requirements.

8.4 ANALYSIS OF DATA

The organization shall determine, collect, and analyze appropriate data to demonstrate the suitability and effectiveness of the QMS and to evaluate where continual improvement of the effectiveness of the QMS can be made. This shall include data generated as a result of monitoring and measurement and from other relevant sources. The analysis of data shall provide information relating to (a) customer satisfaction, (b) conformity to product requirements, (c) characteristics and trends of processes and products, including opportunities for preventive action, and (d) suppliers.

8.5 IMPROVEMENT

8.5.1 Continual Improvement The organization shall continually improve the effectiveness of the QMS through the use of the quality policy, quality objectives, audit results, analysis of data, corrective and preventive actions, and management review.

8.5.2 Corrective Action The organization shall take action to eliminate the causes of nonconformities in order to prevent recurrence. Corrective actions shall be appropriate to the effects of the nonconformities encountered. A documented procedure shall be established to define requirements for (a) reviewing nonconformities (including customer complaints), (b) determining the causes of nonconformities, (c) evaluating the need for action to ensure that nonconformities do not recur, (d) determining and implementing action needed, (e) records of the results of action taken, and (f) reviewing the effectiveness of the corrective action taken.

8.5.3 Preventive Action The organization shall determine action to eliminate the causes of potential nonconformities in order to prevent their occurrence. Preventive actions shall be appropriate to the effects of the potential problems. A documented procedure shall be established to define requirements for (a) determining potential nonconformities and their causes, (b) evaluating the need for action to prevent occurrence of nonconformities, (c) determining and implementing action needed, (d) records of results of action taken, and (e) reviewing the effectiveness of the preventive action taken. Preventive action is taken to prevent occurrence while corrective action is taken to prevent reoccurrence.

Eight total quality management principles form the basis for the QMS standards. They are customer focus, leadership, employee involvement, process approach, system approach to management, continual improvement, factual approach to decision making, and mutually-beneficial supplier relationships. These principles are similar to the core values of the Malcolm Baldrige National Quality Award.

Implementation

There are a number of steps that are necessary to implement a quality management system.

1. Top Management Commitment

The most important step in implementing a quality system that will meet or exceed an ISO 9000 standard is to acquire the full support of upper management. The chief executive officer (CEO) must be willing to commit the resources necessary to achieve certification. This is critical to the success of the project. Without the CEO's support, the process may continuously run into unnecessary roadblocks or even be doomed to failure. Because top management is assigned specific responsibilities in the standard, it is necessary that they be involved in its implementation.

2. Appoint the Management Representative

Once the commitment has been made, the process can proceed by adopting a project team approach and treating it the same as any other business undertaking. The next step is the appointment of a management representative. This person is responsible for coordinating the implementation and maintenance of the quality system and is the contact person for all parties involved in the process, both internal and external. The representative can be a member of the top management group who is able to ensure that the quality system is effectively implemented, documented, and maintained. The implementation of the quality system should involve everyone in the organization.

3. Awareness

This step requires an awareness program. Because the process is going to affect every member of the organization as well as require their input, it stands to reason that everyone should understand the quality system. They should know how it will affect day-to-day operations and the potential benefits. This information can be relayed through short, one-hour awareness training sessions. Be sure everyone knows the intent of the standard. Habibganj station at Bhopal was the first railway station in India to be certified as ISO 9001:2005. It didn't happen until they realized that the new system would allow them to make difference in their day-to-day activities.

4. Appoint an Implementation Team

After everyone has been informed of the organization's intentions to develop the quality system, an implementation team should be assembled. This team should be drawn from all levels and areas of the organization so that it is representative. Committees for each of the five clauses may be used. The team should identify the QMS processes and their sequence and interaction. It is important to keep the project visible for all employees.

5. Training

The implementation team, supervisors, and internal audit team should be trained. This activity can be accomplished by sending team leaders for training and having them train the other team members or by bringing the training in-house for all team members through a one- or two-day seminar.

6. Time Schedule

This activity develops a time schedule for the implementation and registration of the system. This time frame will vary, depending on the size and type of organization and the extent of its existing quality system. Most organizations can complete the entire process in less than 1.5 years. Divide the implementation process into manageable units. Be sure to provide for the celebration of small victories.

7. Select Element Owners

The implementation team selects owners for each of the system elements. Many of these owners will be members of the implementation team. Owners may be assigned more than one element. Each owner has the option of selecting a team to assist in the process. The more people involved, the more effective the system.

8. Review the Present System

Perform a review of the present quality system. Copies of all the quality manuals, procedures, work instructions, and forms presently in use are obtained. These documents are sorted into the system elements to determine what is available and what is needed to complete the system. This activity is a gap analysis and can be performed by the element owners and their teams or by an external consultant.

9. Write the Documents

Prepare written quality policy and procedure manuals—they can be combined into one document. Write appropriate work instructions to maintain the quality of specific functions. This process should involve every employee, because the best person to write a work instruction is the one who performs the job on a regular basis. Stream International of Crawfordsville, IN encouraged employees to expose the flaws in existing processes and document new processes that would work correctly. However, it is important to be prudent when creating documentation. Too much documentation or complicated documentation will destroy the system.

10. Install the New System

Integrate the policies, procedures, and work instructions into the day-to-day workings of the organization, and document what is being done. It is not necessary for all elements to be implemented at the same time. Be sure all people are trained.

11. Internal Audit

Conduct an internal audit of the quality system. This step is necessary to ensure that the system is working effectively and to provide management with information for the comprehensive management review. Minor corrections to the system are made as they occur. A cross-section of trained people should be used for the audit team.

12. Management Review

Conduct a management review. The management review is used to determine the effectiveness of the system in achieving the stated quality goals. The system is revised as needed.

13. Preassessment

This step is optional. If a good job has been done on the previous steps, preassessment is not necessary.

14. Registration

This step has three parts: choosing a registrar, submitting an application, and conducting the registrar's system audit. Considerations in choosing a registrar include cost, lead time, your customer's acceptance of the registrar, the registrar's accreditation, and familiarity with your industry. The application for registration should also include supplying the registrar with the policy and procedure manuals for their review. The time involved in the registrar's system audit will vary depending on the size and complexity of the organization and the number of auditors involved. A registrar's audit usually lasts one to three days and will consist of an opening meeting to describe the process the auditors will follow, the audit itself, and a closing meeting to discuss the findings of the audit.

Some of these steps, such as documentation, internal auditing, and registration are described in greater detail in the sections that follow. Some pitfalls to successful implementation are:

Using a generic documentation program or another organization's documentation program.

Overdocumentation or documentation that is too complex.

Using external consultants without internal ownership and involvement.

Limiting documentation to text rather than other types of media.

Neglecting to obtain top management's involvement.

Developing a system that does not represent what actually occurs.

Documentation

A quality system is the method used to ensure that the quality level of a product or service is maintained. The system documentation can be viewed as a hierarchy containing four tiers, as shown in Figure 8-3. All documentation moves from one level to the next in a descending order. If the system is properly structured, changes at one level will seldom affect the levels above it, but may affect those below.

Policy

The first tier of documentation is the policy manual. This is the document that defines what will be done and why. A quality policy manual should be written so it is clear, precise, practical, and easy to understand.

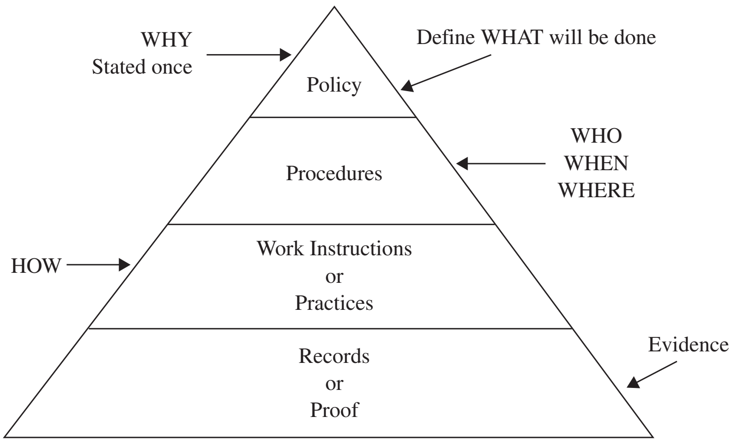

Figure 8-3 The Documentation Pyramid

The why can be stated just once as a quality policy statement. This statement should be a short, simple definition of the organization's quality intentions. For example:

> We are committed to add value to customer's operations by providing quality logistics services through good management practices in the entire supply chain.
>
> TVS LOGISTICS SERVICES LTD

The remainder of the policy manual addresses what will be done to comply with the standard being used. Another way of looking at the policy manual is to think of it as the commandments of the system. Each element of the standard is addressed individually and usually requires one page or less.

Procedure

The second tier of documentation is the quality procedures. These procedures describe the methods that will be used to implement and perform the stated policies. The procedures define who should perform specific tasks, when the task should be done, and where documentation will be made showing that the task was performed. Procedures should be oriented so that they apply to all areas within the organization. They dictate the strategies that will be used to ensure the quality of the system. Procedures are more detailed than the policies; however, they, too, should be written in a manner that will allow for easy understanding. It should be noted that procedures are not required for all elements. Many organizations combine the policy and procedures into one document. A procedure is needed if its absence would adversely affect the activity.

Work Instructions

Work instructions are usually department, machine, task, or product oriented and spell out how a job will be done. These instructions are the most detailed of the documentation hierarchy. A work instruction may be in the form of a detailed drawing, recipe, routing sheet, specific job function (for example, turn nut four turns clockwise), photograph, video, or simply a sample for comparison of conformity. The writing of a work instruction is best carried out by the employee who performs the task. This person knows the process and the problems encountered in that process. However, a documentation specialist may be needed to do the actual writing. This method also creates a pride of ownership in the document, making it more likely to be carried out. Additionally, employee participation helps to ensure that future improvements will be suggested. Not every task requires a work instruction. For example, you don't need to tell a computer specialist to turn on the PC.

Records

Records are a way of documenting that the policies, procedures, and work instructions have been followed. Records may be forms that are filled out, a stamp of approval on a product, or a signature and date on some type of document, such as a routing sheet. Records are used to provide traceability of actions taken on a specific product or batch of products. They provide data for corrective action and a way of recalling products, if necessary.

Document Development

Although documentation is required by the system, its most important purpose is to provide guidelines for internal quality management. In this respect it can be considered one approach to the road of continuing quality improvement and business success. Where does this road start? The answer is with the quality system that is already in place. If an organization has been in business for any length of time, with some degree of success, it has already established procedures for supplying its product or service to customers. This preexisting documentation is the starting point for developing the documents necessary for registration.

To begin creating the documentation system, the implementation team should gather all the existing policies, procedures, work instructions, and forms that are presently in use. Each document should be reviewed and an attempt should be made to fit it into one of the elements. If a document does not appear to pertain to any element, it should be set aside. Where it belongs may become evident at a later time. In addition, the team should decide if the document is currently accurate and up to date. If it is not, it should be updated or discarded.

Now it is time to involve as many employees as possible. Remember, writing the documents will probably be the easy part of the implementation process. Putting the policies and procedures to work will be the most difficult. The more people involved in the creation of the system, the greater the likelihood the system will perform satisfactorily. Involved people are more likely to implement the procedures and ensure that they remain current than people who have had no input. If the organization is large enough, a team of three or more members should be appointed for each element. The team members should come from all areas of the organization, not just from the management or quality areas. Each team is assigned an owner and charged with the responsibility of writing the policy and procedures for that element. They can also be given the responsibility of interviewing personnel and writing the necessary work instructions and applicable documentation forms. A consultant may be needed during this phase to facilitate the team's activities.

As the documents are produced, the implementation team becomes the review committee. If changes appear necessary, suggestions are made and reviewed with the team. The initiating team then either clarifies what has been written or revises the documents as required. When the documents have been completed, they should be formatted in a manner that will allow for simple and effective document control.

Writing the Documents

The basic thought to keep in mind when writing the documents is to create simplicity out of complexity. To accomplish this objective, the documents must be simple and concise.

Simplicity can be obtained by having one idea addressed per paragraph, short subject-verb-object type sentences, and a simple paragraph-numbering system as shown in Figure 8-4. Write to an eighth grade reading

SAMPLE CONTROL

QPol 0 REV:A [Date]

[# of Pages]

0.1 Documents will have this format.

0.2 Samples will be provided for all teams.

0.3 Etc.

Attachments

Flow Diagram

Forms

Figure 8-4 Format Example

level—most newspapers write to the sixth-or seventh-grade level. In addition, use 13- or 14-point type, because it is easier to read and have plenty of white space. Unfortunately, a simple document is not easy to develop—it takes time and a commitment to excellence.

Being concise requires that you write only what's needed. Remove all irrelevant material and avoid the use of special jargon that is common to only one industry or organization. Consider the who, what, when, where, why, and how of the concept being addressed. Write what you are doing. If you need to write "what you ought to be doing" for compliance to an element, then underline it and take the necessary action to achieve compliance. Avoid writing procedures on how to fill out forms. They become records and should be designed to be self-explanatory. Use flow diagrams and check sheets wherever possible rather than lengthy verbiage. The revision process should be as painless as possible. In fact, employees should be encouraged to initiate changes and improvements in procedures and work instructions.[12]

The first step in writing the documents is to create a format that can be used throughout the documentation hierarchy. Although it is not required by ISO, it is helpful to auditors if documents follow the numbering system "QPol" in ISO 9001. Justification for the exclusion of any elements must be stated in Element 4.2.2, Quality Manual. Each document should have a title, a number that is unique to only one document, a date, revision number or letter for control purposes, and the number of pages it contains. In the case of the policy and procedure manuals, the title can be the same as the ISO element they reference. Work instructions and records should have titles that identify their purpose. All policy documents may start with "QPol" to denote a quality policy and be followed by their element number (4.1, 4.2.1, and so forth). Procedures can follow the same system by changing "QPol" to "QPro" followed by the title and element number, and so on, through work instructions, flow diagrams, and records. Figure 8-4 shows a simple and effective method for the formatting of documents.

When designing the manuals, simplicity and ease of use should determine the structure to be used. A cover page will list the organization name and location as well as the title of the document. The table of contents can list the revision letter or number of each document within the manual, as well as the location. The policy manual, being the first tier of the hierarchy, should have a copy of the organization's quality policy and statement of

[12] C. W. Russ Russo, "12 Rules to Make Your ISO 9000 Documentation Simple and Easy to Use," *Quality Progress* (March 1997): 51–53.

the purpose of the quality system. These statements are usually signed by the CEO of the organization. Examples of purpose statements are:

> This quality policy manual has been prepared to provide assistance to all employees in understanding and implementing the quality assurance activities associated with their jobs.

> In recognizing the responsibilities as a manufacturer (service organization) to comply fully with all contractual provisions and statutory requirements of society, we have developed this comprehensive quality system to assure customers that products (services) supplied will be in conformance to requirements and without nonconformities. The program described is in conformance to the requirements of ISO 9001.

A distribution page should be included in the master copy of the manual as a record of who has received a controlled copy. Controlled copies are those that must be updated each time a revision or change is made to the manual. The distribution page provides a method for control of the document, which is required by Element 4.2.3, Control of Documents. Uncontrolled copies may be distributed to customers upon their request and should contain a statement that they will not be automatically updated.

Each of the elements of ISO 9001 should be addressed in the policy manual. Elements that do not pertain to the standard can contain a statement such as, "Not applicable—see Element 4.2.2 for justification." The elements of the standard contain many statements that use the word *shall*, which is a key word in that any statement using it must be addressed by the quality system. An example of the policy statement of a small cast iron foundry that employs 85 people is given below for Element 7.2.2, Review of Requirements Related to the Product.

> Prior to the acceptance of a customer's order, their requirements will be reviewed to determine that:
>
> 1. They are clearly defined and do not differ from the original proposal or sales offer.
> 2. Any differences are resolved and any changes are appropriately recorded and affected people notified.
> 3. Wirco Castings Inc. has the ability to meet them.
>
> Where the customer does not provide requirements, Wirco Castings' standard requirements will be used and the customer so notified.
>
> Record of the review will be recorded in the Part History File.

Analysis of the policy shows that all of the information in the standard has been included. The policy is simply a rewording of the standard. Note that the statement does not include the scope or the purpose, because they are obvious.

The second tier of documentation is the procedures manual. Unless the procedure contains proprietary information, it can be included with the policy. Otherwise, the procedures manual, like the policy manual, should use a cover sheet, distribution page, and table of contents that reflects a current revision letter or number. Procedures are the methods used to carry out the requirements of the policy and are more detailed. Procedure writing can be simplified by using a flow diagram of the required actions. Figure 8-5 is an example of a flow diagram for Element 7.2.2.

The flow diagram shows who does the work, what they do, and the where is obviously in the organization's office. It is short and to the point, simple to audit, contains no unnecessary information, and illustrates the process very effectively.[13] Examples of documents used to show compliance of a procedure can be attached to the procedure or referenced and placed in an appendix. In this case, the policy and the procedure can be on the same page.

[13] Tony Wright, "ISO 9001 without Tears," *Quality Progress* (August 2001): 57–61.

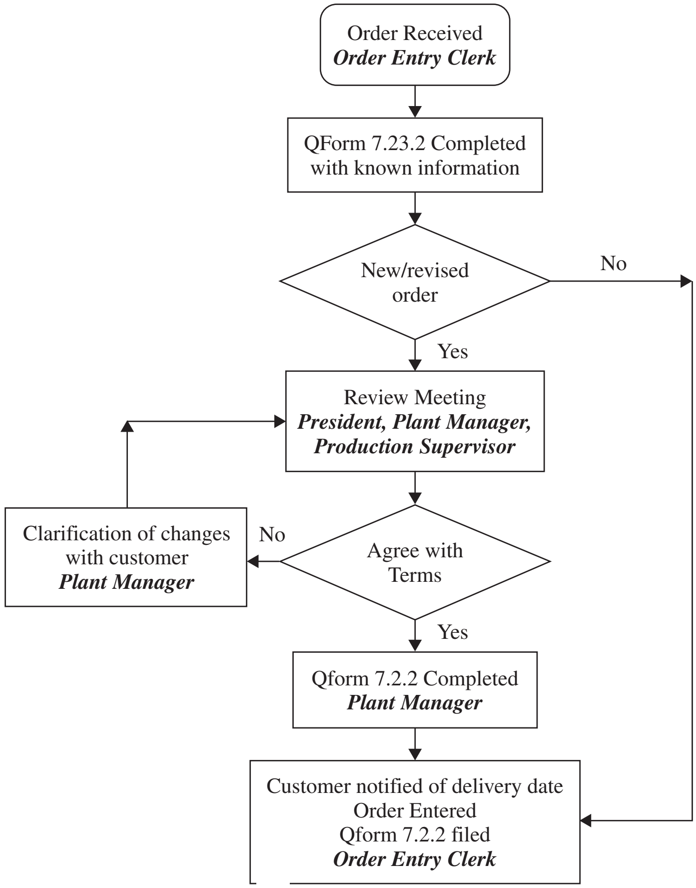

Figure 8-5 Procedure for the Review of Requirements Related to the Product

The third tier of the document pyramid is for work instructions which are specialized and used only as required for quality considerations. They must fit the organization's requirements. As much as possible, however, they should follow the same type of format and numbering system as the policy and procedure manual in order to maintain consistency. Work instructions come in many forms, such as drawings, recipes, routing sheets, operation sheets, samples, photographs, and videos.

The last tier of the pyramid is for records or proof that the policies and procedures have been followed. Most of the records will be readily available and no writing will be necessary. Like work instructions, records use many types of media, such as forms that are filled out, stamp of approval on a product, or a signature and date on a routing sheet. Figure 8-6 shows a check sheet that was used in the procedure for Element 7.2.2. It was filed as evidence that the procedure was followed. The check sheet was designed so that it not only aided the process but so that it also served as the record.

An electronic document control system is an excellent way to manage change and ease collaboration. Such a system allows an organization to store documents in an access-controlled database that can route documents to appropriate personnel for developing, revising, or editing. Collaborated documents can then be routed to the appropriate personnel for electronic signature. An electronic database allows the system to always be current without obsolete policies and procedures available for misuse.

REVIEW OF CUSTOMERS' REQUIREMENTS

QFD m 7.2.2 REV:A[01 Jan 2008]

[1 Page]

Customer Name: ______________________________ Date: ________________

Contact Number: ______________________________ Reviewed By: ________________

Compare With

Description	OK	Comments
Name		
Address		
Telephone Number		
Contact Person		
Casting Price		
Tooling Price		
Quantity		
Engr. Change/Revision		
Material Specification		
Shipping Containers		
Freight Carrier		
F.O.B. Point		
Delivery Date		

Additional Comments: ____

____

____

____

____

____

____

Figure 8-6 **Check Sheet Used with Procedure for the Review of Requirements Related to the Product**

Establishing the database on the Internet or on an intranet provides remote users with the capability to access documents and to participate in development, review, collaboration, and approval processes. This capability allows travelling or offsite employees to stay involved and keep the document control and change management process moving effectively. A web-based system will also provide for external auditing without auditor travel.[14]

[14] Roger Crist, "E-Documenting for Better Control," *Quality Digest* (March 2001): 41–45.

Internal Audits

After the policies, procedures, and work instructions have been developed and implemented, checks must be made to ensure that the system is being followed and the expected results are being obtained. This activity is accomplished through the internal audit, which is one of the key elements of the ISO 9000 standard. All elements should be audited at least once per year and some more frequently, depending on need.

Objectives

There are five objectives of the internal audit. They are to:

- Determine that actual performance conforms to the documented QMS.
- Initiate corrective action activities in response to deficiencies.
- Follow up on noncompliance items from previous audits.
- Provide continued improvement in the system through feedback to management.
- Cause the auditee to think about the process, thereby encouraging possible improvements.

Auditor

Audits should be performed by qualified individuals who have received training in auditing principles and procedures. Training programs are available from several institutes. Training should include classroom information as well as practical demonstration by the trainer and a critiqued audit by the trainee. To be able to audit efficiently, an individual should possess good written and oral communication skills, be a good listener, and be good at taking notes. Other skills should include the ability to concentrate on the task at hand and not be distracted by other activities that are taking place at the same time, be observant and questioning, and be able to separate relevant facts from other information.

The auditor should be objective, honest, and impartial. Of course, the auditor should be prepared by being knowledgeable about the standards.

Techniques

During the actual audit, there are a number of techniques that the auditor should employ. The objective is to collect evidence, and there are three methods: examination of documents, observation of activities, and interviews.

The easiest method is to examine the documents. The auditor should start with the quality manual to determine that the policies cover the QMS standards, and that they are controlled and assessable. Next, the documents are examined in a systematic manner. For example, the auditor would check the purchase orders to determine whether they were accurate and followed the procedures; all appropriate attachments were present; all orders were numbered, signed, and dated; only approved suppliers were used; and so forth. Document control ensures that (1) documents are identified with a title, revision date, and responsible owner; (2) documents are readily available to users; (3) a master list by department or function for procedures, work instructions, and records is appropriately located; (4) there are no obsolete documents at workstations; and (5) changes follow a prescribed procedure.[15]

Observation of activities is also an easy method that requires an aptitude for detail. For example, to evaluate the reservation of product element the auditor would observe the identification, handling, packaging, storage, and protection of the product.

[15] William A. Stimson, "Internal Quality Auditing," *Quality Progress* (November 2001): 39–43.

The most difficult method of collecting evidence is by interviewing the employee or auditee. However, there are ways to make the process easier. First, place the auditee in a nonthreatening environment by starting with introductions and an explanation of the purpose of the audit. This initial conversation can be followed by easy questions such as, "How long have you been working for the organization?" Humor is also very effective in placing one at ease. In addition, use basic human behavior techniques such as giving compliments, using a person's first name, encouraging suggestions, and so forth.

Second, spend as much time listening and as little time as possible talking. Encourage employees to talk about the process. Then paraphrase your interpretations of their statements so there are no misunderstandings.

Third, if and when you find deficiencies in processes and systems, separate the significant from the trivial. Reserve the major issues for your report and the minor ones for the auditee. Focus on the system and not on the auditee.

Fourth, discuss the major issues informally with the auditee first. The auditor's job is to identify problems and allow the organization to determine solutions. Be sure that the auditee understands the problem, agrees that it is a problem, and agrees that corrective action is necessary. If the auditee does not agree, there will be little or no cooperation. Sometimes the auditor, based on his experience, will have an idea that might solve the problem. It should be discussed in such a manner that the auditee believes it is his/her idea.[16]

Fifth, use the appropriate type of question. There are open questions, closed questions, clarifying questions, leading questions, and aggressive questions. Each type is discussed in the paragraphs that follow.

Examples of open questions are:

"When are supplier reviews performed?"

"How is the inspection status identified on this item?"

"Where does this document come from?"

This type of question is designed to get a wide range of answers rather than a simple "yes" or "no." They are used to obtain an opinion, an explanation of a process, a person's attitudes, or the reasoning behind an action. The disadvantage of open questions is that the auditor can receive more information than desired.

Examples of closed questions are:

"Do you have a work instruction for this operation?"

"Does this instrument require calibration?"

"Is this die supplied by the customer?"

This type of question can be answered with yes or no and provides evidence or facts quickly. Closed questions are used to gather specific evidence and reduce any misunderstanding. The disadvantage of closed questions is that the interview can appear to be an interrogation.

Examples of clarifying questions are:

"Tell me more about this operation."

"Please give me some examples."

"What do you mean by parting line mismatch?"

This type of question is used to obtain further information. It helps to prevent misunderstanding and encourages the auditee to relax and be more open. The disadvantages are that these questions can give the

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[16] Peter Hawkins, ed., "Five Steps to 'Win-Win' Audits," *Quality Management* (Issue 1915, August 10, 1996): 1–4.

impression that the auditor is not listening or that the auditor is stupid. Also, when used too often, they are time consuming.

An example of a leading question is:

"Don't you agree that the nonconformity was caused by not understanding the purchase order?"

This type of question should be avoided, because it encourages the auditee to provide a particular answer and will bias the audit findings.

An example of an aggressive question is:

"You don't mean to tell me that this test is the only one you perform?"

This type of question should be avoided because it is offensive and argumentative.

The auditor should primarily use open questions with an occasional closed and clarifying question, as the interview may necessitate. For effective communication, there must be mutual trust between auditor and auditee.

Procedure

Before the audit takes place, an audit plan and checklist should be prepared by the lead auditor. As much time is spent planning as doing. The contents of an audit plan should identify the activity or department to be audited; list the procedures, documents, and regulatory requirements involved; name the audit team; and list who is to be notified of the audit and who will receive audit reports. The plan should also contain a schedule similar to Figure 8-7. This schedule includes audit notification, audit conducted, corrective action required, if any, and follow-up, if any.

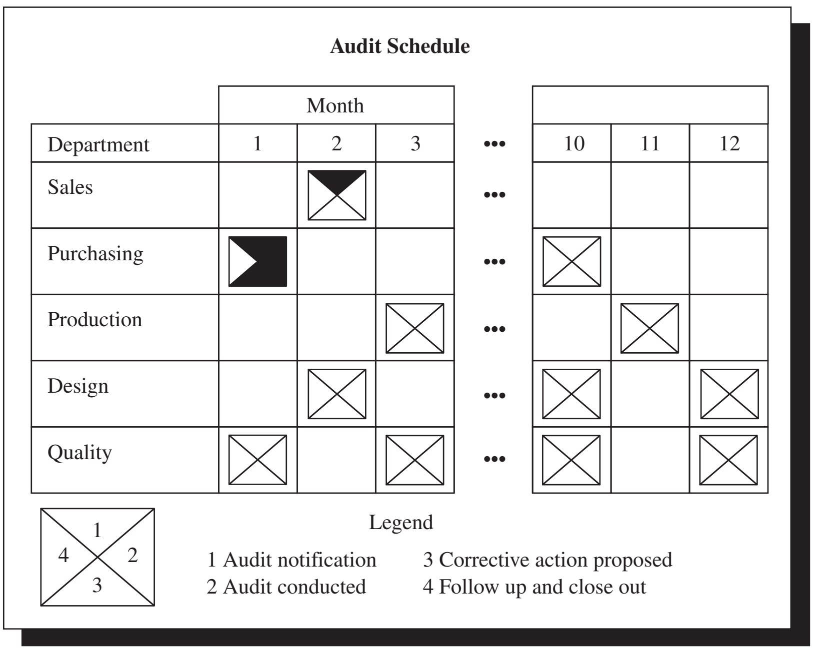

Figure 8-7 Audit Schedule Example

Element	Sales	Purch.	Prod.	Design	QC
4.1	X	X	X	X	X
4.2.1	X	X	X	X	X
⋮	⋮	⋮	⋮	⋮	⋮
7.3.1				X	
7.3.2	X	X	X	X	X
⋮	⋮	⋮	⋮	⋮	⋮
7.4.1		X			
7.4.2		X			
⋮	⋮	⋮	⋮	⋮	⋮
8.5.1	X	X	X	X	X
8.5.2	X	X	X	X	X
8.5.3	X	X	X	X	X

Figure 8-8 Audit Matrix Example

In addition, an audit matrix, as illustrated in Figure 8-8, can be very helpful. It determines the most-affected areas and elements.

Checklists ensure that the audit is efficient and give the auditor control of the process. It can take the form of questions to ask, the sequence in which they should be asked, and space for writing the results. Checklist questions should be based on the procedures, records, and work instructions to be audited, referencing the specific paragraphs being addressed.

The audit itself has three parts, the preaudit meeting, the audit, and a closing meeting. During the preaudit meeting, the audit process and timetable are discussed and prior audits are reviewed. Minutes of the meeting should be recorded and included with the audit documentation. A list of those attending the meeting is recorded in the minutes.

The purpose of the audit is to determine how well the quality system has been implemented and maintained. In large organizations, an escort should be provided by the area being audited. Escorts become witnesses who can provide backup to an event should a finding be challenged at a later time. The escort is usually a supervisor or key person of the audited area. The audit includes interviewing people working in the area and checking various records that back up the interviews. Often what surfaces from records of one area will lead to further questions that will have to be answered in other areas. Notes should be made to be sure that there is adequate follow-up. The audit is not only a measure of conformity to the system, it is also a measure of the system itself. It should determine if the procedure is adequate or if it is time for a change. The object of the auditing process is to provide for continuous improvement and increased customer satisfaction. The audit findings should be written out in detail from the auditors' notes and should include the conforming as well as the nonconforming items. Separate reports are prepared for each nonconformance and should include:

1. The element title and a unique identification number such as NC 7.2.3, where the NC stands for nonconformance and the other numbers give the element number.
2. Where the nonconformance was observed.

3. Objective evidence used as a basis for the nonconformance.
4. The nonconformance worded as closely as possible to the language of the requirement.

At the closing meeting, the lead auditor presents a summary of the audit findings along with the evidence that supports them. An estimate is made of when the final report will be issued. The distribution of the report is agreed upon. Again, minutes of the meeting are recorded, along with a record of attendance. The audit report will:

1. Have a cover sheet that includes the audit date, names of the audit team, areas audited, distribution list, a statement that the audit is only a sample, and a unique reference number, and it will be signed by the lead auditor.
2. List the nonconformances and copies of all nonconformance reports.
3. Outline procedures for corrective action and subsequent follow-up.

Additional Comments

Until 1987, when ISO 9000 was adopted, internal auditing was confined to the control of financial processes. In addition to quality and financial auditing, there are now other assurance functions, such as security, safety, and environment that need to be audited as part of a total risk management package. Top management and other stakeholders are interested in obtaining audit information that is current, reliable, and accurate. They want to know that processes are stable and safe, and that risks are identified and mitigated. It is expected that all of the different audits will be integrated into a generic, value-added model of partnering, assessment, and business process improvement.[17]

Registration

Quality system registration is the assessment and audit of a quality system by a third party, known as a registrar. There are two parts: selecting a registrar and the registration process.

Selecting a Registrar[18]

In the United States, a Registrar Accreditation Board (RAB) was established in 1989 as an affiliate of the American Society of Quality (ASQ) to develop a program to evaluate the quality of the services offered by registrars. The RAB maintains a list of approved registrars. In India, Quality Council of India (QCI), carries out assessment of certification bodies. This is done under the National Accreditation Board for Certification Bodies (NABCB) scheme. Registrar selection can be based on the following criteria.

1. QUALIFICATIONS AND EXPERIENCE

Of particular importance is the number of companies that have been registered, their experience in particular industry sectors, and their customers' structure, such as size and location. *Quality Digest's* annual customer satisfaction survey in the July 2004 issue, rates registrars in five categories—knowledge and ability, consistency in interpretation, service received, thoroughness and understanding auditee's business. It is also

[17] Greg Hutchins, "The State of Quality Auditing," *Quality Progress* (March 2001): 25–29.

[18] Adapted from Stefan Heinloth, "Selecting a Registrar," *Quality Digest* (September 1996): 33–38.

helpful to know the registrar's financial condition to be assured that it will stay in business. The registrar should remain current by participating in the Independent Association of Accredited Registrars.

2. CERTIFICATE RECOGNITION

The registrar must be approved by a regulatory agency such as RAB or NABCB. It must be recognized by existing and potential customers. For example, an organization might sell to a particular country or a specific industry such as the medical industry. Are there international cooperative agreements? The registrar should provide references and prior customer feedback. It may be helpful to interview prior customers.

3. THE REGISTRATION PROCESS

The registrar should have a structured registration procedure that is tailored to the organization's needs. They should be responsive to requests. A significant factor in the registration process is the objective of improving quality and productivity. The registrar should not only evaluate the system but also identify opportunities for more efficient practices. Of future importance is the ability of the registrar to perform multiple types of audits: environmental, quality, security, and workplace safety.

4. TIME AND COST CONSTRAINTS

The evaluation should include the lead time necessary prior to the audit. In addition, the evaluation should include the time and cost required for the initial audit and the surveillance audits. Be wary of additional fees such as the use of a subcontractor that has expert knowledge or language skills.

5. AUDITOR QUALIFICATIONS

Of particular importance is the auditor's qualifications. The ISO 19011 auditing standard requires that auditors: (1) know the standard, (2) know the types of processes, the organization, and the customers, and (3) have the knowledge, temperament, and experience to be credible. Because the auditor and registrar are exposed to sensitive information about the organization, it is vital that a nondisclosure policy be maintained. It is also vital that the auditor has no conflict of interest with the organization. The registrar should provide proof of qualifications, knowledge, and experience. The organization should be able to refuse a particular auditor and have a suitable replacement found.[19]

It is wise to take time to select the best registrar for an organization's needs in order to avoid dissatisfaction. The vice president of Engineered Systems Inc. in Deleware, OH comments about his direct experience with a registrar: "I was frustrated with their level of unresponsiveness. We were never given a "point person" as a contact, and they did not return phone calls." Other areas of dissatisfaction by other organizations are: constantly rescheduling audits, billing undisclosed expenses, arrogant and argumentative auditors, and reporting findings in an untimely fashion.[20]

Registration Process

The registration process has six basic steps: application for registration, document review, preassessment, assessment, registration, and follow-up surveillance. Registrars require a completed application to begin the

[19] Nigel Withey, "How to Select an Auditor," *Quality Digest* (October 1998): 31–34.

[20] Phillip C. Dobyns and Jill C. Smolnik, "Tough Choices!" *Quality Digest* (November 1999): 28–32.

registration process. The application contains the rights and obligations of both parties, determines which standard the applicant will use for the registration, and leads to the formalized contract for services.

After accepting the application and setting a timeframe for registration, the registrar will review the quality system documentation. Some registrars want only the policy manual, whereas others require the policy and procedure manuals. The registrar then compares the organization's documentation with the appropriate standard to determine if the intent of the standard has been met.

Not all registrars require a preassessment; however, most recommend one be conducted. The preassessment is a broad overview of the organization's operations to determine an initial preparedness for a full assessment or audit. A preassessment could identify a major deficiency or lack of documentation that can be corrected before the audit takes place, thus enhancing the possibility of approval on the first audit attempt. In other cases, the preassessment is an option that the organization may not need.

After determining that the organization's documents conform to the selected standard, a full audit or assessment is performed. Typically an audit will take two to four days and will involve two or more auditors at the organization's facility. The audit will follow the same procedure as that outlined in the internal audit procedures and cover all areas and all procedures of the organization in one audit. The client of the audit should be in charge. They should demand capable, honest, and meaningful examinations in return for the money invested. The organization's internal audits should lead to continual improvement; the third-party audit process should verify that the organization's quality management system is performing effectively.[21]

The lead auditor will conduct a closing meeting, which will consist of a verbal summary of the audit findings and a recommendation concerning registration. If the applicant has only minor noncompliances, the recommendation would be for registration. If one or more major noncompliances are registered but appear to be easily corrected, the recommendation may be for a conditional approval pending corrective action. The recommendation for disapproval will be made if it is determined that procedures have not been implemented or at least one element of the standard has not been addressed.

After registration is approved, the registrar will conduct surveillance audits at intervals of six months to a year. These audits will not be full audits but random checks of some elements to ensure that the system continues to function. Registration is good for three years, at which time the organization must be recertified.

Closing Comments

Remember, third-party audits and registration are not a requirement of the ISO 9000 standards. The standards are written for contractual situations between a customer and a supplier. Registration is one way to demonstrate compliance to the standard. The requirements specified in the standards are aimed at preventing nonconformities during all stages of the business functions. Before entering into a contract for registration, management must be able to justify the cost versus the potential gains in continued or increased business.

No single standard has had more universal or worldwide results in increasing the awareness of quality than the ISO 9000 series. As of December 31, 2001, there were over 510,000 organizations registered from 158 countries. It must be pointed out that a quality system is only *one* of the many tools of total quality management. Many organizations have used registration as an end in itself and senior management has abrogated its responsibility and leadership for TQM. The ISO 9000 quality system is an excellent first step towards TQM.[22]

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[21] Dale K. Gordon, "Caveat Emptor," *Quality Progress* (August 2001): 80–81.

[22] Kenneth S. Stephens, "ISO 9000 and Total Quality," *Quality Management Journal* (Fall 1994): 57–69.

TQM Exemplary Organization[23]

With customers in 86 countries, Solar Turbines Inc. is the world's largest supplier of mid-range industrial gas turbine systems. The San Diego-based company's turbine engines and compressors are used in the production and transmission of oil and gas, for industrial power generation, and in the propulsion systems of high-speed ferries. Eighty percent of Solar's 6,200 employees are distributed among 15 locations in the United States; 20% are deployed among sites in 23 foreign nations.

Hallmarks of Solar's approach include a dynamic strategic planning process, which is an extensive teamwork system that is aligned and coordinated throughout the entire company, and an "authority delegation process" that enables employees who are closest to the work to design, manage, and improve work systems and processes. Devised with knowledge gained from benchmarking other organizations, Solar believes its authority delegation process is unique. It has reduced non-value-added steps in decision-making and helped the company to respond quickly to changing customer needs and competitive conditions.

Training and education needs are formally addressed during strategic planning. Solar estimates that total expenditures for training are equivalent to about 15% of its payroll. Awards and bonuses reinforce the workforce's commitment to achieving business goals. Incentive payouts have helped Solar to meet or exceed goals for increasing its return on assets. Payouts increased 7.6% of salary in 1994 to 10.4% of salary in 1997.

Sources of information on customer requirements and competitors' capabilities include competitive business reports by field service representatives, regular visits to customer facilities by Solar executives, annual satisfaction surveys, end-of-project surveys, complaints, and reviews of won and lost bids for business. This and other intelligence gleaned from listening posts around the world is analyzed for emerging business opportunities.

Using a four-phase new product introduction process, the company has been quick to seize opportunities. The process integrates the efforts of 30 or more teams and sub-teams that involve all stakeholders, including customers and suppliers. Since 1994, the new product development cycle has been trimmed from 39 months to 22 months, and quality has improved. The number of warranty claims has decreased significantly since 1995, and non-recoverable commissioning costs have been cut.

For customers, benefits resulting from gains in quality include lower maintenance costs. Industry-sponsored studies show that maintenance costs for Solar-made industrial turbines are 42% lower than the average for all suppliers.

Solar's share of the global market for new turbine engines has risen from less than 20% in 1970 to a position of global market leadership. Since 1988, the company has tripled its annual revenues and increased its profits by a factor of 11. Improvements in productivity have fueled these gains in business performance. Revenues generated per employee increased by 61% between 1993 and 1997.

Summary

Worldwide emphasis on quality and economic competitiveness resulted into wider acceptance of ISO 9000 series of standards. Most countries have adopted this series in their national standards. These standards are written for contractual situations between a customer and supplier.

There are several benefits of ISO 9000 registration. There is an increasing trend to adopt ISO 9000 quality system standard worldwide. The standard is generic in scope and can be tailored to fit into any organization's needs. The third party registration system often gives a very cost-effective alternative to the two-party multiple audit systems.

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[23] Malcolm Baldrige National Quality Award, 1998 Manufacturing Category Recipient, NIST/Baldrige Homepage, Internet.

In addition to this generic series, there are other sector specific quality system standards, such as automotive or aerospace. These standards often use ISO 9000 requirements as the basic framework.

Exercises

1. Briefly describe the purpose of an ISO 9000 quality system.

2. What is a quality policy statement?

3. Describe the four tiers of quality documentation.

4. Determine which element of ISO 9001 is referenced in each of the following situations:

   (a) An audit found that no supplier reviews were being performed.
   (b) There were no inspection records.
   (c) During an audit, it was found that a punch press operator had not received the technical instructions necessary for running the punch press.
   (d) During an audit, it was discovered that no manager had been given the responsibility of ensuring that the quality system was being maintained.

5. What are the basic differences among the quality systems discussed in the text?

6. Why is it important to have element owners?

7. Why is documentation the most common reason for noncompliance?

8. Prepare a list of internal audit questions for three elements.

9. Working as an individual or in a team of three or more people, perform an internal audit and write a report on three elements at a local organization.

10. Describe how a two-party audit system works.

11. What can be accomplished by the addition of a third party registering a quality system?

12. List five benefits that could be realized by implementing an ISO 9000 quality system.

13. How would you determine the registrar to select?

14. Which of the following standards is applicable only to automotive suppliers?

    (a) ISO 9000
    (b) ISO 9001
    (c) ISO/TS 16949
    (d) ISO 14000

15. Appropriate standard for quality assurance of measuring equipment is

    (a) ISO 9001
    (b) ISO 10012
    (c) ISO 14000
    (d) ISO/TS 16949

16. Who is responsible to organize internal audit?

    (a) quality leader
    (b) chief executive
    (c) certification agency
    (d) management representative

17. Which of the following is not an input to management review:

    (a) status of corrective actions
    (b) budget variances
    (c) internal audit findings
    (d) plant rejections

18. Match the pairs:

1	ISO 9001	A	Telecommunication industry quality standard
2	ISO/TS 16949	B	Quality management system requirements
3	AS 9100	C	Guidelines for performance improvement
4	TL 9000	D	Fundamentals and vocabulary
5	ISO 9000	E	Aerospace industry quality system
6	ISO 9004	F	Automotive suppliers–particular requirements for application of ISO 9001

9

Environmental Management System

Chapter Objectives

- Brief overview of environmental management concepts
- Structure of ISO 14000 series standards and their applicability to organizational evaluation and product evaluation
- Overview of requirements and implementation of ISO 14000 series standards and integration with ISO 9000
- Understanding the concept of health and safety

Introduction

The International Organization for Standards (ISO) completed the Quality Management System (ISO 9000) in 1987. Its worldwide success, along with increased emphasis on environmental issues, were instrumental in ISO's decision to develop environmental management standards. In 1991, ISO formed the Strategic Advisory Group on the Environment (SAGE), which led to the formation of Technical Committee (TC) 207 in 1992.

The mission of TC 207 is to develop standards for an environmental management system (EMS) which was identified as ISO 14000. Like the ISO 9000 standards, which do not address the performance of the product or service, the committee used the concept that the standards addressed the process rather than the end goal. Thus, they are process standards rather than performance standards. TC 207 has established six sub-committees: environmental management systems, environmental auditing, environmental labeling, environmental performance evaluation, life-cycle assessment, and terms and definitions. In addition, a working group on environmental aspects in product standards was formed. Each country has a member body of ISO, which for the United States is the American National Standards Institute (ANSI) and, for India, it is Bureau of Indian Standards (BIS).

Experience with ISO 9000 made it easier to develop ISO 14000, and a subsequent revision of ISO 9000 capitalized on many of the improvements in ISO 14000. The EMS is part of a comprehensive management system that addresses how the overall business activities, including its products and services, impact the environment. The EMS maximizes company participation in environmental performance now and in the future. Processes for obtaining registration closely resemble those involved with ISO 9000 and related quality standards. The differences lie mainly in what the standard requires rather than the registration process.[1]

IS/ISO 14001 was originally published in 1997 in India under the dual numbering scheme of BIS adopting first edition of ISO 14001. With the publication of second edition of ISO 14001 in 2004, the revision of IS/ISO 14001 was taken up by BIS.

ISO 14000 Series Standards

The series is divided into two separate areas—the organization evaluation standards and the product evaluation standards. In addition, ISO 14050 covers terms and definitions that are common to both areas. Most recent version of this standard was issued recently in 2009.

Organizational Evaluation Standards

These standards are shown in Figure 9-1 and consist of three categories: Environmental Management System (EMS), Environmental Auditing (EA), and Environmental Performance Evaluation (EPE).

ISO 14001, entitled, "Environmental Management Systems—Specifications with Guidance for Use," gives the elements that organizations are required to conform to if they seek registration. This standard is the heart of the standards and will be discussed in greater detail later in the chapter. The standards given below support the EMS.

ISO 14004, entitled, "Environmental Management Systems—Guidelines on Principles, Systems, and Supporting Techniques," provides supplementary material. It is for information only and is not to be used for registration.

ISO 14010, ISO 14011 and ISO 14012 standards are now superseded by ISO 19011:2002 (Guidelines for quality and environmental management system auditing), which covers a range of audit related functions. It is intended that by using this new standard, organizations can save time and money by:

- Avoiding confusion over objectives of environmental or quality audit programs.
- Establishing agreement of goals between individual audit programs.
- Reducing duplication of efforts.
- Ensuring the use of best audit formats.
- Evaluating competence of audit team members againsts appropriate criteria.

ISO 14031, entitled, "Guidelines on Environmental Performance Evaluation," presents information on recording information to track performance. It helps the organization meet the requirements of ISO 14001, Section 4.5.1, Monitoring and Measuring.

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[1] Joe Lissenden, "ISO 9000 Eases ISO 14001 Registration," *Quality Digest* (May 1999): 41–44.

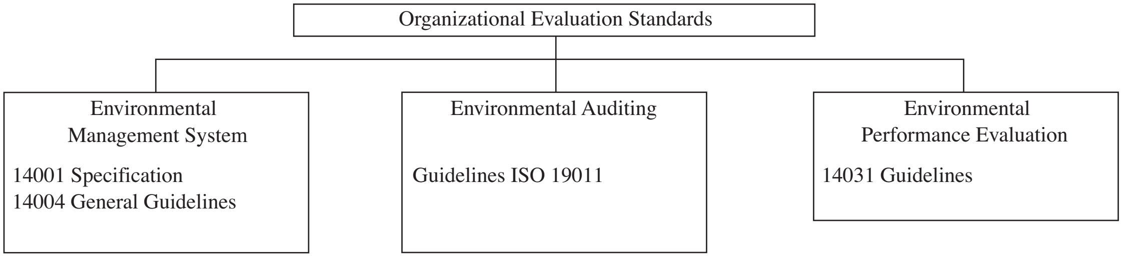

Figure 9-1 Organizational Evaluation Standards

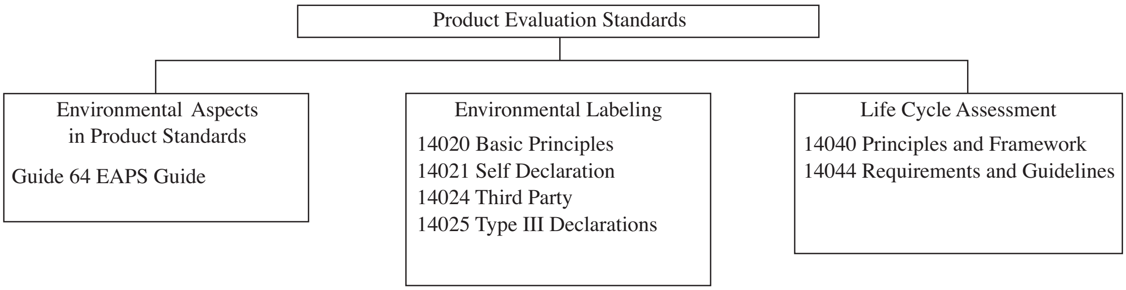

Figure 9-2 Product Evaluation Standards

Product Evaluation Standards

These standards are under development and are shown in Figure 9-2. They consist of three categories: Environmental Aspects in Product Standards (EAPS), Environmental Labeling (EL), and Life-Cycle Assessment (LCA).

ISO Guide 64:2008 entitled, "Environmental Aspects in Product Standards," is designed to help writers develop product standards. Writers should carefully consider the environmental consequences when developing criteria, elements, and characteristics that go into the standard.

ISO 14020:2000, entitled, "Environmental Labels and Declarations—General Principles for All Environmental Labeling," provides guidance on the goals and principles that should be used in development and use of environmental labels and declarations. Product improvement is a desirable benefit but not the objective of the standard. This standard is not intended for use as a specification for certification and registration purposes.

ISO 14021:1999 entitled, "Environmental Labeling—Self-Declaration of Environmental Claims: Terms and Definitions," applies to organizations that are declaring that their product has an environmental attribute such as being recyclable or energy efficient. The standard ensures that this type of labeling is accurate, verifiable, and not deceptive.

ISO 14024, entitled, "Environmental Labeling—Practitioner Programs: Guiding Principles, Practices, and Certification Procedures for Multiple Criteria Programs," establishes criteria for third-party labeling or seal programs. These programs determine which products have overall environmental superiority as compared to other products.

ISO 14025:2006, entitled "Environmental Labels and Declarations—Type III Declarations—Principles and Procedures."

This standard establishes principles for use of environmental information, in addition to those given in ISO 14020:2000. Type III environmental declarations as described in this standard are intended to be used in business communication.

ISO 14040:2006, entitled, "Life-Cycle Assessment—Principles and Framework," provides an overview of the practice, applications, and limitations of LCA. Life-cycle assessment and life-cycle invest (LCI) attempt to determine the long-range environmental effect of a product. This assessment is an enormously difficult task because of the unforeseen and frequently controversial nature of a product's life cycle. This standard along with ISO 14044 is a revision of earlier three standards, namely, ISO 14041, ISO 14042 and ISO 14043.

ISO 14044:2006, entitled "Life-Cycle Assessment—Requirements and Guidelines" specifics requirements and provides guidelines for LCA, LCI and Life-Cycle Impact Assesment (LCIA).

The organizational evaluation standards, are operational and effective because, like ISO 9000, the focus was on the process rather than the product. The development and acceptance of the product evaluation standards will be much more difficult. In particular, scientific knowledge concerning life-cycle assessment is limited.

Concepts of ISO 14001

This standard provides organizations with the elements for an environmental management system (EMS), which can be integrated into other management systems to help achieve environmental and economic goals. It describes the requirements for registration and/or self-declaration of the organization's EMS. Demonstration of successful implementation of the system can be used to assure other parties that an appropriate EMS is in place. It was written to be applicable to all types and sizes of organizations and to accommodate diverse geographical, cultural, and social conditions. As previously mentioned, the requirements are based on the process and not on the product. It does, however, require commitment to the organization's EMS policy, applicable regulations, and continual improvement.

The basic approach to EMS is shown in Figure 9-3. It begins with the environmental policy, which is followed by planning, implementation and operation, checking and corrective action, and management review. The approach follows the PDSA cycle. There is a logical sequence of events to achieve continual improvement. Many of the requirements may be developed concurrently or revisited at any time. The overall aim is to support environmental protection and prevention of pollution in balance with socioeconomic needs.

The standard is not intended to create nontariff barriers or to change an organization's legal obligations. In addition, it does not include aspects of occupational health and safety management, although an organization may include these aspects in the documentation.

In order to understand the requirements, a few definitions are necessary. *Environment* is defined as the global surroundings in which an organization operates and includes air, water, land, natural resources, flora, fauna, humans, and their interaction. *Environmental aspect* is defined as an element of an organization's activities, products, or services that can interact with the environment. Examples are wastewater discharge, air emissions, and energy usage. *Environmental impact* is defined as any change, whether adverse or beneficial, wholly or partially resulting from an organization's environmental aspects. Examples are impacts on habitat, water supply, and soil erosion. *Environmental objective* is an overall environmental goal, arising from the policy statement, that an organization sets for itself and which is quantified when practical. They define how the policy will be achieved. For example, an objective could be to control the temperature of the wastewater effluent. *Environmental target* is a detailed performance requirement that arises from the environmental objectives. For example the wastewater temperature should be controlled between 10° C and 14° C.

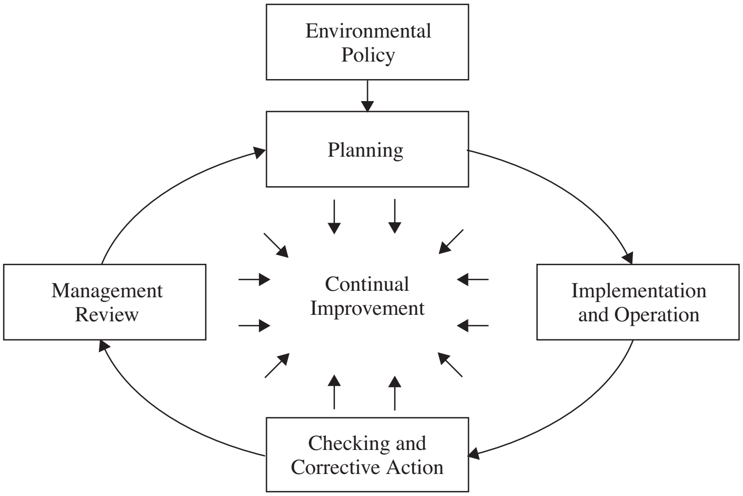

Figure 9-3 Environmental Management System Model

There are four sections to the standard—scope, normative references, definitions, and EMS requirements—and an informative annex. The EMS requirements are given in Section 4 of the standard and are covered next.

Requirements of ISO 14001[2]

The standard is divided into six parts or clauses and has a total of 18 requirements. The numbering system used is identical to the standard.

4.1 General Requirements

The organization shall establish, maintain and continually improve an environmental management system that includes policy, planning, implementation and operation, checking and corrective action, and management review. These requirements are given in the rest of the standard. The organization shall define and document the scope of its environment management system.

Because the document is available to the public and other stakeholders, the organization may wish to include in this narrative a brief description of the company. In addition, this clause is a good place to include manual control and distribution.

In developing the EMS, keep it as simple as possible. It will work better when it is easy to follow and easy to understand. It can always be expanded at a later time, making certain that the registrar is informed of the change. It is not necessary to start over—use existing procedures such as ISO 9000 where applicable. Existing information may need to be reformatted, but this action is easier than starting from scratch.

[2] This section adapted from ANSI/ISO 14001-2004, *Environmental Management Systems—Specification with Guidance for Use,* Department of Environmental Quality, Michigan Government.

4.2 Environmental Policy

The organization's policy statement should be based on its mission and values. It should show management commitment, leadership, and direction for the environmental activities. Management will ensure that the policy is implemented and carried out. An initial environmental review is suggested which includes the following:

Identification of legislative and regulatory requirements.

Identification of environmental aspects of its activities, products, or services that can have significant impact and liabilities.

Identification of existing activities with suppliers.

Identification of existing management policies and procedures.

Evaluation of past performance with regard to the above.

Feedback from investigation of previous incidents of noncompliance.

Identification of opportunities for competitive advantage.

Identification of benchmarking opportunities.

Having this information will help the organization develop its environmental policy.

The policy must be relevant to the organization's nature, scale, and environmental impact of its activities, products, and services. It shall have clear reference to the defined scope.

The policy must ensure that management is committed to continual improvement and prevention of pollution. Total Quality Management practitioners were disappointed that earlier versions of ISO 9000 did not include this requirement. Refer to Chapter 5 (continual process improvement) for information. Management's commitment must be apparent to all the employees because employees tend to do what is important to management.

The policy includes a commitment to comply with relevant legislation and regulations, and with any other requirements applicable to the organization, industry, and locale. Other requirements may include items such as permits, licenses, and voluntary program activities.

The policy provides a framework for setting and reviewing environmental objectives and targets. Their setting should aim to comply with legislative and regulatory requirements. Provision must be made for periodic review of progress in meeting the objectives and targets.

The policy must be documented, implemented, and maintained; it also must be communicated to all employees. Documenting the policy means that it must be in written or electronic format. Implementing it means that it must be put into practice by everyone involved in the EMS. Maintaining it means that the policy is dynamic and provision for updating must be provided. Communicating the policy to all people working for or on behalf of the organization is a never-ending job; it requires repetition and the use of different forms of media.

The policy must be available to the public. Seldom do organizations make internal policies available to the public; however, where the environment is concerned, the public is a major stakeholder. Suggested approaches are to distribute the policy to libraries, chambers of commerce, environmental organizations, or other public access organizations. Of course copies should be made available in the organization's reception area and to anyone that asks for one. Modern organizations often publish their environmental policy on their websites. Each year AmerenUE publishes its average amount of emissions of carbon dioxide, nitrogen oxides, and sulfur dioxide as well as the amount of nuclear waste.

4.3 Planning

This area contains four elements: environmental aspects, legal and other requirements, objectives and targets, and environmental management program(s).

4.3.1 ENVIRONMENTAL ASPECTS

The relationship among the environmental aspects, environmental impacts, and the standard is necessary for successful implementation of the standard. It requires that environmental aspects of an organization's activities, products, and services that it can control and influence be identified within the defined scope in order to determine the environmental impact. The organization shall take into account planning of new developments in new/modified activities, products and services.

ISO 14004 lists nine issues that can be considered in an organization's procedures for the identification of aspects and their impacts.

1. What are the environmental aspects of the organizations activities, products, and services?
2. Do the organization's activities, products, or services create any significant adverse environmental impacts?
3. Does the organization have a procedure for evaluating the environmental consideration, for example, sensitive environmental areas?
4. Does the location of the organization require special environmental consideration, for example, sensitive environmental aspects and their associated impacts?
5. How will any intended changes or additions to activities, products, or services affect the environmental aspects and their associated impacts?
6. How significant or severe are the potential environmental impacts if a process failure occurs?
7. How frequently will the situation arise that could lead to the impact?
8. What are the significant environmental aspects, considering impacts, likelihood, severity, and frequency?
9. Are the significant environmental impacts local, regional, or global in scope?

The process is somewhat similar to a FMEA analysis that is discussed in Chapter 14. Consideration should be given to abnormal and emergency situations, startup and shutdown, and normal operations. It is worth noting that there is a cause-and-effect relationship between the environmental aspect and its impact.

Those aspects that relate to significant impacts shall be considered in setting objectives. It is not necessary for every aspect to have an objective—only that it be considered. This information must be kept current.

4.3.2 LEGAL AND OTHER REQUIREMENTS

The standard requires the organization to have a procedure to identify and have access to all legal and other requirements to which it subscribes. In general, legal environmental requirements are those attributed to governmental legislative and regulatory action. Other requirements usually include industry codes of practice, contracts, agreements with public authorities, and nonregulatory guidelines. Even if some of these requirements are voluntary, the organization is accountable to those with which it agreed to comply. The organization is required to determine how concerned legal and other requirements apply to environmental aspects.

According to ISO 14004, issues to be considered in the procedure should include how the organization:

Accesses and identifies legal and other requirements.

Keeps track of legal and other requirements.

Keeps track of changes to legal and other requirements.

Communicates relevant information about legal and other requirements to employees.

The number and complexity of legal and other requirements throughout the world can make the procedure quite complex; however, the organization need only identify those requirements that are applicable to the environmental aspects of its activities, products, and services. Examples of laws that might apply are Clean Air Act (U.S.), Public Health Act (U.K.), Chemical Products Act (Sweden), and Environmental Protection Act 1986 (India), etc.

Resources that can help include: (1) local, state and federal governments, (2) industry trade associations, (3) consulting services, and (4) external databases.

4.3.3 OBJECTIVES AND TARGETS

The organization shall establish and maintain these objectives and targets at each relevant function and level. They shall be consistent with the policy statement especially in regard to the prevention of pollution and shall be measurable (wherever practical). The objective should demonstrate commitment to continual improvement. An example of an objective for a paper manufacturer would be "Reduce tree cutting," and some targets would be "Increase chipper yield to 90% in next 5 years" and "Increase recycled material to 25% by next 3 years."

In addition to the environmental aspects, and the legal and other requirements which were previously discussed, this clause also requires that the organization consider:

The best technological option to mitigate an aspect.

Economic viability of the option.

Cost-effectiveness of the option.

Appropriateness of the option to the situation.

Affordability of the option, given the organization's financial, operational, and business situation.

Views of interested parties such as: employees, regulatory agencies, and any other stakeholders.

Objectives may apply to one person, group, function, or to the entire organization. They should be developed by those who are involved in their attainment. ISO 14004 lists different forms of objectives, such as:

Reduce waste and the depletion of resources.

Reduce or eliminate the release of pollutants in the environment.

Design products to minimize their environmental impact in production, use, and disposal.

Control the environmental impact of sources of raw material.

Minimize any significant adverse environmental impact of new developments.

Promote environmental awareness among employees and the community.

4.3.4 ENVIRONMENTAL MANAGEMENT PROGRAM(S)

The organization shall establish and maintain a program(s) for achieving the objectives and targets. It shall include designation of the responsible function, team, or individual and a timeframe for achievement.

This requirement can be achieved with a simple form. It will require completion of the following items:

1. State the objective/target.
2. State the purpose (How the objective/target will support the policy).

3. Describe how the objective/target will be achieved.
4. State the program (team) leader.
5. Designate departments and individuals responsible for specific tasks.
6. Establish the schedule for completion of the tasks.
7. Establish the program review, which will include format, content, and review schedule.

Refer to the information on teams in Chapter 4 (employee involvement) and the problem-solving method in Chapter 5 (continuous process improvement).

4.4 Implementation and Operation

This area contains seven elements: structure and responsibility; training, awareness, and competency; communication; EMS documentation; document control; operational control; and emergency preparedness and response.

4.4.1 Resources, Roles, Responsibility and Authority

Roles, responsibilities, and authorities shall be defined, documented, and communicated for all personnel affecting the EMS. They must be given the freedom and authority to take the necessary actions. An organization chart is one method to show the flow of authority. A management representative must be appointed and given the authority to ensure that this standard is being met and to periodically report to senior management the status of EMS with the aim of continued improvement. This appointment must not be viewed by top management as a way to avoid their involvement in the EMS. The management representative can only be as effective as their involvement.

Senior management must provide the resources in terms of people, technology, and money to implement and maintain an effective system that achieves its objectives.

4.4.2 training, awareness, and competency

Training needs should be evaluated on a regular basis, usually annually, to ensure their effectiveness. There are two types of training: general awareness and job competency. Competency requirements for any person(s) performing tasks for or on behalf of an organization shall be defined. General awareness includes the importance of conformance to the EMS, the relationship of significant environmental impacts to the employees' work activities, employee roles and responsibilities, and potential consequences of failing to follow specific operating procedures. Personnel performing tasks that can cause significant environmental impacts shall be competent based on education, training, or experience. Records must be maintained to document that the training requirements have been met.

At a minimum, this training should include:

Record of training needs assessments.

Task competency requirements.

Training procedures.

Training plans.

Records of training delivered to specific employees.

Registrar's audits will require these documented records, and they will be valuable for internal operations and litigation defense if needed.

4.4.3 COMMUNICATION

A key aspect of any management program is communication with all stakeholders. The standard requires that procedures shall be established and maintained for internal communication among all employees. The organization shall decide whether to communicate externally about its significant environmental aspects and shall also astablish suitable mechanism for it.

Effective communication up, down, and laterally should ensure that questions are answered and that understanding is complete and accurate. Internal environmental communication procedures should address reporting on environmental activities to:

Demonstrate management's commitment to the environment and EMS.

Handle concerns and questions about environmental aspects of the organization's activities, products, and services.

Inform appropriate employees of all legal and regulatory changes and all changes to the EMS.

Raise awareness of the organization's environmental activities.

Ensure that all employees are aware of objectives, targets, programs, and achievements.

Publish results of internal and external audits as well as management reviews.

Maintain a high level of employee focus on environmental issues.

In addition, procedures shall be established for receiving, documenting, and responding to relevant external communication from interested parties. It is up to the organization to decide what is or is not relevant. However, from a practical matter, it is best to respond to all external inquiries.

Furthermore, the organization shall consider processes for external communication of its environmental aspects and record its decision to implement or to not implement those processes. Many organizations take a proactive approach and externally communicate their environmental aspects. Some organizations such as the O'Fallon, Illinois Water Department communicate not only their environmental aspects, but their objectives, targets, and achievements periodically to their constituents. Organizations that do not take a proactive approach should record that fact and present reasons for their actions.

AQ 1 Additional information on communication is given in Chapter 2 (leadership).

4.4.4 ENVIRONMENTAL MANAGEMENT SYSTEM DOCUMENTATION

The organization shall establish and maintain information, in paper or electronic form, to describe the core elements of the system and their interaction and provide direction to applicable related documents. ISO 14000 requires a documentation system very similar to ISO 9001, which makes integration of the two systems very easy. The organization must show that it is actually practicing what the documentation states. In other words, "Say what you do and do what you say."

4.4.5 DOCUMENT CONTROL

This element requires that procedures be established and maintained to control all EMS documents. Examples are blueprints, test procedures, work instructions, and, of course, the EMS manual. Provisions must be

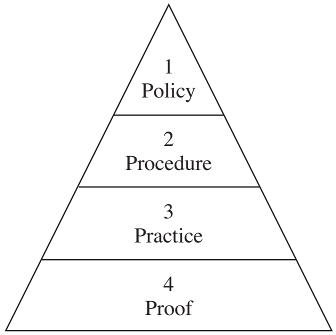

Figure 9-4 Documentation Hierarchy

made for the review and approval of documents for adequacy before they are issued and after any changes. The purpose of document control is to ensure that appropriate and current issues of documents are in place at all locations. Obsolete documents must be removed and destroyed or stored in a safe place if retention for legal purposes is necessary. Documents shall be legible, dated, readily identifiable, and easily located. Documents of external origin should be identified and their distribution should be controlled.

The best document control system is the simplest one that meets the needs of the organization and ISO 14000. If the organization has an existing system such as ISO 9001, it can be used as a model.

ISO documentation can be viewed as four levels as shown in Figure 9-4. Level 1, the policy level, is the EMS manual that includes the environmental policy with policies responding to each clause. Organizational charts and other forms of documentation can be used to clearly define core elements of the system and how they relate to Level 2 procedures. The organization may wish to list environmental aspects; objectives; targets; and legal, regulatory, and other requirements at this level.

Level 2, the procedure level, describes what the organization does to meet Level 1 policies. There are detailed procedures and while only a few are explicitly required to be documented, it is best from an effectiveness standpoint to document all of them.

Level 3, the practice level, describes the work instructions by which operating personnel perform their tasks. They are step-by-step instructions dealing with activities required by the standard. Organizations involved with TQM or ISO 9001 will already have these activities documented.

Level 4, the proof level, is the location of all forms, records, drawings, and so forth that represent the objective evidence or proof of the performance of the EMS.

It is important to note that the system should be an efficient one and not a bureaucratic one—keep it simple. In addition, the documentation must show the interaction of the elements and provide direction to related documents such as flow charts, check sheets, and drawings.

4.4.6 OPERATIONAL CONTROL

This element aligns operations and activities including subcontractors with the identified significant environmental aspects, environmental policy, and environmental objectives and targets. The organization shall plan and implement these activities to ensure that the procedures:

Cover situations where their absence could lead to deviations from the policy and the objectives and targets.

Stipulate operating criteria which are the details and instructions that would normally be included in any process, procedure, or step-by-step work instruction. They include equipment to be used, materials required, process settings, maintenance program, and so forth.

Cover the identification of environmental aspects of goods and services and communicate relevant procedures and requirements to suppliers and contractors. Ford Motor Co., which has 90 plants worldwide requires its suppliers to be certified to ISO 14001. Other major companies such as IBM, General Motors, Xerox, and Honda of America also have made the same stipulation.[3]

4.4.7 EMERGENCY PREPAREDNESS AND RESPONSE

Procedures are required to identify and respond to potential accidents and emergency situations. In addition, the procedures should prevent or mitigate the environmental impact of these accidents and emergency situations. If plans and procedures are required by law, they will usually suffice for the standard. Emergency plans should include at a minimum:

Emergency organization and responsibilities of key personnel.

Details of emergency services such as fire department and spill cleanup services.

Internal and external communication plans.

Actions to be taken for the different types of emergencies.

Information on hazardous materials and their impact, including information about equipment and protective clothing.

Training plans and testing for effectiveness.

These procedures shall be reviewed and revised, if necessary, especially after an emergency. A checklist for lessons learned could include: The proceduces should be reviewed periodically.

Did we follow procedures?

If not, why and how did we deviate?

What did we do that was right?

What did we do that was wrong?

What procedural changes would result in a more effective response?

These questions can also be asked after any emergency drill or simulation which would test the procedures for their effectiveness. The procedures should be reviewed periodically.

4.5 Checking and Corrective Action

This area contains four elements: monitoring and measuring, nonconformance and corrective and preventative action, records, and EMS audit.

4.5.1 MONITORING AND MEASURING

Effective decisions usually require quantifiable data. The organization is required to monitor and measure the key characteristics of its objectives and activities in order to assess its performance in meeting environmental

[3] Stanley Fielding, "ISO 14001 Brings Change and Delivers Profits," *Quality Digest* (November 2000): 32–35.

operations and targets. An example of a key characteristic is energy consumed, and the measurement method is kilowatts and gas/therms. Measuring equipment is of little value if it is not accurate or functioning properly. Procedures must be in place to control, regularly calibrate, maintain, and record all EMS equipment, whether it belongs to the organization, employee, or an outside agency. In addition, procedures are required to periodically evaluate compliance to relevant regulations.

4.5.2 NONCONFORMANCE AND CORRECTIVE AND PREVENTATIVE ACTION

Procedures are required to define responsibility and authority for (1) handling and investigating nonconformance, (2) taking action to mitigate any impacts, (3) initiating corrective and preventative action and (4) evaluating the need for action(s) to prevent non-conformities. Refer to Chapter 5 (continuous process improvement) for information on corrective and preventive action. Briefly, the process should include:

Identifying the root cause of the nonconformance.

Identifying and implementing the necessary corrective action.

Implementing or modifying controls necessary to prevent a recurrence.

Recording any changes in the written procedures.

Since operating personnel are usually the most knowledgeable people concerning the process, they should be involved in the corrective and preventative action activity. Any action taken to eliminate the causes should be appropriate to the magnitude of the problem and commensurate with the environmental impact. In addition, any changes to the procedures resulting from corrective and preventative action should be implemented and recorded.

4.5.3 RECORDS

Procedures are required for the identification, maintenance, and disposition of environmental records such as training, audits, equipment calibration, and reviews. Records shall be legible, identifiable, and traceable to the activity, product, or service. They should be readily retrievable; protected against damage, deterioration, and loss; and provided with retention times. Most organizations use some type of system for storage and retrieval of documents and records that can readily be adapted to ISO 14000.

4.5.4 EMS AUDIT

The purpose of this audit is to ensure that the EMS conforms to plans and is being properly implemented and maintained. Internal or self audit and external audit information should be distributed to senior management to assist in the management review process. Audit procedures should cover the scope, frequency and methodologies, and responsibilities and requirements for conducting audits and reporting results. The audit schedule should be based on the importance of the element and the results of previous audits. Additional information on audits is given in Chapter 8 (quality systems).

4.6 Management Review

Management review and revision, if applicable, is required to ensure the continuing suitability, adequacy, and effectiveness of the EMS. The intent of this clause is to involve top management in the EMS continuous improvement process. Management must evaluate the feedback data and make improvements to the system.

Reviews will most likely occur on a monthly basis and cover some of the elements at each review. A fixed schedule of reviews is required to cover all the elements. ISO 14004 recommends that the review include:

Review of environmental objectives and targets.

Review of environmental performance against legal and other requirements.

Evaluation of the effectiveness of the EMS's elements.

Evaluation of the continued suitability of the policy in light of changing legislation; changing expectations; changing requirements of interested parties; changes in activities, products, and services; new technology; lessons learned; market preferences and expectations; and effectiveness of reporting and communication.

Reviews should make use of information from audit reviews, performance information, changing circumstances, and the commitment to continuous improvement.

Benefits of EMS

EMS benefits can be categorized as global and organizational.

Global[4]

There are three global benefits: (1) facilitate trade and remove trade barriers, (2) improve environmental performance of planet earth, and (3) build consensus that there is a need for environmental management and a common terminology for EMS.

The proliferation of national and regional standards has led to confusion and to trade barriers. This international standard will serve to unify countries in their approach to labeling, environmental management, and life-cycle assessment. This approach also will help to remove trade barriers and facilitate trade. The drafters of the standard have been careful to avoid creating a document that will hamper trade. ISO 14000 provides the framework whereby its successful promotion within countries can lead to progress that will reassure the worldwide community. As the EMS is implemented worldwide, it will increasingly satisfy concerns for environmental protection in trade discussions and agreements.

Although the standard does not specify performance, it is reasonable to expect that ISO 14000 will play a significant role in environmental improvement worldwide. Because of the success of ISO 9000 in improving quality, we can reasonably expect that a significant improvement will occur in the environment. Based on data collected during registration audits, many ISO 14001 EMS lead auditors are convinced that an EMS does improve regulatory compliance.[5]

As the environmental standards are developed and implemented worldwide, it will build worldwide consensus that there is a need to use ISO 14000. In addition, a common terminology allows people in different countries to speak to each other, thereby sharing improvement ideas, prevention information, and system problems.

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[4] This section adapted from Joseph Cascio, Gayle Woodside, and Philip Mitchell, *ISO 14000 Guide* (New York: McGraw-Hill, 1996).

[5] Marilyn Block, "ISO 14001 and Regulatory Compliance," *Quality Progress* (February 2001): 84–85.

Organizational

According to ISO 14004, an organization benefits from an EMS in a number of ways as given below:

- Assuring customers of a commitment to environmental management.
- Meeting customer requirements, the primary reason for organizations to become certified.
- Maintaining a good public/community relations image.
- Satisfying investor criteria and improving access to capital.
- Obtaining insurance at reasonable cost.
- Increasing market share that results from a competitive advantage. After certification, Acushnet Rubber obtained more business from European customers.[6]
- Reducing incidents that result in liability. United Chem-Con Inc.'s plant in Lancing, NC is seeing a reduced potential for accidental releases of hazardous materials.[7]
- Improving defense posture in litigation.
- Conserving input materials and energy. Ford's Michigan truck facility reduced water consumption by almost one million gallons per day and also reduced energy consumption by replacing fluorescent bulbs with metal halide bulbs at a savings of $66,000 per year.[8]
- Facilitating the attainment of permits and authorization.
- Improving industry/government relations.

Many companies such as 3M, Ping, Ford, and Xerox have found that there are other organizational benefits than those given above. These are:

Cost effective. Between 1975, when their "Pollution Prevention Pays" program began, and 2000, 3M saved over $810 million in reduced air emissions, water discharge, and solid waste.[9]

Enhanced internal communications. Ping's design and production groups work with the environmental people prior to implementing any changes in order to evaluate the impact on employees, facilities, and the community.[10]

Effective decision-making. With useful data, management is better able to achieve goals and objectives.

Improved teamwork. By sharing responsibilities, employees feel that they are part of an organization that is doing the right thing.

Focus on prevention. Organizations become more proactive on improving the internal (workplace) and external environment.

Integrating ISO 14000 with ISO 9000

EMS implementation can seem like a time-consuming and costly undertaking. However, organizations that have implemented ISO 9001 have a distinct advantage over those that are unfamiliar with the process.

[6] Joe Lissenden.

[7] Ibid.

[8] Ibid.

[9] Ibid.

[10] Robert T. Driescher, "A Quality Swing With Ping," *Quality Progress* (August 2001): 37–41.

Depending on the company, 25 to 50% of the requirements may already be in place. Most registrars encourage organizations to integrate their EMS with their other management systems such as ISO 9001. By integrating the two systems, there will be less documentation and lower implementation cost.[11] Presently, ISO has a committee studying the two standards for the purpose of minimizing differences.

Ping, a golf equipment manufacturer, was certified to both ISO 9000 and ISO 14000. The audit took place in September 2000 with two quality auditors and two environmental auditors conducting a week-long assessment at Ping's headquarters in Phoenix and their golf bag manufacturer in Mexico. It is rare for a company the size of Ping (1000^+ employees) to achieve certification with no nonconformity reports on the first assessment.[12]

Relationship to Health and Safety

The ISO 14001 standard assumes that cultural transformation occurs through employee involvement and responsibility from the bottom up, not through dictates from the top. That assumption and other concepts present in the standard are applicable to health and safety. Therefore, it is reasonable to consider the use of the standard in an integrated approach that can bring about improvement for all three. For example, we can measure pollutants in employee's work environments to determine if it meets OHSAS permissible exposure level. Then we can monitor the occurrence of illnesses as recorded at the medical clinic and correlate those illnesses to measured airborne concentrations. In effect, we can measure progress in all three areas with a built-in efficiency and cost savings.[13]

The Automotive Research Association of India, Pune, is a service organization that provides research, development, testing and type approval services to automotive manufacturers. It has integrated ISO 9001 with ISO 14001 and OHSAS ISO 18001 since year 2004. The integrated approach has helped them in optimizing their resources and enhancing health and safety at work.[14]

Additional Comments

Many aspects of ISO 14000 are basically the same as ISO 9000; therefore, they are not repeated in this chapter. Refer to Chapter 8 for information on (1) implementation, (2) writing the documents, (3) internal audits, and (4) registration. For the most part, the word *environment* can be substituted for the word *quality*.

By the year 2007 there were about 1,30,000 organizations registered to ISO 14001 worldwide. Since its inception, the rate of growth has been increasing.

TQM Exemplary Organization[15]

The Orchid Hotel in Mumbai was established by the famous Indian Hospitality chain, Kamat Hotels, in the year 1997 and soon it became Asia's first Five Star hotel to win the ECOTEL certification. **ECOTEL**

[11] Joe Lissenden.

[12] Robert T. Driescher.

[13] Joe Cascio and Kent T. Baughn, "Health, Safety, and ISO 14001," Manufacturing Engineering (May 2000): 126–135.

[14] Rashmi Urdhwareshe, Deputy Director and Management Representative, Automotive Research Association of India, Pune.

[15] Malcolm Baldrige National Quality Award, 1992 Small Business Category Recipient, NIST/Baldrige Homepage, Internet.

certification is awarded by HVS Eco Services, a part of the reputed hospitality consulting giant, HVS International, U.S. The certification, which has been granted to less than 33 hotels worldwide, is an acknowledgement of the Orchid's comprehensive ground—up commitment to eco-sensitivity. Orchid Hotel is also the only ECOTEL to be certified to ISO 14001.

Vithal Kamat, Executive Chairman, Kamat Hotels in his famous book in Marathi “Idli, Orchid Aani Mee”, describes the journey to the success.[16]

The Orchid hotel is located in the most coveted and elite locality in Mumbai, next to the domestic airport. Ecological balance by the way of “Reduce-Reuse-Recycle” was chosen as the theme in the conception of this huge construction, which today houses 250 guest rooms.

Mumbai being the coastal city, experiences heavy rains during monsoon and has a hot and humid climate for the major part of the remaining year. Proximity to the busy airport and cargo hub posed the challenge for sound proofing of the interiors. The architecture ensures optimum utilization of natural light and air and also restricts entry of thermal and sound radiations. This has resulted in minimizing their electrical load requirements for central air-conditioning, lighting and noise isolation.

The construction of the building is done using eco-friendly materials such as special Portland cement, autoclaved aerated concrete, QED wall panels, etc. Water conservation is achieved by using aerators, special flush valves in wash rooms, recycling of water and ozone treatment. Interior structures like panels, frames, and doors are made from specially treated rubber wood or fiber wood, which otherwise are waste products. Conservation of electricity is further ensured by use of fuzzy logic controlled equipment and illumination devices. Heat exchangers are cleverly used for capturing thermal energy for useful purposes rather than wasting it. Bio waste is utilized in the wormiculture plant for producing high quality organic manure on which a beautiful orchid garden grown in the plush interiors.

In summary, the hotel claims that they are “zero garbage” hotel.

Employee involvement in eco-drive is also an important aspect of Orchid’s management principles. The employees of the hotel have created a “Green Team”. This team takes up several initiatives towards eco-restoration. Their recent objective is to complete plantation of at least 1,00,000 trees in the city of Mumbai during next 10 years. The hotel also involves their guests, nearby citizens, and schools in such initiatives and thus spread the movement of environmental management to all spheres of their influence.

Summary

Worldwide there is an increasing emphasis on environmental issues. Several standards are developed by ISO for Environmental Management System (EMS) in order guide the organizations to establish good processes. EMS is a part of comprehensive management system that addresses how the overall business activities impact the environment.

ISO 14000 series for EMS is divided into two separate areas, the organization evaluation standards (ISO 14001, 14004, 14031, 19011) and the product evaluation standards (ISO Guide 64, 14020, 14021, 14024, 14025, 14040 and 14044). The organizational evaluation standards are operational and effective. Development of product evaluation standards is more difficult.

ISO 14001 is applicable to all types and sizes of organizations and its requirements are based on processes. Many of the requirements can be easily implemented in other quality systems standards like ISO 9001.

[16] “Idli, Orchid Aani Mee” by Vithal Kamat, Majestic Publication.

EMS implementation results in benefits of improved environment, establishing regulatory compliance, conservation of material and energy inputs, improvement in community relationship, etc. OHSAS 18001 provides an integrated approach towards health and safety.

Exercises

1. Why are the product evaluation standards in the development stage?
2. How does the conceptual approach to ISO 14001 differ from ISO 9001?
3. What is the overall aim of the EMS standard?
4. How is the aim achieved?
5. Which of the elements in ISO 9001 are similar to ISO 14001?
6. Individually or with a team of three or more people, develop a self-assessment questionnaire for ISO 14001.
7. Individually or with a team of three or more people, determine which three EMS benefits would be most important for a hospital, oil company, pharmaceutical company, university, food processor, paint manufacturer, and paper manufacturer.
8. Using the building where you live, determine the environmental aspects and impacts. Establish hypothetical objectives and targets.
9. Visit an organization in your community and determine if their accident and emergency preparedness plan meets the ISO 14001 criteria.
10. You have been appointed the EMS management representative for your organization. Develop a plan to become registered.
11. Match the pairs:

1	ISO 14001	A	Guidelines for EMS auditing
2	ISO 14004	B	Guidelines on principles, systems and supporting techniques
3	ISO 19011	C	Environmental Labelling Basic Principles
4	ISO Guide 64	D	Environmental Labelling Type III declarations
5	ISO 14020	E	Specifications with guidance for use
6	ISO 14025	F	Life Cycle Assessment—Requirements and guidelines
7	ISO 14044	G	EPAS

12. State whether True or False

    1. Experience of ISO 14000 development made it easier to develop ISO 9000 series.

    2. ISO 14000 series is divided into two separate areas, organization evaluation and product evaluation.

3. ISO 14000 series is primarily applicable for manufacturing organizations.

4. Organizations having implemented ISO 9001 find it difficult to integrate the requirements of ISO 14001.

13. Identify the standard for quality and environmental management systems auditing

(a) ISO 9004
(b) ISO 14001
(c) ISO 14004
(d) ISO 19011

14. The appropriate documentation hierarchy is

(a) Policy-practice-procedure-evidence
(b) Policy-procedure-evidence-practice
(c) Policy-procedure-practice-evidence
(d) Vision-mission-policy-goals

Author Queries

AQ1: Chapter 9 has been deleted pls check this text.

10

Quality Function Deployment

Chapter Objectives

- Brief overview of the historical background of quality function deployment (QFD) and use of QFD as a planning tool
- Understanding the benefits of QFD
- How to capture the voice of the customer and organize the information
- Understanding the structured process of developing House of Quality
- Understand the applications of QFD

Introduction

Dr. Mizuno, professor emeritus of the Tokyo Institute of Technology, is credited with initiating the quality function deployment (QFD) system. The first application of QFD was at Mitsubishi, Heavy Industries, Ltd., in the Kobe Shipyard, Japan, in 1972. After four years of case study development, refinement, and training. QFD was successfully implemented in the production of mini-vans by Toyota. Using 1977 as a base, a 20% reduction in startup costs was reported in the launch of the new van in October 1979, a 38% reduction by November 1982, and a cumulative 61% reduction by April 1984. Quality function deployment was first introduced in the United States in 1984 by Dr. Clausing of Xerox. QFD can be applied to practically any manufacturing or service industry. It has become a standard practice by most leading organizations, who also require it of their suppliers.

Quality function deployment (QFD) is a planning tool used to fulfill customer expectations. It is a disciplined approach to product design, engineering, and production and provides in-depth evaluation of a product. An organization that correctly implements QFD can improve engineering knowledge, productivity, and quality and reduce costs, product development time, and engineering changes.

Quality function deployment focuses on customer expectations or requirements, often referred to as the voice of the customer. It is employed to translate customer expectations, in terms of specific requirements, into directions and actions, in terms of engineering or technical characteristics, that can be deployed through:

Product planning

Part development

Process planning

Production planning

Service industries

Quality function deployment is a team-based management tool in which customer expectations are used to drive the product development process. Conflicting characteristics or requirements are identified early in the QFD process and can be resolved before production.

Organizations today use market research to decide what to produce to satisfy customer requirements. Some customer requirements adversely affect others, and customers often cannot explain their expectations. Confusion and misinterpretation are also a problem while a product moves from marketing to design to engineering to manufacturing. This activity is where the voice of the customer becomes lost and the voice of the organization adversely enters the product design. Instead of working on what the customer expects, work is concentrated on fixing what the customer does not want. In other words, it is not productive to improve something the customer did not want initially. By implementing QFD, an organization is guaranteed to implement the voice of the customer in the final product or service.

Quality function deployment helps identify new quality technology and job functions to carry out operations. This tool provides a historic reference to enhance future technology and prevent design errors. QFD is primarily a set of graphically oriented planning matrices that are used as the basis for decisions affecting any phase of the product development cycle. Results of QFD are measured based on the number of design and engineering changes, time to market, cost, and quality. It is considered by many experts to be a perfect blueprint for quality by design.

Quality function deployment enables the design phase to concentrate on the customer requirements, thereby spending less time on redesign and modifications. The saved time has been estimated at one-third to one-half of the time taken for redesign and modification using traditional means. This saving means reduced development cost and also additional income because the product enters the market sooner.

The QFD Team

When an organization decides to implement QFD, the project manager and team members need to be able to commit a significant amount of time to it, especially in the early stages. The priorities of the projects need to be defined and told to all departments within the organization so team members can budget their time accordingly. Also, the scope of the project must be clearly defined so questions about why the team was formed do not arise. One of the most important tools in the QFD process is communication.

There are two types of teams—designing a new product or improving an existing product. Teams are composed of members from marketing, design, quality, finance, and production. The existing product team usually has fewer members, because the QFD process will only need to be modified. Time and inter-team communication are two very important things that each team must utilize to their fullest potential. Using time effectively is the essential resource in getting the project done on schedule. Using inter-team communication to its fullest extent will alleviate unforeseen problems and make the project run smoothly.

Team meetings are very important in the QFD process. The team leader needs to ensure that the meetings are run in the most efficient manner and that the members are kept informed. The meeting format should have some way of measuring how well the QFD process is working at each meeting and should be flexible, depending on certain situations. The duration of the meeting will rely on where the team's members are coming from

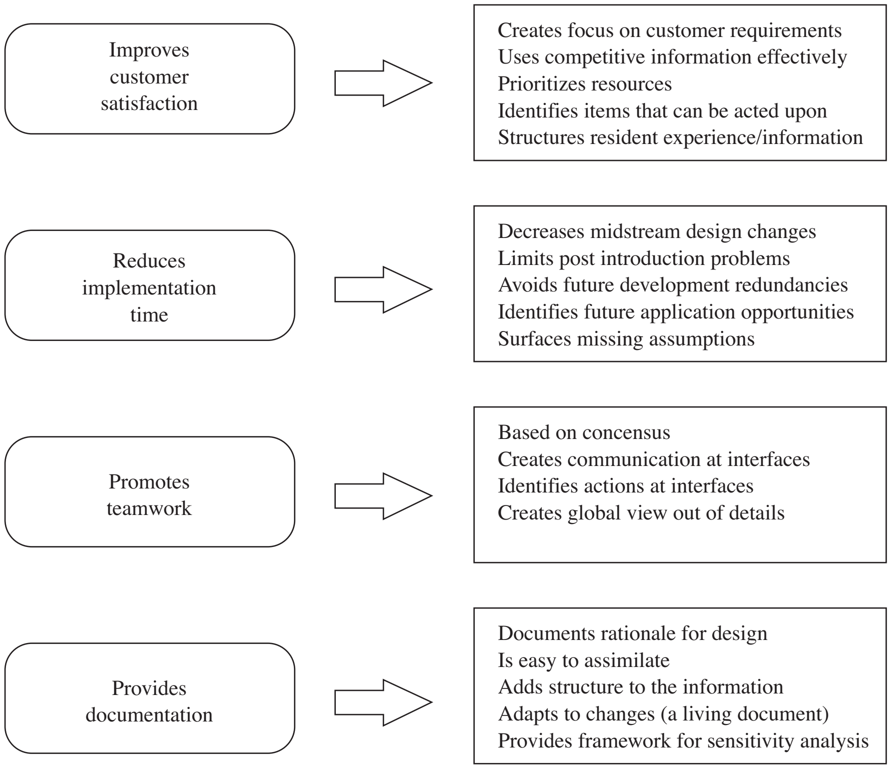

Figure 10-1 Benefits of QFD
Reproduced with permission from James L. Brossert, *Quality Function Deployment—A Practitioner's Approach* (Milwaukee, WI: ASQC Quality Press, 1991).

and what needs to be accomplished. These workshops may have to last for days if people are coming from around the world or for only hours if everyone is local. There are advantages to shorter meetings, and sometimes much more can be accomplished in a shorter meeting. Shorter meetings allow information to be collected between times that will ensure that the right information is being entered into the QFD matrix. Also, they help keep the team focused on a quality improvement goal.

Benefits of QFD

Quality function deployment was originally implemented to reduce start-up costs. Organizations using QFD have reported a reduced product development time. For example, U.S. car manufacturers of the late 1980s and early 1990s needed an average of five years to put a product on the market, from drawing board to showroom, whereas Honda put a new product on the market in two and a half years and Toyota did it in three years. Both organizations credit this reduced time to the use of QFD. Product quality and, consequently, customer satisfaction improve with QFD due to numerous factors depicted in Figure 10-1.

Improves Customer Satisfaction

Quality function deployment looks past the usual customer response and attempts to define the requirements in a set of basic needs, which are compared to all competitive information. All competitors are evaluated equally from customer and technical perspectives. This information can then be prioritized using a Pareto diagram. Management can then place resources where they will be the most beneficial in improving quality. Also, QFD takes the experience and information that are available within an organization and puts them together as a structured format that is easy to assimilate. This is important when an organization's employee leaves a particular project and a new employee is hired.

Reduces Implementation Time

Fewer engineering changes are needed when using QFD, and, when used properly, all conflicting design requirements can be identified and addressed prior to production. This results in a reduction in retooling, operator training, and changes in traditional quality control measures. By using QFD, critical items are identified and can be monitored from product inception to production. Toyota reports that the quality of their product has improved by one-third since the implementation of QFD.

Promotes Teamwork

Quality function deployment forces a horizontal deployment of communication channels. Inputs are required from all facets of an organization, from marketing to production to sales, thus ensuring that the voice of the customer is being heard and that each department knows what the other is doing. This activity avoids misinterpretation, opinions, and miscues. In other words, the left hand always knows what the right hand is doing. Efficiency and productivity always increase with enhanced teamwork.

Provides Documentation

A database for future design or process improvements is created. Data that are historically scattered within operations, frequently lost and often referenced out of context, are now saved in an orderly manner to serve future needs. This database also serves as a training tool for new engineers. Quality function deployment is also very flexible when new information is introduced or things have to be changed on the QFD matrix.

The Voice of the Customer

Because QFD concentrates on customer expectations and needs, a considerable amount of effort is put into research to determine customer expectations. This process increases the initial planning stage of the project definition phase in the development cycle. But the result is a total reduction of the overall cycle time in bringing to the market a product that satisfies the customer.

The driving force behind QFD is that the customer dictates the attributes of a product. Customer satisfaction, like quality, is defined as meeting or exceeding customer expectations. Words used by the customers to describe their expectations are often referred to as the voice of the customer. Sources for determining customer expectations are focus groups, surveys, complaints, consultants, standards, and federal regulations. Frequently, customer expectations are vague and general in nature. It is the job of the QFD team to analyze these customer expectations into more specific customer requirements. Customer requirements must be taken literally and not incorrectly translated into what organization officials desire.

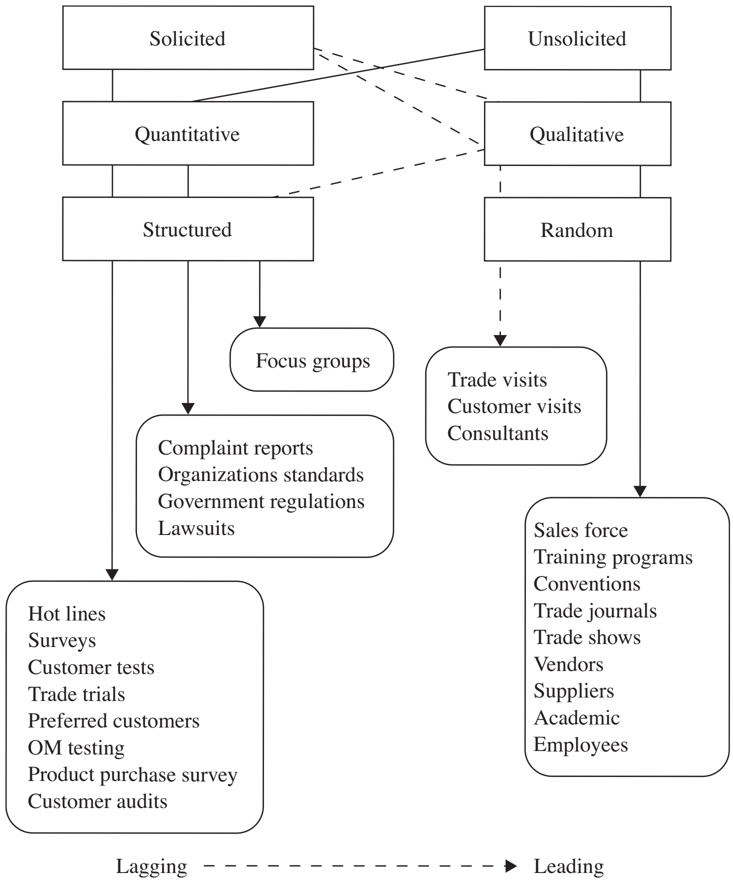

Figure 10-2 Types of Customer Information and How to Collect It
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Quality function deployment begins with marketing to determine what exactly the customer desires from a product. During the collection of information, the QFD team must continually ask and answer numerous questions, such as

What does the customer really want?

What are the customer's expectations?

Are the customer's expectations used to drive the design process?

What can the design team do to achieve customer satisfaction?

There are many different types of customer information and ways that an organization can collect data, as shown in Figure 10-2. The organization can search (solicited) for the information, or the information can be volunteered (unsolicited) to the organization. Solicited and unsolicited information can be further categorized into measurable (quantitative) or subjective (qualitative) data. Furthermore, qualitative information can be found in a routine (structured) manner or haphazard (random) manner.

Customer information, sources, and ways an organization can collect data can be described as follows:

Solicited, measurable, and routine data are typically found by customer surveys, market surveys, and trade trials; working with preferred customers; analyzing products from other manufacturers; and buying back products from the field. This information tells an organization how it is performing in the current market.

Unsolicited, measurable, and routine data tend to take the form of customer complaints or lawsuits. This information is generally disliked; however, it provides valuable learning information.

Solicited, subjective, and routine data are usually gathered from focus groups. The object of these focus groups is to find out the likes, dislikes, trends, and opinions about current and future products.

Solicited, subjective, and haphazard data are usually gathered from trade visits, customer visits, and independent consultants. These types of data can be very useful; however, they can also be misleading, depending on the quantity and frequency of information.

Unsolicited, subjective, and haphazard data are typically obtained from conventions, vendors, suppliers, and employees. This information is very valuable and often relates the true voice of the customer.

The goal of QFD is not only to meet as many customer expectations and needs as possible, but also to exceed customer expectations. Each QFD team must make its product either more appealing than the existing product or more appealing than the product of a competitor. This situation implies that the team has to introduce an expectation or need in its product that the customer is not expecting but would appreciate. For example, cup holders were put into automobiles as an extra bonus, but customers liked them so well that they are now expected in all new automobiles.

Organization of Information

Now that the customer expectations and needs have been identified and researched, the QFD team needs to process the information. Numerous methods include affinity diagrams, interrelationship diagrams, tree diagrams, and cause-and-effect diagrams. These methods are ideal for sorting large amounts of information. The affinity diagram, which is ideally suited for most QFD applications, is discussed next.

Affinity Diagram

The affinity diagram (see Chapter 17) is a tool that gathers a large amount of data and subsequently organizes the data into groupings based on their natural interrelationships. An affinity diagram should be implemented when

Thoughts are too widely dispersed or numerous to organize.

New solutions are needed to circumvent the more traditional ways of problem solving.

Support for a solution is essential for successful implementation.

This method should not be used when the problem is simple or if a quick solution is needed. The team needed to accomplish this goal effectively should be a multidisciplinary one that has the needed knowledge to delve into the various areas of the problem. A team of six to eight members should be adequate to assimilate all of the thoughts. Constructing an affinity diagram requires four simple steps:

1. Phrase the objective.
2. Record all responses.

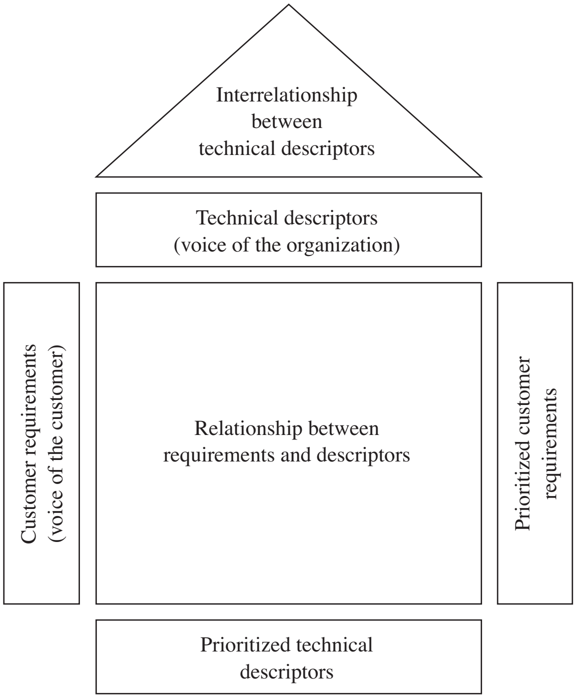


Figure 10-3 House of Quality
Reproduced with permission from James L. Brossert, *Quality Function Deployment—A Practitioner's Approach* (Milwaukee, WI: ASQC Quality Press, 1991).

3. Group the responses.
4. Organize groups in an affinity diagram.

The first step is to phrase the objective in a short and concise statement. It is imperative that the statement be as generalized and vague as possible.

The second step is to organize a brainstorming session in which responses to this statement are individually recorded on cards and listed on a pad. It is sometimes helpful to write down a summary of the discussion on the back of the cards so that, in the future when the cards are reviewed, the session can be briefly explained.

Next, all the cards should be sorted by placing the cards that seem to be related into groups. Then, a card or word is chosen that best describes each related group, which becomes the heading for each group of responses. Finally, lines are placed around each group of responses, and related clusters are placed near each other with a connecting line.

House of Quality

The primary planning tool used in QFD is the house of quality. The house of quality translates the voice of the customer into design requirements that meet specific target values and matches those against how an organization will meet those requirements. Many managers and engineers consider the house of quality to be the primary chart in quality planning.

The structure of QFD can be thought of as a framework of a house, as shown in Figure 10-3.

The parts of the house of quality are described as follows:

The exterior walls of the house are the customer requirements. On the left side is a listing of the voice of the customer, or what the customer expects in the product. On the right side are the prioritized customer requirements, or planning matrix. Listed are items such as customer benchmarking, customer importance rating, target value, scale-up factor, and sales point.

The ceiling, or second floor, of the house contains the technical descriptors. Consistency of the product is provided through engineering characteristics, design constraints, and parameters.

The interior walls of the house are the relationships between customer requirements and technical descriptors. Customer expectations (customer requirements) are translated into engineering characteristics (technical descriptors).

The roof of the house is the interrelationship between technical descriptors. Trade-offs between similar and/or conflicting technical descriptors are identified.

The foundation of the house is the prioritized technical descriptors. Items such as the technical benchmarking, degree of technical difficulty, and target value are listed.

This is the basic structure for the house of quality; once this format is understood, any other QFD matrices are fairly straightforward.

Building a House of Quality

The matrix that has been mentioned may appear to be confusing at first, but when one examines each part individually, the matrix is significantly simplified. A basic house of quality matrix is shown in Figure 10-4. There is a considerable amount of information contained within this matrix. It is easier to understand once each part of the matrix is discussed in detail.

Step 1—List Customer Requirements (WHATs)

Quality function deployment starts with a list of goals/objectives. This list is often referred as the WHATs that a customer needs or expects in a particular product. This list of primary customer requirements is usually vague and very general in nature. Further definition is accomplished by defining a new, more detailed list of secondary customer requirements needed to support the primary customer requirements. In other words, a primary customer requirement may encompass numerous secondary customer requirements. Although the items on the list of secondary customer requirements represent greater detail than those on the list of primary customer requirements, they are often not directly actionable by the engineering staff and require yet further definition. Finally, the list of customer requirements is divided into a hierarchy of primary, secondary, and tertiary customer requirements, as shown in Figure 10-5. For example, a primary customer requirement might be dependability and the corresponding secondary customer requirements could include reliability, longevity, and maintainability.

EXAMPLE PROBLEM

A company that manufactures bicycle components such as cranks, hubs, rims, and so forth wants to expand their product line by also producing handlebar stems for mountain bikes. Begin the development process of designing a handlebar stem for a mountain bike by first listing the customer requirements or WHAT the customer needs or expects in a handlebar stem.

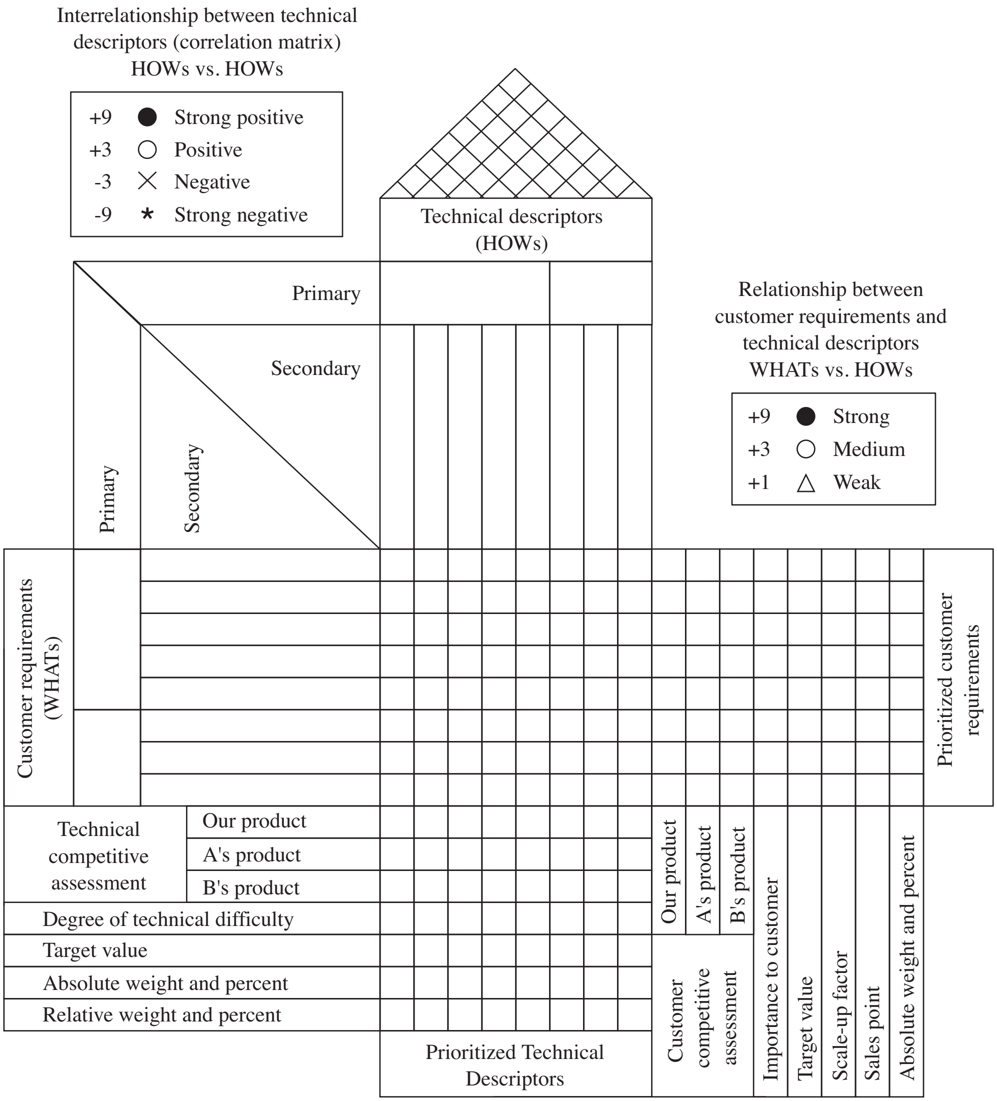


Figure 10-4 Basic House of Quality Matrix

Two primary customer requirements might be aesthetics and performance. Secondary customer requirements under aesthetics might be reasonable cost, aerodynamic look, nice finish, and corrosion resistance. Although reasonable cost is not considered aesthetics, it will be placed under that category for the sake of this example. Secondary customer requirements under performance might be light weight, strength, and durability. Many other customer requirements could be listed; however, for simplicity, only the aforementioned ones will be used. Furthermore, it is not necessary to break down the customer requirements to the tertiary level. These primary and secondary customer requirements are shown in Figure 10-5.

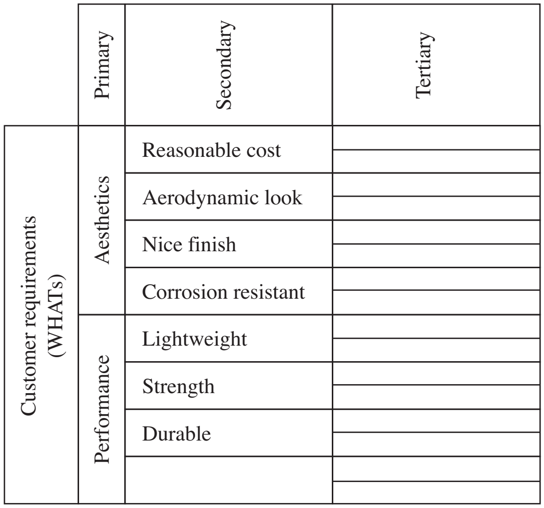


Figure 10-5 Refinement of Customer Requirements

Step 2—List Technical Descriptors (HOWs)

The goal of the house of quality is to design or change the design of a product in a way that meets or exceeds the customer expectations. Now that the customer needs and expectations have been expressed in terms of customer requirements, the QFD team must come up with engineering characteristics or technical descriptors (HOWs) that will affect one or more of the customer requirements. These technical descriptors make up the ceiling, or second floor, of the house of quality. Each engineering characteristic must directly affect a customer perception and be expressed in measurable terms.

Implementation of the customer requirements is difficult until they are translated into counterpart characteristics. Counterpart characteristics are an expression of the voice of the customer in technical language. Each of the customer requirements is broken down into the next level of detail by listing one or more primary technical descriptors for each of the tertiary customer requirements. This process is similar to refining marketing specifications into system-level engineering specifications. Further definition of the primary technical descriptors is accomplished by defining a list of secondary technical descriptors that represent greater detail than those on the list of primary technical descriptors. This is similar to the process of translating system-level engineering specifications into part-level specifications. These secondary technical descriptors can include part specifications and manufacturing parameters that an engineer can act upon. Often the secondary technical descriptors are still not directly actionable, requiring yet further definition. This process of refinement is continued until every item on the list is actionable. Finally, the list of technical descriptors is divided into a hierarchy of primary, secondary, and tertiary technical descriptors, as shown in Figure 10-6.

This level of detail is necessary because there is no way of ensuring successful realization of a technical descriptor that the engineering staff does not know how to accomplish. The process of refinement is further complicated by the fact that through each level of refinement, some technical descriptors affect more than one customer requirement and can even adversely affect one another. For example, a customer requirement for an automobile might be a smooth ride. This is a rather vague statement; however, it is important in the selling of an automobile. Counterpart characteristics for a smooth ride could be dampening, anti-roll, and stability

	Primary	Secondary	Tertiary
Technical descriptors (HOWs)	Material selection	Steel	
		Aluminum	
		Titanium	
	Manufacturing process	Welding	
		Die casting	
		Sand casting	
		Forging	
		Powder metallurgy	

Figure 10-6 Refinement of Technical Descriptors

requirements, which are the primary technical descriptors. Brainstorming among the engineering staff is a suggested method for determining the technical descriptors.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Example) by listing the technical descriptors or HOW the company will design a handlebar stem.

Two primary technical descriptors might be material selection and manufacturing process. Secondary technical descriptors under material selection might be steel, aluminum, and titanium. Secondary technical descriptors under manufacturing process might be welding, die casting, sand casting, forging, and powder metallurgy. Numerous other technical descriptors could be listed, such as finishing process and type of bolt, to name a few; however, for simplicity, only the aforementioned ones will be used. Furthermore, it is not necessary to break down the technical descriptors to the tertiary level. These primary and secondary technical descriptors are shown in Figure 10-6.

Step 3—Develop a Relationship Matrix Between WHATs and HOWs

The next step in building a house of quality is to compare the customer requirements and technical descriptors and determine their respective relationships. Tracing the relationships between the customer requirements and the technical descriptors can become very confusing, because each customer requirement may affect more than one technical descriptor, and vice versa.

STRUCTURING AN L-SHAPED DIAGRAM

One way to reduce the confusion associated with determining the relationships between customer requirements and technical descriptors is to use an L-shaped matrix, as shown in Figure 10-7. The L shape, which is a two-dimensional relationship that shows the intersection of related pairs of items, is constructed by turning

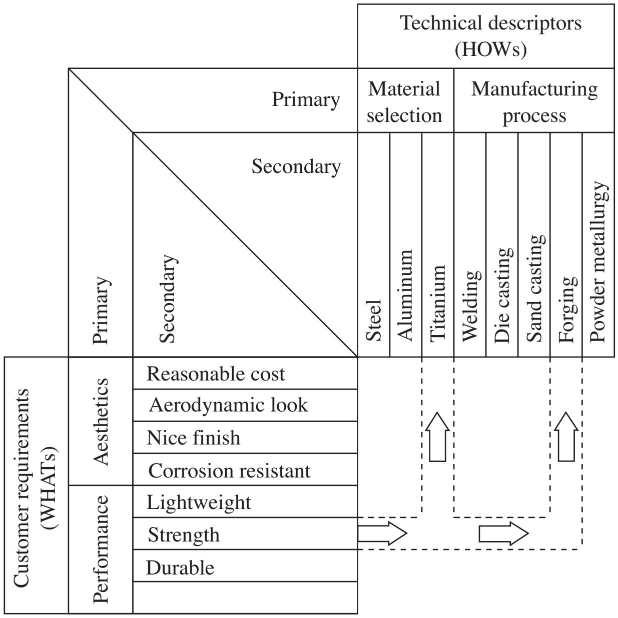


Figure 10-7 Structuring an L-Shaped Diagram

the list of technical descriptors perpendicular to the list of customer requirements. The L-shaped matrix makes interpreting the complex relations very easy and does not require a significant amount of experience.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by structuring an L-shaped diagram.

The L shape is constructed by turning the list of technical descriptors (see Figure 10-6) perpendicular to the list of customer requirements (see Figure 10-5). The L-shaped diagram for designing a handlebar stem for a mountain bike is shown in Figure 10-7.

RELATIONSHIP MATRIX

The inside of the house of quality, called the relationship matrix, is now filled in by the QFD team. The relationship matrix is used to represent graphically the degree of influence between each technical descriptor and each customer requirement. This step may take a long time, because the number of evaluations is the product of the number of customer requirements and the number of technical descriptors. Doing this early in the development process will shorten the development cycle and lessen the need for future changes.

It is common to use symbols to represent the degree of relationship between the customer requirements and technical descriptors. For example,

A solid circle represents a strong relationship.

A single circle represents a medium relationship.

Customer requirements (WHATs)		Technical descriptors (HOWs)							
Primary	Secondary	Material selection			Manufacturing process				
		Steel	Aluminum	Titanium	Welding	Die casting	Sand casting	Forging	Powder metallurgy
Aesthetics	Reasonable cost	●	●	△	●	○	●	○	△
	Aerodynamic look		△	△	△	●	○	○	●
	Nice finish	○	●	●	△	●	△	○	●
	Corrosion resistant	△	●	●	△	○	○	○	○
Performance	Lightweight	△	●	●					△
	Strength	●	○	●	△	○	○	●	△
	Durable	●	○	○	△	●	○	●	○

Relationship between customer requirements and technical descriptors WHATs vs. HOWs

+ 9	●	Strong
+ 3	○	Medium
+ 1	△	Weak

Figure 10-8 Adding Relationship Matrix to the House of Quality

A triangle represents a weak relationship.

The box is left blank if no relationship exists.

It can become difficult to comprehend and interpret the matrix if too many symbols are used. Each degree of relationship between a customer requirement and a technical descriptor is defined by placing the respective symbol at the intersection of the customer requirement and technical descriptor, as shown in Figure 10-8. This method allows very complex relationships to be depicted and interpreted with very little experience.

The symbols that are used to define the relationships are now replaced with numbers; for example,

● = 9
○ = 3
△ = 1

These weights will be used later in determining trade-off situations for conflicting characteristics and determining an absolute weight at the bottom of the matrix.

After the relationship matrix has been completed, it is evaluated for empty rows or columns. An empty row indicates that a customer requirement is not being addressed by any of the technical descriptors. Thus, the customer expectation is not being met. Additional technical descriptors must be considered in order to satisfy that particular customer requirement. An empty column indicates that a particular technical descriptor does not affect any of the customer requirements and, after careful scrutiny, may be removed from the house of quality.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by adding the relationship matrix to the house of quality.

The relationship matrix is constructed by assigning symbols or numbers to represent the degree of influence between each technical descriptor and each customer requirement. For instance, the relationship between the customer requirement of lightweight and the technical descriptor of steel would be weak (+ 1) because steel is heavier than aluminum and titanium. Conversely, the relationship between the customer requirement of reasonable cost and the technical descriptor of steel would be strong (+ 9) because steel is cheaper than aluminum and titanium. The relationship matrix for designing a handlebar stem for a mountain bike is shown in Figure 10-8. Empty spaces indicate that no relationship exists.

Step 4—Develop an Interrelationship Matrix Between HOWs

The roof of the house of quality, called the correlation matrix, is used to identify any interrelationships between each of the technical descriptors. The correlation matrix is a triangular table attached to the technical descriptors, as shown in Figure 10-9. Symbols are used to describe the strength of the interrelationships; for example,

A solid circle represents a strong positive relationship.

A circle represents a positive relationship.

An X represents a negative relationship.

An asterisk represents a strong negative relationship.

The symbols describe the direction of the correlation. In other words, a strong positive interrelationship would be a nearly perfectly positive correlation. A strong negative interrelationship would be a nearly perfectly negative correlation. This diagram allows the user to identify which technical descriptors support one another and which are in conflict. Conflicting technical descriptors are extremely important because they are frequently the result of conflicting customer requirements and, consequently, represent points at which tradeoffs must be made. Tradeoffs that are not identified and resolved will often lead to unfulfilled requirements, engineering changes, increased costs, and poorer quality. Some of the tradeoffs may require high-level managerial decisions, because they cross functional area boundaries. Even though difficult, early resolution of tradeoffs is essential to shorten product development time.

An example of tradeoffs is in the design of a car, where the customer requirements of high fuel economy and safety yield technical descriptors that conflict. The added weight of stronger bumpers, air bags, antilock brakes, and the soon-to-come federal side-impact standards will ultimately reduce the fuel efficiency of the car. In the case of conflicting technical descriptors, Taguchi methods (see Chapter 20) can be implemented, or pure common sense dictates.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by adding the interrelationship matrix to the house of quality.

The interrelationship matrix is constructed by assigning symbols or numbers to represent the degree of correlation (positive or negative) between each of the technical descriptors. For instance, the interrelationship between the technical descriptors of titanium and sand casting would be a strong negative (− 9) correlation because a titanium part would never be sand cast. Conversely, the interrelationship between the technical descriptors of

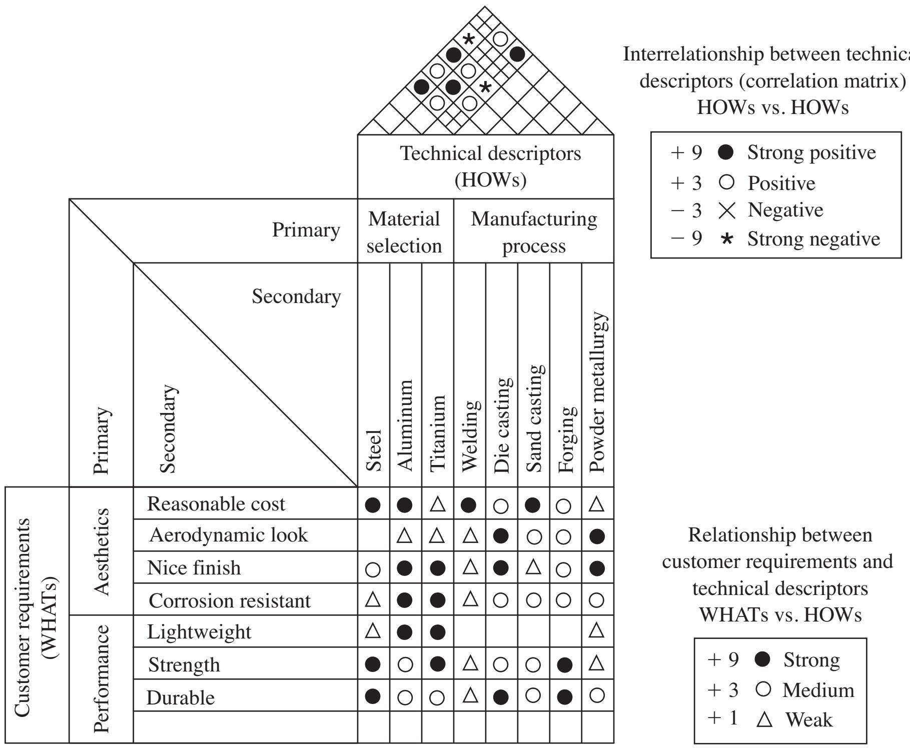


Figure 10-9 Adding Interrelationship Matrix to the House of Quality

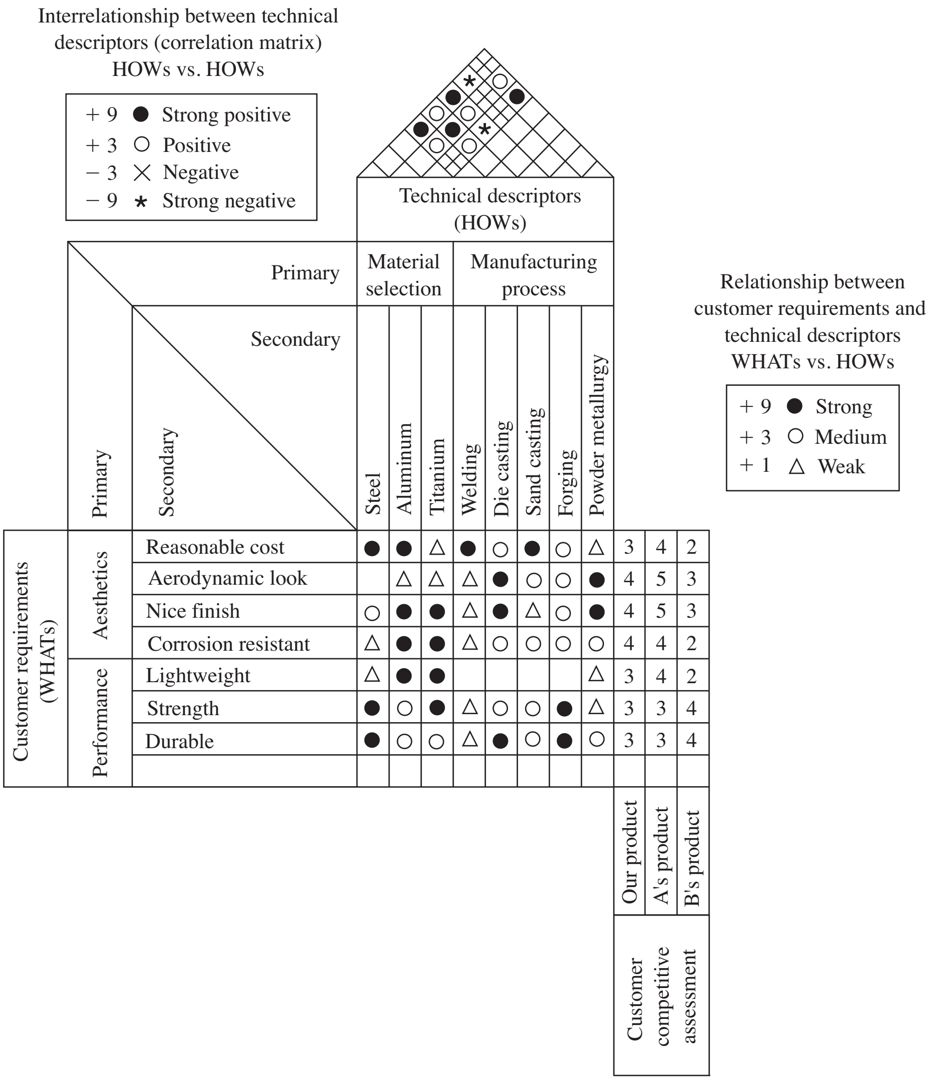
aluminum and die casting would be a strong positive (+ 9) correlation because aluminum is usually die cast. The interrelationship matrix for designing a handlebar stem for a mountain bike is shown in Figure 10-9. Empty spaces indicate that no correlation exists, either positive or negative.

Step 5—Competitive Assessments

The competitive assessments are a pair of weighted tables (or graphs) that depict item for item how competitive products compare with current organization products. The competitive assessment tables are separated into two categories, customer assessment and technical assessment, as shown in Figures 10-10 and 10-11, respectively.

CUSTOMER COMPETITIVE ASSESSMENT

The customer competitive assessment is the block of columns corresponding to each customer requirement in the house of quality on the right side of the relationship matrix, as shown in Figure 10-10. The numbers 1 through 5 are listed in the competitive evaluation column to indicate a rating of 1 for worst and 5 for best. These rankings can also be plotted across from each customer requirement, using different symbols for each product.



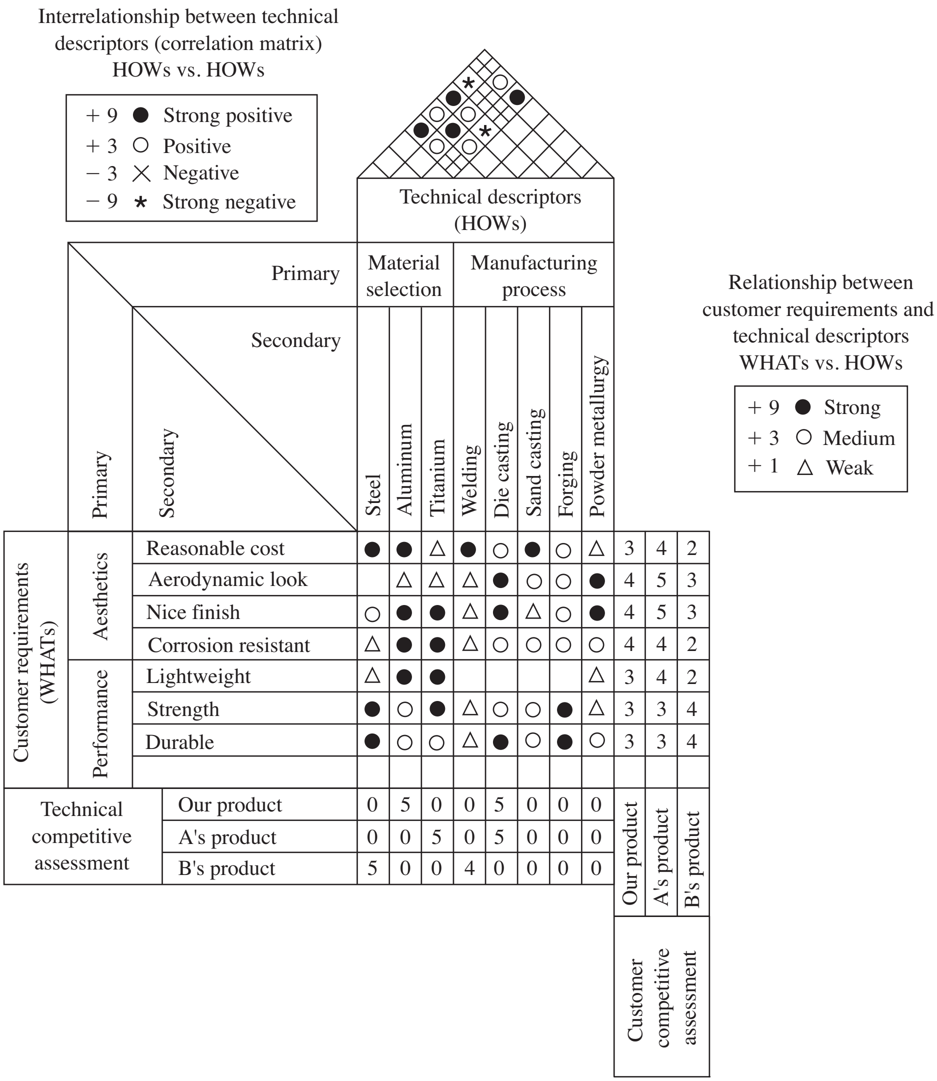
Requirement	Steel	Aluminum	Titanium	Welding	Die casting	Sand casting	Forging	Powder metallurgy	Our product	A's product	B's product
Reasonable cost	●	●	△	●	○	●	○	△	3	4	2
Aerodynamic look		△	△	△	●	○	○	●	4	5	3
Nice finish	○	●	●	△	●	△	○	●	4	5	3
Corrosion resistant	△	●	●	△	○	○	○	○	4	4	2
Lightweight	△	●	●					△	3	4	2
Strength	●	○	●	△	○	○	●	△	3	3	4
Durable	●	○	○	△	●	○	●	○	3	3	4

Figure 10-10 Adding Customer Competitive Assessment to the House of Quality

The customer competitive assessment is a good way to determine if the customer requirements have been met and identify areas to concentrate on in the next design. The customer competitive assessment also contains an appraisal of where an organization stands relative to its major competitors in terms of each customer requirement. Both assessments are very important, because they give the organization an understanding on where its product stands in relationship to the market.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by adding the customer competitive assessment to the house of quality.



		Steel	Aluminum	Titanium	Welding	Die casting	Sand casting	Forging	Powder metallurgy	Our product	A's product	B's product
Aesthetics	Reasonable cost	●	●	△	●	○	●	○	△	3	4	2
	Aerodynamic look		△	△	△	●	○	○	●	4	5	3
	Nice finish	○	●	●	△	●	△	○	●	4	5	3
	Corrosion resistant	△	●	●	△	○	○	○	○	4	4	2
Performance	Lightweight	△	●	●					△	3	4	2
	Strength	●	○	●	△	○	○	●	△	3	3	4
	Durable	●	○	○	△	●	○	●	○	3	3	4
Technical competitive assessment	Our product	0	5	0	0	5	0	0	0			
	A's product	0	0	5	0	5	0	0	0			
	B's product	5	0	0	4	0	0	0	0			

Figure 10-11 Adding Technical Competitive Assessment to the House of Quality

The customer competitive assessment is constructed by assigning ratings for each customer requirement from 1 (worst) to 5 (best) for the new handlebar stem and major competitor A's and B's handlebar stem. The customer competitive assessment for designing a handlebar stem for a mountain bike is shown in Figure 10-10.

TECHNICAL COMPETITIVE ASSESSMENT

The technical competitive assessment makes up a block of rows corresponding to each technical descriptor in the house of quality beneath the relationship matrix, as shown in Figure 10-11. After respective units have been established, the products are evaluated for each technical descriptor.

Similar to the customer competitive assessment, the test data are converted to the numbers 1 through 5, which are listed in the competitive evaluation row to indicate a rating, 1 for worst and 5 for best. These rankings can then be entered below each technical descriptor using the same numbers as used in the customer competitive assessment.

The technical competitive assessment is often useful in uncovering gaps in engineering judgment. When a technical descriptor directly relates to a customer requirement, a comparison is made between the customer's competitive evaluation and the objective measure ranking.

Customer requirements and technical descriptors that are strongly related should also exhibit a strong relationship in their competitive assessments. If an organization's technical assessment shows its product to be superior to the competition, then the customer assessment should show a superior assessment. If the customer disagrees, then a mistake in engineering judgment has occurred and should be corrected.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by adding the technical competitive assessment to the house of quality.

The technical competitive assessment is constructed by assigning ratings for each technical descriptor from 1 (worst) to 5 (best) for the new handlebar stem and major competitor A's and B's handlebar stem. The technical competitive assessment for designing a handlebar stem for a mountain bike is shown in Figure 10-11.

Step 6—Develop Prioritized Customer Requirements

The prioritized customer requirements make up a block of columns corresponding to each customer requirement in the house of quality on the right side of the customer competitive assessment as shown in Figure 10-12. These prioritized customer requirements contain columns for importance to customer, target value, scale-up factor, sales point, and an absolute weight.

IMPORTANCE TO CUSTOMER

The QFD team—or, preferably, the focus group—ranks each customer requirement by assigning it a rating. Numbers 1 through 10 are listed in the importance to customer column to indicate a rating of 1 for least important and 10 for very important. In other words, the more important the customer requirement, the higher the rating.

Importance ratings represent the relative importance of each customer requirement in terms of each other. Assigning ratings to customer requirements is sometimes difficult, because each member of the QFD team might believe different requirements should be ranked higher. The importance rating is useful for prioritizing efforts and making trade-off decisions.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by determining the importance to customer of each customer requirement.

The importance to customer is determined by rating each customer requirement from 1 (least important) to 10 (very important). For instance, if light weight is important to the customer, then it could be assigned a value of 7. Conversely, if durability is not very important to the customer, then it could be assigned a value of 3. The importance to customer for designing a handlebar stem for a mountain bike is shown in Figure 10-12.

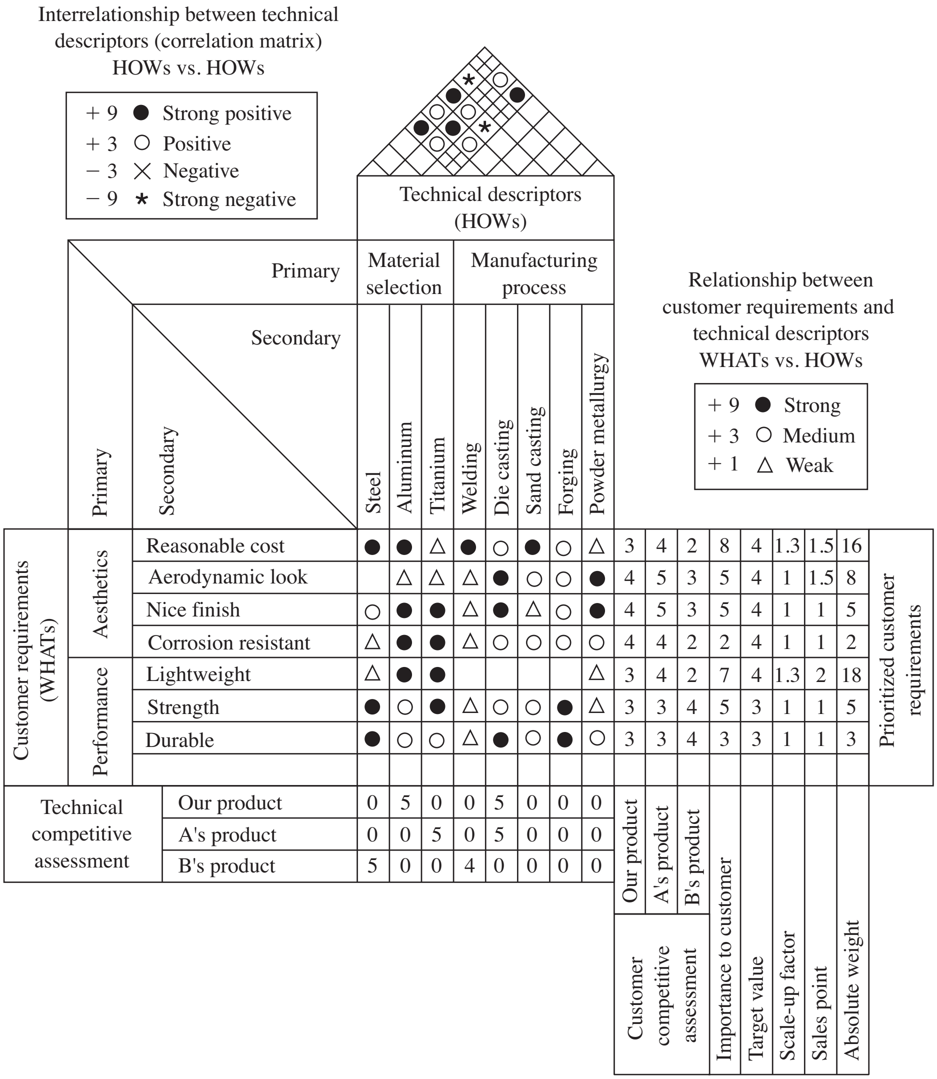


Figure 10-12 Adding Prioritized Customer Requirements to the House of Quality

TARGET VALUE

The target-value column is on the same scale as the customer competitive assessment (1 for worst, 5 for best can be used). This column is where the QFD team decides whether they want to keep their product unchanged, improve the product, or make the product better than the competition.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by determining the target value for each customer requirement.

The target value is determined by evaluating the assessment of each customer requirement and setting a new assessment value that either keeps the product as is, improves the product, or exceeds the competition. For instance, if lightweight has a product rating of 3 and the QFD team wishes to improve their product, then the target value could be assigned a value of 4. The target value for designing a handlebar stem for a mountain bike is shown in Figure 10-12.

SCALE-UP FACTOR

The scale-up factor is the ratio of the target value to the product rating given in the customer competitive assessment. The higher the number, the more effort is needed. Here, the important consideration is the level where the product is now and what the target rating is and deciding whether the difference is within reason. Sometimes there is not a choice because of difficulties in accomplishing the target. Consequently, the target ratings often need to be reduced to more realistic values.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by determining the scale-up factor for each customer requirement.

The scale-up factor is determined by dividing the target value by the product rating given in the customer competitive assessment. For instance, if lightweight has a product rating of 3 and the target value is 4, then the scale-up factor is 1.3. The scale-up factor for designing a handlebar stem for a mountain bike is shown in Figure 10-12. Note that the numbers for scale-up factor are rounded off in Figure 10-12.

SALES POINT

The sales point tells the QFD team how well a customer requirement will sell. The objective here is to promote the best customer requirement and any remaining customer requirements that will help in the sale of the product. For example, the sales point is a value between 1.0 and 2.0, with 2.0 being the highest.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by determining the sales point for each customer requirement.

The sales point is determined by identifying the customer requirements that will help the sale of the product. For instance, an aerodynamic look could help the sale of the handlebar stem, so the sales point is given a value of 1.5. If a customer requirement will not help the sale of the product, the sales point is given a value of 1. The sales point for designing a handlebar stem for a mountain bike is shown in Figure 10-12.

ABSOLUTE WEIGHT

Finally, the absolute weight is calculated by multiplying the importance to customer, scale-up factor, and sales point:

$$\text{Absolute Weight} = (\text{Importance to Customer})(\text{Scale-up Factor})(\text{Sales Point})$$

A sample calculation is included in Figure 10-12. After summing all the absolute weights, a percent and rank for each customer requirement can be determined. The weight can then be used as a guide for the planning phase of the product development.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by determining the absolute weight for each customer requirement.

The absolute weight is determined by multiplying the importance to customer, scale-up factor, and sales point for each customer requirement. For instance, for reasonable cost the absolute weight is $8 \times 1.3 \times 1.5 = 16$. The absolute weight for designing a handlebar stem for a mountain bike is shown in Figure 10-12. Note that the numbers for absolute weight are rounded off in Figure 10-12.

Step 7—Develop Prioritized Technical Descriptors

The prioritized technical descriptors make up a block of rows corresponding to each technical descriptor in the house of quality below the technical competitive assessment, as shown in Figure 10-13. These prioritized technical descriptors contain degree of technical difficulty, target value, and absolute and relative weights. The QFD team identifies technical descriptors that are most needed to fulfill customer requirements and need improvement. These measures provide specific objectives that guide the subsequent design and provide a means of objectively assessing progress and minimizing subjective opinions.

DEGREE OF DIFFICULTY

Many users of the house of quality add the degree of technical difficulty for implementing each technical descriptor, which is expressed in the first row of the prioritized technical descriptors. The degree of technical difficulty, when used, helps to evaluate the ability to implement certain quality improvements.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by determining the degree of difficulty for each technical descriptor.

The degree of difficulty is determined by rating each technical descriptor from 1 (least difficult) to 10 (very difficult). For instance, the degree of difficulty for die casting is 7, whereas the degree of difficulty for sand casting is 3 because it is a much easier manufacturing process. The degree of difficulty for designing a handlebar stem for a mountain bike is shown in Figure 10-13.

TARGET VALUE

A target value for each technical descriptor is also included below the degree of technical difficulty. This is an objective measure that defines values that must be obtained to achieve the technical descriptor. How much it takes to meet or exceed the customer's expectations is answered by evaluating all the information entered into the house of quality and selecting target values.

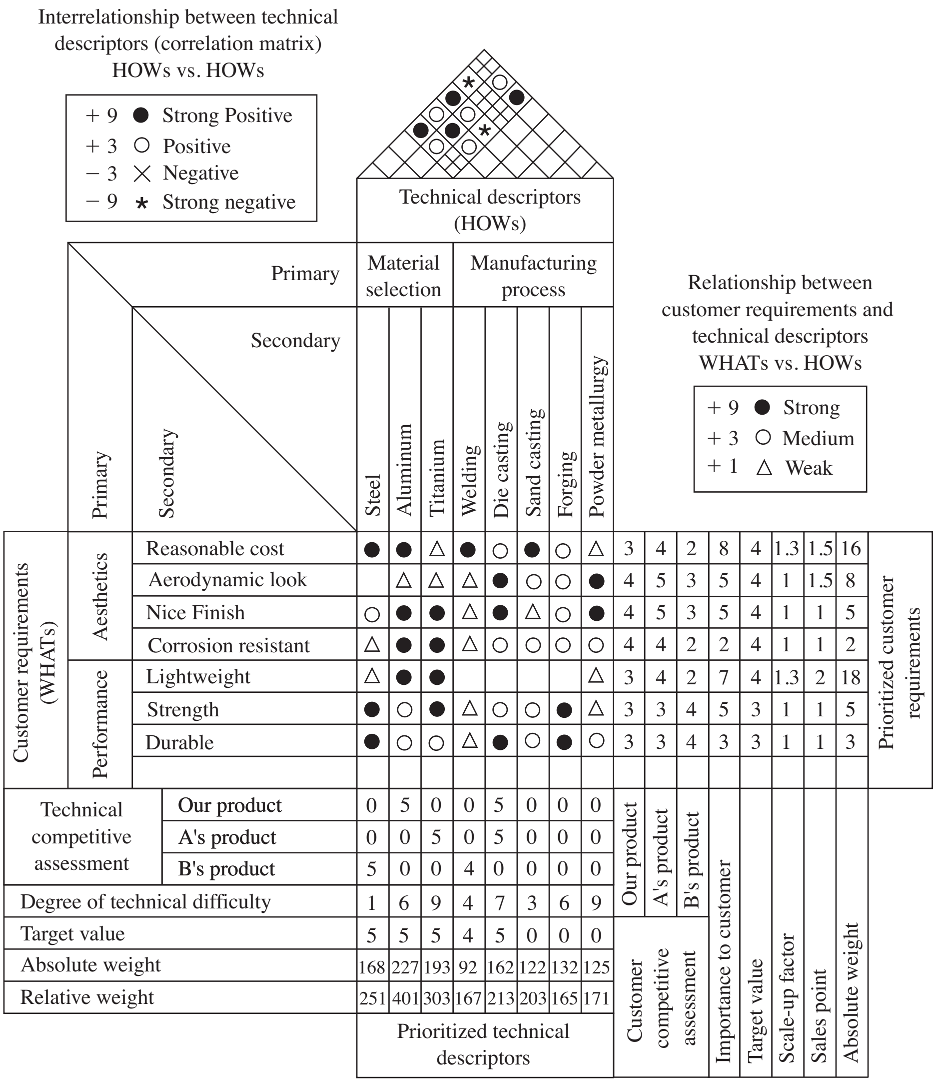


Figure 10-13 Adding Prioritized Technical Descriptors to the House of Quality

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by determining the target value for each technical descriptor.

The target value for each technical descriptor is determined in the same way that the target value was determined for each customer requirement (see appropriate Example). The target value for designing a handlebar stem for a mountain bike is shown in Figure 10-13.

ABSOLUTE WEIGHT

The last two rows of the prioritized technical descriptors are the absolute weight and relative weight. A popular and easy method for determining the weights is to assign numerical values to symbols in the relationship matrix symbols, as shown previously in Figure 10-8. The absolute weight for the *j*th technical descriptor is then given by

$$a_j = \sum_{i=1}^{n} R_{ij} C_i$$

where a_j = row vector of absolute weights for the technical descriptors ($i = 1, \ldots, m$)
R_{ij} = weights assigned to the relationship matrix ($i = 1, \ldots, n$, $j = 1, \ldots, m$)
c_i = column vector of importance to customer for the customer requirements ($i = 1, \ldots, n$)
m = number of technical descriptors
n = number of customer requirements

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by determining the absolute weight for each technical descriptor.

The absolute weight for each technical descriptor is determined by taking the dot product of the column in the relationship matrix and the column for importance to customer. For instance, for aluminum the absolute weight is

$$9 \times 8 + 1 \times 5 + 9 \times 5 + 9 \times 2 + 9 \times 7 + 3 \times 5 + 3 \times 3 = 227.$$

The absolute weight for designing a handlebar stem for a mountain bike is shown in Figure 10-13. The greater values of absolute weight indicate that the handlebar stem should be an aluminum die casting.

RELATIVE WEIGHT

In a similar manner, the relative weight for the *j*th technical descriptor is then given by replacing the degree of importance for the customer requirements with the absolute weight for customer requirements. It is

$$b_j = \sum_{i=1}^{n} R_{ij} d_i$$

where b = row vector of relative weights for the technical descriptors ($j = 1, \ldots, m$)
d_i = column vector of absolute weights for the customer requirements ($i = 1, \ldots, n$)

Higher absolute and relative ratings identify areas where engineering efforts need to be concentrated. The primary difference between these weights is that the relative weight also includes information on customer scale-up factor and sales point.

These weights show the impact of the technical characteristics on the customer requirements. They can be organized into a Pareto diagram to show which technical characteristics are important in meeting customer requirements. Along with the degree of technical difficulty, decisions can be made concerning where to allocate resources for quality improvement.

Each QFD team can customize the house of quality to suit their particular needs. For example, columns for the number of service complaints may be added.

EXAMPLE PROBLEM

Continue the development process of designing a handlebar stem for a mountain bike (see previous Examples) by determining the relative weight for each technical descriptor.

The relative weight for each technical descriptor is determined by taking the dot product of the column in the relationship matrix and the column for absolute weight in the prioritized customer requirements. For instance, for die casting the relative weight is

$$3 \times 16 + 9 \times 8 + 9 \times 5 + 3 \times 2 + 0 \times 18 + 3 \times 5 + 9 \times 3 = 213.$$

The relative weight for designing a handlebar stem for a mountain bike is shown in Figure 10-13. The greater values of relative weight also indicate that the handlebar stem should be an aluminum die casting.

QFD Process

The QFD matrix (house of quality) is the basis for all future matrices needed for the QFD method. Although each house of quality chart now contains a large amount of information, it is still necessary to refine the technical descriptors further until an actionable level of detail is achieved. Often, more than one matrix will be needed, depending on the complexity of the project. The process is accomplished by creating a new chart in which the HOWs (technical descriptors) of the previous chart became the WHATs (customer requirements) of the new chart, as shown in Figure 10-14. This process continues until each objective is refined to an actionable level. The HOW MUCH (prioritized technical descriptors) values are

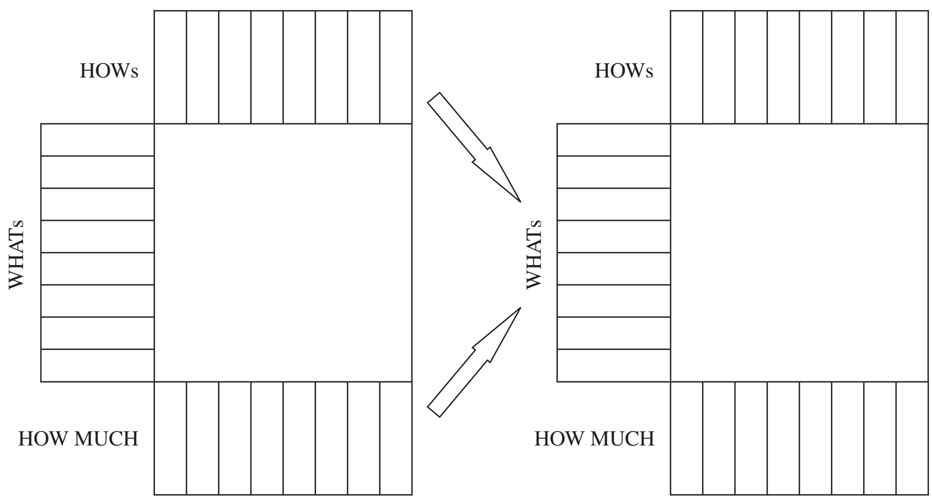


Figure 10-14 Refinement of the QFD Chart

usually carried along to the next chart to facilitate communication. This action ensures that the target values are not lost during the QFD process. If the target values are changed, then the product is not meeting the customer requirements and not listening to the voice of the customer, which defeats the purpose of QFD.

An example of the complete QFD process from the beginning to the end is shown in the flow diagram in Figure 10-15. The first chart in the flow diagram is for the product-planning phase. For each of the customer requirements, a set of design requirements is determined, which, if satisfied, will result in achieving customer requirements. The next chart in the flow diagram is for part development. Design requirements from the first chart are carried to the next chart to establish part-quality characteristics. The term *part-quality characteristics* is applied to any elements that can aid in measuring the evolution of quality. This chart translates the design requirements into specific part details. Once the part-quality characteristics have been defined, key process operations can be defined in the process-planning phase. The next step is process planning, where key process operations are determined from part-quality characteristics. Finally, production requirements are determined from the key process operation.

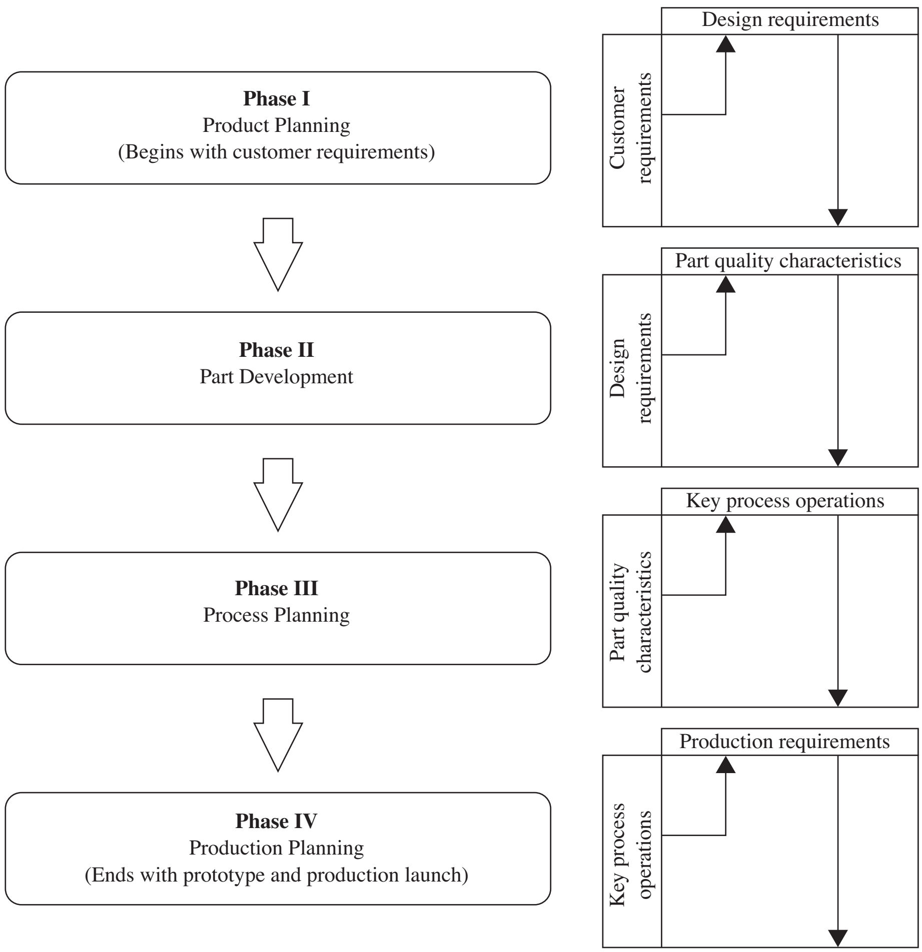


Figure 10-15 The QFD Process

Numerous other house of quality planning charts can be used to improve quality and customer satisfaction. Some of these are the following:

The demanded quality chart uses analysis of competitors to establish selling points.

The quality control process chart shows the nature of measurement and corrective actions when a problem arises.

The reliability deployment chart is done to ensure a product will perform as desired. Tests are done, such as failure mode and effect analysis (FMEA), to determine the failure modes for each part.

The technology deployment chart searches for the advanced or, more importantly, the proper technologies for the operations.

The use of these charts is dependent upon the type of product and scope of the project.

An example of the QFD approach can be found in the corrosion problems with Japanese cars of the 1960s and 1970s that resulted in large warranty expenses. The Toyota Rust QFD Study resulted in a virtual elimination of corrosion warranty expenses. The customer requirement of years of durability was achieved, in part, by the design requirement of no visible rust in three years. It was determined that this could be obtained by ensuring part-quality characteristics, which include a minimum paint film build and maximum surface-treatment crystal size. The key process operation that provides these part-quality characteristics consists of a three-coat process, which includes a dip tank. The production requirements are the process parameters within the key process operations, which must be controlled in order to achieve the required part-quality characteristics and customer requirements.

Examples

There are hundreds of examples of organizations employing quality function deployment techniques in new product development and improvement of existing products, however, examples of the use of quality function deployment in the service industries is very limited. The following examples concentrate on the application of quality function deployment in the service industry, namely higher education.

1. In 1997, Rainstar University, a science-based, holistic health institution in Scottsdale, AZ, adopted quality function deployment to ensure meeting customer (graduates) and accreditation needs.[1] Quality function deployment was used to not only design the course content and curriculum based on customer needs, but also to ensure that each academic unit focused on the graduate.
2. Tennessee Technological University's College of Business Administration used quality function deployment to redesign their internal research resources center (RRC).[2] The RRC serves faculty and students in the areas of computer applications, research, test preparation, manuscript preparation, and so forth at the university. Customer requirements included reliability, responsiveness, assurance, empathy, and tangibles such as appearance of the physical facility, equipment, personnel, and materials. Numerous recommendations resulted from the study, such as: a better document handling procedure, a formal training procedure, and a new layout of the facility.

[1] Ian D. Bier and Robert Cornesky, "Using QFD to Construct a Higher Education Curriculum," *Quality Progress* (April 2001): 64–68.

[2] R. Nat Natarajan, Ralph E. Martz and Kyosuke Kurosaka, "Applying QFD to Internal Service System Design," *Quality Progress* (February 1999): 65–70.

TQM Exemplary Organization[3]

Established in 1963, today Los Alamos National Bank (LANB) is the largest independent bank in New Mexico. LANB provides a full range of financial services to consumer, commercial, and government markets in northern New Mexico. LANB was created originally to address the banking needs of its unique namesake community. LANB is owned and operated by Trinity Capital Corp., a one-bank holding company. With assets of $700 million, LANB has 184 employees and branches in Los Alamos, White Rock, and Santa Fe.

Senior leaders set the bank's long-term strategic direction and annual corporate objectives, following detailed analyses of leading and lagging indicators of trends in the economy, markets, customer behavior, technology, employee skills, supplier capabilities, and other key factors. At the departmental level, planning becomes an organization-wide activity involving all personnel. Corporate objectives are accomplished through action plans that often span several departments. Totaling about 90 in the year 2000, action plans are converted into individual work goals for all employees, about a third of whom participate on long- or short-term teams.

Under the leadership of LANB's Quality Council, which has members from every area and level of the company, the performance appraisal system was redesigned to magnify the direct link between job performance and corporate performance. Once employees complete the annual appraisal process, they have a complete snapshot of what they must do to perform at a high level and to earn the attendant incentives and rewards, which includes profit sharing and employee stock ownership. Such incentive payouts average over 21% of an employee's annual salary.

Employees are expected to create value for customers, and they are given the authority and resources to act proactively and decisively. For example, all workers have the authority to resolve complaints on the spot.

LANB was quick to embrace the Internet and to provide online banking services, which have been received enthusiastically by customers. Introduced in March 1999, the service was being used by more than 6,000 LANB customers as of the end of 2000.

In its most recent survey, 80% of LANB customers said they were "very satisfied" with the service they received—considerably better than the levels received by its primary competitors and the national average of 55% for all banks. Returns on key financial indicators exceed local competitors and the national average. For example, the bank's net income has increased by more than 60% over the last five years, and earnings per share increased from $1.20 to nearly $2.00. For the past three years, employee satisfaction results have been well above those of banks its size in five of eight key indicators of employee satisfaction.

In 1999, LANB received New Mexico's highest quality award, the Zia. In 1996, *Inc*. magazine named LANB one of the 26 "Banks We Love."

Summary

Quality function deployment—specifically, the house of quality—is an effective management tool in which customer expectations are used to drive the design process or to drive improvement in the service industries. Some of the advantages and benefits of implementing QFD are:

An orderly way of obtaining information and presenting it.

Shorter product development cycle.

[3] Malcolm Baldrige National Quality Award, 2000 Service Category Recipient, NIST/Baldrige Homepage.

Considerably reduced start-up costs.

Fewer engineering changes.

Reduced chance of oversights during the design process.

An environment of teamwork.

Consensus decisions.

Everything is preserved in writing.

QFD forces the entire organization to constantly be aware of the customer requirements. Every QFD chart is a result of the original customer requirements that are not lost through misinterpretation or lack of communication. Marketing benefits because specific sales points that have been identified by the customer can be stressed. Most importantly, implementing QFD results in a satisfied customer.

Exercises

1. Working individually or in a team, list four or more primary customer requirements for one or more of the following production items or service industries. Also, refine the primary customer requirements to a second level.

    (a) Mountain bike
    (b) Racing bike
    (c) Pizza
    (d) Textbook
    (e) Automatic teller machine
    (f) Automobile cruise control
    (g) Coffee maker
    (h) Computer mouse
    (i) Rechargeable drill/driver
    (j) University academic department
    (k) Call center
    (l) Restaurant
    (m) Hospital or medical center
    (n) Department store
    (o) Website for computer sales
    (p) Hair salon
    (q) Grocery store

2. Working individually or in a team, list six or more primary technical descriptors for one or more of the selections used in Exercise 1. Make an attempt to address all the customer requirements from Exercise 1 and refine the secondary technical descriptors to a second level.

3. Working individually or in a team, form an L-shaped matrix and complete the relationship matrix, including weights, for one or more of the selections used in Exercises 1 and 2.

4. Working individually or in a team, complete the interrelationship matrix for one or more of the selections used in Exercise 2.

5. Working individually or in a team, compare two similar products or service industries based on the customer assessment of the customer requirements used in Exercise 1. Choose one of the products to be your organization's product.

6. Working individually or in a team, compare two similar products or service industries based on technical assessment of the technical descriptors used in Exercise 2. Choose one of the products to be your organization's product.

7. Working individually or in a team, complete the house of quality and comment on the results for one or more of the selections used in Exercises 1 through 6.

8. While using QFD, the customer requirements are often processed using

   (a) Fishbone diagram
   (b) Affinity Diagram
   (c) Tree Diagram
   (d) Force field analysis

9. A team has performed QFD. They have found that one of the columns in the relationship matrix is blank. The team should

   (a) consider that the corresponding technical feature is used in advertising aggressively
   (b) Take note of this but need not take any action
   (c) Interview the customers again to verify correctness of the CTQs
   (d) consider that the corresponding technical feature can be omitted

10. A team has performed QFD. They have found that one of the rows in the relationship matrix is blank. The team should

    (a) Interview the customers again to verify correctness of the CTQs
    (b) Review the concept and add some features to the product to satisfy the corresponding CTQ
    (c) Take note of this but need not take any action
    (d) realize that the corresponding CTQ has little importance to the customer

11. In Quality Function Deployment, technical descriptors are captured in the

    (a) top row
    (b) left column
    (c) bottom row
    (d) Right Column

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11

Quality by Design

Chapter Objectives

- Overview of quality by design approach as compared to over-the-wall approach to product development
- Brief overview of "quality by design" approach
- Understanding the change to multidisciplinary teams by studying the team structure and the role of top management
- Implementing quality by design
- Overview of important organizational tools for successful implementation, namely, TQM, computer networks, quality function deployment, virtual meeting tools and enterprise resource planning system
- Overview of product development tools, such as finite element analysis, computer aided drafting and designing, rapid prototyping, failure mode and effect analysis, design for Six Sigma and designing for reliability
- Overview of production tools, such as robotics, computer-aided manufacturing, just-in-time, lean, etc.
- Brief overview of statistical tools like design of experiments, tolerance stack-up analysis, statistical process control and reliability analysis
- Understanding the pitfalls of quality by design approach and tools

Introduction

Quality by design principles are changing the way managers think and conduct business. Loosely defined, quality by design is the practice of using a multidisciplinary team to conduct conceptual thinking, product design, and production planning all at one time. It is also known as concurrent engineering, simultaneous engineering, or parallel engineering. The team is composed of specialists from business, engineering, production, and the customer base. Suppliers of process equipment, purchased parts, and services are also included on the team at appropriate times. Quality by design has recently encouraged changes in management structures. Some managers claim to have used it informally before it became popular.

In the past, the major functions within an organization would complete their task by "throwing it over the wall" to the next department in the sequence and would not be concerned with any internal customer problems that might arise. Hence, the term *sequential engineering* was used to describe the process. Quality by design, or concurrent engineering, requires the major functions to be performed at the same time. This system provides immediate feedback, which prevents problems with quality and productivity from occurring.

A broad definition of quality by design is a team of specialists who simultaneously design and develop a product to ensure ease of producibility and customer satisfaction. Figure 11-1 shows flow diagrams for both sequential (or traditional) engineering on the left and quality by design or concurrent engineering on the right. In quality by design, engineering (such as mechanical, electrical, structural, quality, material), production, and business (such as purchasing, marketing, finance) as well as suppliers and customers brainstorm together to develop a product that considers all facets of its functionality as well as its costs. When each of the specialists has early input to the product definition and specifications, cost is minimized and performance is maximized. Thus, better-quality products are manufactured for less cost with shorter time to market.

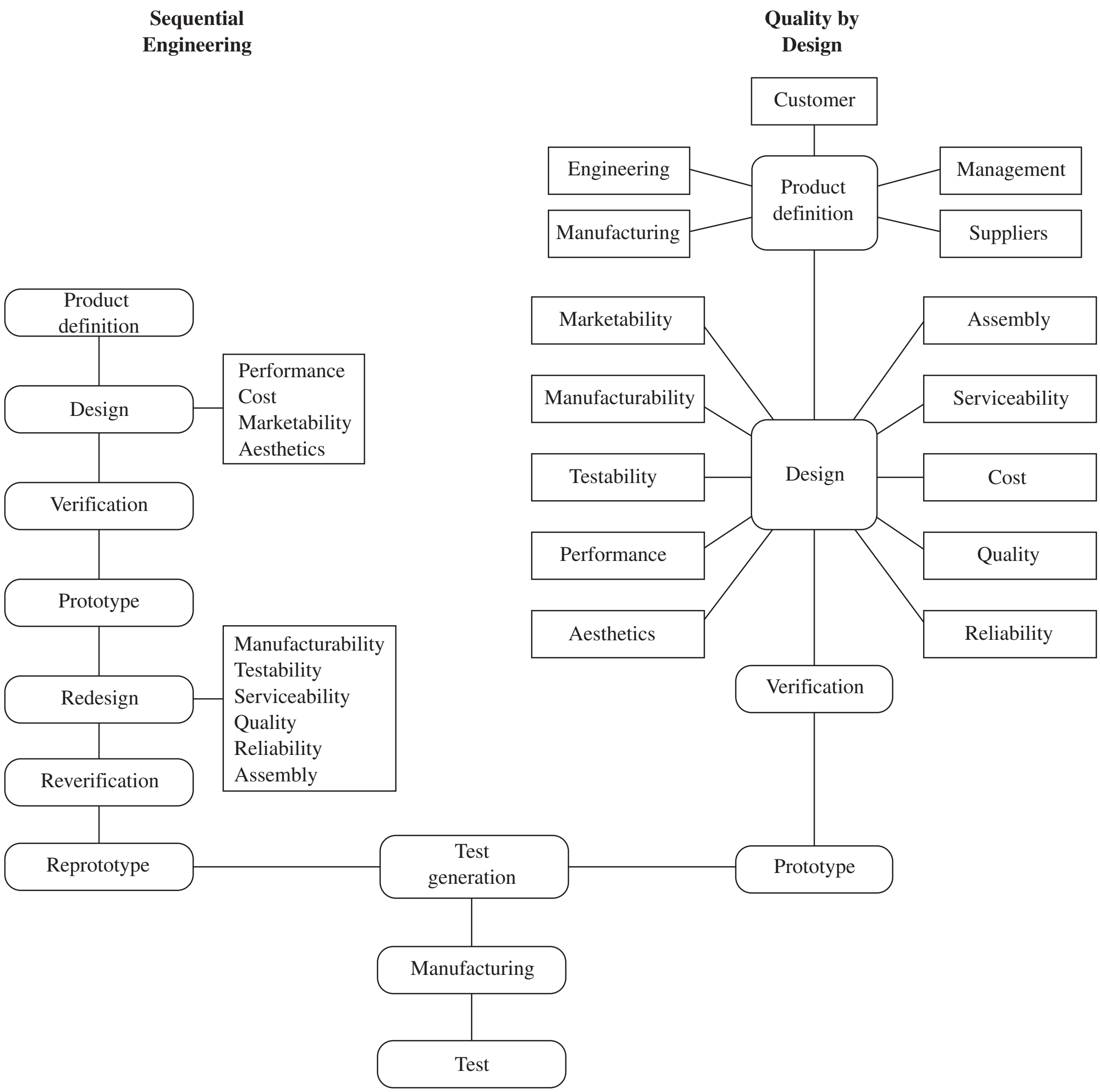

Figure 11-1 Product Development Flow Diagram

Getting input at the beginning from all areas eliminates engineering changes later in the project. Communication flows better and people are more apt to compromise to assure better manufacturability instead of unknowingly creating more work for the next discipline. As mentioned previously, designs would be thrown over the wall to the next area. For instance, it would be difficult for the electrical engineers to know why the structural engineers designed sections in a component that would require special processes in order to run wires through the product. These simple problems, which arise from ignorance of other specialization areas, are eliminated from projects, and thus, lead times to market are shortened.

As shown in Figure 11-1, sequential engineering requires repeated steps of redesign, reverification, and reprototype in order to compile all previous design stages. For example, during the first design phase in sequential engineering, only performance, cost, marketability, and aesthetics might be considered. After verifying the design and building the first prototype, it is determined that the product needs to be redesigned for producibility, testability, serviceability, quality, and reliability. In the quality by design (or concurrent) engineering model, however, the initial design phase encompasses all of the aforementioned attributes, thus eliminating the need for redesign.

There is obviously a longer lead time involved in the traditional method, because each step is performed independently and sequentially, one after another. As problems arise, the project is sent back to the appropriate area and the process starts over. Because there is a high level of technical specialization at each step, numerous cycles are common. The quality by design (or concurrent) engineering method combines all these steps into one. The product is designed to be successful at each stage of its life cycle. It is designed correctly the first time, considering all attributes and facets of its life, such as marketability, assembly, and serviceability, before release to testing and, finally, to production.

Rationale for Implementation

Project budgets for all industries are becoming more crucial to any product's marketability. In the 1970s, accounting methods and budgets were not as critical as they are today. U.S. producers were able to pass unaccounted costs to the consumer through price increases. In the past, consumers had only a few brands to choose from, so the price was dictated by the cost of production plus a reasonable profit. Imported products helped balance the demand for quality products at reasonable prices and allowed consumers to set the market price. Often, there was little to no markup on goods, forcing inefficient suppliers to close their doors or produce specialized products that had higher contribution margins.

Design changes that occur late in the product development cycle cause increased lead times and, thus, higher costs. This is like a double hump camel! (See Figure 11.2). If we do not spend enough efforts and resources at the design stage, we are forced to solve problems later. Quality by design helps control design changes by shifting all the design to the beginning of the project rather than throughout its whole life cycle, as shown in Figure 11-3. The shifting of all design to the beginning of the project increases the time required for initial design; however, the future benefits outweigh this increase. For example, a change made during the design stage could cost up to ten times as much as one made during the testing stage. Spending ten times as much to change features that could have been designed into the product at the beginning justifies the purchase of high-powered product development software. The amount of time required in the quality by design model for product definition and specifications can be significantly greater than that required in the sequential engineering model. However, the increased time is warranted because the brainstorming sessions among specialists result in a more complete final product definition.

Fewer design changes and shorter product lead times both equate to a quicker response to customer needs; however, there are even better reasons for using quality by design. Lower reject and scrap rates on the shop floor quickly improve profits.

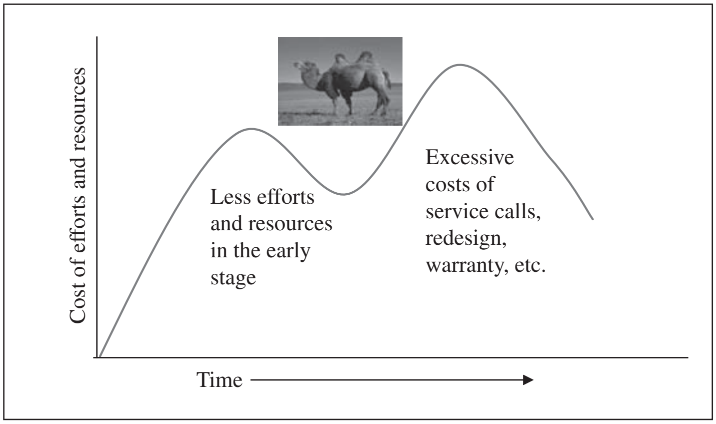

Figure 11-2

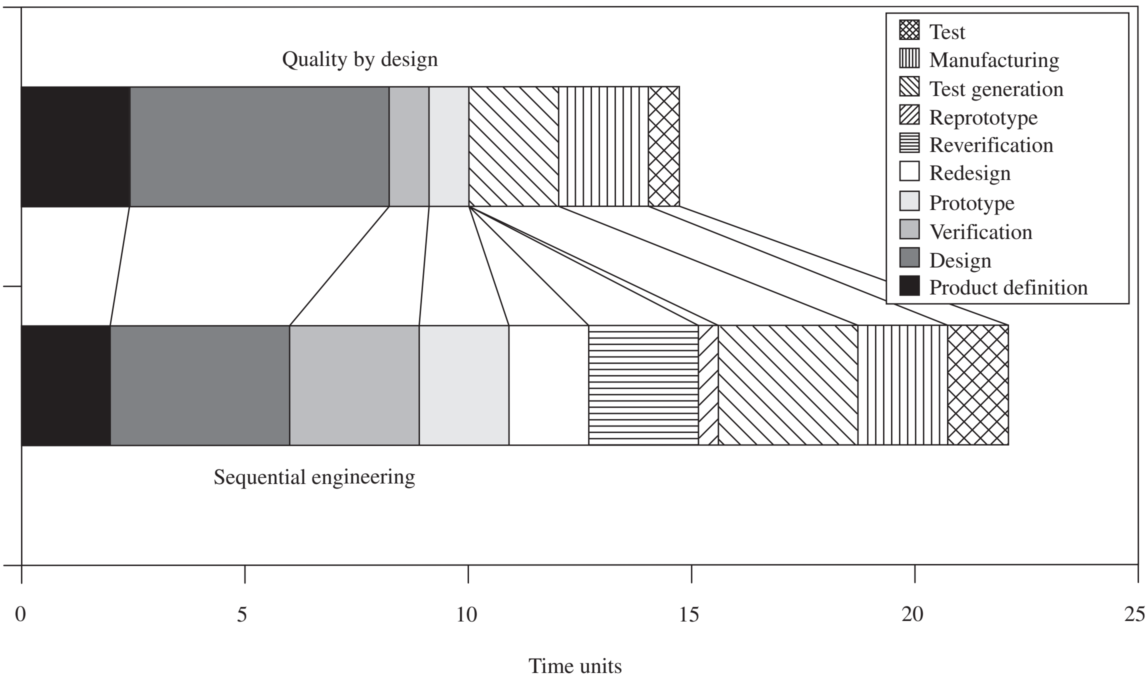

Figure 11-3 Hypothetical Product Development Time Line

Cash flow is crucial to an organization's operating budget. Sales dollars pay the present period expenses, which keeps the facility producing the products that will be sold tomorrow. Customer returns can take a large bite out of an organization's operating budget and can hinder product scheduling in order to perform rework.

By using quality by design, the product is designed within production capabilities in order for statistical process control to be effective. Producing products well within process capabilities will cause a chain reaction of customer satisfaction. Customer returns will decrease, and rework costs will also decrease. As a result, profit margins become larger, because the time that was previously used to rework in-house non-conformities and customer returns can now be used to produce new products. Thus, organizations are taking two steps forward and one giant step back every day they continuously inspect products that could have been designed within process capabilities rather than at or below process capabilities.

Benefits

Because consumer trends drive market demands, an organization's ability to react six months before the competition can significantly improve profits. Obviously, timing is important, but consumers will switch brands if they can get a similar product of the same quality for less money. Furthermore, if a product is not designed with costs in mind, inefficiencies will soon erode the profits gained from short lead times. Quality by design provides manufacturers with the tools and communication and management techniques required to develop products in a timely and cost-efficient manner from the beginning and throughout a product's life.

The primary benefit of implementing quality by design techniques is a significant decrease in time to market. Other benefits of quality by design techniques are:

Faster product development.

Better quality.

Less work in progress.

Fewer engineering change orders.

Increased productivity.

The above benefits are also the underlying reason for a decrease in a product's time to market.

According to the National Institute of Standards and Technology, implementation of quality by design methods can reduce engineering changes by 65% to 90%. This decrease in engineering changes can cut product development times by 30% to 70%, reduce time to market by 90%, and increase quality by as much as 200% to 600%. Furthermore, due to the improvements in quality, less rework significantly reduces direct labor costs.

Design for Six Sigma

In the recent past, a refinement of the quality by design has been evolved and is used by some companies world wide. This refinement is known as "Design for Six Sigma" (DFSS). DFSS has been adapted by companies like Motorola, GE, Cummins, Ford, John Deere to name a few. DFSS roadmap is described as follows.

- Define the project goals and customer deliverables.
- Measure and determine customer needs and specifications.
- Analyze to generate innovative concepts, and evaluate and select the best concept for the design.
- Design details, optimize the design, and plan for design verification and validation. This phase often requires simulations.
- Verify and validate the design reliability and capability to meet customer requirements.

DFSS can result in reduced defects, reduced cycle times, better reliability, higher customer satisfaction and market share.[1]

Teams

Quality by design utilizes teams to take advantage of prior experience, emphasize early high-quality decisions, and support the fulfillment of customer requirements, feedback constraints, and the efficient management of risk and change as the product moves from conceptual design to sales. These teams include product developers from marketing, research and development, design, production, test, and logistics, to name a few, along with project and program management. Suppliers and customers should also be included as part of the team when appropriate. To work concurrently, everyone must share ideas and work toward a common goal.

In order for quality by design to work, a change in the way business is done must occur. Quality by design techniques require a change in the "business as usual" philosophy by removing the walls that stand in the way of faster product development and, consequently, lower costs. People can no longer be concerned with only their own function—an exchange of ideas must travel upstream as well as downstream. The input from production, quality, and service departments, in addition to supplier and customer input, are invaluable to the design and development of a product.

Implementing the quality by design philosophy requires a top-down commitment. Bringing together team members from business, engineering, and production requires either that they be co-located or that a system to share information be installed. Team members must be committed to the project, not to their functional departments. The right people need to be put into management roles, and it is vital to know the strengths and weaknesses of all team members. The job needs to be done right the first time by statistically validating every process to assure produceability.

More produceable designs will be achieved through better interaction between design team members. This process begins when design, testing, production, and other members provide input during the final revisions of the product proposal from marketing instead of after the product has already been designed.

Studies have shown that somewhere between 60% and 95% of the overall product cost is determined during the design phase. A product's parts, assembly, test, and service costs are dictated far more often in the product's design than in the actual production, testing, or servicing. The earlier these design decisions are made, the larger their impact.

To avoid problems with teams, reward team members for extra work, level the playing field, and compensate team members more or less equally. Suppliers must have the trust of the team to keep highly engineered parts confidential. Team members should treat other team members as internal customers. These are just a few examples of how to increase the benefits of quality by design.

Today, with reduced travel budgets, time constraints, and joint ventures throughout the world, more and more companies are relying on virtual project teams or distance management to conduct business. There are numerous potential difficulties associated with participating in or leading a virtual team. Some of the effective leadership skills needed to manage a virtual team are very similar to those needed in any leadership role:[2]

Use technology that fits the situation.

Communicate effectively.

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[1] Design for Six Sigma for Green Belts and Champions by Howard S. Giltow, David M. Levine and Edward A. Popovich, published by Pearson Education, 2006.

[2] Joyce Thompson, "Leading Virtual Teams," *Quality Digest* (September 2000): 42–46.

Build a community based on high-quality values among members.

Establish goals, expectations, purpose, and vision.

Lead by example with focus on results.

Coordinate across organizational boundaries.

Whenever working in or leading a virtual team, it is of utmost importance to allow the dynamics of the team to evolve and react quickly to changes.

Examples of Teams

There are numerous examples of organizations, from manufacturing to service, employing teams to save money and improve quality. The following examples give a wide range of successful organizations that applied teams.

1. A 15-member quality-improvement team at Pacific Bell won the 1994 RIT/USA Today Quality Cup in the service category by reducing damage to buried cables by 24% the previous year.[3] The team accomplished the reduction by first determining that the majority of cable cuts was the result of construction. They then persuaded contractors to work in better harmony with Pacific Bell to drastically reduce construction problems.

2. In 1995, Sun Microsystems launched its SunTeams program to implement a team-improvement process as part of its quality initiative.[4] The program focuses on employees taking ownership of a process and improving it, such as increasing customer satisfaction or loyalty. Since its inception, some SunTeams have reduced product failures by 80% and cut workstation-manufacturing time from ten days to two days.

3. Lear's auto supplier plant in Strasburg, Virginia won the 1999 RIT/USA Today Quality Cup in the manufacturing category by reducing paint spots on auto parts.[5] A nine-member multi-disciplinary team decided to replace a waterfall with a vacuum filter made of cardboard. The problem fix resulted in a reduction of 16% in the scrap rate and a reduction of 25% in defects, a 33% increase in productivity, and a savings of $112,000 per year.

4. A multi-disciplinary virtual team of workers from American Airlines, Federal Express, Airbus Industries, General Electric, and primarily Allied Signal won the 1998 RIT/USA Today Quality Cup in the manufacturing category by reducing the repair rate on an airflow valve in jet engines.[6] The team increased the time between valve repairs by 75% and produced a possible savings of over $5,000 per plane per year.

5. In 2009, cross-functional design team from John Deere India won prize in the Design for Six Sigma (DFSS) category at the Lean and Six Sigma Awards instituted by Symbiosis Center for Management and Human Resource Development (SCMHRD), Pune. Their design project was Optimization of Steering System. Less steering effort of tractor was identified as customer delighter. A project was, therefore, taken up to reduce steering effort and also to reduce cost. Using the DFSS, the team achieved 19% cost reduction while reducing the steering effort by about 20%.

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[3] 1994 RIT/USA Today Quality Cup.

[4] Elizabeth Larson, "Teams Shine at Sun Microsystems," *Quality Digest* (May 1999): 10.

[5] 1999 RIT/USA Today Quality Cup.

[6] 1998 RIT/USA Today Quality Cup.

6. Rayovac formed a quality by design team composed of people from design, engineering, sales, quality, manufacturing, purchasing, customer service, finance, and the plastic parts supplier to design their new fluorescent camping light. Using this quality by design team, they were able to reduce the usual product development time from three years to one year.

Communication Models

The communication flow for sequential engineering is in series, compared with quality by design (or concurrent) engineering, which has a parallel communication flow. The traditional model for communication in organizations across the United States uses a hierarchy of units, as shown in Figure 11-4. For simplicity, not all departments are included within each discipline (for example, design and finance could have also been included in engineering and business, respectively). Although needed for the effective management of resources, this hierarchy does not foster communications across the organization, but rather only up the chain of command. The traditional model allows for a great many structured communication paths among similar functional units in the organization. For example, all the various engineering groups in the organization can usually easily communicate with any other engineering group. However, this model is structured to impede communication between product engineering and marketing, for instance.

In the traditional organizational structure, each level in the hierarchy should only perform duties that are assigned from the level above. Thus, if the system is designed well, cross communications need not be necessary. This system worked well in the face of no competition. However, as can be seen by U.S. industry in the 1970s and 1980s, this system had difficulty surviving against the more advanced organizational systems of other countries. In order to circumvent the lack of flexibility in the traditional organizational structure, a quality by design organization structure should be adopted, as shown in Figure 11-5.

In the quality by design organizational structure, information paths are opened up between departments in different disciplines. In other words, a field service employee can talk directly with a production engineer about a common service problem that could be easily remedied in the production phase of product development.

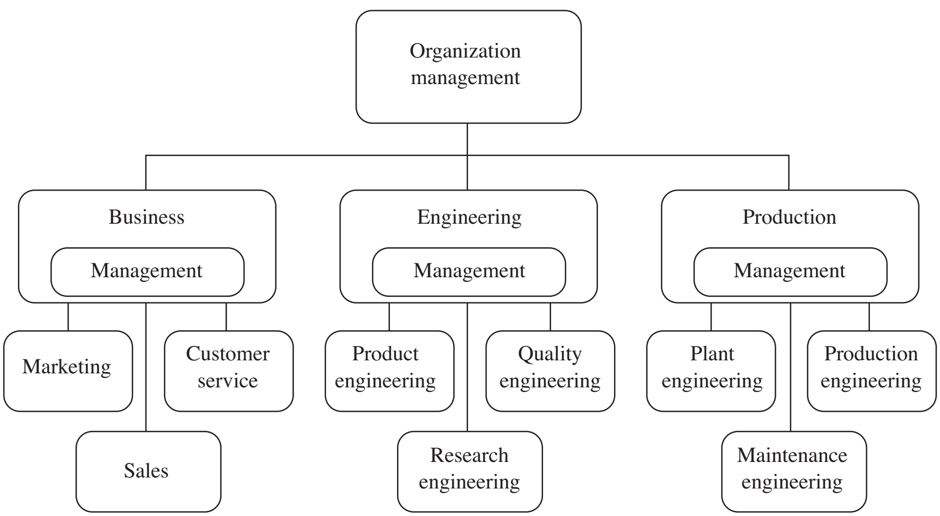

Figure 11-4 Traditional Organization Structure and Information Paths

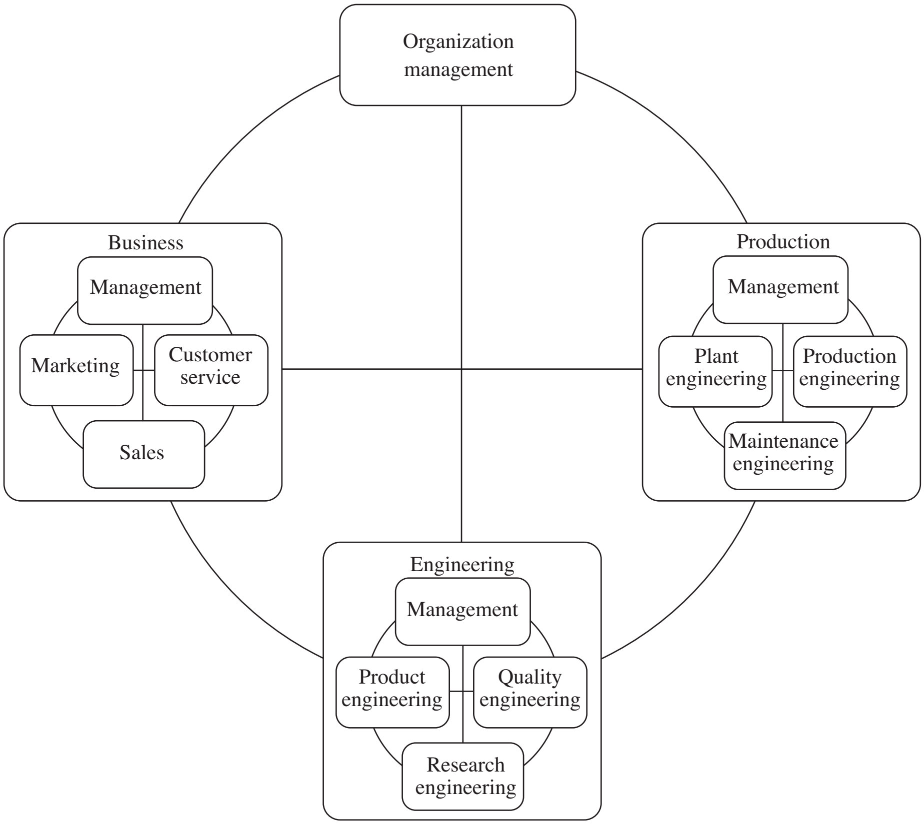

Figure 11-5 Quality by Design Organization Structure and Information Paths

Similarly, design engineers can consult with production workers about difficulties in assembling their designs. The primary advantage of the quality by design organizational structure is the opening of communication paths between employees and their subsequent empowerment in the decision-making process.

Implementation

The implementation of quality by design is no easy task for any organization. A great deal of time, effort, and money needs to be expended in order for the culture of the organization to accept the various basic concepts that make quality by design work. These concepts, which include looking at the whole product life cycle, agreeing that there are indeed both internal customers and suppliers as well as outside ones, and having a commitment to quality for the entire process of making the product and not just the product itself, are key to the success of quality by design.

The easiest way for an organization to progress toward a quality by design environment is simply to gather together everyone who will be involved in a project at its beginning and allow the communication channels to open. This meeting of all project members can reap great rewards. The first of such benefits is that project members can meet face to face all their internal and external customers and suppliers, which has the effect of personalizing the project for each member. It also opens personal channels of communication, because there are now people, not just faceless names, associated with each phase of the project. Another important feature of the initial meeting is that the members of the project come to understand the overall goals of the project. The meeting can also be used to quickly clear up any misconceptions project members may have about the project.

Once this initial meeting has taken place, there should be regular meetings at set intervals to allow the project members to renew communication paths and to exchange ideas and complaints about various phases of the project. The intervals between project meetings must be long enough to allow for meaningful questions to develop but short enough so that important design decisions can be discussed by the group. With this in mind, the project leader must schedule the meetings while also considering the constraints on the schedules of each member of the group. Unfortunately, this scheduling quickly becomes a logistical nightmare.

By using dedicated project teams, the hindrance of regular meetings can be eliminated. This is a system in which members of each functional unit are either recruited or assigned to a project team that stays together from project to project. By implementing such a system, the organization can establish project teams that have a sense of togetherness, whose paths of communication are already in place, and where each member fully knows everyone's capabilities. This approach is a very elegant solution to implementing quality by design; however, it is only a partial one. The reason that the system is flawed is due to the aging of the project team. As the team does more and more projects together, a sense of stability and settling occurs in communication between the members. They no longer try to find better and better solutions to problems that the project faces, but instead they rely on solutions that the team has arrived at in past projects. This limitation can be attributed to the fact that newer solutions require more communication.

By placing the team members in the same location (co-locating), the project team can be continuously stimulated to find solutions to the problems of the project. Co-location dramatically increases communication between project members and, thus, stimulates continuous improvements. However, there are a number of disadvantages associated with co-location. The first is the high cost of moving and providing for the project members. Second, by moving individual members out of their functional unit environment, the organization takes away the paths of communication that previously existed within the respective units. For example, in moving a die designer out of his department, the designer can no longer effectively communicate with other designers, which can result in a sub-optimal die design.

Computer network technology allows the organization to have the advantages of a co-located team but still retain all advantages of a functional organization. By networking the team together, the project is turned into a managed set of resources and applications through which the team communicates. This technology has a threefold advantage. First, it eliminates the cost of co-location. Second, it allows for maximum communication between project members and outside consultants. Finally, it records the progress of the project for management and accounting uses.

Although each of the aforementioned steps toward implementing quality by design adds advantages, it also increases costs. These costs, both in time and in money, must be considered before any model is applied to an organization. Each solution also requires progressively more difficult culture changes in the organization for the solution to be effective. By first establishing project meetings, management can slowly begin to change the culture of the organization. After these cultural changes have become ingrained, the organization may add a project facilitator or go directly into dedicated project teams. Once these teams have been established, the organization may wish to co-locate each project team or even try to network all the projects.

The implementation of quality by design can be viewed as a path of stepping-stones on the way to true quality by design. The pace of the travel on the stepping-stones should be dictated only by how far the organization wants to step and how much they want to risk falling off the path.

The Chrysler Corporation is an example of a successful organization that has implemented co-location of teams and workspace restructuring.

Chrysler Corporation used a quality by design approach to bring the Viper model from an auto-show concept car to full production in less than three years with a budget of $50 million. This was accomplished by co-locating the team and knocking down barriers between design and production in order to maximize communication and working relationships. Chrysler flattened the vertical hierarchy of the organization into three levels, consisting of team members, team leaders, and a project manager. Experts and outside suppliers were brought in on an as-needed basis to help resolve problems before they occurred.

Tools

Computer-aided drafting (CAD) and computer-aided manufacturing (CAM) have bridged the gap between design and rapid prototypes. Computer-aided drafting files can be converted to tool path geometry and then downloaded directly to a computer numerically controlled (CNC) machine. A model can then be cut for the design team to evaluate and discuss in terms of design options. The following sections describe many of the tools needed to make quality by design work. Without these tools, quality by design is not as effective. It is only when the proper mix of tools is judiciously implemented that quality by design will radically reduce lead times.

Chronology of Quality by Design Tools

Many quality by design tools were not readily available to the business, engineering, and production departments of organizations until the late 1980s and early 1990s. The prime mover for the explosion of quality by design tools has been the exponential growth of desktop computer processing power with advanced computer graphics capabilities. To realize the phenomenal growth in quality by design tools resulting from the personal computer revolution, one need only look at the advances in word processing, drafting, and engineering analysis.

Until the early 1980s, secretaries throughout the world relied on typewriters for the word processing of all documents. Editing of these documents and bulk mailings required substantial amounts of time and organization resources in addition to the original effort. Often, organizations employed more secretaries and support staff than employees directly related to product development and production. Since the late 1980s, almost every office assistant has had access to a personal computer with word processing software. These software programs make bulk mailings as simple as writing a single letter, and editing a document can take a fraction of the time required for the original manuscript.

Major aircraft manufacturers have used CAD software since the late 1970s. However, it is only since the late 1980s that small to medium-sized organizations have utilized the power of personal computer-based CAD. Computer-aided drafting software now allows engineers at organizations of all sizes to draw designs and make changes in a fraction of the time required by the old pencil-and-paper techniques.

An even more dramatic example is the explosion of personal computer-based engineering analysis software packages such as finite element analysis. The theoretical background for finite element analysis was first developed in the 1950s and 1960s and coincides with the early advances in digital computers. Until the late 1980s, only aircraft organizations, automobile manufacturers, and government laboratories utilized the advantages of engineering analysis software because of their access to high-powered supercomputers. In the 1990s, even the smallest of organizations could purchase a personal computer-based finite element software package.

Organizational Tools

Many of the tools implemented by an organization need to be understood by all employees. The primary organizational tools for a quality by design environment are:

Total Quality Management philosophies.

Computer networks.

ISO 9000.

ISO 14000.

Total productive maintenance.

Quality function deployment.

Information technology.

Electronic meeting software.

Enterprise resource planning software.

Total Quality Management (TQM) is a new way of doing business. (It was defined in Chapter 1.) All employees must understand these principles so they can also understand the organization goals and help achieve them.

Computer networks consist of both local area networks and global information networks. Local area networks allow users to share information between interconnected personal computers within an organization. Global information networks allow users to share information between different computer systems separated by thousands of miles.

ISO stands for International Organization for Standards. The ISO 9000 (QMS) series is a standardized quality system that was discussed in Chapter 8. The ISO 14000 (EMS) series is a standardized environmental management system that is discussed in Chapter 9.

Total productive maintenance is a system for keeping a plant and its equipment at their highest productive levels through the cooperation of all levels of production and maintenance. It is defined in Chapter 13.

Quality function deployment (QFD) relates customer requirements or expectations with engineering characteristics and production processes. QFD was discussed in Chapter 10. QFD is a means to translate the voice of the customer into design parameters that can be deployed horizontally through product planning, design, engineering, production, assembly, and field service. Results of QFD are measured based on the number of design and engineering changes, time to market, cost, and quality. Thus, QFD is considered by many experts to be a perfect blueprint for quality by design.

Electronic meeting software (EMS) provides a means for individuals to communicate their opinions within a group in a structured and creative manner.[7] By using EMS, companies can nurture individuals without the inhibitions and distractions associated with face-to-face contact. EMS works by first posing a question or problem to a user group. Then, the users all respond anonymously at the same time. Once everyone has responded, every user can see all of the answers. This creates an environment where people respond to a question, not a person, and are guaranteed no reprisals. In this manner, better outcomes (solutions) can be achieved, compared to the typical (face-to-face) meeting style.

Enterprise resource planning (ERP) software unites numerous applications and/or separate systems (financials, human resources, sales, distribution, manufacturing, materials procurement, manufacturing, and so forth) within the management of a company under the umbrella of one software database.[8] For instance, ERP allows product-scanning software to interface with financials, materials procurement, sales, and distribution databases or software. Product data management (PDM) software is a subset of ERP and is used by companies to perform many time-intensive tasks, such as design reviews and approvals, transforming conceptual designs into end products.[9] Both ERP and PDM are used extensively by companies successful in e-commerce via the

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[7] Elizabeth Scott Anderson and Jill Smith Slater, “Electronic Meeting Software Makes Communicating Easier,” *Quality Progress* (April 1995): 83–86.

[8] Patrick Waurzyniak, “ERP Embraces the Web,” www.sme.org/manufacturingengineering (October 2000): 42–52.

[9] Steve Shoaf, “PDM or ERP: Making the Connection,” www.sme.org/manufacturingengineering (May 1999): 144–147.

Internet. Furthermore, these tools are now being developed using the XML language (successor to HTML), so they are compliant with future Internet innovations, such as the semantic web.

Product Development Tools

Quality by design tools that decrease total product development time utilize high-powered software and the latest in desktop computers. The primary quality by design tools for product development are:

Computer-aided drafting software.

Solid modeling software.

Finite element analysis software.

Parametric analysis software.

Rapid prototyping techniques.

Design for manufacture and assembly (and service and environment) techniques.

Design for reliability.

Design for maintainability or serviceability.

Failure mode and effect analysis.

Computer-aided drafting (CAD) software is used by organizations to produce engineering production drawings. These drawings can be done in planar view, isometric, and/or three-dimensional perspectives, with complete dimensioning and tolerancing. The power of CAD allows engineering changes to be easily incorporated into the drawings in a fraction of the time required by the old pencil-and-paper techniques. Another major advantage of CAD is its compatibility with downstream engineering and production software and hardware. Drawings from CAD software can be easily incorporated into software packages such as finite element analysis, computer-aided manufacturing, design for manufacture, and CNC machines.

Geometric modeling software is used to create a visual verification of a component or a system of components. By viewing a three-dimensional solid model, problems between part interactions can be easily identified prior to analysis and production. Geometric modeling is often referred to as solid modeling. Numerous geometric modeling software packages are available; however, the major computer-aided drafting packages are equipped to handle add-on modeling software. Today, advanced solid modeling software (sometimes call CAD for computer aided design versus computer aided drafting) packages are capable of doing die and mold tooling design from solid part models, sheet metal forming, and other advanced features.[10] They have also evolved to work seamlessly with computer aided manufacturing software by using solid models instead of wire-frame and surface models.[11]

Finite element analysis (FEA) software packages are widely regarded as the most powerful tool available for a design engineer. The scope of finite element techniques encompasses all engineering fields, such as solid mechanics, fluid mechanics, heat transfer, vibrations, and electromagnetics, to name the broadest categories. The advantage of a finite element analysis software package lies in its power to analyze and optimize the response of a system prior to prototype development and testing. This tool can help detect problems early,

[10] Patrick Waurzyniak, "CAD/CAM Tools Raise the Bar," www.sme.org/manufacturingengineering (January 2001): 52–60.

[11] Jean Owen, "CAM Embraces Solids," *Manufacturing Engineering* (February 1999): 80–90.

allowing the quality by design team to implement alternative changes together and quickly test the product changes to see the effects on quality and performance.

Parametric analysis software is an extension on the concept of a combination between geometric or solid modeling software and finite element software. Typically, an analysis using the finite element method involves defining the part geometry and material properties and its loading; determining the solution for stress, temperature, flow, and so forth; and interpreting the solution results. When the results indicate that a design change is necessary, the part geometry must be changed and the solution process repeated. Repeating this procedure numerous times can be very costly and time consuming. The procedure is especially laborious if the model is complex or if many changes must be made. Parametric analysis software gives the user the ability to automate any changes by programming the software to make decisions based on specified functions, variables, and selected analysis criteria. The software can be programmed to give the user control over virtually any variable such as dimensions, materials, loadings, constraint locations, and mesh refinement. Parametric analysis software expands the capabilities of geometric or solid modeling software and FEA software to include parametric modeling from parts libraries and design optimization.

Rapid prototyping techniques are used to quickly produce a physical "one-piece" model of a component or product. There are six rapid prototyping techniques commercially available. These are: stereolithography (STL), solid ground curing (SGC), selective laser sintering (SLS), fused deposition modeling (FDM), direct shell production casting (DSPC), and laminated object method (LOM). These techniques utilize information from CAD and geometric modeling software to produce exact geometric replicas of an engineering design in significantly less time than traditional machining processes. In stereolithography, in one of the most popular techniques, a three-dimensional plastic model of a part is produced by curing a liquid photomonomer with a laser. Similarly, solid ground curing produces a plastic model by curing a liquid resin with a UV light source. In the selective laser sintering process, plastic powders and waxes are sintered with an infrared laser to produce a model. Plastic or wax wire is melted and delivered by means of an extrusion head to produce a model in a process called fused deposition modeling. The aforementioned processes produce a solid part, whereas in the direct shell production casting method an ink jet nozzle applies a liquid binder to a ceramic powder to produce a shell mold of the part. In the laminated object method, a sheet of paper is rolled onto a platform and then a laser is used to cut away the excess paper to form a model. It should be noted that rapid prototyping techniques do not produce a model with realistic mechanical characteristics. However, recently, a new form of rapid prototyping, called rapid toolmaking, can actually make a metal mold for a short production run. Rapid toolmaking bridges the gap between the need for a small number of prototypes and full production by using special materials or post-processes, such as copper polyamide, heat sintered stainless steel powders, and epoxy/steel blends, to name a few.[12]

Design for manufacture and assembly (DFMA) is a design philosophy that identifies production and assembly problems. Software programs alert engineers of design problems prior to production. Potential problems, such as excessive costs due to part complexity, number of parts, difficult assembly procedures, increased assembly times, and unreasonable or unwarranted tolerances, can be identified, and changes in a design can be made before design effort continues or, more importantly, before full production commences. Recently, DFMA has evolved to also include design for service and design for environment. In design for service, a product or process is designed for efficient repair and maintenance by establishing assembly and disassembly sequences, generating a degree of difficulty and time estimate for service, and identifying the service life of particular parts. In design for environment, a product or process is designed such that its disposal presents no adverse environmental impact while being cost-effective.

[12] Robert Aronson, "Toolmaking Through Rapid Prototyping," *Manufacturing Engineering* (November 1998): 52–56.

Design for reliability (DFR) is a philosophy of assuring, that reliability is built into the design. Reliability is the probability that a product will perform its intended function, for a given time under stated conditions. Typical DFR tools include the following:

- Failure mode and effects analysis (FMEA).
- Stress strength analysis to minimize the chances of failure.
- Part selection, considering operating conditions and load factors.
- Derating means using the system at lower than rated load to increase reliability.
- Redundancy is a technique similar to a “stand-by” subsystem.
- Reliability growth models to monitor whether system reliability meets the target.
- Accelerated life testing (ALT) is done at the increased stress and/or faster operation to reduce the test duration.
- Multiple Environment Overstress Tests (MEOST) is a technique of applying combined loads to simulate all failure modes in the lab tests.

Design for Maintainability or Serviceability (DFS) has strong relationship with the design for assembly. Some underlying principles include the following:

- low fastener count
- low tool count
- predictable maintenance schedules
- one-step service functions
- extend maintenance intervals since predictable failures are relatively less expensive when compared to random failures, for example, filter change, oil change
- provide diagnostics and monitoring facilities

Failure mode and effect analysis (FMEA) is an analytical technique to identify foreseeable failure modes of a product or process and plan for their elimination. In other words, FMEA can be explained as a group of activities intended to: recognize and evaluate the potential failure of a product or process and its effects; identify actions that could eliminate or reduce the chance of the potential failure occurring; and document the process. FMEA requires a team effort to most easily and inexpensively alleviate changes in design and production. There are two primary types of FMEA: design and process (covered in Chapter 12).

Production Tools

Improving the quality of manufactured parts and decreasing the production cycle time requires the use of high-powered software programs integrated with computer-controlled machine tools and modern facilities. The primary quality by design tools for production are:

Robotics.

Computer-aided manufacturing.

Computer numerical controlled tools.

Continuous process improvement.

Just-in-time production.

Virtual manufacturing software.

Agile (or lean) manufacturing.

Advanced measurement and verification.

Since the 1960s and 1970s robots have steadily become more advanced and more prevalent in manufacturing. From what began as simple automation processes evolved into robots performing advanced welding operations, tolerance verification, material handling and precision painting on automobile assembly lines. The advantages of robotics is obvious (reduced overhead and labor costs, significantly faster throughput, and a potential for zero defects, scrap and rework, to name a few), however, the capital investment can at times be prohibitive. Robots have become faster and have better controllers for very sophisticated operations, and have increased load capacity compared to their predecessors.[13] They are capable of operating within the open-architecture personal computers, and they interact seamlessly with most major CAD/CAM software packages.[14] Today, an engineer can design a product in any major CAD package and then transfer the design to robot simulation software to consider manufacturing options. At this point in their development, the only limitation to their future advancement is the human interface. Robots are now being developed as autonomous systems, and robots, of the marsupial type, were even used in the search and rescue operation at the World Trade Center after the events of September 11, 2001.

Computer-aided manufacturing (CAM) software is used to identify machine tool paths and other production parameters to optimize the machining of a part. After a part has been completely drawn using a CAD or geometric modeling program, CAM software identifies critical machining parameters based primarily on the part geometry, size, dimensions and tolerances, and material. Critical machining parameters include machine tool feed rates, stock required, bit size, and optimum tool path, to name a few. Today, CAM systems work almost seamlessly with most computer aided design software. They have achieved a high level of intelligence with full associativity between the solid model and tool path, standardized feature recognition, higher speeds, and knowledge- (or history-) based machining.[15]

Machine tools, such as mills, lathes, and presses, that are completely controlled by a microprocessor are called computer numerical control (CNC) machine tools. Advanced CNC machines and modern facilities also can automate material handling. Specialized computer languages, such as G and M codes, and coordinate locations are used for programming CNC machines. Once a part has been completely drawn using a CAD or geometric modeling program, it can be easily transferred to a CAM program and then machined through an interface between the CAM program and CNC machine. Typically, the operator needs little knowledge of the actual programming languages involved because of user-friendly interfaces between the software packages.

Continuous process improvement (CPI), as it applies to quality by design, is a systematic year-after-year study to improve the production processes involved in production. Production processes are continuously improved by making them effective, efficient, and adaptable to changes. This process involves eliminating waste and rework, reducing scrap and cycle time, eliminating activities that do not increase product value, and eliminating nonconformities wherever they occur.

Just-in-time (JIT) production is a process-control method and production philosophy that provides parts, components, and assemblies to production at the exact time they are needed. The result of JIT production is less inventory of raw materials, smaller inventories of parts, less work in process, and shorter lead times. Benefits of JIT production are a significant reduction in floor space, less overhead, and, most importantly, a reduction in cost. A possible pitfall of JIT production is a reduction of inventories to critically low levels. Consequently, care must be taken to choose suppliers with excellent quality products and services as well as a knowledge of production lead and process times.

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[13] Russ Olexa, "More Brawn and Brains," www.sme.org/manufacturingengineering (September 2001): 90–120.

[14] Patrick Waurzyniak, "Robotics Revolution," *Manufacturing Engineering* (February 1999): 40–50.

[15] Patrick Waurzyniak, "CAM Gets Smarter," www.sme.org/manufacturingengineering (July 2000): 56–69.

With virtual manufacturing software, production engineers are able to create a factory on their desktop computer. They can simulate a production facility with mechanical handling robots, automated arc and spot welding systems, drilling and riveting machinery, automated painting and coating, numerically-controlled machining, coordinated measuring, and assembly processes showing the complete manufacturing and production operations in a virtual setting. Virtual manufacturing software allows production engineers to analyze and debug production facilities prior to the capital equipment investment.

Agile manufacturing helps organizations thrive in a rapidly changing, competitive marketplace by incorporating versatility into the manufacturing environment. An agile manufacturing environment responds quickly to marketplace demands by quickly incorporating new technologies into products and easily adapting to many different customer needs. Recently, flexible manufacturing systems, also called manufacturing cells and centers, have become commonplace. These cells or centers are capable of doing multiple machining operations, materials handling, and so forth while also being modular in design and easily adaptable to new configurations.[16] Although similar in nature to agile manufacturing, because the focus is on bringing a cost-effective product to market quicker, lean manufacturing strives to do more with less. That is, less human effort, less factory space, less capital investment and less engineering to produce the product in half the time.[17] To accomplish lean manufacturing, many technological changes must take place with the organization: production should be a continuous flow or at least a supermarket flow; the cyclic nature of the supply and demand on the production system should be smoothed out; agile (flexible) manufacturing systems should be implemented; total productive maintenance should be practiced by empowering employees; waste should be eliminated; and the organization should strive for 100% quality prior to inspection.[14,18]

Recently, advances in measurement and verification have brought together the worlds of computer-oriented product development tools and computer-oriented manufacturing tools. Coordinate (also called computer) measuring machines (CMMs) can automatically measure a three-dimensional object and transfer the information back and forth to computer aided design software for measurement, alignment, dimensioning, and verification.[19] What started from a two-dimensional physical probe system has evolved into three-dimensional probe systems,[20] hand-held probes, photogrammetry dots, laser trackers, and more recently, laser radar,[21] laser stripe illumination, and line-scan camera technology.[22] The newest systems are capable of defining part shapes automatically with extremely high precision. For instance, the latest technology is capable of measuring the complex curvature of an airfoil for a turbine engine.[23] Today, CMMs can also be used in an automated process to verify a machined part in real-time to make necessary adjustments.

Statistical Tools

Quality engineers are the primary users of statistical tools associated with a quality by design environment; however, all employees should be able to use statistical tools where appropriate. The primary statistical tools that cover all facets of design, testing, and production are:

Statistical tolerance stack-up analysis.

Reliability and life data analysis.

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16 Robert Aronson, "Cells and Centers," *Manufacturing Engineering* (February 1999): 52–60.

17 Drew Lathin and Ron Mitchell, "Learning from Mistakes," *Quality Progress* (June 2001): 39–45.

18 John Allen, "Make Lean Manufacturing Work for You," www.sme.org/manufacturingengineering (June 2000): 34–40.

19 Simon Raab, "CAD's Final Frontier," *Manufacturing Engineering* (April 1999): 84–90.

20 Marco Manganelli, "Measuring the Real World with High-Performance Scanning Systems," *Quality Digest* (September 2000): 37–41.

21 David A. White, "Coherent Laser Radar," *Quality Digest* (August 1999): 35–38.

22 Robert Green, "Measuring Complex Curves with a New Twist," *Quality Digest* (September 1999): 35–38.

23 Ibid.

Design of experiments.

Response surface methods.

Statistical process control.

Statistical tolerance stack-up analysis is performed to prevent any functional or assembly problems due to incorrect tolerances. Simulation is performed to anticipate problems if any, before physical manufacturing of the parts.

Reliability and life data analysis is preformed to estimate measures such as Mean Time Between Failures (MTBF) or B_{10} life which is the time period by which 10% of the parts or systems will fail. Reliability data is most often incomplete, that is, the data of failures and survivals. Such data requires different approach from statistical analyses to draw conclusions about reliability validation.

Design of experiments (DOE) or experimental design, is a numerical study that identifies the variables in a process or product that are the critical parameters or cause significant variation in the process. By using AQ1 formal experimental techniques, the effect of many variables can be studied at one time. Changes to the process or product are introduced in a random fashion or by carefully planned, highly structured experiments. There are three approaches to DOE: classical, Taguchi (see Chapter 16) and Shainin. The wise practitioner will become familiar with all three approaches and develop his own methodology.

Response Surface Methods (RSM) are used to optimize the solution obtained through DOE when the response in nonlinear.

Statistical process control (SPC) is the primary TQM tool (see Chapter 15). It is a charting technique used to monitor process variations and correct problems before producing scrap. Because DOE identifies the critical parameters and their target values, its use should actually precede SPC in most circumstances. It is not unusual to find after an experiment that SPC was controlling the wrong variable or that the target was incorrect.

Pitfalls of Quality by Design Tools

Note that, by the title of this section, there are no negatives to implementing quality by design tools. Keep in mind that before any of the aforementioned tools will help in the quality by design process, employees must have experience—and often expertise—with them. In fact, due to inexperience, these tools will initially lengthen lead times. For example, when a design engineer/drafter is first introduced to computer-aided drafting software, his/her first production drawing could take triple the previous time. However, after proper training and even limited experience, the same drawing could take one-third less time and significantly reduce the time allocated towards future modifications.

Without proper training, many of these tools can be dangerous in the wrong hands. Therefore, it is important to have technical people in the quality by design group who are proficient with the tools. An organization intending to implement a quality by design philosophy needs to allocate significant resources toward employee professional development and education. Because of the initial capital investment, the rewards of a quality by design environment are very rarely realized in the short term. On the positive side, an investment in the quality by design tools often results in an increase in employee retention and satisfaction.

Examples of Tools

There are numerous examples of organizations, from manufacturing to service, employing quality by design tools in product development and production to reduce their time to market, to reduce costs, and to improve quality. The following examples give a wide range of organizations, albeit primarily larger organizations, that have successfully applied quality by design. However, there are also small organizations throughout the world benefiting from quality by design.

1. Possibly one of the greatest examples of quality by design is the design and construction of the Boeing 777 that was nearly 100% designed, analyzed, and tested using multi-disciplinary teams, design for manufacture and assembly, computer-aided-design and analysis software, computer numerical control machines, and a vast array of computer networking with their suppliers. More recently, a team from Boeing and Boeing won the 2000 RIT/USA Today Quality Cup for manufacturing when it increased the wear-out rate on an ozone converter from one year to three years.[24] Using quality by design, the team saved $20 million and created another $10 million in business from additional sales.

2. Another example of quality by design in the aircraft industry is the design and construction of the F-22 joint strike fighter produced by Lockheed Martin and X-32 joint strike fighter produced by Boeing.

   a. A team of individuals from primarily TRW and Lockheed, and also Motorola, Rockwell, Texas Instruments, ITT, and GEC won the 1994 RIT/USA Today Quality Cup for manufacturing by using quality by design approaches adapted from the automobile industry and relying on constant teleconferencing.[25] As a result of the team's effort, the team cut the cost of F-22 communication and navigation systems from $2.1 million to $1.6 million per jet. The team convinced the Department of Defense that commercial parts (versus rigid military specification) could be used for many of the components. The team also reduced the number of semiconductor-driven boxes from 12 to 1.

   b. Lockheed Martin used extensive simulations and numerous software programs in its F-22 program to address manufacturing, fixtures, maintenance, ergonomics, cutting time, and costs.[26] They used digital manufacturing software and other solutions to improve quality and reduce labor costs. For instance, some jobs that took 96 man-hours were reduced to one and one-half man-hours.

   c. Likewise, Boeing used virtual numerical control software and simulation and verification software to automate tool paths before metal cutting.[27]

3. Iomega Corp. was the co-winner of the 2001 RIT/USA Today Quality Cup in the manufacturing category by using various principles of quality by design in the design of their new HipZip that plays digital music files.[28] Because of a very quick time to market deadline, team members at Iomega used a multi-fold strategy: the design was based on what the customer (not the engineer) wanted; aluminum molds for evaluation were made in several days compared to three months; product testing was performed in sequence with the design process; and the product was designed for easy manufacturability (for example one type of screw was used in the whole design).

4. Starting in the early 1980s with the purchase of The Harley-Davidson Motor Company from AMF, the company rebounded from extremely poor performance (and products) in the previous decade(s) by using many of the facets of quality by design. Throughout the late 1980s and 1990s they implemented many programs to enhance their company performance, such as: materials as needed (part of JIT), a successful TPM program, computer-aided manufacturing, design for manufacturing and assembly, and agile (or lean) manufacturing. As a result of their efforts, they are one of the most stable and successful companies in the world, in not only motorcycle production and sales, but also in all facets of the global economy.

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[24] 2000 RIT/USA Today Quality Cup.

[25] 1994 RIT/USA Today Quality Cup.

[26] "Simulation Aids Manufacturability for the Joint Strike Fighter," www.sme.org/manufacturingengineering (October 2001): 30–32.

[27] Patrick Waurzyniak, "Simulations Speed Production," www.sme.org/manufacturingengineering (April 2001): 36–40.

[28] Matt Krantz, "Engineers Get in Tune to Save Time," *USA Today* (May 10, 2001): 3B.

5. BMW's X5 SUV was the first BMW automobile to be 100% digitally designed using 3-D computer-aided design programs.[29] Using CAD, they reduced vehicle development time, achieved tighter manufacturing tolerances, performed design tests and structural evaluation, including simulations, and verified safety issues (rollover), allowing BMW to respond faster to customer needs (changes) in future versions of the vehicle.

6. For the big three U.S. automakers, implementing quality by design techniques has increased their profits and helped regain their market share and dominance. For instance, General Motors eliminated 900 parts from the 1995 Chevrolet Lumina compared to the 1994 model and reduced assembly time by 33%. At Ford Motor Company, the 1994 Mustang was redesigned in just 35 months using quality by design. In the new Plymouth Neon, only 300 kinds of fasteners are used, compared to 650 for most vehicles, making the Neon one of the big three's first profitable small cars.

7. General Electric Aerospace applied quality by design to a ground-based radar system. What normally would have taken six to nine months to design and put into production only took three months, equating to a 60% reduction in engineering and testing time.

8. Ingersoll-Rand Corporation incorporated quality by design in a recent product development project. They designed a hand-held, air-powered grinder that normally would have taken four years, total development. Development took only one year using quality by design.

9. Lamb Technicon, a subsidiary of Litton Industries, used virtual manufacturing software for Chrysler Corporation's Cirrus and Stratus vehicle assembly. By simulating the operation of 40 spot welding and mechanical handling robots with virtual manufacturing software, the amount of time required to program the robots was reduced from an estimated 1600 engineering manhours to 300.

10. The product development team from Delphi could achieve flawless launch requirements. Their customers required the use of laser transmission welding to attach the cover of the product to its case with a leak-proof seal. This required the laser transmission welding of polymers which is a relatively new technology, and there are varying and contradictory philosophies about the approach among equipment suppliers. With this background, Delphi team decided to use DFSS approach to optimize the laser welding process. The DFSS method allowed the team to exceed project goals. The team reduced capital equipment requirements, exceeded customer performance requirements, and achieved greater than Six Sigma process capability. The method also minimized the team's development costs by guiding it to use a very efficient experimental strategy. Without the use of these methods, the gains would not have been realized and the likelihood of meeting launch requirements flawlessly would have been greatly reduced.[30]

These are success stories of organizations that implemented quality by design tools properly, but one must keep in mind that many of these organizations had not only mastered the technical tools needed. They also maximized the use of the technical tools by improving communication within the team(s) at the beginning of the project.

Misconceptions and Pitfalls

Some organizations claim to have been using quality by design for quite some time. This may be so, but it is also possible that they have redefined quality by design to fit their methods rather than changing their present management styles. The following is a list of some of the common misconceptions that should be understood by those claiming to have used quality by design.

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[29] Robert A. Green, "BMW Drives Safety with Quality," *Quality Digest* (August 2001): 26–28.

[30] "DFSS Lights the Way" by Carl Berardinelli and others, Six Sigma Forum Magazine, published by ASQ, May 2009.

1. Quality by design is not simultaneous design and production; it encourages just the opposite. Nothing is produced until all designs are agreed upon between all the producers required to fabricate the product.

2. Quality by design is not a quick fix or magical formula for success; it is a way of thinking. The people involved in the quality by design group must be specialists before they are incorporated in the group. If this technical expertise is not present, little will be gained with quality by design principles.

3. Quality by design does not require multiple tests of the product to be conducted until the optimum design is achieved. Quality by design applies a one-pass design, where the product passes testing the first time.

4. Quality by design is often confused with inspection techniques used in TQM. Quality by design is highly dependent upon a TQM environment, but the same inspection methods are not required. Quality by design incorporates repeatability into its products, either automatically or manually. Quality by design considers and applies what was learned about process capabilities in the TQM setting. Thus, products are stringently designed well within process capabilities to facilitate SPC.

With the promise of huge savings, many organizations may see the benefit of quality by design and invest in massive amounts of technology, hire consultants, tear down walls between departments, and purchase software and hardware, only to be disappointed with the return on their investment. The following is a list of some of the common pitfalls to avoid if an organization is considering implementing quality by design.

1. Team members should be assigned to functional departments, as in sequential engineering; however, their primary loyalty lies with the quality by design team. Do not eliminate the sequential engineering process; instead, perform all design up front as a group with improved communication. For instance, do not plan for ten man-years to optimize component designs after a system has been fully prototyped or plan for multiple design iterations of a new product before manufacturing.

2. Avoid promising to meet an unobtainable schedule, because missing an unobtainable schedule carries a more severe penalty than meeting a longer one. For instance, do not inflate a fabrication lead time to allow for anticipated or uncontrolled design changes.

3. Avoid using tight tolerances and stringent requirements to obtain a one-pass design.

4. Avoid changing product definition and specifications during the design phase. Costs increase exponentially when features are added through the development cycle that cause design, tooling, and production systems to change.

5. Avoid "business as usual" parts vendoring by using the low bidder.

6. Avoid automating the product development phase before it is simplified.

Of course, these are only some of the possible pitfalls, and the manner in which an organization implements quality by design depends on its size, structure, and product line.

TQM Exemplary Organization[31]

Founded in 1979, privately-held Trident manufactures precision sheet metal components, electromechanical assemblies, and custom products, mostly in the office-equipment, medical-supply, computer, and defense industries. It has grown from a three-person operation to an employer of 167 people, occupying a modern, 83,000-square-foot facility.

[31] Malcolm Baldrige National Quality Award, 1996 Manufacturing Category Recipient, NIST/Baldrige Homepage, Internet.

Trident has established "quality as its basic business plan" to accomplish short- and long-term goals for each of its five key business drivers: customer satisfaction, employee satisfaction, shareholder value, operational performance, and supplier partnerships. All goals, however, contribute to achieving Trident's overarching aim of total customer satisfaction. Each improvement project begins with a thorough analysis of how to meet or exceed customer requirements in four critical areas: quality, cost, delivery, and service. Metrics are designed to ensure that progress toward the customer-targeted improvements can be evaluated. The company's data-collection system provides all personnel with a current record of the company's progress toward its goals. Performance data also are reviewed daily in each department and weekly by the Senior Executive Team. Once each month, this team aggregates the data for the entire company and reports on progress toward goals set for each of the five key business drivers.

Regular contact with customers and suppliers is an essential element of Trident's quality strategy. Senior executives meet twice a year with representatives of each customer company for in-depth discussions on Trident's performance as a supplier, while 41 customer-contact personnel interact with these firms on a daily basis. Customers, as well as key suppliers, also participate in Continuous Involvement Meetings, initiated by Trident, to gain full understanding of a customer's new or modified product design.

Trident also uses technology to strengthen links to customers and suppliers. Electronic data interchange capabilities, for example, permit paperless transactions, while file-exchange capabilities enable customers to send their designs electronically to Trident's computer-aided design and manufacturing equipment.

Organized into functional departmental teams, employees "own" specific processes and are given responsibility for identifying problems and opportunities for improvement. To foster innovation, employees have the authority to modify their process, using the company's documented process improvement procedure, which focuses attention on non-value-added activities that can be eliminated.

The company also relies heavily on the contributions of cross-functional teams, and it encourages employees to diversify their work skills and abilities. Eighty percent of Trident workers are trained in at least two job functions, well on the way to the 1998 goal of 100 percent.

To reinforce worker commitment to continuous improvement, the company regularly acknowledges exemplary performance. Reward and recognition of employees have climbed steadily, from just nine incidents in 1988 to 1,201 in 1995.

Improvements set in motion by Trident's total quality strategy has catalyzed performance gains that have cascaded throughout the organization and generated benefits reaped by customers. Employee turnover has declined dramatically, from 41% in 1988 to 5% in 1994 and 1995. The company correlates these positive workforce trends with increasing productivity and rising levels of customer satisfaction. Sales per employee rose from $67,000 in 1988 to $116,000 in 1995.

Nonconformance rates have fallen consistently, so much so that Trident now offers a full guarantee against nonconformances in its custom products. Customer complaints have fallen 80%, and time spent on rework has decreased 90%. On the service side, the company has greatly improved its on-time delivery performance from 87% in 1990 to 99.94% in 1995. Machines made for one of Trident's major customers go directly to that company's distribution center for shipping. For the past two years, no nonconformances have been reported in these Trident-built machines.

Employees have submitted over 125 process improvement ideas per month and 97% have been implemented. These and other improvements have enabled Trident to maintain its status as key supplier to major customers, even after those organizations trimmed suppliers by 65 to 75%.

Summary

The quality by design approach as compared with other approaches offers significant benefits compared to the "over-the-wall" to product development. This requires a major change from "over-the-wall" to "simultaneous engineering" and allows working in multidisciplinary teams. Top management plays a major role in managing this change as it requires change in the organization design and communication flow.

There are a number of useful organizational tools for successful implementation such as TQM, computer networks, quality function deployment, virtual meeting tools, and enterprise resource planning system. The product development tools include finite element analysis, computer aided drafting and designing, rapid prototyping, failure mode and effects analysis, design for Six Sigma, and designing for reliability. Quality by design can be even more effective, when combined with production tools such as robotics, computer aided manufacturing, just-in-time, lean etc. Statistical tools such as design of experiments, tolerance stack-up analysis, statistical process control, and reliability analysis provide a punch for developing optimized reliable product.

It is necessary to take certain actions to prevent pitfalls of quality by design. Some of these include building over the sequential engineering rather than completely eliminating and promising unobtainable schedules.

Exercises

1. Briefly describe the difference between sequential engineering and quality by design (or concurrent) engineering.

2. List 15 general attributes that a quality by design team should consider during the product design phase of product development.

3. Select members of a quality by design team for the development and production of two or more of the following products. If possible, the team should be limited to ten members of different disciplines.
   (a) Ballpoint pen
   (b) Car windshield sunscreen
   (c) Manual can opener
   (d) Computer keyboard
   (e) Clothes iron

4. Design the workspace for two or more of the items you used in Exercise 3.

5. Using trade journals and professional society magazines, list three or more commercially-available software packages for two of the following quality by design tools. Also, try to compare the software packages on the basis of cost, attributes, and performance.
   (a) Computer networks
   (b) Computer-aided drafting
   (c) Solid modeling
   (d) Finite element analysis
   (e) Parametric analysis
   (f) Rapid prototyping
   (g) Computer-aided manufacturing
   (h) Virtual manufacturing
   (i) Statistical process control
   (j) Experimental design
   (k) Other quality by design software

6. Using trade journals, professional society magazines, periodicals, and your networking ability, identify three examples of quality by design success stories and discuss their results.

7. Individually or with a team, identify an organization in your local area with which you are associated or have familiarity that practices quality by design and discuss the effectiveness of the practices.

8. Individually or with a team, identify an organization in your local area with which you are associated or have familiarity that does not practice quality by design and describe facets of the organization that you would change to improve time to market and lower costs.

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12

Failure Mode and Effect Analysis

Chapter Objectives

- Understanding the Failure Mode and Effects Analysis (FMEA) as a proactive analytical team tool for reliability improvement
- Understanding the process of developing design FMEA and process FMEA
- Brief overview of FMEA formats and rating system for design and process FMEA
- Understanding the application example of design FMEA

Introduction

Failure Mode and Effect Analysis is an analytical technique (a paper test) that combines the technology and experience of people in identifying foreseeable failure modes of a product or process and planning for its elimination. In other words, FMEA can be explained as a group of activities intended to

> Recognize and evaluate the potential failure of a product or process and its effects.
>
> Identify actions that could eliminate or reduce the chance of potential failures.
>
> Document the process.

FMEA is a "before-the-event" action requiring a team effort to easily and inexpensively alleviate changes in design and production.

There are several types of FMEA: design FMEA, process FMEA, equipment FMEA, maintenance FMEA, concept FMEA, service FMEA, system FMEA, environmental FMEA, and others. However, for all intents and purposes, all of the types can be broadly categorized under either design FMEA or process FMEA. For instance, equipment, service, and environmental FMEA are just slightly modified versions of process FMEA, and system FMEA is a combination of design and process FMEA. For this reason, the remainder of this chapter will concentrate primarily on design FMEA and process FMEA.

Design FMEA aids in the design process by identifying known and foreseeable failure modes and then ranking failures according to relative impact on the product. Implementing Design FMEA helps establish priorities based on expected failures and severity of those failures and helps uncover oversights, misjudgments, and errors that may have been made. Furthermore, design FMEA reduces development time and cost of manufacturing processes by eliminating many potential failure modes prior to operation of the process and by specifying the appropriate tests to prove the designed product.

Process FMEA is used to identify potential process failure modes by ranking failures and helping to establish priorities according to the relative impact on the internal or external customer. Implementing process FMEA helps to identify potential manufacturing or assembly causes in order to establish controls for occurrence reduction and detection. Furthermore, design and process FMEA document the results of the design and production processes, respectively.

Reliability

Reliability is one of the most important characteristics of any product, no matter what its application. Reliability is also an important aspect when dealing with customer satisfaction, whether the customer is internal or external. Customers want a product that will have a relatively long service life, with long times between failures. However, as products become more complex in nature, traditional design methods are not adequate for ensuring low rates of failure. This problem gave rise to the concept of designing reliability into the product itself.

Reliability may be defined as the probability of the product to perform as expected for a certain period of time, under the given operating conditions, and at a given set of product performance characteristics. One important consideration when performing reliability studies is the safety of the product or the process. The criticality of a product or process changes drastically when human safety considerations are involved. Reliability tests and studies can form the basis for safety studies.

Reliability Requirements

In all cases, the acceptance of a certain product or process is subject to meeting a certain set of given requirements for reliability of the product or process. It is, however, important to realize that although the definition for reliability is relatively simple, the customer and the supplier may have different definitions of what constitutes failure. This common agreement on what constitutes reliability should be defined in terms of influence on other related systems, the reliability of past similar systems, the complexity of the failure, and finally the relative criticality of the failure.

It is the engineer's task to define all of the previously-stated items, and in many instances, the engineer has only past experience and personal knowledge of like systems to define these different aspects of failure accurately. A simple example of this task is comparing a certain nonconformity that causes the product to become inoperable to another type of nonconformity that causes only slight inconvenience to the consumer. There is no great analysis needed to determine that the first failure has a greater criticality than the second failure, which only slightly inconveniences the customer.

Based on the definition of the part, assembly, or process under consideration, the reliability of each subsystem and the factors involved in the reliability must be found, and the appropriate relationships for each part, class, or module of the product must be computed. This will help to develop an approved parts list, parts application study, critical components list, and an organized method for changing parameters as needed. This information then leads to a formal system for managing FMEA based on probability of the nonconformity occurring, probability of the customer noticing the nonconformity (defect), and the probability of the nonconformity actually being undetected and being shipped to the customer.

Failure Rate

A vast majority of products follow a very familiar pattern of failure. When no information is known about the reliability (probability of survival) or, conversely, failure of a product, component, system or process, except the failure rate which is a constant, periods of failure can conveniently be modeled by an exponential distribution. The probability of survival of this type of product using an exponential distribution may be expressed as

$$R_t = e^{-t\lambda} = e^{-\frac{t}{\theta}}$$

where R_t = the reliability or probability of survival
t = the time specified for operation without failure
λ = the failure rate
θ = the mean time to failure

EXAMPLE PROBLEM

Assume that a product has a constant failure rate of $\lambda = 0.002$ per hour. What is the probability that it will survive or be reliable during the first 100 hours of operation?

$$R_t = e^{-t\lambda} = e^{-(100)(0.002)} = e^{-0.2} = 0.980$$

Thus, there is a 98% chance that the product will survive during the first 100 hours of operation.

The failures of most products can be classified into three main categories: debug, chance, and wear out. The first of these (debug) includes a high failure rate at the initial stages because of inappropriate use or flaws in the design or manufacturing. The next category (chance) is the failure of the product due to accidents, poor maintenance, or limitations on the design. The final category (wear out) covers failure after the product or process has performed as expected for at least the amount of time given by the manufacturer as the product or process life. A successful design or process should ideally fail only in this last method.

Intent of FMEA

Continually measuring the reliability of a machine, product, or process is an essential part of Total Quality Management. When acquiring new machines, creating a new product, or even modifying an existing product, it is always necessary to determine the reliability of the product or process. One of the most powerful methods available for measuring the reliability of the process or product is FMEA. As previously stated, FMEA is an analytical technique that combines the technology and experience of people in identifying foreseeable failure modes of a product or process and planning for its elimination. This method can be implemented in both the design and the process areas and basically involves the identification of the potential failure modes and the effect of those on both the internal and the external customer.

FMEA attempts to detect the potential product-related failure modes. The technique is used to anticipate causes of failure and prevent them from happening. FMEA uses occurrence and detection probability criteria in conjunction with severity criteria to develop risk prioritization numbers for prioritization of corrective action considerations. This method is an important step in debugging and preventing problems that may occur in the manufacturing process. It should be noted that for FMEA to be successful, it is extremely important to treat the FMEA as a living document, continually changing as new problems are found and being updated to ensure that the most critical problems are identified and addressed quickly.

The FMEA evaluation should be conducted immediately following the design phase of product production and, definitely in most cases, before purchasing and setting up any machinery. One purpose of FMEA is to compare the design characteristics relative to the planned manufacturing or assembly methods to make certain that the product meets the customers' requirements. Corrective actions should begin as soon as a failure mode is identified. Another purpose of FMEA is to provide justification for setting up a process in a certain manner. FMEA may be viewed as the formal manner in which engineers will analyze all possible nonconformities and problems that may arise in a given process or with a certain product. This will, in a sense, encourage all the engineers' analyses and findings to be in an organized, user-friendly format.

The use of FMEA in both the product and process areas of manufacturing is more important today than it has ever been. Current products are more complicated than ever, and this requires more organization and precaution than ever. It will take far more planning to produce current products with the same reliability as prior products. Consumers today also are far more particular than they have been in the past, demanding products of the highest quality for the lowest possible cost. FMEA also allows the engineer to keep a record of all thoughts and actions taken to ensure a safe and reliable product. This becomes extremely important with the customers' current mode of thinking—needing to assign blame whenever something is not exactly as expected. In addition, the judicial system has become increasingly strict and more unforgiving than ever before. The most important aspect of this discussion is to follow up on any and all concerns that seem critical and to document the concerns and changes made, continuously updating the FMEA. All changes and concerns between the design stage and the delivery of the product to the consumer should be noted in a thorough, precise, and organized manner.

Design (product) FMEA or process FMEA can provide the following benefits:

1. Having a systematic review of component failure modes to ensure that any failure produces minimal damage to the product or process.
2. Determining the effects that any failure will have on other items in the product or process and their functions.
3. Determining those parts of the product or the process whose failure will have critical effects on product or process operation (those producing the greatest damage), and which failure modes will generate these damaging effects.
4. Calculating the probabilities of failures in assemblies, sub-assemblies, products, and processes from the individual failure probabilities of their components and the arrangements in which they have been designed. Since components have more than one failure mode, the probability that one will fail at all is the sum of the total probability of the failure modes.
5. Establishing test program requirements to determine failure mode and rate data not available from other sources.
6. Establishing test program requirements to verify empirical reliability predictions.
7. Providing input data for trade-off studies to establish the effectiveness of changes in a proposed product or process or to determine the probable effect of modifications to an existing product or process.
8. Determining how the high-failure-rate components of a product or process can be adapted for higher-reliability components, redundancies, or both.

9. Eliminating or minimizing the adverse effects that assembly failures could generate and indicating safeguards to be incorporated if the product or the process cannot be made fail-safe or brought within acceptable failure limits.
10. Helping uncover oversights, misjudgments, and errors that may have been made.
11. Helping reduce development time and cost of manufacturing processes by eliminating many potential modes prior to operation of the process and by specifying the appropriate tests to prove the designed product.
12. Providing training for new employees.
13. Tracking the progress of a project.
14. Communicating to other professionals who may have similar problems.

The FMEA document, however, cannot solve all design and manufacturing problems and failures. The document, by itself, will not fix the identified problems or define the action that needs to be taken. Another misconception is that FMEA will replace the basic problem-solving process (see Chapter 5).

FMEA Team

The FMEA methodology is a team effort where the responsible engineer involves assembly, manufacturing, materials, quality, service, supplier, and the next customer (whether internal or external). The team leader has certain responsibilities, which include determining the meeting time and place, communicating with the rest of the team, coordinating corrective action assignments and follow-up, keeping files and records of FMEA forms, leading the team through completion of the forms, keeping the process moving, and finally, drawing everyone into participation. There also should be a recorder who records the results on the form and distributes results to participants in a timely manner.

FMEA Documentation

As stated before, the concept of FMEA is nothing new to engineers. Engineers, or anyone designing and building a product, have always incorporated the concepts of FMEA in their thinking process. However, FMEA does help keep those ideas available for future use and for the use of others. One engineer may find a potential problem elementary and not worth extra attention; a second engineer may not realize the problem altogether. The purpose of the FMEA document is to allow all involved engineers to have access to others' thoughts and to design and manufacture using this collective group of thoughts, thus promoting a team approach. It cannot be stressed enough that in order for the document to be effective, representatives from *all* affected areas must be consulted and their input always included. Also, for the document to be effective, it *must* be continually updated as changes occur throughout the design and manufacturing process.

Block Diagram

Design FMEA should always begin with a block diagram. The block diagram can be used to show different flows (information, energy, force, fluid, and so forth) involved with the component being analyzed. The primary purpose of the block diagram is to understand the input to the block, the function of the block, and the output of the design. Another purpose is to establish a logical order to the analysis. Any and all block diagrams used in developing the FMEA document should be included with the document throughout all phases of development.

A block diagram is started by first listing all of the components of the system, their functions, and the means of connection or attachment between components. Then, the components of the system are placed in blocks, and their functional relationships are represented by lines connecting the blocks. For example, the system components for a low-cost child's remote-control car could be:

Chassis.

Body.

Steering servo.

Motor.

Steering linkage.

Battery holder.

Drive shaft.

Front and rear wheels.

Batteries.

Remote sending and receiving units.

These system components would be attached to one another using the following connection methods:

Screws.

Snap fit.

Press fit.

Compressive fit.

Cotter pins.

Wires.

Bushings.

Shaft couplings.

In order to construct the block diagram, as shown in Figure 12-1, of a low-cost child's remote-control car, each of the system components represents a block, and certain blocks are connected to one another. For example, the motor is connected to the chassis with screws, to the drive shift with a shaft coupling, to the battery holder with wires, and to the remote receiving unit with wires.

For a more complicated system of components, a hierarchical representation can be used to aid in determining the interconnection between components. Of course, each component of the system can be further decomposed into its individual components (for example, a wheel could be decomposed into a hub and a tire). Furthermore, if certain components are not to be included in the FMEA, dotted lines can be used for the blocks, as illustrated by the remote sending unit in Figure 12-1.

Boundary Diagram

This is an additional requirement as per fourth edition of AIAG FMEA manual. A boundary diagram is a graphical illustration of the relationships among the subsystems, assemblies, subassemblies, and components within the object as well as, the interfaces with the neighbouring systems and environments. It breaks the FMEA into manageable levels.

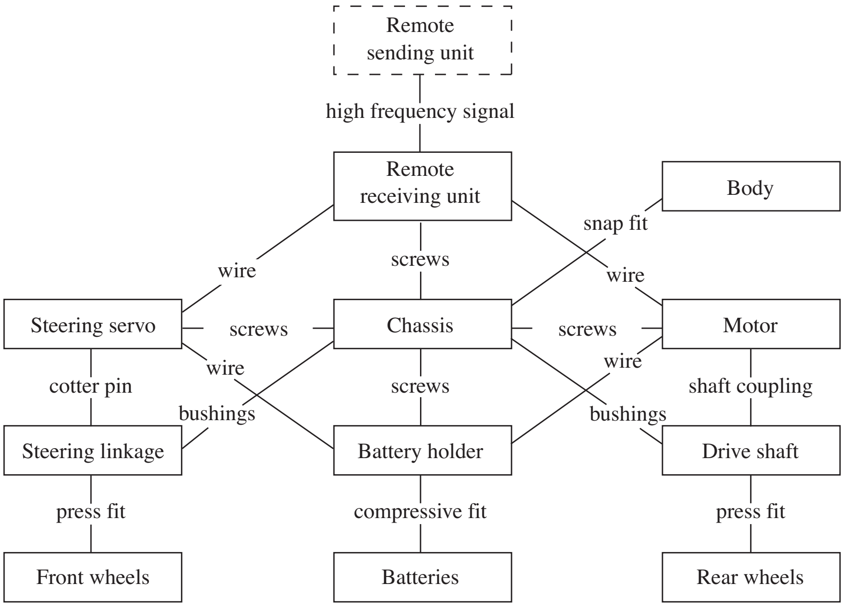

Figure 12-1 Functional Block Diagram of a Child's Low-Cost Remote Control Car

Parameter Diagram or P-Diagram

A parameter diagram is also an additional requirement as per fourth edition of AIAG FMEA manual. It is a graphical representation of the input and output responses. The inputs are categorized as:

1. control factors.
2. noise factors.
3. signal factors.

The output responses are categorized as

1. "Ideal Function" or desirable response.
2. Error state or undesirable response.

Interface Matrix

Another additional requirement as per fourth edition of AIAG FMEA manual is Interface Matrix. A system interface matrix illustrates the relationships among the subsystems, assemblies, subassemblies, and components within the object as well as, the interfaces with the neighbouring systems and environments.

Boundary diagram, P-diagram, and interface matrix are inputs to design FMEA.

Other Documentation

The other three documents needed are the design or process intent, the customer needs and wants, and the FMEA form, which is explained in detail in the remainder of this chapter.

Stages of FMEA

The four stages of FMEA are given below:

1. Specifying Possibilities
   a. Functions
   b. Possible Failure Modes
   c. Root Causes
   d. Effects
   e. Detection/Prevention
2. Quantifying Risk
   a. Probability of Cause
   b. Severity of Effect
   c. Effectiveness of Control to Prevent Cause
   d. Risk Priority Number
3. Correcting High Risk Causes
   a. Prioritizing Work
   b. Detailing Action
   c. Assigning Action Responsibility
   d. Check Points on Completion
4. Re-evaluation of Risk
   a. Recalculation of Risk Priority Number

General forms for design FMEA and process FMEA are shown in Figures 12-2 and 12-3, respectively.

The Design FMEA Document

The top section in the form (see Figure 12-2) is used mainly for document tracking and organization.

FMEA Number

On the top left corner of the document is the FMEA Number, which is only needed for tracking.

System, Subsystem, Component, Model Year/Number

This space is used to clarify the level at which DFMEA is performed. Appropriate part or other number should be entered along with information about the specific model and year.

Potential
Failure Mode and Effects Analysis
(Design FMEA)

___ System
___ Subsystems
___ Component :
Model Year / Vehicle (s) :
Core Team :

Design Responsibility :
Key Date :

FMEA Number :
Prepared by :
FMEA Date (Orig.) : (Rev.) :

Item / Function	Potential Failure Mode	Potential Effects of Failure	Severity	Class	Potential Causes / Mechanisms of Failure	Current Design Controls Prevention	Occurrence	Current Design Controls Detection	Detect	R.P.N.	Recommended Actions	Responsibility & Target Completion Date	Action Results				
													Actions Taken	Severity	Occur	Detection	R.P.N.

Figure 12-2 Design FMEA Form
Reprinted, with permission, from the *FMEA Manual*, 4th ed., 2008 (Chrysler, Ford, General Motors Supplier Quality Requirements Task Force).

Design Responsibility

The team in charge of the design or process should be identified in the space designated Design Responsibility. The name and company (or department) of the person or group responsible for preparing the document should also be included.

Prepared By

The name, telephone number, and address should be included in the Prepared By space for use when parts of the document need explanation.

Key Date

The date the initial FMEA is due should be placed in the Key Date space.

FMEA Date

The date the original FMEA was compiled and the latest revision date should be placed in the FMEA Date space.

Core Team

In the space reserved for Core Team, the names of the responsible individuals and departments that have authority to perform tasks should be listed. If the different people or departments involved are not working closely or are not familiar with each other, team members' names, departments, and phone numbers should be distributed.

Item/Function

In this section, the name and number of the item being analyzed is recorded. This information should be as precise as possible to avoid confusion involving similar items. Next, the function of the item is to be entered below the description of the item. No specifics should be left out in giving the function of the item. If the item has more than one function, they should be listed and analyzed separately. The function of the item should be completely given, including the environment in which the system operates (including temperature, pressure, humidity, and so forth); it should also be as concise as possible.

Potential Failure Mode

The Potential Failure Mode information may be one of two things. First, it may be the method in which the item being analyzed may fail to meet the design criteria. Second, it may be a method that may cause potential failure in a higher-level system or may be the result of failure of a lower-level system. It is important to consider and list each potential failure mode. All potential failure modes must be considered, including those that may occur under particular operating conditions and under certain usage conditions, even if these conditions are outside the range given for normal usage. A good starting point when listing potential failure modes is to consider past failures, concern reports, and group "brainstorming." Also, potential failure modes must be described in technical terms, not terms describing what the customer will see as the failure. Some typical failure modes may include cracked, deformed, loosened, leaking, sticking, short circuited, oxidized, and fractured.[1]

Potential Effect(s) of Failure

The potential effects of failure are the effects of the failure as perceived by the customer. Recall that the customer may be internal or may be the end user of the product. The effects of failure must be described in terms of what the customer will notice or experience, so if conditions are given by the customer there will be no dispute as to which mode caused the particular failure effect. It must also be stated whether the failure will impact personal safety or break any product regulations. This section of the document must also forecast what effects the particular failure may have on other systems or sub-systems in immediate contact with the system failure. For example, a part may fracture, which may cause vibration of the sub-system in contact with the fractured part, resulting in an intermittent system operation. The intermittent system operation could cause performance to degrade and then ultimately lead to customer dissatisfaction. Some typical effects of failure may include noise, erratic operation, poor appearance, lack of stability, intermittent operation, and impaired operation.[2]

Severity (S)

Severity is the assessment of the seriousness of the effect of the potential failure mode to the next component, sub-system, system, or customer if it occurs. It is important to realize that the severity applies only to the effect of the failure, not the potential failure mode. Reduction in severity ranking must not come from any reasoning except for a direct change in the design. It should be stressed that no single list of severity criteria is applicable to all designs; the team should agree on evaluation criteria and on a ranking system that are consistent throughout the life of the document. Severity should be rated on a 1-to-10 scale, with a 1 being none and a 10 being the most severe. The example of evaluation criteria given in Table 12-1 is just that, *an example*; the actual evaluation criteria will be diverse for a variety of systems or sub-systems evaluated.

Classification (CLASS)

This column is used to classify any special product characteristics for components, sub-systems, or systems that may require additional process controls. There should be a special method to designate any item that may require special process controls on the form.

Potential Cause(s)/Mechanism(s) of Failure

Every potential failure cause and/or mechanism must be listed completely and concisely. Some failure modes may have more than one cause and/or mechanism of failure; each of these must be examined and listed separately. Then, each of these causes and/or mechanisms must be reviewed with equal weight. Typical failure causes may include incorrect material specified, inadequate design, inadequate life assumption, over-stressing, insufficient lubrication capability, poor environment protection, and incorrect algorithm. Typical failure mechanisms may include yield, creep, fatigue, wear, material instability, and corrosion.

[1,2] Reprinted, with permission, from the *FMEA Manual* (Chrysler, Ford, General Motors Supplier Quality Requirements Task Force).

TABLE 12-1
Ranking Severity of Effect for Design FMEA

EFFECT	CRITERIA: SEVERITY OF EFFECT ON PRODUCT (CUSTOMER EFFECT)	RANK
Failure to Meet Safety and/or Regulatory Requirements	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning.	10
	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation with warning.	9
Loss or Degradation of Primary Function	Loss of primary function (vehicle inoperable, does not affect safe vehicle operation).	8
	Degradation of primary function (vehicle operable, but at a reduced level of performance).	7
Loss or Degradation of Secondary Function	Loss of secondary function (vehicle operable, but comfort/convenience functions inoperable).	6
	Degradation of secondary function (vehicle operable, but comfort/convenience functions at reduced level of performance).	5
Annoyance	Appearance or Audible noise, vehicle operable, item does not conform and noticed by most customers (>75%).	4
	Appearance or Audible noise, vehicle operable, item does not conform and noticed by many customers (50%).	3
	Appearance or Audible noise, vehicle operable, item does not conform and noticed by discriminating customers (<25%).	2
No Effect	No discernible effect.	1

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Current Design Control Prevention

There are two approaches to Design Control:

- Prevention of the cause of failure
- Detection of the cause of failure

Prevention controls should always be preferred over detection controls where possible. Examples of design controls to prevent occurrence of the failure mode can be a design review, design calculations, finite element analysis, computer simulation, mathematical modelling, tolerance stack-up study, etc. These activities tend to prevent the failure mode before the design is released for production.

Occurrence (O)

Occurrence is the chance that one of the specific causes/mechanisms will occur. This must be done for every cause and mechanism listed. Reduction or removal in occurrence ranking must not come from any reasoning except for a direct change in the design. Design change is the only way a reduction in the

TABLE 12-2
Criteria for Occurrence Ranking in DFMEA

LIKELIHOOD OF FAILURE	CRITERIA: OCCURRENCE OF CAUSE —DFMEA (DESIGN LIFE/RELIABILITY OF ITEM/VEHICLE)	CRITERIA: OCCURRENCE OF CAUSE—DFMEA (INCIDENTS PER ITEMS/VEHICLES)	PPK	RANK
Very High	New technology/new design with no history.	≥100 per thousand ≥1 in 10	< 0.55	10
High	Failure is inevitable with new design, new application, or change in duty cycle/operating conditions.	50 per thousand 1 in 20	≥ 0.55	9
	Failure is likely with new design, new application, or change in duty cycle/operating conditions.	20 per thousand 1 in 50	≥ 0.78	8
	Failure is uncertain with new design, new application, or change in duty cycle/operating conditions.	10 per thousand 1 in 100	≥ 0.86	7
Moderate	Frequent failures associated with similar designs or in design simulation and testing.	2 per thousand 1 in 500	≥ 0.94	6
	Occasional failures associated with similar designs or in design simulation and testing.	5 per thousand 1 in 2,000	≥ 1.00	5
	Isolated failures associated with similar designs or in design simulation and testing.	1 per thousand 1 in 10,000	≥ 1.10	4
Low	Only isolated failures associated with almost identical design or in design simulation and testing.	.01 per thousand 1 in 100,000	≥ 1.20	3
	No observed failures associated with almost identical design or in design simulation and testing.	≤001 per thousand 1 in 1,000,000	≥ 1.30	2
Very Low	Failure is eliminated through preventative control.	Failure is eliminated through preventative control	≥ 1.67	1

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occurrence ranking can be effected. Like severity criteria, the likelihood of occurrence is based on a 1-to-10 scale, with 1 being the least chance of occurrence and 10 being the highest chance of occurrence. Some evaluation questions are:

What is the service history/field experience with similar systems or sub-systems?

Is the component similar to a previous system or sub-system?

How significant are the changes if the component is a “new” model?

Is the component completely new?

Is the component application any different than before?

Is the component environment any different than before?[3]

The example of occurrence criteria given in Table 12-2 is just that, *an example*; the actual occurrence criteria will be diverse for a variety of systems or sub-systems evaluated. The team should agree on an evaluation criteria and ranking system that remains consistent throughout the life of the design FMEA.

Current Design Control Detection

These are design controls which are expected to detect the failure mode before the release of the design. These include the reliability tests such as fatigue tests, salt spray tests, prototype tests, functional tests, etc.

Detection (D)

This section of the document is a relative measure of the assessment of the ability of the design control to detect either a potential cause/mechanism or the subsequent failure mode before the component, sub-system, or system is completed for production. Most typically, in order to achieve a lower detection ranking in subsequent versions of the document, the planned design control must be improved. As with the occurrence criteria given earlier, the example of detection criteria given in Table 12-3 is just that, *an example*; the actual detection criteria will be diverse for a variety of systems or sub-systems evaluated. The team should agree on an evaluation criteria and ranking system that remains consistent throughout the life of the design FMEA.

Risk Priority Number (RPN)

By definition, the Risk Priority Number is the product of the severity (S), occurrence (O), and detection (D) rankings, as shown below:

$$RPN = (S) \times (O) \times (D)$$

This product may be viewed as a relative measure of the design risk. Values for the *RPN* can range from 1 to 1000, with 1 being the smallest design risk possible. This value is then used to rank order the various concerns in the design. For concerns with a relatively high *RPN*, the engineering team must make efforts to take corrective action to reduce the *RPN*. Likewise, because a certain concern has a relatively low *RPN*, the engineering team should not overlook the concern and neglect an effort to reduce the *RPN*. This is especially true when the severity of a concern is high. In this case, a low *RPN* may be extremely misleading, not placing enough importance on a concern where the level of severity may be disastrous. In general, the purpose of the *RPN* is to rank the various concerns on the document. However, every concern should be given the full attention of the team, and every method available to reduce the *RPN* should be exhausted.

As per the fourth edition of the AIAG FMEA manual, there is no threshold value for RPNs. In other words, there is no value above which it is mandatory to take a recommended action or below which the team is automatically excused from an action.

[3] Reprinted, with permission, from the *FMEA Manual* (Chrysler, Ford, General Motors Supplier Quality Requirements Task Force).

TABLE 12-3
Likelihood of Detection by Design Control

OPPORTUNITY FOR DETECTION DETECTION	CRITERIA: LIKELIHOOD OF DETECTION	RANK	LIKELIHOOD OF BY DESIGN CONTROL
No Detection Opportunity	No current design control; Cannot detect or is not analyzed	10	Almost Impossible
Not Likely to Detect at any Stage	Design analysis/detection controls have a weak detection capability; Virtual analysis (e.g., CAE,FEA, etc) is *not correlated* to expected actual operating conditions	9	Very Remote
	Product verification/validation after design freeze and prior to launch with *pass/fail* testing (Subsystem or system testing with acceptance criteria such as ride and handling, shipping, evaluation, etc.).	8	Remote
Post Design Freeze and Prior to Launch	Product verification/validation after design freeze and prior to launch with *test to failure* testing (Subsystem or system testing until failure occurs, testing of system interactions, etc.).	7	Very Low
	Product verification/validation after design freeze and prior to launch with *degradation* testing (Subsystem or system testing after durability test, e.g., function check).	6	Low
	Product validation (reliability testing, development or validation tests) prior to design freeze using *pass/fail* testing (e.g., acceptance criteria for performance, function checks, etc.).	5	Moderate
Prior to Design High Freeze	Product validation (reliability testing, development or validation tests) prior to design freeze using *test to failure* (e.g., until leaks, yields, cracks, etc.).	4	Moderately
	Product validation (reliability testing, development or validation tests) prior to design freeze using *degradation* testing (e.g., data trends, before/after values, etc.).	3	High
Virtual Analysis-Correlated	Design and analysis/detection controls have a strong detection capability. Virtual analysis (e.g., CAE, FEA, etc.) *is highly correlated* with actual or extended operating conditions prior to design freeze.	2	Very High
Detection not Applicable; Failure Prevention	Failure cause or failure mode can not occur because it is fully prevented through design solutions (e.g., proven design standard, best practice or common material, etc.).	1	Almost Certain

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Recommended Actions

After every concern has been examined, the team should begin to examine the corrective actions that may be employed. According to the 4th edition of AIAG FMEA manual, the actions must be prioritized for high severity first (9 and 10), followed by high occurrence and then high detection numbers. Earlier, it was expected to be prioritized based on the RPN. the emphasis on RPN has been reduced in the 4th edition.

The purpose of the recommended actions is to reduce one or more of the criteria that constitute the risk priority number. An increase in design validation actions will result in a reduction in only the detection ranking. Only removing or controlling one or more of the causes/mechanisms of the failure mode through design revision can effect a reduction in the occurrence ranking. And only a design revision can bring about a reduction in the severity ranking. Some actions that should be considered when attempting to reduce the three rankings include, but are not limited to: design of experiments, revised test plan, revised design, and revised material selection/specification.

It is important to enter "None" if there are no recommended actions available to reduce any of the ranking criteria. This is done so future users of the document will know the concern has been considered.

Responsibility and Target Completion Dates

Here the individual or group responsible for the recommended actions and the target completion date should be entered as reference for future document users.

Actions Taken

After an action has been implemented, a brief description of the actual action and its effective date should be entered. This is done after the action has been implemented so future document users may track the progress of the plan.

RESULTING *RPN*

After the corrective actions have been identified, the resulting severity, occurrence, and detection rankings should be re-estimated. Then the resulting *RPN* should be re-calculated and recorded. If no actions are taken, this section should be left blank. If no actions are taken and the prior rankings and *RPN* are simply repeated, future document users may reason that there were recommended actions taken, but that they had no effect. After this section is completed, the resulting *RPN*s should be evaluated, and if further action is deemed necessary, steps from the Recommended Actions section should be repeated.

The Process FMEA Document

The basic philosophy concerning the process FMEA document (see Figure 12-3) is almost identical to that of the design FMEA document examined earlier. Process FMEA is an analytical technique utilized by a Manufacturing Responsible Engineering Team as a means to assure that, to the extent possible, potential failure modes and their associated causes/mechanisms have been considered and addressed. Like design FMEA, the concept of the process FMEA document is nothing new to engineers. However, as with design FMEA, the concepts in creating and maintaining the document previously were kept only as thoughts of the engineer. Process FMEA is only documentation of the opinions of the responsible engineering team as a whole. Process

Potential
Failure Mode and Effects Analysis
(Process FMEA)

Item:
Process Responsibility :
Model Year / Vehicle (s) :
Key Date :
Core Team :

FMEA Number :
Prepared by :
FMEA Date (Orig.) :
(Rev.) :

Process / Function	Potential Failure Mode	Potential Effects of Failure	Severity	Class	Potential Causes / Mechanisms of Failure	Current Process Controls Prevention	Occurrence	Current Process Controls Detection	Detect	R.P.N.	Recommended Actions	Responsibility & Target Completion Date	Action Results				
													Actions Taken	Severity	Occur	Detection	R.P.N.

Figure 12-3 Process FMEA Document
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FMEA is just as important as design FMEA and for the same reasons. Notable similarities between the design and process FMEA include:

Actively involving representatives from all affected areas.

Including all the concerns from all the involved departments.

Treating the document as a living document that is being revised constantly and updated over time.

A process FMEA is required for all new parts/processes, changed parts/processes, and carryover parts/processes in new applications or environments. The process FMEA document should be initiated before or at the feasibility stage, prior to tooling for production, and take into account all manufacturing operations, from individual components to assemblies. Early review and analysis of new or revised processes is promoted to anticipate, resolve, or monitor potential process concerns during the manufacturing planning stages of a new model or component program.

When creating and/or revising the process FMEA document, it may be assumed that the product will meet the design intent as designed. However, knowledge of potential failures due to a design weakness can be included in process FMEA, if desired. Process FMEA does not rely on product design changes to overcome weaknesses in the process, but it does take into consideration a product's design characteristics relative to the planned manufacturing or assembly process to assure that, to the extent possible, the resulting product meets customer needs and expectations.

Just as the philosophies of design FMEA and process FMEA are similar, so are the corresponding documents. For this reason, instead of reviewing the entire process FMEA document, as was done for the design FMEA document, only the differences in the two documents will be given. All other aspects in the two documents may be assumed to be identical, for their respective purposes. The top section of the document has the same form and purpose as the design FMEA document, except Design Responsibility becomes Process Responsibility.

Process Function/Requirements

Instead of entering the item being analyzed and its function, as in the design FMEA, a description of the process being analyzed is given here. Examples of this process include, but are not limited to, turning, drilling, tapping, welding, and assembling. The purpose of the process should be given as completely and concisely as possible. If the process being analyzed involves more than one operation, each operation should be listed separately along with its description.

Potential Failure Mode

In process FMEA, one of three types of failures should be listed here. The first and most prevalent is the manner in which the process could potentially fail to meet the process requirements. The two remaining modes include potential failure mode in a subsequent (downstream) operation and an effect associated with a potential failure in a previous (upstream) operation. It should, for the most part, be assumed that the incoming parts and/or material are correct according to the general definition of nonconformity. Each potential failure mode for the particular operation must be listed in terms of a component, sub-system, system, or process characteristic. The assumption is made that the failure could but may not necessarily occur. Another aspect of viewing what is and what is not acceptable must come from the side of the customer, whether internal or external. Some knowledge of design FMEA is needed in this aspect of process FMEA.

Potential Effect(s) of Failure

Like design FMEA, the potential effects of failure are the effects as perceived by the customer, whether internal or external (the end-user). The effects of failure must be described in terms of what the customer will notice or experience, so if conditions are given by the customer there will be no dispute as to which mode caused the particular failure effect. It must also be stated whether the failure will impact personal safety or break any product regulations.

Severity (*S*)

Severity has the same role as it does in design FMEA. If need be, the severity section for a design FMEA should be reviewed. It is worth mentioning that severity applies only to effect. Also, a different type of severity criteria than for design FMEA is used. If the customer affected by a failure mode is the assembly plant or product user, assessing the severity may lie outside the immediate process engineer's field of experience. And like the severity for design FMEA, the severity for process FMEA is estimated on a scale from 1 to 10. The following example of evaluation criteria given in Table 12-4 is just that, *an example*; the actual evaluation criteria will be diverse for a variety of processes evaluated.

Classification (CLASS)

This column is used to classify any special product characteristics for components, sub-systems, or systems that may require additional process controls. There should be some special method to designate any item that may require special process controls on the form.

Potential Cause(s)/Mechanism(s) of Failure

Potential cause of failure is defined as how the failure could occur, described in terms of something that can be corrected or controlled. Every possible failure cause for each failure mode should be listed as completely and concisely as possible. Many causes are not mutually exclusive, and to correct or control the cause, design of experiments may be considered to determine which root causes are major contributors and which can be controlled. Only specific errors and malfunctions should be listed; ambiguous phrases should not be used.

Current Process Controls Prevention

This column is added in the third edition and has been further changed in the fourth edition. The column now appears before the occurrence ranking. List out the process controls aimed at preventing the occurrence of failure modes under consideration. These controls are aimed at minimizing the occurrence. The controls may include process reviews, capability study, preventive maintenance, calibration, operator training, etc.

Occurrence (*O*)

The occurrence section of process FMEA is the same as in design FMEA. Recall, occurrence is how frequently the specific failure cause/mechanism is projected to occur. Also note that the occurrence ranking number has a meaning rather than just a relative value. Table 12-5 contains only an example of occurrence criteria; criteria specific to a specific application should be used.

TABLE 12-4
Guidelines for Severity Ranking for Process FMEA

This ranking results when a potential failure mode results in a final customer and/or a manufacturing/assembly plant defect. The final customer should always be considered first. If both occur, use the higher of the two severities.

EFFECT	CRITERIA: SEVERITY OF EFFECT ON PRODUCT (CUSTOMER EFFECT)	CRITERIA: SEVERITY OF EFFECTON PROCESS (MANUFACTURING/ ASSEMBLY EFFECT)	RANK
Failure to Meet Safety and/or Regulatory Requirements	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning.	May endanger operator (machine or assembly) without warning.	10
Failure to Meet Safety and/or Regulatory Requirements	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation with warning.	Or may endanger operator (machine or assembly) with warning.	9
Loss or Degradation of Primary Function (Major Disruption)	Loss of primary function (vehicle inoperable, does not affect safe vehicle operation).	100% of product may have to be scrapped. Line shutdown or stop ship.	8
Loss or Degradation of Primary Function (Major Disruption)	Degradation of primary function (vehicle operable, but at reduced level of performance).	A portion of the production run may have to be scrapped. Deviation from primary process including decreased line speed or added manpower.	7
Loss or Degradation of Secondary Function (Moderate Disruption)	Loss of secondary function (vehicle operable, but comfort/convenience function inoperable).	100% of production run may have to be reworked off line and accepted.	6
	Degradation of secondary function (vehicle operable, but comfort/convenience functions at reduced level of performance).	A portion of the production run may have to be reworked off line and accepted.	5
Annoyance (Moderate Disruption)	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by most customers (>75%).	100% of production run may have to be reworked in station before it is processed.	4
Annoyance (Moderate Disruption)	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by many customers (>50%).	A portion of the production run may have to be reworked in station before it is processed.	3
Annoyance (Minor Disruption)	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by discriminating customers (>25%).	Slight inconvenience to process, operation, or operator.	2
No effect	No discernible effect.	No discernible effect.	1

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TABLE 12-5
Criteria for Occurrence Ranking for Process FMEA

LIKELIHOOD OF FAILURE	CRITERIA: OCCURRENCE OF CAUSE (INCIDENTS PER ITEMS/VEHICLES)	PPK	RANK
Very High	≥100 per thousand pieces ≥ 1 in 10	<0.55	10
High	50 per thousand pieces 1 in 20	≥0.55	9
	20 per thousand pieces 1 in 50	≥0.78	8
	10 per thousand pieces 1 in 100	≥0.86	7
Moderate	2 per thousand pieces 1 in 500	≥0.94	6
	.5 per thousand pieces 1 in 2,000	≥1.00	5
	.1 per thousand pieces 1 in 10,000	≥1.10	4
Low	0.01 per thousand pieces 1 in 1,000,000	≥1.20	3
	0.001 per thousand pieces 1 in 1,000,000	≥1.30	2
Very Low	Failure is eliminated through preventative control	≥1.67	1

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Current Process Controls Detection

List the controls that are effective but will detect the failure mode, after the component is produced. This will typically include inspection and test controls. Examples could be statistical process control, 100% inspection with gauge, final inspection with inspection fixture and patrol inspection.

Detection (*D*)

Detection is an assessment of the probability that the proposed current process control will detect a potential weakness or subsequent failure mode before the part or component leaves the manufacturing operation or assembly location. Assume the failure has occurred and then assess the capabilities of the current process control to prevent shipment of the part having this nonconformity (defect) or failure mode. Never automatically assume that detection ranking is low because occurrence is low, but do assess the ability of the process controls to detect low frequency failure modes or prevent them from going further in the process. The evaluation criteria and ranking system (see Table 12-6) should be agreed on by the entire team and should remain consistent throughout the FMEA process.

The remaining sections of process FMEA do not differ from the sections of design FMEA. The design-responsible engineer is responsible for assuring that all actions recommended have been implemented or

TABLE 12-6
Guidelines for Detection Ranking for Process FMEA

OPPORTUNITY FOR DETECTION	CRITERIA: LIKELIHOOD OF DETECTION BY PROCESS CONTROL	RANK	LIKELIHOOD OF DETECTION
No Detection Opportunity	No current process control; Cannot detect or is not analyzed.	10	Almost Impossible
Not Likely to Detect at Any Stage	Failure Mode and/or Error (Cause) is not easily detected (e.g., random audits)	9	Very Remote
Problem Detection Post Procession	Failure Mode detection post-processing by operator through visual/tactile/audible means	8	Remote
Problem Detection at Source	Failure Mode detection in-station by operator through visual/tactile/audible means or post-processing through use of attribute gauging (go/no-go, manual torque check/clicker wrench, etc.	7	Very Low
Problem Detection Post Processing	Failure Mode detection post-processing by operator through use of variable gauging or in-station by operator through the use of attribute gauging (go/no-go, manual torque check/clicker wrench, etc.)	6	Low
Problem Detection at Source	Failure Mode or Error (Cause) detection in-station by operator through use of variable gauging or by automated controls in-station that will detect discrepant part and notify operator (light, buzzer, etc.). Gauging performed on setup and first-piece check (for set-up causes only)	5	Moderate
Problem Detection Post Processing	Failure Mode detection post-processing by automated controls that will detect discrepant part and lock part to prevent further processing.	4	Moderately High
Problem Detection	Failure Mode detection in-station by automated controls that will detect discrepant part and automatically lock part in station to prevent further processing at Source	3	High
Error Detection and/or Problem Prevention	Error (Cause) detection in-station by automated controls that will detect error and prevent discrepant part from being made	2	Very High
Detection not Applicable; Error Prevention	Error (Cause) prevention as a result of fixture design, machine design or part design or part design. Discrepant parts cannot be made because item has been error-proofed by process/product design	1	Almost Certain

adequately addressed. FMEA is a living document and should always reflect the latest design level and the latest relevant actions, including those occurring after start of production. The last portion of this chapter contains a simple example of how to prepare the FMEA document.

Other Types of FMEA

As stated at the beginning of this chapter, there are numerous types of FMEA other than design FMEA and process FMEA. Some of the other types are described below.

By making some simple modifications to process FMEA, it can be used for maintenance (or equipment) FMEA. In maintenance FMEA two column headings from process FMEA are modified as follows:[4] Process Function Requirements becomes Equipment/ Process Function; Current Process Controls becomes Predictive Methods/Current Controls; and the Class column is eliminated. Maintenance (or equipment) FMEA could be used to diagnose a problem on an assembly line or test the potential failure of prospective equipment prior to making a final purchase.

Similar to maintenance FMEA, environmental FMEA is also only a slight modification of process FMEA. In environmental FMEA, the columns of process FMEA are modified as follows:[5] Process Function Requirements becomes Sub Process/Function; Potential Failure Mode becomes Environmental Aspect; Potential Effect(s) of Failure becomes Environmental Impact; Potential Cause(s)/Mechanism(s) of Failure becomes Condition/Situation; Current Process Controls becomes Present Detection Systems; and the Class column is eliminated. Environmental FMEA could be used to evaluate the environmental impact or correct the impact of manufacturing. For example, the effect of chemicals used in the semiconductor industry could be evaluated.

Another type of FMEA, service FMEA, is a modification to the standard process FMEA, because most types of services can be considered processes. For example, a moving van company performs a service that involves the following functions as part of the service to the customer: receive request, schedule van, go to client, pack client material, store material, deliver to new address, unpack material, and collect for services. During any one of these functions, there are possible failure modes, such as: while receiving the request, the customer can't find the number, the phone is busy, customer loses number, or customer changes mind. So, essentially, a process FMEA document can be used for service FMEA.

Processes within the service industry can be analyzed prior to customers seeing them, thereby preventing any initial loss of business. For example, service FMEA can be used to analyze a new web-based youth sports registration system prior to debut to prevent the loss of participants. Some of the major airlines have used service FMEA to completely analyze the way they are servicing their customers. Service FMEA has also been used as a prevention tool in the services offered by a medical clinic cafeteria, resulting in effective prevention of errors.[6]

Example of FMEA Document Preparation

The example shown in Figure 12-4 goes through the process of preparing an FMEA document—in this case, a design FMEA document. As stated earlier, the top portion of the document requires no explanation. It is used strictly for tracking and information about the FMEA item, team, and important dates. Next is the

[4] Teodor Cotnareanu, "Old Tools—New Uses: Equipment FMEA," *Quality Progress* (December 1999): 48–52.

[5] Willy W. Vandenbrande, "How to Use FMEA to Reduce the Size of Your Quality Toolbox," *Quality Progress* (November 1998): 97–100.

[6] Roberto G. Rotondaro and Claudia L. deOliveira, "Using Failure Mode Effect Analysis (FMEA) to Improve Service Quality," Proceedings of the 12th Annual Conference of the Production and Operations Management Society, (2001).

POTENTIAL
FAILURE MODE AND EFFECTS ANALYSIS
(DESIGN FMEA)

_____ System
_____ Subsystem
_____ Component ____B____
Model Year(s)/Program(s) ____D____
Core Team ____G____

Design Responsibility ____C____
Key Date ____E____

FMEA Number ____A____
Page ________ of ________
Prepared By: ____H____
FMEA Date (Orig.) ____F____

Item / Function	Requirement	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Classification	Potential Cause(s) of Failure	Current Design: Controls Prevention	Occurrence	Controls Detection	Detection	RPN	Recommended Action	Responsibility & Target Completion Date	Action Results: Actions Taken Completion Date	Severity	Occurrence	Detection	RPN
Front Door L.H H8HX-0000-A	Maintain integrity of inner door panel	Integrity breach allows environ. access of inner door panel	Corroded interior lower door panels Deteriorated life of door leading to: •Unsatisfactory appearance due to rust through paint over time. • Impaired function of interior door hardware	5		Upper edge of protective wax application specified for inner door panels is too low	Design requirements (#31268) and best practice (BP 3455)	3	Vehicle durability test. T-118 (7)	7	105	Laboratory accelerated corrosion test	A. Tate Body Engineer 0X 09 03	Based on test results (test no. 1481) upper edge spec raised 125 0X 09 30	5	2	3	30
						Insufficient wax thickness specified	Design requirements (#31268) and best practice (BP 3455)	3	Vehicle durability test. T-118 (7)	7	105	Laboratory accelerated corrosion test	A. Tate Body Engineer 0X 09 03	Test results (Test No. 1481) show specified thickness is adequate. 0X 09 30	5	2	3	30
												Design of Experiments (DOE) on Wax Thickness	J. Smythe Body Engineer 0X 10 18	DOE shows 25% variation in specified thickness is acceptable 0X 10 25	5	2	3	30
						Inappropriate wax formulation specified	Industry standard MS-1893	2	Physical and Chemical Lab test - Report No. 1265 (5) Vehicle durability test. T-118 (7)	5	50	None						
						Corner design prevents spray equip from reaching all areas		5	Design aid with non-functioning spray head (8) Vehicle durability test. T-118 (7)	7	175	Team evaluation using production spray equipment and specified wax	T. Edwards Body Engineer and Assy Ops 0X 11 15	Based on test: 3 additional vent holes provided in affected areas. (error-proofed) 0X 12 15	5	1	1	5
						Insufficient room between panels for spray head access		4	Drawing evaluation of spray head access (4) Vehicle durability test. T-118 (7)	4	80	Team evaluation using design aid buck and spray head	Body Engineer and Assy Ops 0X 11 15	Evaluation showed adequate access 0X 12 15	5	2	4	40
a1	a2	b	c	d	e	f	h	g	h	i	j	k	l	m	n			

SAMPLE

Figure 12-4 Example of Design FMEA Form
Reprinted, with permission, from the *FMEA Manual*, 4th ed., 2008 (Chrysler, Ford, General Motors Supplier Quality Requirements Task Force).

Item/Function section of the document. Notice that both a brief but complete description of the item (front door of car) and all functions of the item are given in this section. Care should be taken not to leave out any function the item might have. The Potential Failure Mode (corroded interior lower door panels) is then shown. The description in this section should be as specific as possible so that there is no ambiguity as to which mode is being analyzed. Remember that the remainder of the sections should be completed for only one item and potential failure mode at a time.

Though there is only one item and potential failure mode, it can be seen that there may be multiple Potential Effect(s) of Failure associated with each item and potential failure mode. It is necessary for all the potential effects of failure (unsatisfactory appearance due to rust and impaired function of interior door hardware) to be given here. Even one potential effect missing could cause confusion throughout the engineering team. A consensus should be used when determining the Severity (S) of each potential failure mode. No matter how many potential effects of failure are present, only one value of severity should be used for each potential failure mode. After this, all possible Potential Cause(s)/Mechanism(s) of Failure (upper edge of protective wax application is too low on door and wax application plugs door drain holes) should be listed. Care should be taken to include all possible causes and mechanisms of failure, no matter how trivial some may seem. In this portion of the document, it is imperative that all team members are involved in the brainstorming process. For each of these potential causes/mechanisms of failure, there needs to be a separate Occurrence (O), Current Design Controls, and Detection (D) ranking. These rankings should also be given a value agreed upon by the entire group, using criteria supported by the entire group. Once these portions of the document are filled, the RPN can be found, and the different causes and effects of failure can be compared.

If there are any Recommended Actions (Add lab accelerated corrosion test) agreed upon by the team, they should be listed next. These include any actions that may help to bring the RPN to a lower level. However, in many instances there may not be any recommended actions to list. Instead of leaving the portion empty, it is advisable to enter "None" in the area. This is done so future readers of the document will realize that thought was given to recommended actions, but the group could find none. It is important to realize that if there are no recommended actions for a particular cause and effect of failure, there is no method in which to improve the RPN. Also, the Responsibility and Target Completion Date section of the document will be left blank. If there is a recommended action, however, this section cannot be left blank, and a new RPN should be calculated using new rankings. This example proves how orderly and concisely a group of engineers' thoughts can be recorded not only for their own future use but also for the use of others.

TQM Exemplary Organization[7]

Employee-owned Operations Management International, Inc. (OMI) runs more than 170 wastewater and drinking water treatment facilities in 29 states and eight other nations. Between 1998 and 2000, OMI's public customers realized first-year savings that averaged $325,000, their operating costs decreased more than 20%, and facility compliance with environmental requirements improved substantially.

Annual average revenue per associate improved from $92,600 in 1997 to almost $108,000 in 2000—an increase of more than 15%. Associate turnover decreased from 25.5% in 1994 to 15.5% in 1999, better than the national average of 18.6% and the service industry average of 27.1%.

Market share in its core business segment has increased to 60%, up from 50% in 1996. Over this span, total revenue grew at an average annual rate of 15%, as compared with 4.5% for OMI's top competitor.

[7] Malcolm Baldrige National Quality Award, 2000 Service Category Recipient, NIST/Baldrige Homepage, Internet.

OMI's *Obsessed With Quality* process which corresponds with the principles and criteria of the Malcolm Baldrige National Quality Award, spans the entire company, links all personnel levels, and creates a common foundation and focus for OMI's far-flung operations.

OMI uses a variety of approaches and tools to initiate and then drive progress toward the organization's short-term objectives and five-year improvement goals. For example, long-standing focus teams provide continuity of effort and sustain organization-wide commitment in five key areas: leadership, information and analysis, human resources, process management, and customer satisfaction. Like many other teams at OMI, membership spans the entire organization in terms of function and personnel, including top management and hourly employees. Other techniques to foster alignment and to ensure that important information flows to all OMI offices and facilities include newsletters, regional meetings, e-mail, and the organization's annual project management summit. Information among OMI operated facilities on best practices, emerging technologies, and training results is exchanged at these summits.

The company uses surveys, interviews, focus groups, and market research to learn customers' current and long-term requirements. A contract renewal rate of almost 95% in 1999 and the industry's top rank in the average length of customer retention indicates that OMI is well versed in the requirements of its customers. For all six components of customer satisfaction, scores show an eight-year improvement trend, all rising above 5 on a 7-point scale for which 1 means "very poor" and 7 means "excellent."

For OMI, protecting the environment is part of its contractual obligation. However, many OMI-managed facilities are model performers. The company has won more than 100 federal and state awards for excellence in the past five years; more than half of these were earned in the last two years.

Summary

FMEA is an analytical team tool aimed to prevent failure modes before they reach the customer or the user. Design FMEA is used to identify potential failure modes and evaluate the risk associated with each possible cause, while designing a product. Process FMEA is deployed prior to installation of the new processes. Risk is quantified based on severity of each failure mode, probability of occurrence of each cause, and chances of detection, if the cause occurs. Each of these three are quantified, between 1 to 10 from lowest to highest risk. Product of these three ratings is the risk priority number and can range between 1 to 1000. Actions are taken based on the severity and risk associated with each cause.

Exercises

1. A major manufacturer of computers has determined that their new machines will have a constant failure rate of 0.2 per year under normal operating conditions. How long should the warranty be if no more than 5% of the computers are returned to the manufacturer for repair?

2. A company in the service industry gives a one-year, money-back guarantee on their service assuming that only 10% of the time will they have to return money due to an unsatisfied customer. Assuming a constant value, what is the company's failure rate?

3. Working individually or in a team, construct a block diagram for one or more of the following products.
   (a) Flashlight
   (b) Computer mouse
   (c) Home hot-water heater

(d) Toaster
(e) Rechargeable drill/driver
(f) Toddler's toy, such as a walking chair
(g) Sub-system of your automobile
(h) Bicycle
(i) 3-1/2″ floppy disk
(j) Automobile roof-top rack

4. Working individually or in a team, perform design FMEA on one or more of the following products listed in Exercise 3. Start the design FMEA process by identifying a common failure mode for that product or a potential failure mode. Then, complete the design FMEA form by addressing all categories listed in the form.

5. Perform process FMEA to anticipate what you could do to eliminate any problems while changing a tire. Assume that you have just pulled off to the side of the road and have opened the trunk to remove the jack. Think of the process of replacing the tire and what you can put in place to avoid problems the next time you change a tire. Complete the process FMEA form.

6. Working individually or in a team, perform process FMEA to anticipate what you could do to eliminate any problems in one or more of the following processes.
   (a) Making a pizza
   (b) Sorting and washing five loads of laundry
   (c) Following a recipe for cookies
   (d) Mowing your lawn
   (e) Waking up in the morning and going to work or school

7. Which of the following is not a function in DFMEA?
   (a) Leak
   (b) Clamp
   (c) Locate
   (d) Insulate

8. If likelihood of failure is 10%, Occurrence rating in DFMEA will be
   (a) 5
   (b) 10
   (c) 7
   (d) 8

9. Which of the following elements is more important for effective use of FMEA?
   (a) Each team member is present
   (b) Start FMEA on time
   (c) Accurate rating and consensus
   (d) Recommended Action Plan

10. When should we conduct FMEA ?
   (a) When new part is designed
   (b) When part failures are reported

(c) When material is changed
(d) All of the above

11. If we do not know the probability of occurrence, what occurrence rating is appropriate?
    (a) 5
    (b) 7
    (c) 10
    (d) 8

13

Total Productive Maintenance

Chapter Objectives

- Appreciate the need for total productive maintenance for the continued productivity and the basic goals of Total Productive Maintenance (TPM)
- Understand how to plan and manage the change
- Quantify the six major losses, identify the gaps and set the goal for improvement
- Study some examples of successful TPM implementation

Introduction

Good maintenance is fundamental to a productive manufacturing system; try running a production line with faulty equipment. Total Productive Maintenance (TPM) is keeping the current plant and equipment at its highest productive level through cooperation of all areas of the organization. Generally, the first task is to break down the traditional barriers between maintenance and production personnel so they are working together. Individuals working together without regard to organizational structure, using their skills and ingenuity, have a common objective—peak performance or total productivity.

This approach does not mean that such basic techniques as predictive and preventative maintenance are not used; they are essential to building a foundation for a successful TPM environment. Predictive maintenance is the process of using data and statistical tools to determine when a piece of equipment will fail, and preventative maintenance is the process of periodically performing activities such as lubrication on the equipment to keep it running.

The total maintenance function should be directed towards the elimination of unplanned equipment and plant maintenance. The objective is to create a system in which all maintenance activities can be planned and not interfere with the production process. Surprise equipment breakdowns should not occur. Before the advent of computer-aided manufacturing, operators in some organizations were responsible for their machines and took a certain pride of ownership. With the help of maintenance technicians, operators spent part of their work time keeping their equipment in good running order. Recent technical advances have given us more tools to perform the maintenance function.

Analyzing TPM into its three words, we have:

Total = All encompassing by maintenance and production individuals working together.

Productive = Production of goods and services that meet or exceed customers' expectations.

Maintenance = Keeping equi pment and plant in as good as or better than the original condition at all times.

The overall goals of TPM are:

1. Maintaining and improving equipment capacity.
2. Maintaining equipment for life.
3. Using support from all areas of the operation.
4. Encouraging input from all employees.
5. Using teams for continuous improvement.

Organizations that apply principles (programs in) of total quality management, failure mode effect analysis, employee involvement, continuous improvement, just-in-time manufacturing, statistical process control, and experimental design, to name a few, cannot be successful without also paralleling the principles (program in) total quality management.[1] For example, when equipment downtime and equipment failures are not regular, how can a company implement just-in-time manufacturing? Or, how can organizations practice employee involvement when machine operators or people in the maintenance department are not part of the team and encouraged to report problems?

The Plan

The first activity in any assessment of performance is to determine the current operating parameters. Where are we today? What systems do we have in place, and how do they work? What is the current condition of the plant and equipment? Are we starting from scratch, or do we have workable systems that only need to be improved?

Total Productive Maintenance (TPM) is an extension of the Total Quality Management (TQM) philosophy to the maintenance function. Seven basic steps get an organization started toward TPM:

1. Management learns the new philosophy.
2. Management promotes the new philosophy.
3. Training is funded and developed for everyone in the organization.
4. Areas of needed improvement are identified.
5. Performance goals are formulated.
6. An implementation plan is developed.
7. Autonomous work groups are established.

There is no single correct method for implementation; however, these steps will provide a good framework.

[1] Eugene Sprow, "TPM—Good for Everyone," *Manufacturing Engineering* (April 1995): 12.

Learning the New Philosophy

One of the most difficult things for senior management to deal with is change. They need to learn about TPM and how it will affect their operations. There are many successful examples; there are also many organizations that have tried various techniques to improve performance and failed. Benchmarking with a successful organization will provide valuable information.

Any cultural change takes a special dedication, by management to provide long-term, top to bottom support for improvement. The easy approach is to accept today's good performance numbers and say, "Why change?" The answer is to gain a competitive edge and to increase profits. Many of an organization's competitors are most likely improving and will be far ahead of other non-changing organizations in the future. There also exists, in management, the concept that somehow because "I am the chief, I know more than those who work here."

TPM is merely trying to tap into an unused resource, the brain power and problem-solving ability of all the organization's employees. Thus, it is necessary to allow people to make decisions. This approach is not permissive management, because management is still responsible for the performance of the organization. It does, however, represent a different way of managing.

Many organizations have had the flavor-of-the-month approach to changing management techniques. This approach has led to credibility problems with employees. Management is changed and the new manager does not build on past accomplishments but develops a "new system" that will presumably solve all of the organization's problems. Lack of ownership seems to cause low morale and dissatisfaction with management. Ownership should be based on what is good for the customer and for the employees that serve the customer. A look at approaches at Southwest Airlines or Hewlett Packard helps to understand what needs to be done. These organizations, and others, emphasize employee well-being and empowerment. It is difficult to argue with their performance numbers.

Initially this change will require more work by management. Eventually, it will mean less work as all individuals start solving their own problems.

Promoting the Philosophy

Senior management must spend significant time in promoting the system. They must sell the idea and let the employees know that they are totally committed to its success. Like TQM or any other major change in an organization, there must be total commitment from the top. If the belief in the new philosophy and commitment are not there, then positive results will not happen. Too often lip service is given to a "new idea." This action is usually brought on by a belief that the new system will solve some immediate problems and lead to an immediate return on investment. A long-term commitment to the new philosophy is required. It has been proven by other organizations to be a better way of doing business.[2]

Management should lead the way by practicing the new philosophy. Organizations that are having difficulties owe it, in part, to insincere leadership. One of the best ways to implement the new philosophy is just to start doing it. In other words, start giving the maintenance and production personnel more autonomy. Once the employees realize that management is serious about taking the organization in a new, more positive direction, employees usually respond. Introducing TPM with a huge fanfare leads employees to shrug it off as the latest method for getting them to work harder. Management must first build credibility, and the best way to accomplish that task is to change first and lead the way.

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[2] Seiichi Nakajima, *Total Productive Maintenance* (Productivity Press Inc., 1988).

Training

Teach the philosophy to managers at all levels. Begin with senior management, and work down to first-line supervisors.

Don't just teach the HOW: also teach the WHY. Senior management must spend time learning about and understanding the ramifications of applying this philosophy to their organization. Is senior management dedicated to the long-term commitment required to achieve positive results? Some managers may need to be replaced or take early retirement because they will not change their way of dealing with people. Those managers who readily respond to the new philosophy should also be identified.

Middle management must learn how to deal with the team approach and become familiar with how small autonomous work groups function. This organizational level seems to have the greatest difficulty with this type of change. In recent years, downsizing has come at the expense of middle managers. Of course, historically this has been an inflated area of management. The philosophies that are promoted within TPM and TQM do lead to flatter management structures. When you allow people to make their own decisions, you do not need as many layers of managers making sure employees are doing their job correctly.

First-line supervisors need to learn their role in what most likely will be a new environment. Supervisors who have been used to guiding their groups will find this an easy transition. The day of the autocratic manager has disappeared. Those managers who have been telling employees everything to do will find this difficult. Supervisors will relinquish some of their power, although that power may be more perceived than actual. A highly-educated workforce does not tolerate that management style. In reality, a supervisor is only as good as their ability to coach their team.

Employees need to learn about the various tools used in performing their tasks as part of an autonomous work group. There needs to be some instruction in the area of jobs that maintenance people do and jobs that production people do. A great benefit of TPM is the cross-pollination of ideas between maintenance technicians and production operators.

Improvement Needs

There are usually some machines that seem to be on the verge of breaking down or require an excessive amount of maintenance. Employees who work with the equipment on a daily basis are better able to identify these conditions than anyone else in the organization. A good first step is to let the operators and maintenance technicians tell management which machines and systems need the most attention. An implementation team of operators and technicians to coordinate this process is essential. This action will build credibility and start the organization towards TPM.

One of the first steps for the team is to identify the current status. In other words, what is the baseline? The following measurements were developed by the Japanese and are accepted by most practitioners.

Six major loss areas need to be measured and tracked:

Downtime Losses

1. Planned
    a. Start-ups
    b. Shift changes
    c. Coffee and lunch breaks
    d. Planned maintenance shutdowns

2. Unplanned Downtime
    a. Equipment breakdown
    b. Changeovers
    c. Lack of material

Reduced Speed Losses

3. Idling and minor stoppages
4. Slow-downs

Poor Quality Losses

5. Process nonconformities
6. Scrap

These losses can be quantified into three metrics and can be summarized into one equipment effectiveness metric. Equations for these metrics follow.

Downtime losses are measured by equipment availability using the equation

$$A = \left(\frac{T}{P}\right) \times 100$$

where A = availability
T = operating time (P − D)
P = planned operating time
D = downtime

Reduced speed losses are measured by tracking performance efficiency using the equation

$$E = \left(\frac{C \times N}{T}\right) \times 100$$

where E = performance efficiency
C = theoretical cycle time
N = processed amount (quantity)

Poor quality losses are measured by tracking the rate of quality products produced using the equation

$$R = \left(\frac{N - Q}{N}\right) \times 100$$

where R = rate of quality products
N = processed amount (quantity)
Q = nonconformities

Equipment effectiveness is measured as the product of the decimal equivalent of the three previous metrics using the equation

$$EE = A \times E \times R$$

where EE = equipment effectiveness, or overall equipment effectiveness (OEE)

The target for improvement is 85% equipment effectiveness.

EXAMPLE PROBLEM

Last week's production numbers on machining center JL58 were as follows:

Scheduled operation = 10 hours/day; 5 days/week

Manufacturing downtime due to meetings, material outages, training, breaks, and so forth = 410 minutes/week

Maintenance downtime scheduled and equipment breakdown = 227 minutes/week

Theoretical (standard) cycle time = 0.5 minutes/unit

Production for the week = 4450 units

Defective parts made = 15 units

P = 10 hours/day $\times$ 5 days/week $\times$ 60 minutes/hour = 3000 minutes/week

D = 410 minutes/week + 227 minutes/week = 637 minutes/week

$T = (P - D) = 3000 - 637 = 2363$ minutes

$$\begin{aligned} A &= \left(\frac{T}{P}\right) \times 100 \\ &= \left(\frac{2363}{3000}\right) \times 100 \\ &= 78.8\% \end{aligned}$$

$$\begin{aligned} E &= \left(\frac{C \times N}{T}\right) \times 100 \\ &= \left(\frac{0.5 \times 4450}{2363}\right) \times 100 \\ &= 94.2\% \end{aligned}$$

$$\begin{aligned} R &= \left(\frac{N - Q}{N}\right) \times 100 \\ &= \left(\frac{4450 - 15}{4450}\right) \times 100 \\ &= 99.7\% \end{aligned}$$

$$\begin{aligned} EE &= A \times E \times R \\ &= 0.788 \times 0.942 \times 0.997 \\ &= 0.740 \text{ or } 74.0\% \end{aligned}$$

Clearly the equipment availability should be improved to reach the goal of 85% equipment effectiveness.

Goal

Goals should be set after the improvement needs are identified. A good first goal is to establish the timeframe for fixing the first prioritized problem. Technicians and operators will probably want it done faster than management because it causes them more problems on a daily basis. Identifying needs and setting goals begins the process of getting the organization to work together as a team.

Developing Plans

First, develop and implement an overall plan of action for training all employees. Plans for developing the autonomous work groups should take place during the training phase.

Plan to use teams of maintenance technicians and operators to work on particularly troublesome problems. Priorities can be set and management can make a commitment with resources to correct some of the basic problems. Using the team approach will set the stage for the development of autonomous work groups, which are teams established for daily operations. At this point, employees should have input into how these autonomous teams are structured.

Part of the planning process should take into consideration that autonomous work groups will change over time. As processes and procedures are improved, the structure of the whole organization will change. It would be unreasonable not to expect autonomous work groups to change also.

Autonomous Work Groups

Autonomous work groups are established based on the natural flow of activity. First, make the operator responsible for the equipment and the level of maintenance that he is capable of performing. Next, identify the maintenance personnel who work in certain areas or have certain skill levels. Operators and maintenance personnel are brought together, resulting in an autonomous work group. These groups must have the authority to make decisions about keeping the equipment in first-class running order.

The structure of autonomous work groups will vary with different applications and types of industries. The team approach given in Chapter 4, Employee Involvement, provides the necessary information to determine the structure.

Maintenance technicians are also consultants to the operating personnel. They train operators in how to do certain tasks, such as oiling, minor troubleshooting, and set-ups.

The overall goal of the autonomous work group is to reduce the occasions for maintenance activity. A side benefit is freeing up highly skilled maintenance technicians from the more mundane routine tasks. Skilled technicians are utilized more effectively in doing major overhauls and assisting with troubleshooting problems that the autonomous work group cannot handle.

Examples

There are numerous examples of organizations employing total productive maintenance to empower their production workers and to save time and money on maintenance. The following examples give a wide range of organizations that applied total productive maintenance.

1. The U.S. Postal Service of Albany, New York used total productive maintenance to save $86,000 annually by standardizing procedures and reducing the use of outside contractors for vehicle work.[3] Based on their revision of maintenance procedures, 11 other facilities in the Northeast are changing their practices, and $4.5 million could be saved if 179 sites nationwide also change their practices. Because of their efforts, the U.S. Postal Service of Albany, New York was a 2000 RIT/USA Today Quality Cup finalist.

2. Yamato Kogyo Corp. of Japan, a motorcycle control-cable maker, received a total productive maintenance award from Yamaha Corp. in the 1990s.[4] Using total productive maintenance, they improved productivity by 130%, cut accidents by 90%, reduced defects by 95%, and increased the employee suggestion rate by over 300% to 5 per employee per month.

3. A team of workers at Kadena Air Base in Japan won the 1995 RIT/USA Today Quality Cup for government by using total productive maintenance to reduce the failure rate of AIM-9 missiles from 102 per month to 15 or less per month.[5] After the multi-disciplinary team brainstormed the missile malfunctions and repairs, they focused on the argon gas used to cool the missile as the source of the problems. Results of the team's total productive maintenance program included: repair after a missile fails to launch the first time; technicians verify that the argon bottles seal properly; fit all argon bottles with new $0.13 O-ring seals; train pilots to describe malfunctions to technicians; and begin tracking repairs on the metal probes to which the argon bottle attaches.

4. Sonic Ishikawa Corp. of Japan, a suspension and steering components subcontractor for Japanese automakers, received an award from the Japan Institute for Plant Maintenance, for its total productive maintenance effort.[6] Their effort in total productive maintenance involved four phases: (1) organizing teams to reduce equipment failures and defects; (2) better design for manufacturability and better production management; (3) improving plant automation; and (4) improving office automation. The results of their effort on total productive maintenance were a 75% reduction in defects, 50% higher productivity, and a 95% reduction in equipment breakdowns.

5. An eight-person multi-disciplinary team of workers at the Tennessee Valley Authority's Brown Ferry nuclear plant won the 1997 RIT/USA Today Quality Cup for government and former Vice President Al Gore's Hammer award, by using total productive maintenance to save $12.7 million in maintenance costs over an 18-month period.[7] The team's primary focus was to reduce the hand-to-hand processing of paperwork by implementing several software programs. As a result of the team's work, change procedures were reduced from 25 hours to 8 hours, processing work orders were reduced from 37 hours to 22 hours, and reactor shutdown, for maintenance, was reduced from 32 days to 19 days.

There are numerous other success stories of organizations using total productive maintenance: Daihatsu Motors in 1988, Suzuki in 1992, Harley-Davidson in 1993, and others, such as, Eastman-Kodak, Du Pont, Texas Instruments, Proctor & Gamble, and AT&T.

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[3] 2000 RIT/USA Today Quality Cup.

[4] David A. Turnbide, "Japan's New Advantage: Total Productive Maintenance," *Quality Progress* (March 1995): 121–123.

[5] 1997 RIT/USA Today Quality Cup for government.

[6] David A. Turnbide, "Japan's New Advantage: Total Productive Maintenance," *Quality Progress* (March 1995): 121–123.

[7] 1997 RIT/USA Today Quality Cup for government.

TQM Exemplary Organization[8]

The Ritz-Carlton Hotel Company, an independent division of Marriott International, Inc., manages 36 luxury hotels in North America, Europe, Asia, Australia, the Middle East, Africa, and the Caribbean. All have received four- or five-star ratings from the Mobil Travel Guide and diamond ratings from the American Automobile Association.

More than 85% of the company's 17,000 employees—known as "The Ladies and Gentlemen of The Ritz-Carlton"—are front-line workers in hotels. Through extensive training programs and by offering opportunities for professional development, the company encourages personnel to advance in the organization. Ritz-Carlton President and Chief Operating Officer Horst Schulze began his career in the hospitality industry as a waiter's apprentice at a hotel in Europe.

The organization's mission is: "To be the premier worldwide provider of luxury travel and hospitality products and services." Everyone receives a wallet-sized copy of the "Gold Standards," which consist of the company's Motto, Credo, Employee Promise, Three Steps of Service, and The Ritz-Carlton Basics—essentially a listing of performance expectations and the protocol for interacting with customers and responding to their needs. These are reinforced in training (which totals 250 hours for first-year front-line employees), in the daily five- to 10-minute briefing at the start of every shift, and through the company's reward and recognition system.

At every level, The Ritz-Carlton is detail-oriented. Steps for all quality-improvement and problem-solving procedures are documented, methods of data collection and analysis are reviewed by third-party experts, and standards are established for all processes. Key processes also are dissected to identify points at which errors may occur.

To cultivate customer loyalty, The Ritz-Carlton has instituted an approach of "customer customization," which relies on extensive data gathering and capitalizes on the capabilities of advanced information technology. Information gathered during various types of customer contacts, such as responses to service requests by overnight guests or post-event reviews conducted with meeting planners, are systematically entered into a database, which holds almost one million files. Accessible to all Ritz-Carlton hotels worldwide, the database enables hotel staff to anticipate needs of returning guests and to initiate steps that will help to ensure a high-quality experience.

In an independent survey, 99% of guests said they were satisfied with their overall experience; more than 80% were "extremely satisfied." Any employee can spend up to $2,000 to immediately correct a problem or handle a complaint. First-year managers and employees receive 250 to 310 hours of training.

Financial performance also is trending upward. Total fees; earnings before income taxes, depreciation and amortization; and pre-tax return on investment have nearly doubled since 1995, with return on investment increasing from 5.3% in 1995 to 9.8% in 1998. Revenue per available room (the industry's measure of market share) continues to grow, exceeding the industry average by more than 300%.

From a field of 3,528 nominees, Ritz-Carlton was selected "Overall Best Practices Champion"—1998 study by Cornell School of Hotel Administration and McGill University.

Summary

The seven-step plan outlined in this chapter provides a framework to establish TPM. It should be modified to meet different organizational needs. An effective total productive maintenance program will lead to improved quality and productivity and, of course, an improved bottom line.

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[8] Malcolm Baldrige National Quality Award, 1999 Service Category Recipient, NIST/Baldrige Homepage, Internet.

TPM is an extension of TQM to maintenance function. Like any other improvement initiative, management must manage the change by demonstrating commitment, getting involved, promoting the philosophy, providing resources, and supporting training.

One of the first steps for the teams is to identify and quantify the six big losses on an identified critical machine, which require excessive maintenance and most attention. Based on the current status, goals are decided and an action plan is prepared. Autonomous workgroups should be developed during the training phase. As a part of this process, operator is made accountable for the routine maintenance functions, which he/she is capable of and the maintenance person with specified skill level is assigned to the autonomous work group. TPM has been successfully implemented in many organizations across the world.

Exercises

1. The bearing department is planning their schedule for the following week. They need an understanding of last week's performance. The schedule called for two 8-hour shifts per day for five days. Downtime charged to production averaged 76 minutes per day. Downtime charged to maintenance averaged 135 minutes per day. Calculate the actual running time and the percentage of available time.

2. Refer to Exercise 1. The total products produced was 1,235. The standard called for a production run of 1500. Calculate the theoretical and actual cycle time per unit. Assume 10% planned downtime for theoretical cycle time. What was the performance efficiency?

3. What is the rate of quality products if 35 units out of the 1,235 completed in Exercise 2 are nonconforming?

4. What is the equipment effectiveness for the information given in Exercises 1,2, and 3?

5. Find the equipment effectiveness percentage for an organization with the following data.

   Schedule is one ten-hour shift, five days per week.
   Total downtime allowed is 9% of schedule.
   Actual run time to theoretical has averaged 92% over the past six months.
   Quality acceptance rate has been running at 98%.

6. Working individually or in a team, brainstorm how total productive maintenance could be applied to some of the following service industries.

   (a) Photo printing business
   (b) Copy center
   (c) Transmission shop
   (d) Bagel shop
   (e) Quick oil change shop
   (f) Gas station

7. In TPM, which of the following task is not performed by the regular operator?

   (a) Routine Maintenance
   (b) Overhaul

(c) Filling of coolant and oil
(d) Mounting of tools and dies

8. A bus driver is driving at slower speed due to some vibrations in a bus. This loss can be categorized as:

(a) Performance Efficiency
(b) Poor quality Loss
(c) Unplanned Loss
(d) Availability

9. In TPM, typical target for improvement is

(a) 100%
(b) 95%
(c) 90%
(d) 85%

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14

Management Tools

Chapter Objectives

The objective of this chapter is to learn various non-statistical tools for problem solving, grouping ideas and finding important ones in the complex situation, prioritizing ideas or projects, planning projects and designing counter-measures to handle contingencies. The following tools have been covered in this chapter:

- Why-why
- Forced field analysis
- Nominal group techniques
- Affinity diagram
- Interrelationship digraph
- Tree diagram
- Matrix diagram
- Prioritization matrix
- Process decision program chart
- Activity network diagram

Introduction

While the statistical process control (SPC) tools discussed in Chapter 15 are excellent problem-solving tools, there are many situations where they are not appropriate. This chapter discusses some additional tools that can be very effective for teams and, in some cases, for individuals. They do not use hard data but rely on subjective information. Application of these tools has been proven useful in process improvement, cost reduction, policy deployment, and new-product development.

Why, Why

Although this tool is very simple, it is effective. It can be a key to finding the root cause of a problem by focusing on the process rather than on people. The procedure is to describe the problem in specific terms and then ask why. You may have to ask why three or more times to obtain the root cause. An example will help illustrate the concept.

Why did we miss the delivery date?

It wasn't scheduled in time.

Why?

There were a lot of engineering changes.

Why?

Customer requested them.

The team suggested changing the delivery date whenever engineering changes occurred.

This tool is very beneficial in developing critical thinking. It is frequently a quick method of solving a problem.

Forced Field Analysis

This analysis is used to identify the forces and factors that may influence the problem or goal. It helps an organization to better understand promoting or driving and restraining or inhibiting forces so that the positives can be reinforced and the negatives reduced or eliminated. The procedure is to define the objective, determine criteria for evaluating the effectiveness of the improvement action, brainstorm the forces that promote and inhibit achieving the goal, prioritize the forces from greatest to least, and take action to strengthen the promoting forces and weaken the inhibiting forces. An example will illustrate the tool.

Objective: Stop Smoking

Promoting Forces	→	←	***Inhibiting Forces***
Poor Health	→	←	Habit
Smelly Clothing	→	←	Addiction
Poor Example	→	←	Taste
Cost	→	←	Stress
Impact on Others	→	←	Advertisement

The benefits are the determination of the positives and negatives of a situation, encouraging people to agree and prioritize the competing forces, and identify the root causes.

Nominal Group Technique

This technique provides for issue/idea input from everyone on the team and for effective decisions. An example will illustrate the technique. Let's assume that the team wants to decide which problem to work on. Everyone writes on a piece of paper the problem they think is most important. The papers are collected, and all problems are listed on a flip chart. Then each member of the team uses another piece of paper to rank the problems from least important to most important. The rankings are given a numerical value starting at 1 for least important and continuing to the most important. Points for each problem are totaled, and the item with the highest number of points is considered to be the most important.

Affinity Diagram

This diagram allows the team to creatively generate a large number of issues/ideas and then logically group them for problem understanding and possible breakthrough solution. The procedure is to state the issue in a full sentence, brainstorm using short sentences on self-adhesive notes, post them for the team to see, sort ideas into logical groups, and create concise descriptive headings for each group. Figure 14-1 illustrates the technique.

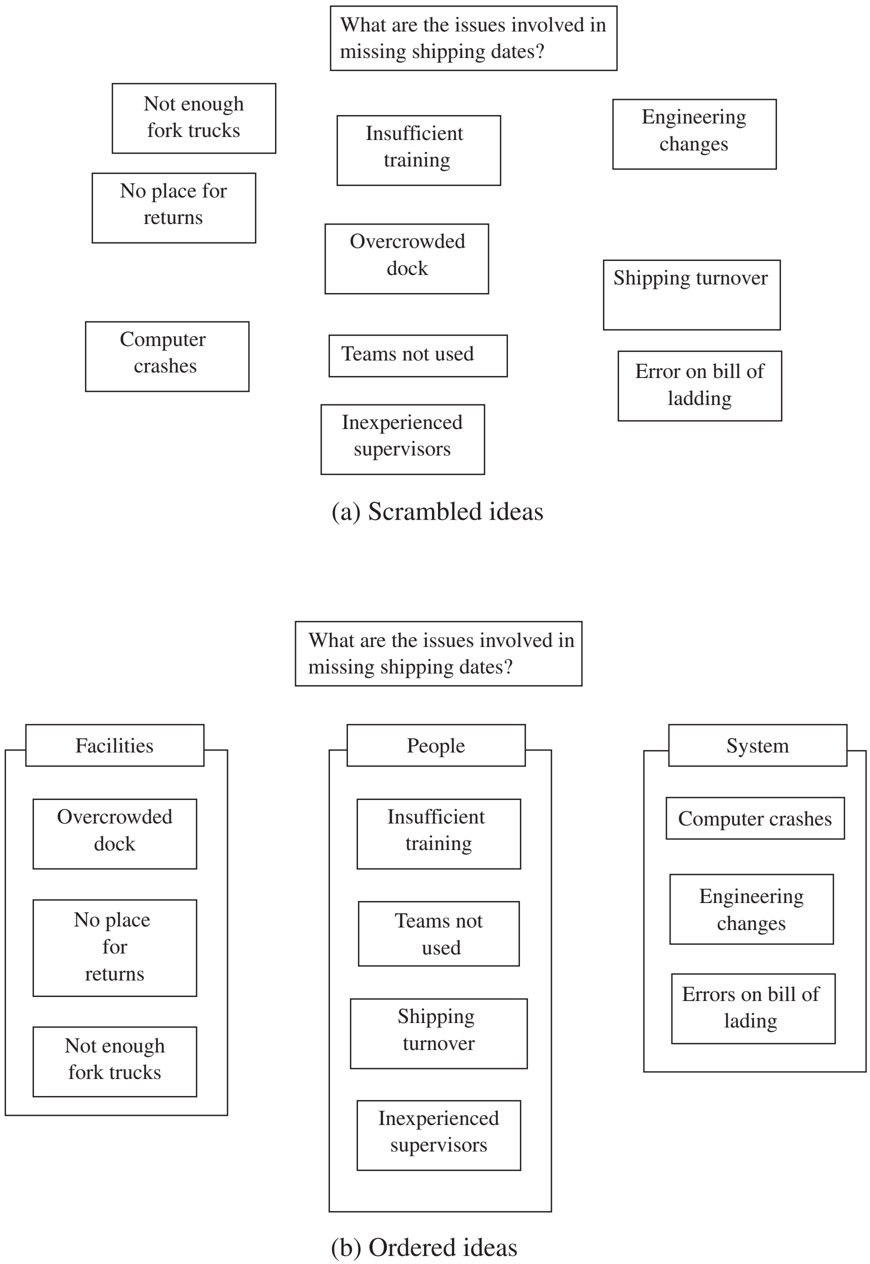

Figure 14-1 Affinity Diagram

Large groups should be divided into smaller groups with appropriate headings. Notes that stand alone could become headers or placed in a miscellaneous category. Affinity diagrams encourage team creativity, break down barriers, facilitate breakthroughs, and stimulate ownership of the process.

Interrelationship Digraph[1]

The Interrelationship Diagraph (ID) clarifies the interrelationship of many factors of a complex situation. It allows the team to classify the cause-and-effect relationships among all the factors so that the key drivers and outcomes can be used to solve the problem. The procedure is somewhat more complicated than the previous tools; thus, it will be itemized.

1. The team should agree on the issue or problem statement.

2. All of the ideas or issues from other techniques or from brainstorming should be laid out, preferably in a circle as shown in Figure 14-2(a).

3. Start with the first issue, "Lack of respect for others" (A), and evaluate the cause-and-effect relationship with "Lack of awareness of impact" (B). In this situation, Issue B is stronger than Issue A; therefore, the arrow is drawn from Issue B to Issue A as shown in Figure 14-2(c). Each issue in the circle is compared to Issue A as shown in Figure 14-2(c), (d), (e), and (f). Only Issues B and E have a relationship with Issue A. The first iteration is complete.

4. The second iteration is to compare Issue B with Issues C, D, E, and F. The third iteration is to compare Issue C with Issues D, E, and F. The fourth iteration is to compare Issue D with Issues E and F. The fifth iteration is to compare Issue E with Issue F.

5. The entire diagram should be reviewed and revised where necessary. It is a good idea to obtain information from other people on upstream and downstream processes.

6. The diagram is completed by tallying the incoming and outgoing arrows and placing this information below the box. Figure 14-3(d) shows a completed diagram.

Issue B is the "driver" because it has zero incoming arrows and five outgoing arrows. It is usually the root cause. The issue with the highest incoming arrows is Issue E. It is a meaningful measure of success.

A relationship diagram allows a team to identify root causes from subjective data, systematically explores cause-and-effect relationships, encourages members to think multidirectionally, and develops team harmony and effectiveness.

Tree Diagram

This tool is used to reduce any broad objective into increasing levels of detail in order to achieve the objective. The procedure is to first choose an action-oriented objective statement from the interrelationship diagram, affinity diagram, brainstorming, team mission statement, and so forth. Second, using brainstorming, choose the major headings as shown in Figure 14-4 under Means.

The third step is to generate the next level by analyzing the major headings. Ask, "What needs to be addressed to achieve the objective?" Repeat this question at each level. Three levels below the objective are

[1] This section adapted, with permission, from Michael Brassard, *The Memory Jogger Plus+* (Methuen, Mass.: GOAL/QPC, 1989).

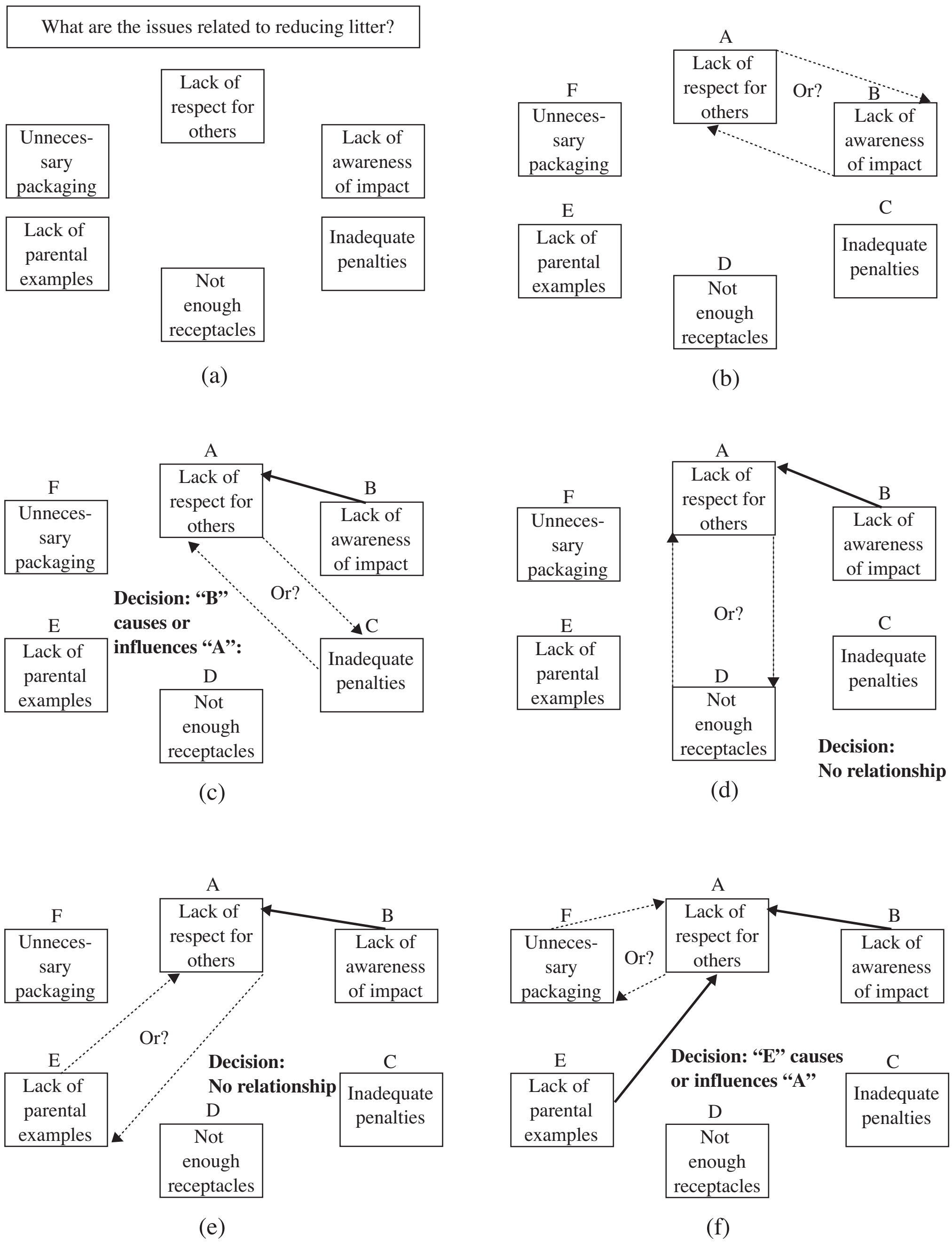

Figure 14-2 Interrelationship Diagram for First Iteration

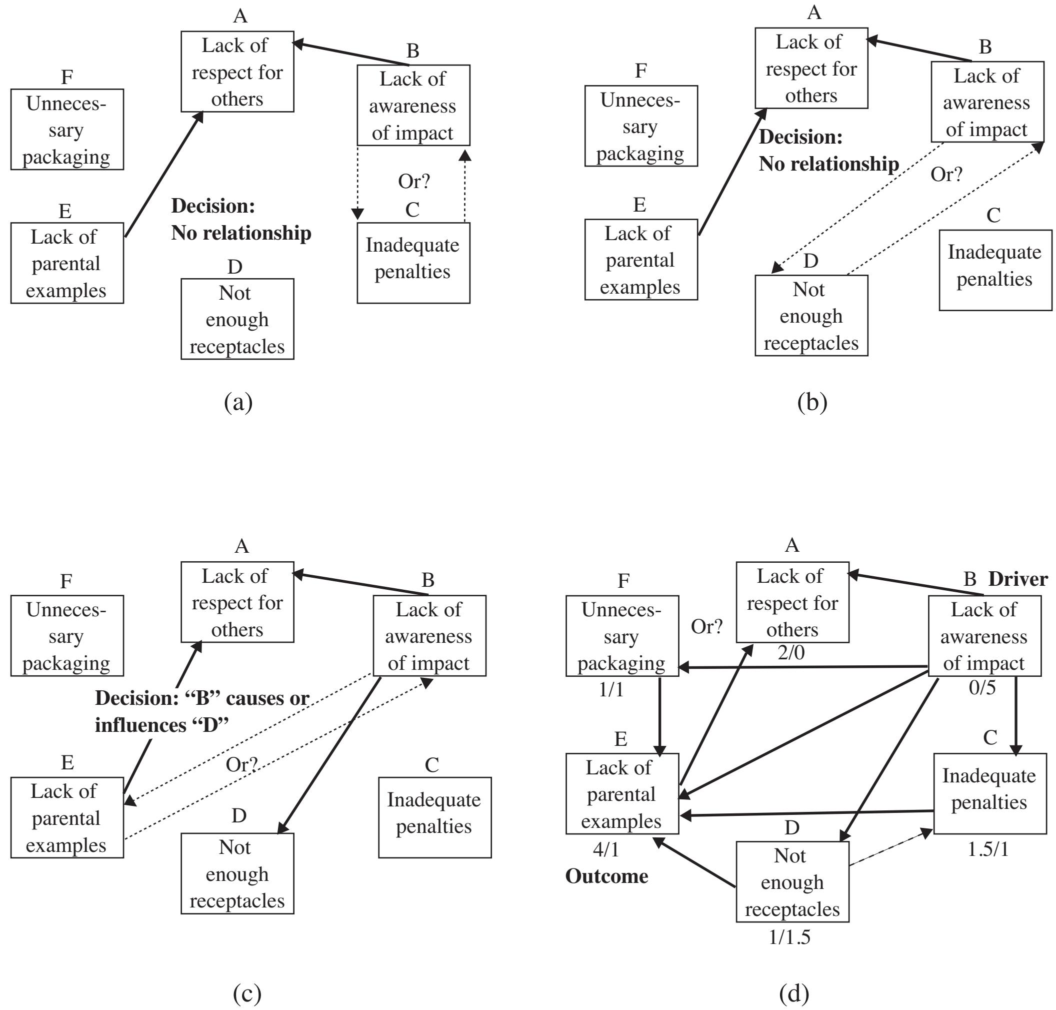

Figure 14-3 Completed Interrelationship Diagram

usually sufficient to complete the diagram and make appropriate assignments. The diagram should be reviewed to determine if these actions will give the results anticipated or if something has been missed.

The tree diagram encourages team members to think creatively, makes large projects manageable, and generates a problem-solving atmosphere.

Matrix Diagram

The matrix diagram allows individuals or teams to identify, analyze, and rate the relationship among two or more variables. Data are presented in table form and can be objective or subjective, which can be given symbols with or without numerical values. Quality function deployment (QFD), which was discussed in Chapter 10, is an outstanding example of the use of the matrix diagram. There are at least five standard formats:

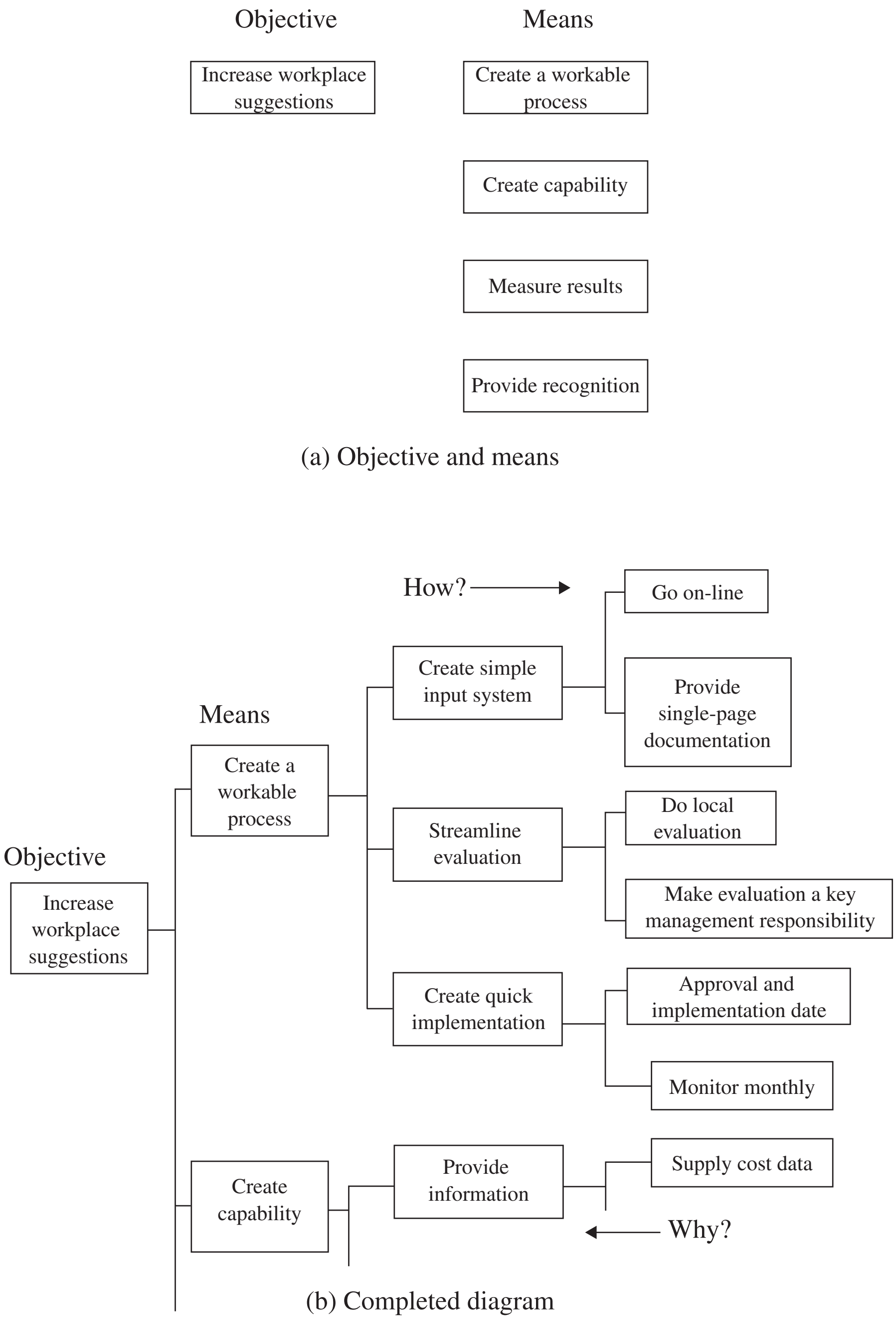

Figure 14-4 Tree Diagram

Use / Tool	Creativity	Analysis	Consensus	Action
Affinity diagram	○		○	△
Interrelationship digraph		○	◎	
Tree diagram		◎		◎
Prioritization matrix			○	
Matrix diagram		○	◎	○
PDPC	◎	◎	◎	○
Activity network diagram			◎	○

Legend: Always ○ Frequently ◎ Occasionally △

Figure 14-5 Matrix Diagram for Uses of the Seven Management Tools
Reproduced, with permission, from Ellen R. Domb, "7 New Tools: The Ingredients for Successful Problem Solving," *Quality Digest* (December 1994).

L-shaped (2 variables), T-shaped (3 variables), Y-shaped (3 variables), C-shaped (3 variables), and X-shaped (4 variables). Our discussion will be limited to the L-shaped format, which is the most common.[2]

Figure 14-5 illustrates a matrix diagram for using the seven management and planning tools. The procedure for the diagram is for the team to first select the factors affecting a successful plan. Next select the appropriate format, which in this case is the L-shaped diagram. That step is followed by determining the relationship symbols. Any symbols can be adopted, provided the diagram contains a legend as shown in the bottom of the figure. Numerical values are sometimes associated with the symbol as we previously did with QFD. The last step is to complete the matrix by analyzing each cell and inserting the appropriate symbol.

The matrix diagram clearly shows the relationship of the two variables. It encourages the team to think in terms of relationships, their strength, and any patterns.

Prioritization Matrices

These tools prioritize issues, tasks, characteristics, and so forth, based on weighted criteria using a combination of tree and matrix diagram techniques. Once prioritized, effective decisions can be made. Prioritization matrices are designed to reduce the team's options rationally before detailed implementation planning occurs. It utilizes a combination of tree and matrix diagrams as shown in Figure 14-6. There are 15 implementation options; however, only the first three, beginning at "train supervisors," and the last one "purchase fork-trucks," are shown in the tree diagram. There are four implementation criteria, however,

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[2] Detailed information on the other formats is available from Michael Brassard, *The Memory Jogger Plus+* (Methuen, Mass.: GOAL/QPC, 1996).

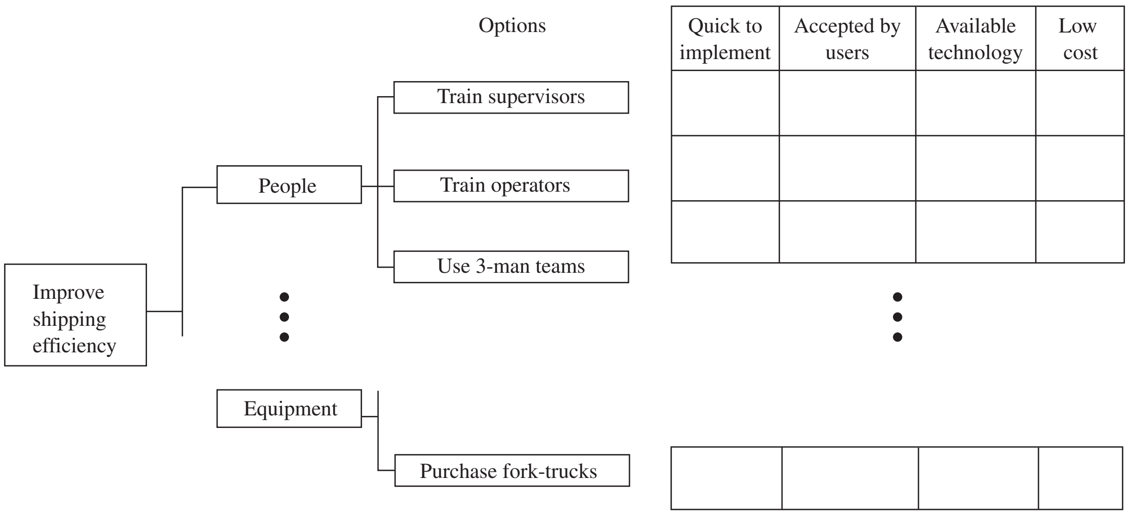


Figure 14-6 Prioritization Matrix for Improving Shipping Efficiency

as shown at the top of the matrix. Prioritization matrices are the most difficult of the tools in this chapter; therefore, we will list the steps for creating one.

1. Construct an L-shaped matrix combining the options, which are the lowest level of detail of the tree diagram with the criteria. This information is given in Table 14-1.

Criteria	***Member #1***	***Member #2***		***Total***
Accepted by users	.30	.25		1.50
Low cost	.15	.20	•••	0.35
Quick to implement	.40	.30		2.10
Available technology	.15	.25		0.45
	1.00	1.00		

2. Determine the implementation criteria using the nominal group technique (NGT) or any other technique that will satisfactorily weight the criteria. Using NGT, each team member submits the most important criteria on a piece of paper. They are listed on a flip chart, and the team members submit another piece of paper rank ordering those listed on the flip chart. Those criteria with the greatest value are the most important. The team decides how many of the criteria to use. In this situation, the team decides to use the four criteria shown at the top of the matrix.

3. Prioritize the criteria using the NGT. Each team member weights the criteria so the total weight equals 1.00, and the results are totaled for the entire team as shown below:

4. Using NDT, rank order the options in terms of importance by each criterion, average the results, and round to the nearest whole number. Thus, this ranking should be from one to the number of options for each criterion. For example, train operators is ranked 13 for quick to implement.

5. Compute the option importance score under each criterion by multiplying the rank by the criteria weight as shown in Table 14-1. The options with the highest total are those that should be implemented first.

There are two other techniques that are more complicated. (For information on these techniques, see *The Memory Jogger Plus+*).

TABLE 14-1
Improve Shipping Efficiency Using the Consensus Criteria Method

	CRITERIA				
Options	*Quick to Implement*	*Accepted by Users*	*Available Technology*	*Low Cost*	*Total*
Train Operators	13(2.10) = 27.3	15(1.50) = 22.5	11(0.45) = 5.0	13(0.35) = 4.6	59.4
Train Supervisors	12(2.10) = 25.2	11(1.50) = 16.5	12(0.45) = 5.4	8(0.35) = 2.8	49.9
Use 3-person Teams	8(2.10) = 16.8	3(1.50) = 4.5	13(0.45) = 5.9	14(0.35) = 4.9	32.1
⋮	⋮	⋮	⋮	⋮	⋮
Purchase Fork-trucks	6(2.10) = 12.6	12(1.50) = 18	10(0.45) = 4.5	1(0.35) = 0.4	35.5

Process Decision Program Chart

Programs to achieve particular objectives do not always go according to plan, and unexpected developments may have serious consequences. The process decision program chart (PDPC) avoids surprises and identifies possible countermeasures. Figure 14-7 illustrates the PDPC.

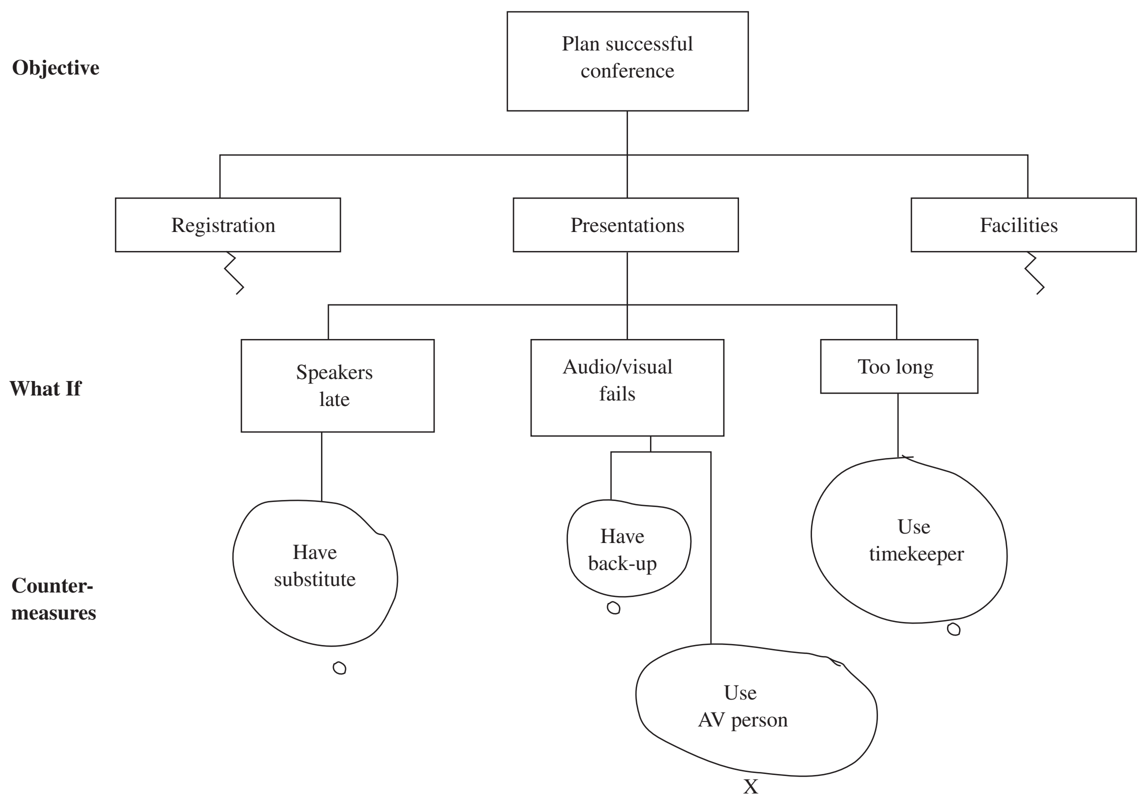


Figure 14-7 PDPC for Conference Presentation

The procedure starts with the team stating the objective, which is to plan a successful conference. That activity is followed by the first level, which is the conference activities of registration, presentations, and facilities. Only the presentation activity is illustrated. In some cases a second level of detailed activities may be used. Next, the team brainstorms to determine what could go wrong with the conference, and these are shown as the "what-if" level. Countermeasures are brainstormed and placed in a balloon in the last level. The last step is to evaluate the countermeasures and select the optimal ones by placing an *O* underneath. Place an *X* under those that are rejected.

The example has used a graphical format. PDPC can also use an outline format with the activities listed. The probability, in percent, that a "what-if" will occur can be included in the box. Countermeasures should be plausible. PDPC should be used when the task is new or unique, complex, or potential failure has great risks. This tool encourages team members to think about what can happen to a process and how countermeasures can be taken. It provides the mechanism to effectively minimize uncertainty in an implementation plan.

Activity Network Diagram

This tool goes by a number of different names and deviations, such as program evaluation and review technique (PERT), critical path method (CPM), arrow diagram, and activity on node (AON). It allows the team to schedule a project efficiently. The diagram shows completion times, simultaneous tasks, and critical activity path. Given below is the procedure to follow:

1. The team brainstorms or documents all the tasks to complete a project. These tasks are recorded on self-adhesive notes so all members can see them.

2. The first task is located and placed on the extreme left of a large view work surface, as shown in Figure 14-8(a).

<table>
<tr><td rowspan="2">Activity
time
[T]</td><td>Earliest
Start
[ES]</td><td>Earliest
Finish
[EF]</td></tr>
<tr><td>Latest
Start
[LS]</td><td>Latest
Finish
[LF]</td></tr>
</table>

3. Any tasks that can be done simultaneously are placed below, as shown in Figure 14-8(b).

4. Repeat Steps 2 and 3 until all tasks are placed in their correct sequence, as illustrated in Figure 14-8(c). Note: Because of space limitations, not all of the tasks are shown.

5. Number each task and draw connecting arrows. Determine the task completion time and post it in the lower left box. Completion times are recorded in hours, days, or weeks.

6. Determine the critical path by completing the four remaining boxes in each task. As shown below, these boxes are used for the earliest start time (ES), earliest finish (EF), latest start (LS), and latest finish (LF).

The ES for Task 1 is 0, and the EF is 4 weeks later using the equation EF = ES + T; the ES for Task 2 is 4 weeks, which is the same as the EF of Task 1, and the EF of Task 2 is 4 + 3 = 7. This process is repeated for Tasks 4 and 5, which gives a total time of 29 weeks through the completion of the internal audit. If the project is to stay on schedule, the LS and LF for each of these tasks must equal the ES and EF, respectively. These values can be calculated by working backwards—subtracting the task time. They are shown in Figure 14-8(d).

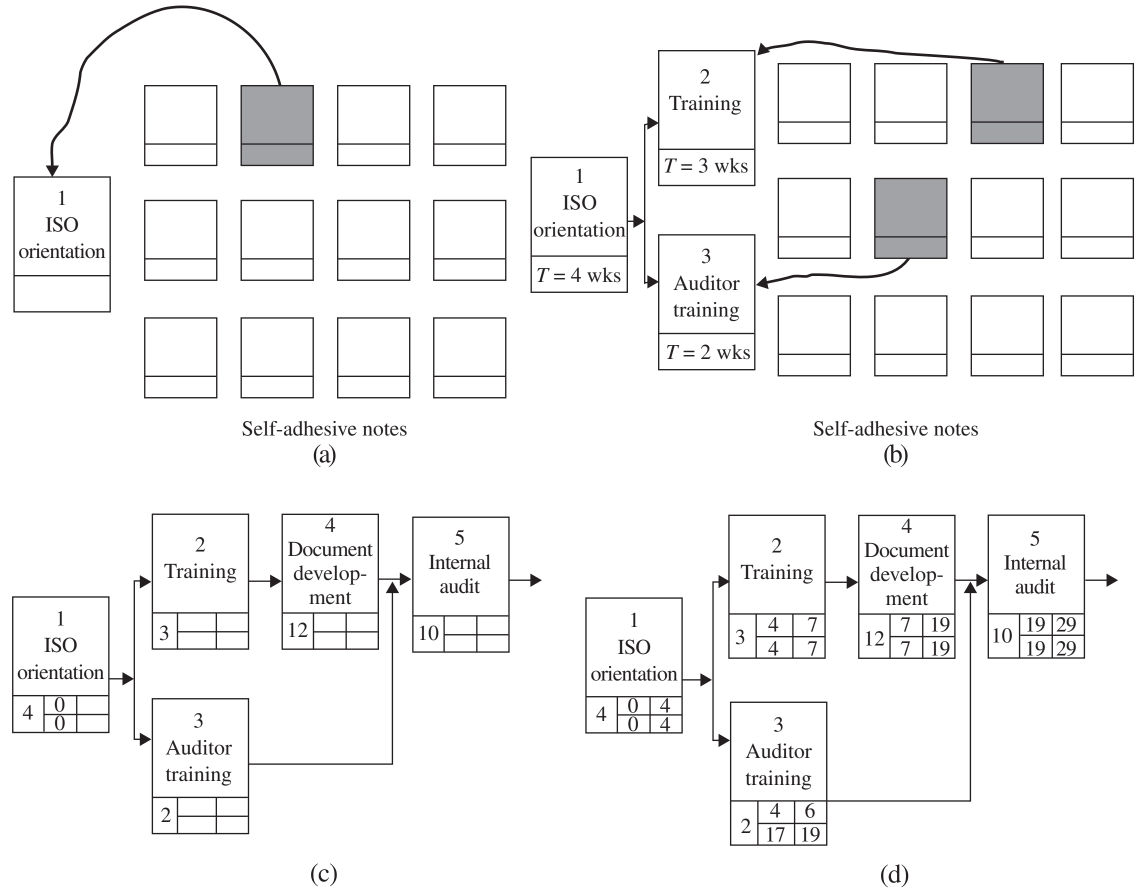


Figure 14-8 Activity Network Diagram

Task 3, auditor training, does not have to be in sequence with the other tasks. It does have to be completed during the 19th week, because the ES for Task 5 is 19. Therefore, the LF for Task 3 is also 19 and the LS is 17. Auditor training could start after Task 1, which would give an ES of 4 and an EF of 6. The slack for Task 3 equals LS − ES [17 − 4 = 13]. The critical path is the longest cumulative time of connecting activities and occurs when the slack of each task is zero; thus, it is 1, 2, 4, and 5.

The benefits of an activity network diagram are (1) a realistic timetable determined by the users, (2) team members understand their role in the overall plan, (3) bottlenecks can be discovered and corrective action taken, and (4) members focus on the critical tasks. For this tool to work, the task times must be correct or reasonably close.

TQM Exemplary Organization[3]

The case study of Community Health Care is given here to illustrate how the principles of TQM can be effectively deployed in a unique manner. Data based problem-solving approach combined with scientific analysis resulted in a glorious contribution that improved community health in the tribal regions of India.

[3] Malcolm Baldrige National Quality Award, 2001 Education Category Recipient, NIST/Baldrige Homepage, Internet.

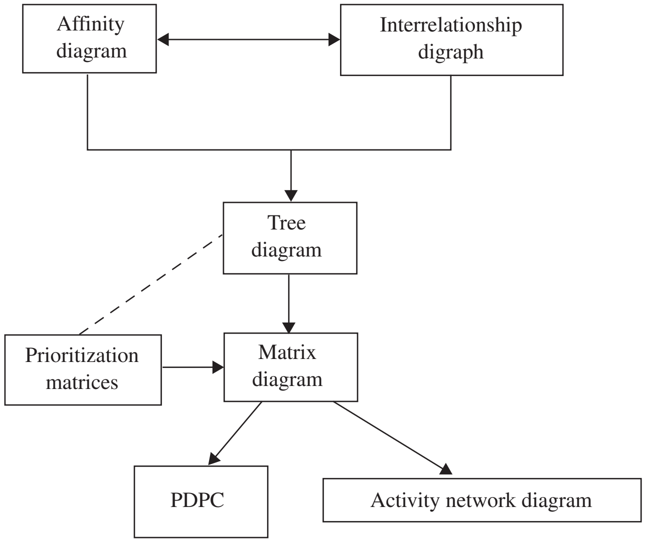


Figure 14-9 System Flow Diagram

In 1986, Dr. Abhay and his wife, Dr. Rani Bang set up a non-government organization known as "Society for Action and Research in Community Health" or "SEARCH". Both Abhay and Rani were gold medallist and were post graduates in public health from John Hopkins University. They were inspired by the Gandhian principles. The primary mission of SEARCH was to improve the overall health of the extremely backward and poor tribes in and around Gadchiroli, situated in the central part or India. Due to the absence of any reliable data on health in this region, they spent considerable time in understanding the needs and priorities of the tribals.

By conducting the first ever study in two villages of Gadchiroli district was published in the Lancet Journal, Dr. Rani Bang first brought to the notice of the world that rural women had a large hidden burden of gynaecological deceases. She subsequently trained the Traditional Birth Attendants (TBAs) or Daai's in the villages to make them village-level health workers. With convincing evidence, she advocated the need for a comprehensive reproductive healthcare package for rural women in India.

Based on the surveys and interactions with the people around they decided to prioritize on reducing the infant mortality rates. SEARCH collected the data of infant mortalities and concluded that pneumonia was the largest contributor to infant mortality with more than 25% deaths in children under 5 years. This was a fact-based revelation, contradictory to the widely then published information.

With a number of constraints on account of poverty and illiteracy, an innovative but profound and systematic approach was used to solve this problem. A number of village health workers (VHWs) and TBAs, were trained to diagnose and treat pneumonia. Four messages were given.

- Cough in a child without fast breathing can be treated at home.
- Fast breathing or difficulty in breathing, may indicate pneumonia and needs treatment.
- Treatment is available in the villages with the medical facilities.
- An effective medicine called "kotra" (for co-trimoxazole) was made available for free.

To spread awareness, two health carnivals or "Jatras" were held in the area.

They soon realized that the visual method used by the illiterate TBAs to diagnose pneumonia resulted in wrong diagnosis in close to 41% cases with the borderline respiratory rates. A simple device, named "Breath Counter" was therefore designed and TBAs were trained to diagnose pneumonia in children using this instrument. Breath Counter was a simple, cheap, and effective and could be used even by illiterate (TBAs could not count more than 12 in most cases!!) to diagnose pneumonia in children. The Breath Counter used an abacus, with two rows of beads for various age groups of children. Five beads were white and 1 was red. It had a sand clock of one minute duration. The method was simple: one white bead was moved with every 10 breaths. If a red bead was required, pneumonia was diagnosed. The diagnosis correctness improved significantly to 82% by the use of Breath Counter. It also overcame the constraint that the TBAs were not able to count more than 12!

If diagnosed positive, children with pneumonia were treated with proper medicine. Cost of the medicines was US$ 2.64 per child saved.

After the first year of intervention, the infant mortality rates for children of age less than 5 years due to pneumonia dropped to about 8.1 per 1000 children as compared to 17.5, in the "control" areas were the actions were not initiated.

Abhay and Rani Bang along with their colleagues have developed a model for a village healthcare program, which is now being recognized both nationally and internationally. They have demonstrated how pneumonia in children can be managed in villages, and recently, how neonatal care can be provided at the village level. Their innovative approach of empowering the village women to take care of their community's health has reduced the infant mortality rate in their work area from 121 to 30, which is the best indicator of their efforts. This model has been successfully replicated by the NGOs and Indian Council of Medical Research (ICMR) of the Government of India, in 5 states; and recently has been incorporated in the 11th Five Year Plan of India.

Abhay Bang has served as a consultant to both the World Health Organization and the Government of India for which he is currently a member of the National Commission on Population. He also serves on the advisory board for the Global Saving Newborn Lives Initiative. He is the recipient of several awards, including, the Maharashtra Bhushan and the prestigious Mahatma Gandhi Award.

Rani Bang has been awarded with national award for Women's Development through Application of Science and Technology in recognition of her outstanding and pioneering contribution for the past two-and-a-half decades on improving women's health in rural India through innovative and powerful approach of research with the people and for the people. She has spearheaded the development of a comprehensive village healthcare program, which has now become a nationally and internationally acclaimed model. This innovative approach of empowering rural women to take care of their community's health has reduced the infant mortality in Gadchiroli, Maharashtra by over 75 %. The award was conferred upon her by the president of India, Smt. Pratibha Devisingh Patil at the National Conference on "Showcasing Cutting Edge Science and Technology by Women" in New Delhi.

Sources:

1 "Heroes of Health", *The Time magazine*, 31 October 2005.

2 Bulletin of the World Health Organization, 1994.

3 "Breath Counter: A New Devise for Household Diagnosis of Pneumonia", Abhay Bang, The Indian Journal of Paediatrics, vol. 59, 1992.

4 http://dst.gov.in/whats_new/press-release08/national-award-rani-bang.htm.

Summary

Many real-life problems require non-statistical tools which use knowledge, experience, wisdom, and judgement of the team members. Tools such as Why-Why, Force Field Analysis, and Nominal Group Technique are often used in problem-solving. In complex situations ideas need to be generated, grouped, and their relationship needs to be mapped. Affinity Diagrams and Interrelationship Digraph are useful in such situations Matrix Diagrams are useful in mapping relationship between the variables. Tools such as Network Diagram and Process Decision Program Chart are useful in project planning and initiating counter-measures in case things go wrong.

Exercises

1. Determine why you did poorly on a recent examination by using the why, why tool.
2. Use the forced field analysis to
   (a) Lose weight.
   (b) Improve your GPA.
   (c) Increase your athletic ability in some sport.
3. Prepare an affinity diagram, using a team of three or more people, to plan
   (a) An improvement in the cafeteria.
   (b) A spring-break vacation.
   (c) A field trip to a local organization.
4. Using a team of three or more people, prepare an interrelationship digraph for the
   (a) Computer networking of nine locations in the organization's facility.
   (b) Implementation of a recognition and reward system.
   (c) Performance improvement of the accounting department or any other work group.
5. Develop a tree diagram, using a team of three or more people, for
   (a) The customer requirements for a product or service.
   (b) Planning a charity walk-a-thon.
6. The church council is planning the activities for a successful carnival. Using a team of three or more people, design a tree diagram to determine detailed assignments.
7. Develop a matrix diagram to design an organization-wide training or employee involvement program. Use a team of three or more people.
8. Using a team of three or more people, construct a matrix diagram to
   (a) Determine customer requirements for a new product or service.
   (b) Allocate team assignments to implement a project such as new student week.
   (c) Compare teacher characteristics with potential student performance.
9. Develop a prioritization matrix, using the tree diagram developed in Exercise 6.
10. Construct a PDPC for
    (a) A charity walk-a-thon (see Exercise 5).
    (b) The church carnival of Exercise 6.
    (c) The matrix diagram developed in Exercise 7.

11. Using a team of three or more people, construct an activity network diagram for

    (a) Constructing a cardboard boat.
    (b) An implementation schedule for a university event such as a graduation.
    (c) Developing a new instructional laboratory.

12. Select a problem or situation and, with a team of three or more people, use the seven management and planning tools to implement an action plan. If one of the tools doesn't fit, justify its exclusion.

13. While using Interrelationship Digraph, the root cause is indicated as

    (a) The one with maximum incoming arrows
    (b) The one with minimum incoming arrows
    (c) The minimum outgoing arrows
    (d) The maximum outgoing arrows

14. Activities on Critical path have

    (a) Zero float
    (b) Zero duration
    (c) Long duration
    (d) Large floats

15. Which of the following tools can be useful to judge chances of success while implementing a change?

    (a) Affinity Diagram
    (b) Force Field Analysis
    (c) Process Decision Program Chart
    (d) Interrelationship Digraph

16. Management wants to implement a new process. Which tools can be useful to plan for contingencies?

    (a) Process Decision Program Chart
    (b) Force Field Analysis
    (c) Interrelationship Digraph
    (d) Activity Network Diagram

17. A team wants to organize their thoughts about a completely new project. They should use:

    (a) Activity Network Diagram
    (b) Force Field Analysis
    (c) Matrix Diagram
    (d) Affinity Diagrams

15

Statistical Process Control[1]

Chapter Objectives

- Understanding the seven QC tools of continuous improvement and solving problems: Pareto charts, checksheets and histograms, process flow diagrams and cause and effect diagrams
- Understanding basic statistical concepts like measures of central tendency and dispersion, population, sample and normal distribution
- Overview of application of data-based approach for basic statistical tools for continuous improvement and solving problems
- Studying statistical control charts, types and some application examples

Introduction

One of the best technical tools for improving product and service quality is *statistical process control* (SPC). There are seven basic techniques. Since the first four techniques are not really statistical, the word *statistical* is somewhat of a misnomer. Furthermore, this technical tool not only *controls* the process but has the capability to improve it as well.

Pareto Diagram

Alfredo Pareto (1848–1923) conducted extensive studies of the distribution of wealth in Europe. He found that there were a few people with a lot of money and many people with little money. This unequal distribution of wealth became an integral part of economic theory. Dr. Joseph Juran recognized this concept as a universal that could be applied to many fields. He coined the phrases *vital few* and *useful many*.

A Pareto diagram is a graph that ranks data classifications in descending order from left to right, as shown in Figure 15-1. In this case, the data classifications are types of coating machines. Other possible data classifications are problems, complaints, causes, types of nonconformities, and so forth. The vital few are on the left, and the useful many are on the right. It is sometimes necessary to combine some of the useful many into one classification called "other". When this category is used, it is placed on the far right.

[1] Adapted, with permission, from Dale H. Besterfield, Quality Control, 6th ed. (Upper Saddle River, NJ: Prentice Hall, 2001).

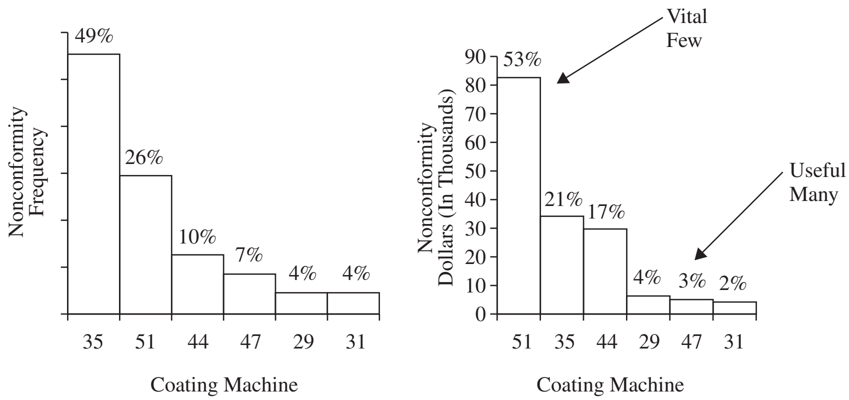


Figure 15-1 Pareto Diagram

The vertical scale is dollars (or frequency), and the percent of each category can be placed above the column. In this case, Pareto diagrams were constructed for both frequency and dollars. As can be seen from the figure, machine 35 has the greatest number of nonconformities, but machine 51 has the greatest dollar value. Pareto diagrams can be distinguished from histograms (to be discussed) by the fact that the horizontal scale of a Pareto diagram is categorical, whereas the scale for the histogram is numerical.

Pareto diagrams are used to identify the most important problems. Usually, 75% of the total results from 25% of the items. This fact is shown in the figure, where coating machines 35 and 51 account for about 75% of the total.

Actually, the most important items could be identified by listing them in descending order. However, the graph has the advantage of providing a visual impact, showing those vital few characteristics that need attention. Resources are then directed to take the necessary corrective action.

Examples of the vital few are:

A few customers account for the majority of sales.

A few processes account for the bulk of the scrap or rework cost.

A few nonconformities account for the majority of customer complaints.

A few suppliers account for the majority of rejected parts.

A few problems account for the bulk of the process downtime.

A few products account for the majority of the profit.

A few items account for the bulk of the inventory cost.

Construction of a Pareto diagram is very simple. There are five steps:

1. Determine the method of classifying the data: by problem, cause, nonconformity, and so forth.
2. Decide if dollars (best), frequency, or both are to be used to rank the characteristics.
3. Collect data for an appropriate time interval or use historical data.
4. Summarize the data and rank order categories from largest to smallest.
5. Construct the diagram and find the vital few.

Note that a quality improvement of the vital few, say, 50%, is a much greater return on investment than a 50% improvement of the useful many. Also, experience has shown that it is easier to make a 50% improvement in the

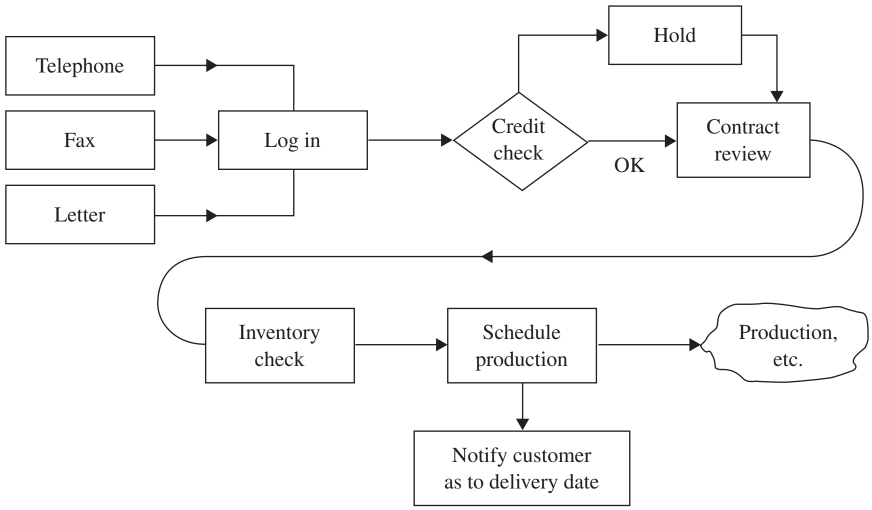


Figure 15-2 Flow Diagram for an Order Entry Activity

vital few. The use of a Pareto diagram is a never-ending process. For example, let's assume that coating machine 51 is the target for correction in the improvement program. A project team is assigned to investigate and make improvements. The next time a Pareto analysis is made, another machine, say, 35 becomes the target for correction, and the improvement process continues until coating machine nonconformities become an insignificant quality problem.

The Pareto diagram is a powerful quality improvement tool. It is applicable to problem identification and the measurement of progress.

Process Flow Diagram

For many products and services, it may be useful to construct a process flow diagram. Figure 15-2 shows a flow diagram for the order entry activity of a make-to-order company that manufactures gasoline filling station hose nozzles. These diagrams show the flow of the product or service as it moves through the various processing operations. The diagram makes it easy to visualize the entire system, identify potential trouble spots, and locate control activities. It answers the question, "Who is the next customer?" Improvements can be accomplished by changing, reducing, combining, or eliminating steps.

Standardized symbols are used by industrial engineers; however, they are not necessary for problem solving. The symbols used in the figure should be sufficient.

Cause-and-Effect Diagram

A cause-and-effect (C&E) diagram is a picture composed of lines and symbols designed to represent a meaningful relationship between an effect and its causes. It was developed by Dr. Kaoru Ishikawa in 1943 and is sometimes referred to as an Ishikawa diagram or a fishbone diagram because of its shape.

C&E diagrams are used to investigate either a "bad" effect and to take action to correct the causes or a "good" effect and to learn those causes that are responsible. For every effect, there are likely to be numerous

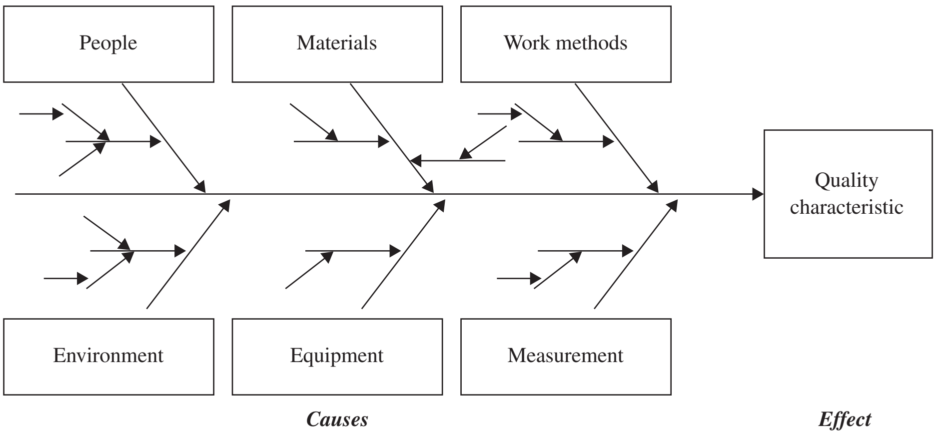


Figure 15-3 Cause-and-Effect Diagram

causes. Figure 15-3 illustrates a C&E diagram with the effect on the right and causes on the left. The effect is the quality characteristic that needs improvement. Causes are sometimes broken down into the major causes of work methods, materials, measurement, people, equipment, and the environment. Other major causes could be used for service-type problems, as indicated in the chapter on customer satisfaction.

Each major cause is further subdivided into numerous minor causes. For example, under work methods, we might have training, knowledge, ability, physical characteristics, and so forth. C&E diagrams are the means of picturing all these major and minor causes. Figure 15-4 shows a C&E diagram for house paint peeling using four major causes.

The first step in the construction of a C&E diagram is for the project team to identify the effect or quality problem. It is placed on the right side of a large piece of paper by the team leader. Next, the major causes are identified and placed on the diagram.

Determining all the minor causes requires brainstorming by the project team. Brainstorming is an idea-generating technique that is well suited to the C&E diagram. It uses the creative thinking capacity of the team.

Attention to a few essentials will provide a more accurate and usable result:

1. Participation by every member of the team is facilitated by each member taking a turn giving one idea at a time. If a member cannot think of a minor cause, he or she passes for that round. Another idea may occur

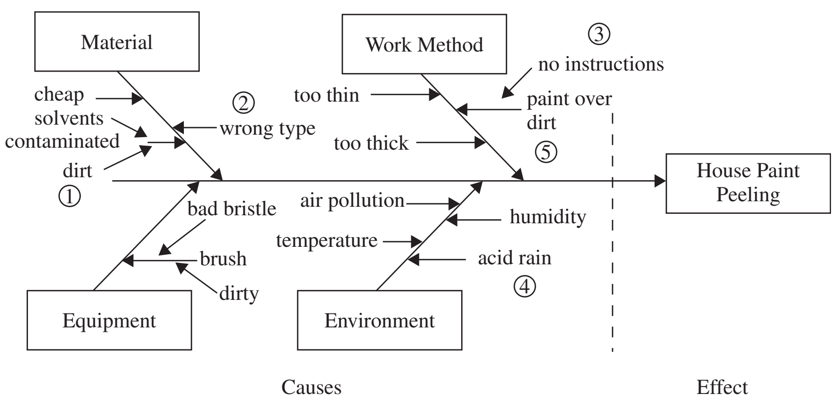


Figure 15-4 Cause-and-Effect Diagram of House Paint Peeling

at a later round. Following this procedure prevents one or two individuals from dominating the brainstorming session.

2. Quantity of ideas, rather than quality, is encouraged. One person's idea will trigger someone else's idea, and a chain reaction occurs. Frequently, a trivial, or "dumb," idea will lead to the best solution.

3. Criticism of an idea is not allowed. There should be a freewheeling exchange of information that liberates the imagination. All ideas are placed on the diagram. Evaluation of ideas occurs at a later time.

4. Visibility of the diagram is a primary factor of participation. In order to have space for all the minor causes, a 2-foot by 3-foot piece of paper is recommended. It should be taped to a wall for maximum visibility.

5. Create a solution-oriented atmosphere and not a gripe session. Focus on solving a problem rather than discussing how it began. The team leader should ask questions using the why, what, where, when, who, and how techniques.

6. Let the ideas incubate for a period of time (at least overnight) and then have another brainstorming session. Provide team members with a copy of the ideas after the first session. When no more ideas are generated, the brainstorming activity is terminated.

Once the C&E diagram is complete, it must be evaluated to determine the most likely causes. This activity is accomplished in a separate session. The procedure is to have each person vote on the minor causes. Team members may vote on more than one cause. Those causes with the most votes are circled, as shown in Figure 15-4, and the four or five most likely causes of the effect are determined.

Solutions are developed to correct the causes and improve the process. Criteria for judging the possible solutions include cost, feasibility, resistance to change, consequences, training, and so forth. Once the team agrees on solutions, testing and implementation follow.

Diagrams are posted in key locations to stimulate continued reference as similar or new problems arise. The diagrams are revised as solutions are found and improvements are made.

The C&E diagram has nearly unlimited application in research, manufacturing, marketing, office operations, service, and so forth. One of its strongest assets is the participation and contribution of everyone involved in the brainstorming process. The diagrams are useful to

1. Analyze actual conditions for the purpose of product or service quality improvement, more efficient use of resources, and reduced costs.
2. Eliminate conditions causing nonconformities and customer complaints.
3. Standardize existing and proposed operations.
4. Educate and train personnel in decision-making and corrective-action activities.

Check Sheets

The main purpose of check sheets is to ensure that the data is collected carefully and accurately by operating personnel. Data should be collected in such a manner that it can be quickly and easily used and analyzed. The form of the check sheet is individualized for each situation and is designed by the project team. Figure 15-5 shows a check sheet for paint nonconformities for bicycles.

Figure 15-6 shows a check sheet for temperature. The scale on the left represents the midpoint and boundaries for each temperature range. Data for this type of check sheet is frequently recorded by placing an "X" in the appropriate square. In this case, the time has been recorded in order to provide additional information for problem solving.

CHECK SHEET		
Product: Bicycle 32	Number inspected: 2217	
Nonconformity type	Check	Total
Blister	卌 卌 卌 卌 |	21
Light spray	卌 卌 卌 卌 卌 卌 卌 |||	38
Drips	卌 卌 卌 卌 ||	22
Overspray	卌 卌 |	11
Runs	卌 卌 卌 卌 卌 卌 卌 卌 卌 ||	47
Others	卌	5
	Total	144
Number Nonconforming	卌 |||	113

Figure 15-5 Check Sheet for Paint Nonconformities

387.4 385 382.5							
382.4 380 377.5							
37 375 372.5	10.0						
372.4 370 367.5							
367.4 365 362.5	7.0	7.5	9.0				
362.4 360 357.5	8.0	8.5					
357.4 355 352.5	9.5						

Figure 15-6 Check Sheet for Temperature

Whenever possible, check sheets are also designed to show location. For example, the check sheet for bicycle paint nonconformities could show an outline of a bicycle, with X's indicating the location of the nonconformities. Creativity plays a major role in the design of a check sheet. It should be user-friendly and, whenever possible, include information on time and location.

Histogram

The first "statistical" SPC technique is the histogram. It describes the variation in the process, as illustrated by Figure 15-7. The histogram graphically estimates the process capability and, if desired, the relationship to the specifications and the nominal (target). It also suggests the shape of the population and indicates if there are any gaps in the data.

In industry, business, and government the mass of data that have been collected is voluminous. Even one item, such as the number of daily billing errors of a large bank, can represent such a mass of data that it can be more confusing than helpful. For example, consider the data shown in Table 15-1. Clearly these data, in this form, are difficult to use and are not effective in describing the data's characteristics. Some means of summarizing the data are needed to show what value the data tend to cluster about and how the data are dispersed or spread out. Two techniques are needed to accomplish this summarization of data—graphical and analytical.

Ungrouped Data

The graphical technique is a plot or picture of a frequency distribution, which is a summarization of how the data points (observations) occur within each subdivision of observed values or groups of observed values. Analytical techniques summarize data by computing a measure of the central tendency (average, median, and

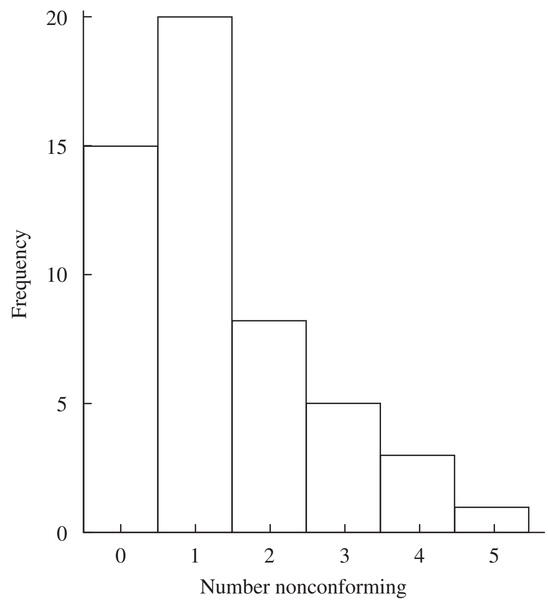


Figure 15-7 Frequency Histogram

TABLE 15-1
Number of Daily Accounting Errors

0	1	3	0	1	0	1	0
1	5	4	1	2	1	2	0
1	0	2	0	0	2	0	1
2	1	1	1	2	1	1	
0	4	1	3	1	1	1	
1	3	4	0	0	0	0	
1	3	0	1	2	2	3	

mode) and a measure of the dispersion (range and standard deviation). Sometimes both the graphical and analytical techniques are used.

Because unorganized data are virtually meaningless, a method of processing the data is necessary. Table 15-1 will be used to illustrate the concept. An analyst reviewing the information as given in this table would have difficulty comprehending the meaning of the data. A much better understanding can be obtained by tallying the frequency of each value, as shown in Table 15-2.

The first step is to establish an *array*, which is an arrangement of raw numerical data in ascending or descending order of magnitude. An array of ascending order from 0 to 5 is shown in the first column of the table. The next step is to tabulate the frequency of each value by placing a tally mark under the tabulation column and in the appropriate row. Start with the numbers 0, 1, 1, 2, ... of Table 15-1 and continue placing tally marks until all the data have been tabulated. The last column of the table is the numerical value for the number of tallies and is called the *frequency*.

Analysis of Table 15-2 shows that one can visualize the distribution of the data. If the "Tabulation" column is eliminated, the resulting table is classified as a frequency distribution, which is an arrangement of data to show the frequency of values in each category. The frequency distribution is a useful method of visualizing data and is a basic statistical concept. To think of a set of numbers as having some type of distribution is fundamental to solving quality control problems. There are different types of frequency distributions, and the type of distribution can indicate the problem-solving approach.

When greater visual clarity is desired, frequency distributions are presented in graphical form called histograms. A *histogram* consists of a set of rectangles that represent the frequency of the observed values in each

TABLE 15-2
Tally of Number of Daily Accounting Errors

Number Nonconforming	*Tabulation*	*Frequency*
0	𝍸 𝍸 𝍸	15
1	𝍸 𝍸 𝍸 𝍸	20
2	𝍸 |||	8
3	𝍸	5
4	|||	3
5	|	1

category. Figure 15-7 is a histogram for the data in Table 15-2. Because this is a discrete variable, a vertical line in place of a rectangle would have been theoretically correct. However, the rectangle is commonly used.

Grouped Data

When the number of categories becomes large, the data are grouped into cells. In general, the number of cells should be between 5 and 20. Broad guidelines are as follows: Use 5 to 9 cells when the number of observations is less than 100; use 8 to 17 cells when the number of observations is between 100 and 500; and use 15 to 20 cells when the number of observations is greater than 500. To provide flexibility, the number of cells in the guidelines are overlapping. Figure 15-8 shows a histogram for grouped data of the quality characteristic, temperature. The data were collected using the check sheet for temperature (see Figure 15-6). The *interval* is the distance between adjacent cell midpoints. Cell *boundaries* are halfway between the cell midpoints. If an odd cell interval is chosen, which in this case is five degrees, the midpoint value will be to the same degree of accuracy as the ungrouped data. This situation is desirable, because all values in the cell take on the midpoint value when any additional calculations are made.

Histogram Shapes

Histograms have certain identifiable characteristics, as shown in Figure 15-9. One characteristic of the distribution concerns the symmetry or lack of symmetry of the data. Are the data equally distributed on each side

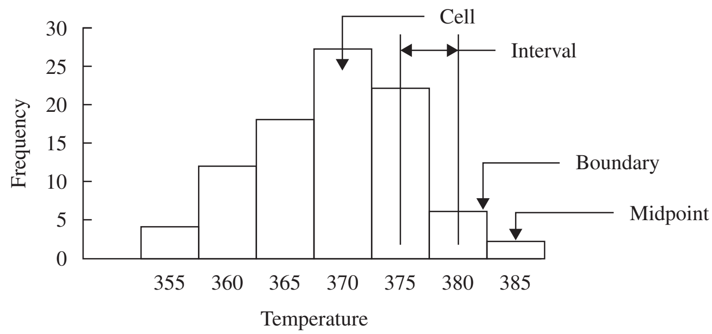


Figure 15-8 Histogram for Grouped Data

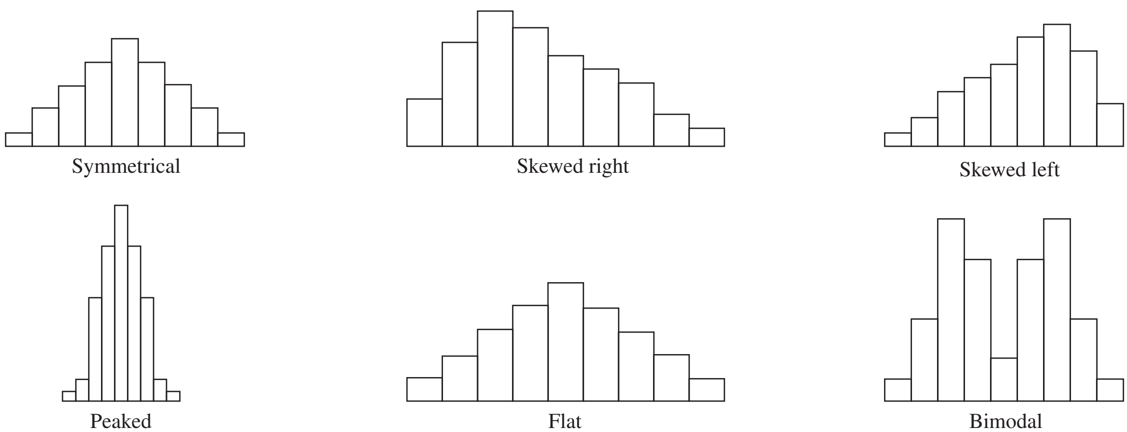


Figure 15-9 Different Historgram Shapes

of the center, or are the data skewed to the right or to the left? Another characteristic concerns the peakedness, or *kurtosis*, of the data.

A final characteristic concerns the number of modes, or peaks, in the data. There can be one mode, two modes (bi-modal), or multiple modes.

Histograms can give sufficient information about a quality problem to provide a basis for decision making without further analysis. They can also be compared in regard to location, spread, and shape. A histogram is like a snapshot of the process showing the variation. Histograms can determine the process capability, compare with specifications, suggest the shape of the population, and indicate discrepancies in the data, such as gaps.

Statistical Fundamentals

Before a description of the next SPC tool, it is necessary to have a background in statistical fundamentals. *Statistics* is defined as the science that deals with the collection, tabulation, analysis, interpretation, and presentation of quantitative data. Each division is dependent on the accuracy and completeness of the preceding one. Data may be collected by a technician measuring the tensile strength of a plastic part or by an operator using a check sheet. It may be tabulated by simple paper-and-pencil techniques or by the use of a computer. Analysis may involve a cursory visual examination or exhaustive calculations. The final results are interpreted and presented to assist in the making of decisions concerning quality.

Data may be collected by direct observation or indirectly through written or verbal questions. The latter technique is used extensively by market research personnel and public opinion pollsters. Data that are collected for quality control purposes are obtained by direct observation and are classified as either variables or attributes. Variables are those quality characteristics that are measurable, such as a weight measured in grams. Attributes, on the other hand, are those quality characteristics that are classified as either conforming or not conforming to specifications, such as a "go–no go" gauge.

A histogram is sufficient for many quality control problems. However, with a broad range of problems a graphical technique is either undesirable or needs the additional information provided by analytical techniques. Analytical methods of describing a collection of data have the advantage of occupying less space than a graph. They also have the advantage of allowing for comparisons between collections of data. They also allow for additional calculations and inferences. There are two principal analytical methods of describing a collection of data: measures of central tendency and measures of dispersion.

Measures of Central Tendency

A measure of central tendency of a distribution is a numerical value that describes the central position of the data or how the data tend to build up in the center. There are three measures in common use in quality: (1) the average, (2) the median, and (3) the mode.

The average is the sum of the observations divided by the number of observations. It is the most common measure of central tendency and is represented by the equation[2]

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

[2] For data grouped into cells, the equation uses ΣfX, where f = cell frequency and X = cell midpoint.

where $\overline{X}$ = average and is read as "X bar"
n = number of observed values
X_i = observed value
Σ = sum of

Unless otherwise noted, $\overline{X}$ stands for the average of observed values, $\overline{X}_x$. The same equation is used to find

$$\begin{aligned} \overline{\overline{X}} \text{ or } \overline{X}_{\overline{X}} &- \text{average of averages} \\ \overline{R} &- \text{average of ranges} \\ \overline{p} &- \text{average of proportions, etc.} \end{aligned}$$

Another measure of central tendency is the median, Md, which is defined as the value that divides a series of ordered observations so that the number of items above it is equal to the number below it. Two situations are possible—when the number in the series is odd and when the number in the series is even. When the number in the series is odd, the median is the midpoint of the values, provided the data are ordered. Thus, the ordered set of numbers 3, 4, 5, 6, 8, 8, and 10 has a median of 6. When the number in the series is even, the median is the average of the two middle numbers. Thus, the ordered set of numbers 3, 4, 5, 6, 8, and 8 has a median that is the average of 5 and 6, which is (5 + 6)/2 = 5.5.

The mode, Mo, of a set of numbers is the value that occurs with the greatest frequency. It is possible for the mode to be nonexistent in a series of numbers or to have more than one value. To illustrate, the series of numbers 3, 3, 4, 5, 5, 5, and 7 has a mode of 5; the series of numbers 22, 23, 25, 30, 32, and 36 does not have a mode; and the series of numbers 105, 105, 105, 107, 108, 109, 109, 109, 110, and 112 has two modes, 105 and 109. A series of numbers is referred to as unimodal if it has one mode, bimodal if it has two modes, and multimodal if there are more than two modes. When data are grouped into a frequency distribution, the midpoint of the cell with the highest frequency is the mode, because this point represents the highest point (greatest frequency) of the histogram.

The average is the most commonly-used measure of central tendency. It is used when the distribution is symmetrical or not appreciably skewed to the right or left; when additional statistics, such as measures of dispersion, control charts, and so on, are to be computed based on the average; and when a stable value is needed for inductive statistics. The median becomes an effective measure of the central tendency when the distribution is positively (to the right) or negatively (to the left) skewed. The median is used when an exact midpoint of a distribution is desired. When a distribution has extreme values, the average will be adversely affected, whereas the median will remain unchanged. Thus, in a series of numbers such as 12, 13, 14, 15, 16, the median and average are identical and are equal to 14. However, if the first value is changed to a 2, the median remains at 14, but the average becomes 12. A control chart based on the median is user-friendly and excellent for monitoring quality. The mode is used when a quick and approximate measure of the central tendency is desired. Thus, the mode of a histogram is easily found by a visual examination. In addition, the mode is used to describe the most typical value of a distribution, such as the modal age of a particular group.

Measures of Dispersion

A second tool of statistics is composed of the measures of dispersion, which describe how the data are spread out or scattered on each side of the central value. Measures of dispersion and measures of central tendency are both needed to describe a collection of data. To illustrate, the employees of the plating and the assembly departments of a factory have identical average weekly wages of \$325.36; however, the plating department has a high of \$330.72 and a low of \$319.43, whereas the assembly department has a high of \$380.79 and a low of \$273.54. The data for the assembly department are spread out, or dispersed, farther from the average than are those of the plating department.

One of the measures of dispersion is the range, which for a series of numbers is the difference between the largest and smallest values of observations. Symbolically, it is represented by the equation

$$R = X_h - X_l$$

where R = range
X_h = highest observation in a series
X_l = lowest observation in a series

The other measure of the dispersion used in quality is the standard deviation. It is a numerical value in the units of the observed values that measures the spreading tendency of the data. A large standard deviation shows greater variability of the data than does a small standard deviation. In symbolic terms, it is represented by the equation

$$s = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}{n-1}}$$

where s = sample standard deviation
X_i = observed value
$\overline{X}$ = average
n = number of observed values

Unless otherwise noted, s stands for s_X, the sample standard deviation of observed values. The same equation is used to find

$S_{\overline{X}}$ = sample standard deviation of averages
s_p = sample standard deviation of proportions
s_s = sample standard deviation of standard deviations, etc.

The standard deviation is a reference value that measures the dispersion in the data. It is best viewed as an index that is defined by the formula. The smaller the value of the standard deviation, the better the quality, because the distribution is more closely compacted around the central value. The standard deviation also helps to define populations, as discussed in the next section.

In quality control the range is a very common measure of the dispersion. It is used in one of the principal control charts. The primary advantage of the range is in providing a knowledge of the total spread of the data. It is also valuable when the amount of data is too small or too scattered to justify the calculation of a more precise measure of dispersion. As the number of observations increases, the accuracy of the range decreases, because it becomes easier for extremely high or low readings to occur. It is suggested that the use of the range be limited to a maximum of ten observations. The standard deviation is used when a more precise measure is desired.

The average and standard deviation are easily calculated with a hand calculator.

EXAMPLE PROBLEM

Determine the average, median, mode, range, and standard deviation for the height of seven people. Data are 1.83, 1.91, 1.78, 1.80, 1.83, 1.85, 1.87 meters.

$$\bar{X} = \Sigma X/n = (1.83 + 1.91 + \cdots + 1.87)/7 = 1.84$$
$$\text{Md} = \{1.91,\ 1.87,\ 1.85,\ 1.83,\ 1.83,\ 1.80,\ 1.78\} = 1.83$$
$$\text{Mo} = 1.83$$
$$R = X_h - X_l = 1.91 - 1.78 = 0.13$$
$$s = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}{n-1}} = \sqrt{\frac{(1.91 - 1.84)^2 + \cdots + (1.78 - 1.84)^2}{7-1}}$$
$$= 0.04$$

Population and Sample

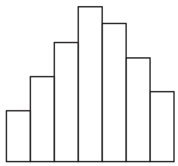
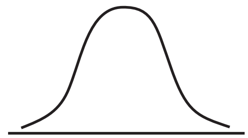
At this point, it is desirable to examine the concept of a population and a sample. In order to construct a frequency distribution of the weight of steel shafts, a small portion, or sample, is selected to represent all the steel shafts. The population is the whole collection of steel shafts. When averages, standard deviations, and other measures are computed from samples, they are referred to as statistics. Because the composition of samples will fluctuate, the computed statistics will be larger or smaller than their true population values, or parameters. Parameters are considered to be fixed reference (standard) values or the best estimate of these values available at a particular time. The population may have a finite number of items, such as a day's production of steel shafts. It may be infinite or almost infinite, such as the number of rivets in a year's production of jet airplanes. The population may be defined differently, depending on the particular situation. Thus, a study of a product could involve the population of an hour's production, a week's production, 5,000 pieces, and so on.

Because it is rarely possible to measure all of the population, a sample is selected. Sampling is necessary when it may be impossible to measure the entire population; when the expense to observe all the data is prohibitive; when the required inspection destroys the product; or when a test of the entire population may be too dangerous, as would be the case with a new medical drug. Actually, an analysis of the entire population may not be as accurate as sampling. It has been shown that 100% manual inspection of low percent nonconforming product is not as accurate as sampling. This is probably due to the fact that boredom and fatigue cause inspectors to prejudge each inspected item as being acceptable.

When designating a population, the corresponding Greek letter is used. Thus, the sample average has the symbol $\bar{X}$ and the population mean the symbol μ (mu). Note that the word *average* changes to *mean* when used for the population. The symbol $\bar{X}_0$ is the standard or reference value. Mathematical concepts are based on μ, which is the true value— $\bar{X}_0$ represents a practical equivalent in order to use the concepts. The sample standard deviation has the symbol s, and the population standard deviation the symbol σ (sigma). The symbol s_0 is the standard or reference value and has the same relationship to σ that $\bar{X}_0$ has to μ. The true population value may never be known; therefore, the symbol $\hat{\mu}$ and $\hat{\sigma}$ are sometimes used to indicate "estimate of." A comparison of sample and population is given in Table 15-3. A sample frequency distribution is represented by a histogram, whereas a population frequency distribution is represented by a smooth curve. To some extent, the sample represents the real world and the population represents the mathematical world. The equations and concepts are based on the population.

The primary objective in selecting a sample is to learn something about the population that will aid in making some type of decision. The sample selected must be of such a nature that it tends to resemble or represent the population. How successfully the sample represents the population is a function of the size of the sample, chance, the sampling method, and whether or not the conditions change.

TABLE 15-3
Comparison of Sample and Popultion

Sample	Population
Statistic X—average s—sample standard deviation	Parameter (X_0)—mean $\sigma(s_0)$—standard deviation
	

Normal Curve

Although there are as many different populations as there are conditions, they can be described by a few general types. One type of population that is quite common is called the normal curve, or Gaussian distribution. The normal curve is a symmetrical, unimodal, bell-shaped distribution with the mean, median, and mode having the same value. A curve of the normal population for the resistance in ohms of an electrical device with population mean, μ, of 90 Ω and population standard deviation, σ, of 2 Ω is shown in Figure 15-10. The interval between dotted lines is equal to one standard deviation, σ.

Much of the variation in nature and in industry follows the frequency distribution of the normal curves. Thus, the variations in the weights of elephants, the speeds of antelopes, and the heights of human beings will follow a normal curve. Also, the variations found in industry, such as the weights of gray iron castings, the lives of 60-watt light bulbs, and the dimensions of steel piston rings, will be expected to follow the normal curve. When considering the heights of human beings, we can expect a small percentage of them to be extremely tall and a small percentage to be extremely short, with the majority of human heights clustering about the average value. The normal curve is such a good description of the variations that occur to most quality characteristics in industry that it is the basis for many quality control techniques.

There is a definite relationship among the mean, the standard deviation, and the normal curve. Figure 15-11 shows three normal curves with different mean values; note that the only change is in the location. Figure 15-12 shows three normal curves with the same mean but different standard deviations. The figure illustrates the principle that the larger the standard deviation, the flatter the curve (data are widely dispersed), and the smaller the standard deviation, the more peaked the curve (data are narrowly dispersed). If the standard deviation is zero, all values are identical to the mean and there is no curve.

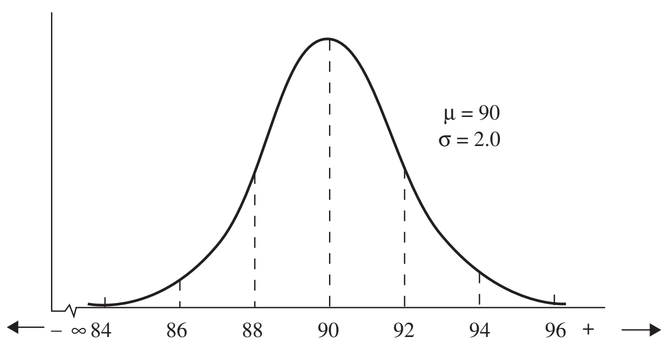


Figure 15-10 Normal Distribution for Resistance of an Electrical Device

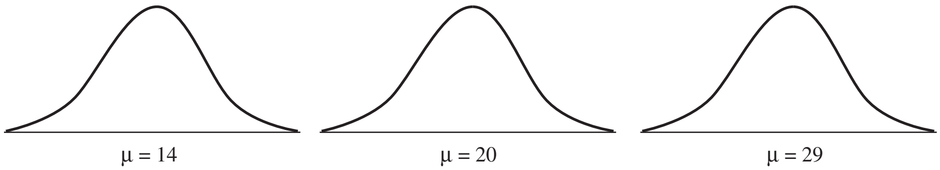


Figure 15-11 Normal Curves with Different Means but identical Standard Deviations

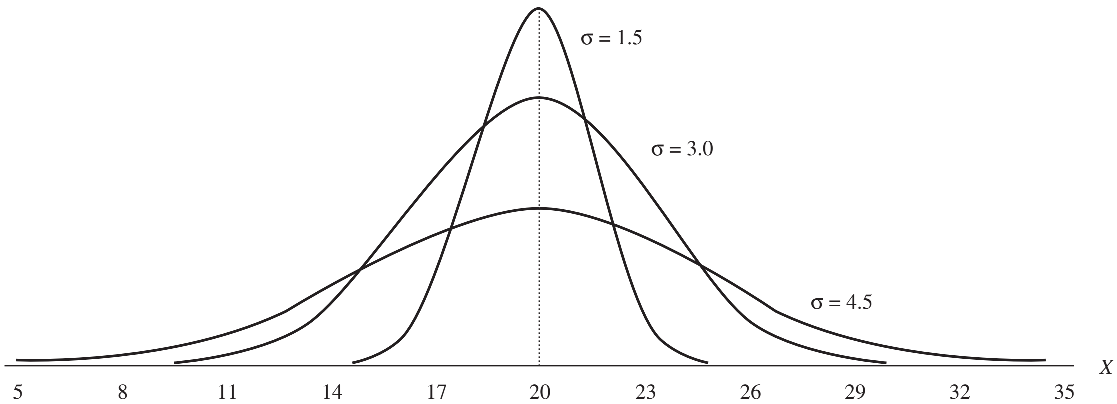


Figure 15-12 Normal Curves with Different Standard Deviations but identical Means

The normal distribution is fully defined by the population mean and population standard deviation. Also, as seen by Figures 15-11 and 15-12, these two parameters are independent. In other words, a change in one parameter has no effect on the other.

A relationship exists between the standard deviation and the area under the normal curve, as shown in Figure 15-13. The figure shows that in a normal distribution, 68.26% of the items are included between the limits of $\mu + 1\sigma$ and $\mu - 1\sigma$, 95.46% of the items are included between the limits $\mu + 2\sigma$ and $\mu - 2\sigma$, and 99.73% of the

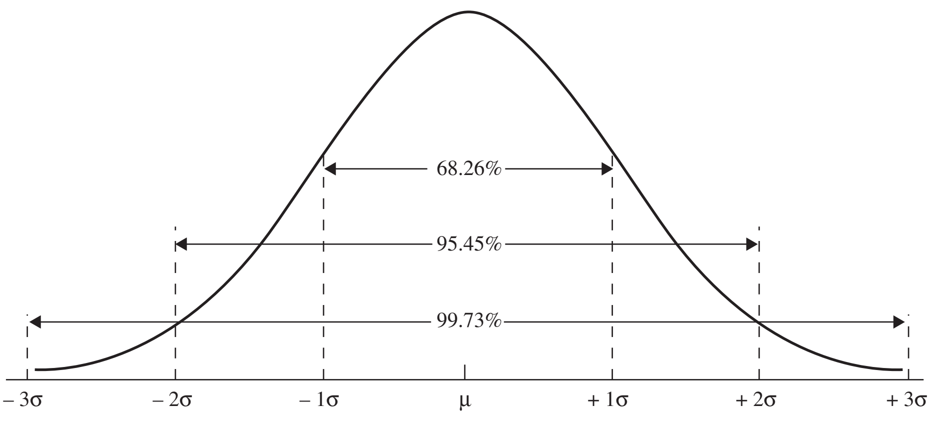


Figure 15-13 Percent of Values Included Between Cetain Values of the Standard Deviation

items are included between $\mu + 3\sigma$ and $\mu - 3\sigma$. One hundred percent of the items are included between the limits $+\infty$ and $-\infty$. These percentages hold true regardless of the shape of the normal curve. The fact that 99.73% of the items are included between $\pm 3\sigma$ is the basis for variable control charts.

Introduction to Control Charts

Variation

One of the axioms, or truisms, of production is that no two objects are ever made exactly alike. In fact, the variation concept is a law of nature because no two natural items in any category are the same. The variation may be quite large and easily noticeable, such as the height of human beings, or the variation may be very small, such as the weights of fiber-tipped pens or the shapes of snowflakes. When variations are very small, it may appear that items are identical; however, precision instruments will show differences. If two items appear to have the same measurement, it is due to the limits of our measuring instruments. As measuring instruments have become more refined, variation has continued to exist; only the increment of variation has changed. The ability to measure variation is necessary before it can be controlled.

There are three categories of variations in piece part production:

1. Within-piece variation is illustrated by the surface roughness of a piece, wherein one portion of the surface is rougher than another portion or the width of one end of a keyway varies from the other end.

2. Piece-to-piece variation occurs among pieces produced at the same time. Thus, the light intensity of four consecutive light bulbs produced from a machine will be different.

3. Time-to-time variation is illustrated by the difference in product produced at different times of the day. Thus, product produced in the early morning is different from that produced later in the day, or as a cutting tool wears, the cutting characteristics change.

Categories of variation for other types of processes such as a continuous and batch are not exactly the same; however, the concept is similar.

Variation is present in every process due to a combination of the equipment, materials, environment, and operator. The first source of variation is the equipment. This source includes tool wear, machine vibration, workholding-device positioning, and hydraulic and electrical fluctuations. When all these variations are put together, there is a certain capability or precision within which the equipment operates. Even supposedly identical machines will have different capabilities. This fact becomes a very important consideration when scheduling the manufacture of critical parts.

The second source of variation is the material. Because variation occurs in the finished product, it must also occur in the raw material (which was someone else's finished product). Such quality characteristics as tensile strength, ductility, thickness, porosity, and moisture content can be expected to contribute to the overall variation in the final product.

A third source of variation is the environment. Temperature, light, radiation, particle size, pressure, and humidity all can contribute to variation in the product. In order to control environmental variations, products are sometimes manufactured in white rooms. Experiments are conducted in outer space to learn more about the effect of the environment on product variation.

A fourth source is the operator. This source of variation includes the method by which the operator performs the operation. The operator's physical and emotional well-being also contribute to the variation. A cut finger, a twisted ankle, a personal problem, or a headache can make an operator's quality performance vary. An operator's lack of understanding of equipment and material variations due to lack of training may lead to frequent machine adjustments, thereby compounding the variability. As our equipment has become more automated, the operator's effect on variation has lessened.

The preceding four sources account for the true variation. There is also a reported variation, which is due to the inspection activity. Faulty inspection equipment, the incorrect application of a quality standard, or too heavy a pressure on a micrometer can be the cause of the incorrect reporting of variation. In general, variation due to inspection should be one-tenth of the four other sources of variations. Note that three of these sources are present in the inspection activity—an inspector or appraiser, inspection equipment, and the environment.

Run Chart

A run chart, which is shown in Figure 15-14, is a very simple technique for analyzing the process in the development stage or, for that matter, when other charting techniques are not applicable. The important point is to draw a picture of the process and let it "talk" to you. A picture is worth a thousand words, provided someone is listening. Plotting the data points is a very effective way of finding out about the process. This activity should be done as the first step in data analysis. Without a run chart, other data analysis tools—such as the average, sample standard deviation, and histogram—can lead to erroneous conclusions.

The particular run chart shown in Figure 15-14 is referred to as an $\overline{X}$ chart and is used to record the variation in the average value of samples. Other charts, such as the *R* chart (range) or *p* chart (proportion) would have also served for explanation purposes. The horizontal axis is labeled "Subgroup Number," which identifies a particular sample consisting of a fixed number of observations. These subgroups are plotted by order of production, with the first one inspected being 1 and the last one on this chart being 25. The vertical axis of the graph is the variable, which in this particular case is weight measured in kilograms.

Each small solid diamond represents the average value within a subgroup. Thus, subgroup number 5 consists of, say, four observations, 3.46, 3.49, 3.45, and 3.44, and their average is 3.46 kg. This value is the one posted on the chart for subgroup number 5. Averages are used on control charts rather than individual

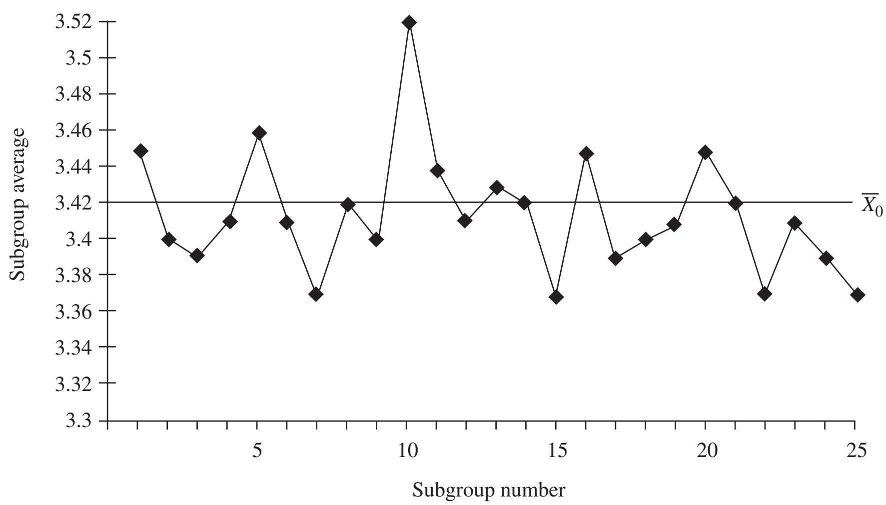


Figure 15-14 Example of a Run Chart

observations because average values will indicate a change in variation much faster. Also, with two or more observations in a sample, a measure of the dispersion can be obtained for a particular subgroup.

The solid line in the center of the chart can have three different interpretations, depending on the available data. First, it can be the average of the plotted points, which in the case of an $\overline{X}$ chart is the average of the averages or "X-double bar." Second, it can be a standard or reference value, $\overline{X}_0$, based on representative prior data, an economic value based on production costs or service needs, or an aimed-at value based on specifications. Third, it can be the population mean, μ, if that value is known.

Control Chart Example

One danger of using a run chart is its tendency to show every variation in data as being important. In order to indicate when observed variations in quality are greater than could be left to chance, the control chart method of analysis and presentation of data is used. The control chart method for variables is a means of visualizing the variations that occur in the central tendency and dispersion of a set of observations. It is a graphical record of the quality of a particular characteristic. It shows whether or not the process is in a stable state by adding statistically determined control limits to the run chart.

Figure 15-15, is the run chart of Figure 15-14 with the control limits added. They are the two dashed outer lines and are called the upper and lower control limits. These limits are established to assist in judging the significance of the variation in the quality of the product. Control limits are frequently confused with specification limits, which are the permissible limits of a quality characteristic of each individual unit of a product. However, control limits are used to evaluate the variations in quality from subgroup to subgroup. Therefore, for the $\overline{X}$ chart, the control limits are a function of the subgroup averages. A frequency distribution of the subgroup averages can be determined with its corresponding average and standard deviation.

The control limits are then established at $\pm$ 3σ from the central line. Recall, from the discussion of the normal curve, that the number of items between + 3σ and $-$ 3σ equals 99.73%. Therefore, it is expected that more than 997 times out of 1,000, the subgroup values will fall between the upper and lower limits. When this situation occurs, the process is considered to be in control. When a subgroup value falls outside the limits, the process is considered to be out of control, and an assignable cause for the variation is present. Subgroup number 10 in Figure 15-15 is beyond the upper control limit; therefore, there has been a change in the stable nature of the process, causing the out-of-control point. As long as the sources of variation fluctuate in a natural or expected manner, a stable pattern

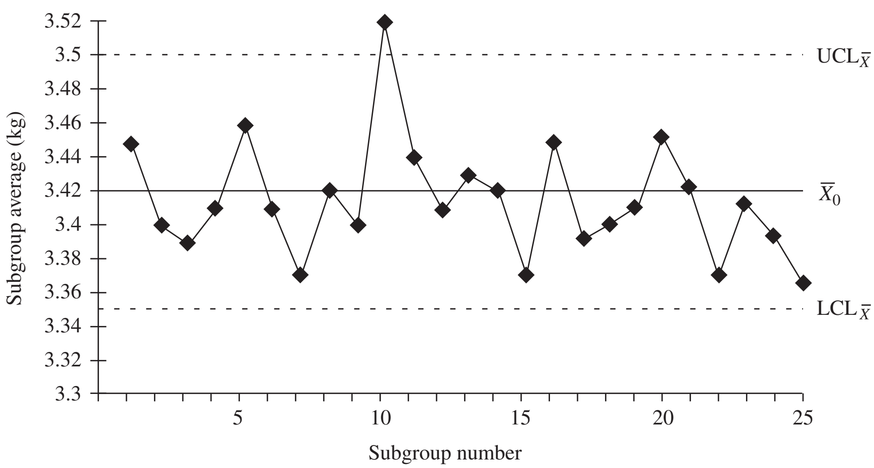


Figure 15-15 Example of a Control Chart

of many chance causes (random causes) of variation develops. Chance causes of variation are inevitable. Because they are numerous and individually of relatively small importance, they are difficult to detect or identify. Those causes of variation that are large in magnitude, and therefore readily identified, are classified as assignable causes.[3] When only chance causes are present in a process, the process is considered to be in a state of statistical control. It is stable and predictable. However, when an assignable cause of variation is also present, the variation will be excessive, and the process is classified as out of control or beyond the expected natural variation of the process.

Unnatural variation is the result of assignable causes. Usually, but not always, it requires corrective action by people close to the process, such as operators, technicians, clerks, maintenance workers, and first-line supervisors. Natural variation is the result of chance causes—it requires management intervention to achieve quality improvement. In this regard, between 80% and 85% of the quality problems are due to management or the system and 15% to 20% are due to operations. Operating personnel are giving a quality performance as long as the plotted points are within the control limits. If this performance is not satisfactory, the solution is the responsibility of the system rather than of the operating personnel.

Variable Control Charts

In practice, control charts are posted at individual machines or work centers to control a particular quality characteristic. Usually, an $\overline{X}$ chart for the central tendency and an R chart for the dispersion are used together. An example of this dual charting is illustrated in Figure 15-16, which shows a method of charting and reporting inspection results for rubber durometer.

At work center number 365-2 at 8:30 A.M., the operator selects four items for testing and records the observations of 55, 52, 51, and 53 in the rows marked X_1, X_2, X_3, and X_4, respectively. A subgroup average value of 52.8 is obtained by summing the observation and dividing by 4, and the range value of 4 is obtained by subtracting the low value, 51, from the high value, 55. The operator places a small solid circle at 52.8 on the $\overline{X}$ chart and a small solid circle at 4 on the R chart and then proceeds with his other duties.

The frequency with which the operator inspects a product at a particular machine or work center is determined by the quality of the product. When the process is in control and no difficulties are being encountered, fewer inspections may be required. Conversely, when the process is out of control or during start-up, more inspections may be needed. The inspection frequency at a machine or work center can also be determined by the amount of time that must be spent on noninspection activities. In the example problem, the inspection frequency appears to be every 60 or 65 minutes.

At 9:30 A.M. the operator performs the activities for subgroup 2 in the same manner as for subgroup 1. It is noted that the range value of 7 falls on the upper control limit. Whether to consider this in control or out of control would be a matter of organization policy. It is suggested that it be classified as in control and a cursory examination for an assignable cause be conducted by the operator. A plotted point that falls exactly on the control limit is a rare occurrence.

The inspection results for subgroup 2 show that the third observation, X_3, has a value of 57, which exceeds the upper control limit. It is important to remember the earlier discussion on control limits and specifications. In other words, the 57 value is an individual observation and does not relate to the control limits. Therefore, the fact that an individual observation is greater than or less than a control limit is meaningless.

Subgroup 4 has an average value of 44, which is less than the lower control limit of 45. Therefore, subgroup 4 is out of control, and the operator will report this fact to the departmental supervisor. The operator and supervisor will then look for an assignable cause and, if possible, take corrective action. Whatever

[3] Dr. Edwards Deming uses the words *common* and special for "chance" and "assignable."

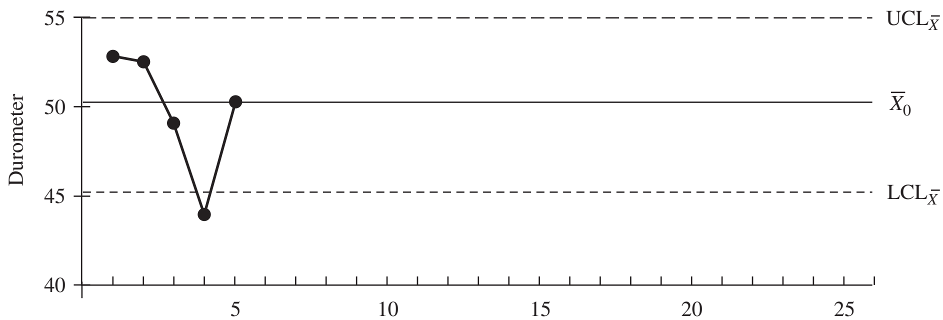
$\overline{X}$ and *R* Charts

Work Center Number 365-2

QualityCharacteristic Durometer   Date 3/6/93

Time	8:30 AM	9:30 AM	10:40 AM	11:50 AM	1:30 PM								
Subgroup	1	2	3	4	5	6	7	8	9	10	11	12	13
X_1	55	51	48	45	53								
X_2	52	52	49	43	50								
X_3	51	57	50	45	48								
X_4	53	50	49	43	50								
Sum	211	210	196	176	201								
$\overline{X}$	52.8	52.5	49	44	50.2								
R	4	7	2	2	5								

$\overline{X}$ Chart



***R* Chart**

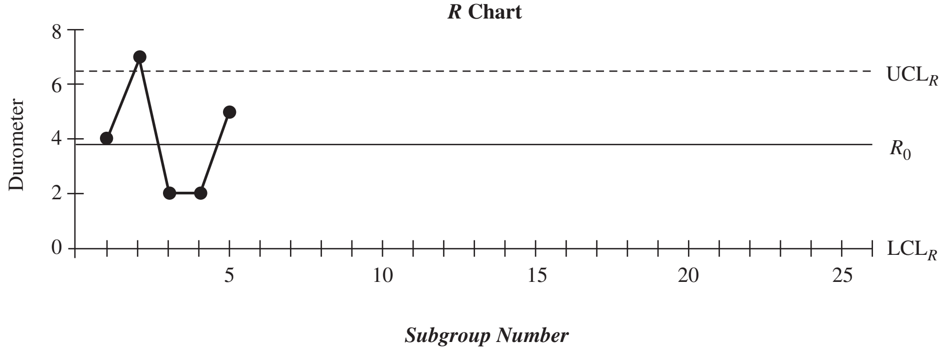


Figure 15-16 Example of a Method of Reporting Inspection Results

corrective action is taken will be noted by the operator on the $\overline{X}$ and R charts or on a separate form. The control chart indicates when and where trouble has occurred. The identification and elimination of the difficulty is a production problem. Ideally, the control chart should be maintained by the operator, provided time is available and proper training has been given. When the operator cannot maintain the chart, then it is maintained by quality control.

The control chart is used to keep a continuing record of a particular quality characteristic. It is a picture of the process over time. When the chart is completed and stored in an office file, it is replaced by a fresh chart. The chart is used to improve the process quality, to determine the process capability, to determine when to leave the process alone and when to make adjustments, and to investigate causes of unacceptable or marginal quality. It is also used to make decisions on product or service specifications and decisions on the acceptability of a recently-produced product or service.

Quality Characteristic

The variable that is chosen for the $\overline{X}$ and R charts must be a quality characteristic that is measurable and can be expressed in numbers. Quality characteristics that can be expressed in terms of the seven basic units (length, mass, time, electrical current, temperature, substance, or luminous intensity), as well as any of the derived units, such as power, velocity, force, energy, density, and pressure, are appropriate.

Those quality characteristics affecting the performance of the product would normally be given first attention. These may be a function of the raw materials, component parts, subassemblies, or finished parts. In other words, high priority is given to the selection of those characteristics that are giving difficulty in terms of production problems and/or cost. An excellent opportunity for cost savings frequently involves situations where spoilage and rework costs are high. A Pareto analysis is also useful for establishing priorities. Another possibility occurs where destructive testing is used to inspect a product.

In any organization, a large number of variables make up a product or service. It is, therefore, impossible to place $\overline{X}$ and R charts on all variables. A judicious selection of those quality characteristics is required.

Subgroup Size and Method

As previously mentioned, the data that are plotted on the control chart consist of groups of items called rational subgroups. It is important to understand that data collected in a random manner do not qualify as rational. A rational subgroup is one in which the variation within the group is due only to chance causes. This within-subgroup variation is used to determine the control limits. Variation between subgroups is used to evaluate long-term stability. Subgroup samples are selected from product or a service produced at one instant of time or as close to that instant as possible, such as four consecutive parts from a machine or four documents from a tray. The next subgroup sample would be similar, but for product or a service produced at a later time—say, one hour later.

Decisions on the size of the sample or subgroup require a certain amount of empirical judgment; however, some helpful guidelines are:

1. As the subgroup size increases, the control limits become closer to the central value, which makes the control chart more sensitive to small variations in the process average.
2. As the subgroup size increases, the inspection cost per subgroup increases. Does the increased cost of larger subgroups justify the greater sensitivity?
3. When costly and/or destructive testing is used and the item is expensive, a small subgroup size of two or three is necessary, because it will minimize the destruction of expensive product.
4. Because of the ease of computation, a sample size of five is quite common in industry; however, when inexpensive electronic hand calculators are used, this reason is no longer valid.

5. From a statistical basis a distribution of subgroup averages, $\bar{X}$'s, is nearly normal for subgroups of four or more even when the samples are taken from a nonnormal population. This statement is proved by the central limit theorem.

There is no rule for the frequency of taking subgroups, but the frequency should be often enough to detect process changes. The inconveniences of the factory or office layout and the cost of taking subgroups must be balanced with the value of the data obtained. In general, it is best to sample quite often at the beginning and reduce the sampling frequency when the data permit.

The precontrol rule for the frequency of sampling could also be used. It is based on how often the process is adjusted. If the process is adjusted every hour, then sampling should occur every 10 minutes; if the process is adjusted every 2 hours, then sampling should occur every 20 minutes; if the process is adjusted every 3 hours, then sampling should occur every 30 minutes; and so forth.

Data Collection

Assuming that the quality characteristic and the plan for the rational subgroup have been selected, a team member such as a technician can be assigned the task of collecting the data as part of his normal duties. The first-line supervisor and the operator should be informed of the technician's activities; however, no charts or data are posted at the work center at this time.

Because of difficulty in the assembly of a gear hub to a shaft using a key and keyway, the project team recommends using $\bar{X}$ and R charts. The quality characteristic is the shaft keyway depth of 6.35 mm (0.250 in.). Using a rational subgroup of four, a technician obtains five subgroups per day for five days. The samples are measured, the subgroup average and range are calculated, and the results are recorded on the form as shown in Table 15-4. Additional recorded information includes the date, time, and any comments pertaining to the process. For simplicity, individual measurements are coded from 6.00 mm. Thus, the first measurement of 6.35 is recorded as 35.

It is necessary to collect a minimum of 25 subgroups of data. A fewer number of subgroups would not provide a sufficient amount of data for the accurate computation of the control limits, and a larger number of subgroups would delay the introduction of the control chart.

Trial Central Lines and Control Limits

The central lines for the $\bar{X}$ and R charts are obtained using the equations

$$\bar{\bar{X}} = \Sigma \bar{X}_i/g \qquad \bar{R} = \Sigma R_i/g$$

where $\bar{\bar{X}}$ = average of the subgroup averages (read "X double bar")
$\bar{X}_i$ = average of the th subgroup
g = number of subgroups
$\bar{R}$ = average of the subgroup ranges
R_i = range of the ith subgroup

Trial control limits for the charts are established at ± 3σ from the central line, as shown by the equations

$$UCL_{\bar{X}} = \bar{\bar{X}} + 3\sigma_{\bar{X}} \qquad UCL_R = \bar{R} + 3\,\sigma_R$$
$$LCL_{\bar{X}} = \bar{\bar{X}} - 3\sigma_{\bar{X}} \qquad LCL_R = \bar{R} - 3\,\sigma_R$$

TABLE 15-4
Data on the Depth of the Keyway (millimeters)

Subgroup Number	*Date*	*Time*	MEASUREMENTS X_1	X_2	X_3	X_4	*Average* $\bar{X}$	*Range* R	*Comment*
1	7/23	8:50	35	40	32	37	6.36	0.08	
2		11:30	46	37	36	41	6.40	0.10	
3		1:45	34	40	34	36	6.36	0.06	
4		3:45	69	64	68	59	6.65	0.10	New, temporary operator
5		4:20	38	34	44	40	6.39	0.10	
.	.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	.	
17	7/29	9:25	41	40	29	34	6.36	0.12	
18		11:00	38	44	28	58	6.42	0.30	Damaged oil line
19		2:35	35	41	37	38	6.38	0.06	
20		3:15	56	55	45	48	6.51	0.11	Bad material
21	7/30	9:35	38	40	45	37	6.40	0.08	
22		10:20	39	42	35	40	6.39	0.07	
23		11:35	42	39	39	36	6.39	0.06	
24		2:00	43	36	35	38	6.38	0.08	
25		4:25	39	38	43	44	6.41	0.06	
Sum							160.25	2.19	

where UCL = upper control limit
LCL = lower control limit
$\sigma_{\bar{X}}$ = population standard deviation of the subgroup averages
σ_R = population standard deviation of the range

In practice, the calculations are simplified by using the product of the average of the range ($\bar{R}$) and a factor A_2 to replace the three standard deviations ($A_2\bar{R} = 3\sigma_{\bar{X}}$) in the equation for the $\bar{X}$ chart. For the R chart, the range is used to estimate the standard deviation of the range. Therefore, the derived equations are

$$\mathrm{UCL}_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R} \qquad \mathrm{UCL}_R = D_4\bar{R}$$
$$\mathrm{LCL}_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R} \qquad \mathrm{LCL}_R = D_4\bar{R}$$

where A_2, D_3, and D_4 are factors that vary with the subgroup size and are found in Appendix A. For the $\bar{X}$ chart, the upper and lower control limits are symmetrical about the central line. Theoretically, the control limits for an R chart should also be symmetrical about the central line. But, for this situation to occur, with subgroup sizes of six or less, the lower control limit would need to have a negative value. Because a negative range is impossible, the lower control limit is located at zero by assigning to D_3 the value of zero for subgroups of six or less.

When the subgroup size is seven or more, the lower control limit is greater than zero and symmetrical about the central line. However, when the R chart is posted at the work center, it may be more practical to keep the lower control limit at zero. This practice eliminates the difficulty of explaining to the operator that points below the lower control limit on the R chart are the result of exceptionally good performance rather than poor performance. However, quality personnel should keep their own charts with the lower control limit in its proper location, and any out-of-control low points should be investigated to determine the reason for the exceptionally good performance. Because subgroup sizes of seven or more are uncommon, the situation occurs infrequently.

In order to illustrate the calculations necessary to obtain the trial control limits and the central line, the data concerning the depth of the shaft keyway will be used. From Table 15-4, $\Sigma\overline{X} = 160.25$, $\Sigma R = 2.19$, and $g = 25$; thus, the central lines are

$$\overline{\overline{X}} = \Sigma\,\overline{X}/g = 160.25/25 = 6.41 \text{ mm}$$
$$\overline{R} = \Sigma\,R/g = 2.19/25 = 0.0876 \text{ mm}$$

From Appendix Table A, the values for the factors for a subgroup size (n) of four are $A_2 = 0.729$, $D_3 = 0$, and $D_4 = 2.282$. Trial control limits for the $\overline{X}$ chart are

$$\begin{aligned}\text{UCL}_{\overline{X}} &= \overline{\overline{X}} + A_2\overline{R}\\ &= 6.41 + (0.729)(0.0876)\\ &= 6.47 \text{ mm}\end{aligned} \qquad \begin{aligned}\text{LCL}_{\overline{X}} &= \overline{\overline{X}} - A_2\overline{R}\\ &= 6.41 - (0.729)(0.0876)\\ &= 6.35 \text{ mm}\end{aligned}$$

Trial control limits for the R chart are

$$\begin{aligned}\text{UCL}_{R} &= D_4\overline{R}\\ &= (2.282)(0.0876)\\ &= 0.20 \text{ mm}\end{aligned} \qquad \begin{aligned}\text{LCL}_{R} &= D_3\overline{R}\\ &= (0)(0.0876)\\ &= 0 \text{ mm}\end{aligned}$$

Figure 15-17 shows the central lines and the trial control limits for $\overline{X}$ and R charts for the preliminary data.

Revised Central Lines and Control Limits

Revised central lines and control limits are established by discarding out-of-control points with assignable causes and recalculating the central lines and control limits. The R chart is analyzed first to determine if it is stable. Because the out-of-control point at subgroup 18 on the R chart has an assignable cause (damaged oil line), it can be discarded from the data. The remaining plotted points indicate a stable process.

The $\overline{X}$ chart can now be analyzed. Subgroups 4 and 20 had an assignable cause, whereas the out-of-control condition for subgroup 16 did not. It is assumed that subgroup 16's out-of-control state is due to a chance cause and is part of the natural variation of the process.

The recalculated values are $\overline{X}_0 = 6.40$ mm and $R_0 = 0.079$. They are shown in Figure 15-18. For illustrative purposes, the trial values are also shown. The limits for both the $\overline{X}$ and R charts became narrower, as was expected. No change occurred in LCL_R because the subgroup size is less than 7. The figure also illustrates a simpler charting technique in that lines are not drawn between the points. Also, $\overline{X}_0$ and R_0, the standard or reference values, are used to designate the central lines.

The preliminary data for the initial 25 subgroups are not plotted with the revised control limits. These revised control limits are for reporting the results for future subgroups. To make effective use of the control

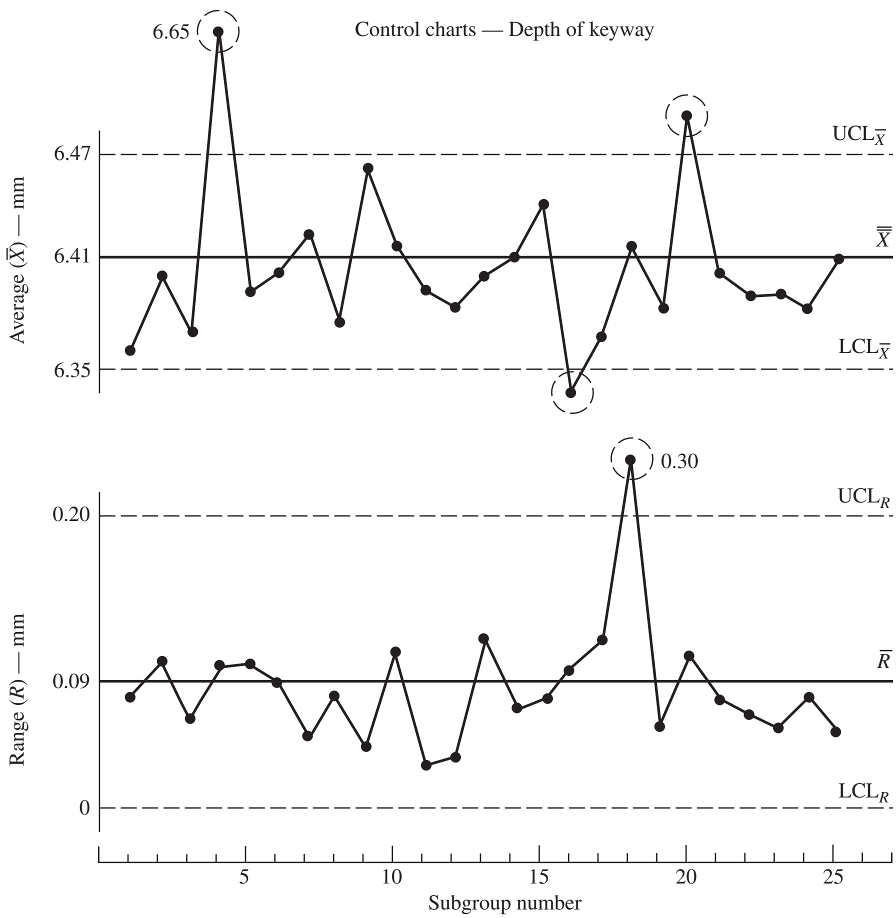


Figure 15-17 $\bar{X}$ and R Charts for Preliminary Data with Trial Control Limits

chart during production, it should be displayed in a conspicuous place, where it can be seen by operators and supervisors.

Before proceeding to the action step, some final comments are appropriate. First, many analysts eliminate this step in the procedure because it appears to be somewhat redundant. However, by discarding out-of-control points with assignable causes, the central line and control limits are more representative of the process. If this step is too complicated for operating personnel, its elimination would not affect the next step.

Second, the central line $\bar{X}_0$ for the $\bar{X}$ chart is frequently based on the specifications. In such a case, the procedure is used only to obtain R_0. If, in our example problem, the nominal value of the characteristic is 6.38 mm, then $\bar{X}_0$ is set to that value and the upper and lower control limits are

$$\begin{aligned} \text{UCL}_{\bar{X}} &= \bar{X}_0 + A_2 R_0 \\ &= 6.38 + (0.729)(0.079) \\ &= 6.44 \text{ mm} \end{aligned} \qquad \begin{aligned} \text{LCL}_{\bar{X}} &= \bar{X}_0 - A_2 R_0 \\ &= 6.38 - (0.729)(0.079) \\ &= 6.32 \text{ mm} \end{aligned}$$

The central line and control limits for the R chart do not change. This modification can be taken only if the process is adjustable. If the process is not adjustable, then the original calculations must be used.

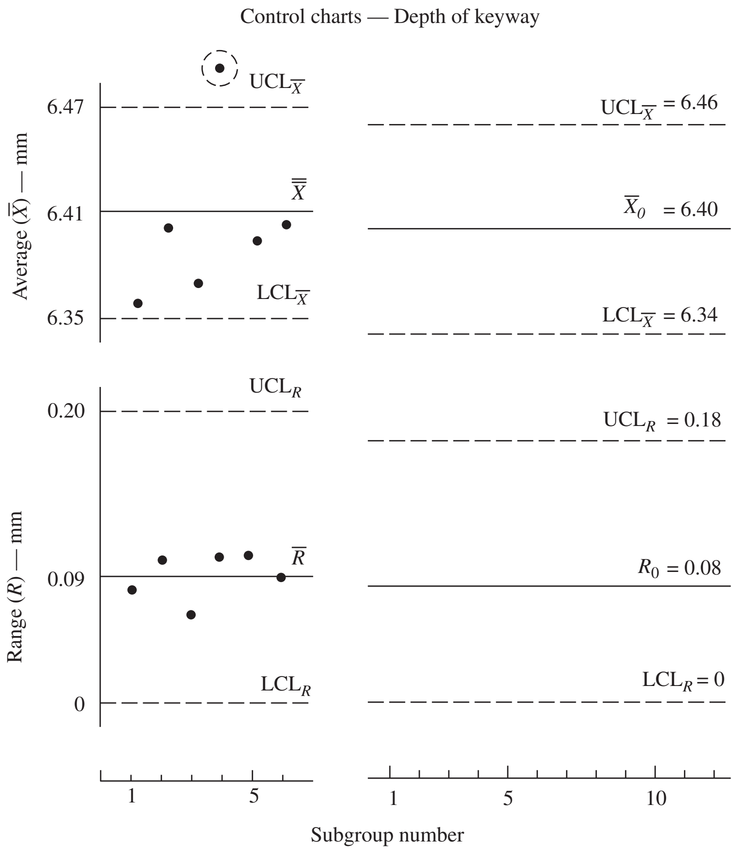


Figure 15-18 Trial Control Limits and Revised Control Limits for $\bar{X}$ and R Charts

Third, it follows that adjustments to the process should be made while taking data. It is not necessary to run nonconforming material while collecting data, because we are primarily interested in obtaining R_0, which is not affected by the process setting. The independence of $\bar{X}$ and R_0 provides the rationale for this concept.

Fourth, the process determines the central line and control limits. They are not established by design, manufacturing, marketing, or any other department, except for $\bar{X}_0$ when the process is adjustable.

Achieving the Objective

When control charts are first introduced at a work center, an improvement in the process performance usually occurs. This initial improvement is especially noticeable when the process is dependent on the skill of the operator. Posting a quality control chart appears to be a psychological signal to the operator to improve performance. Most workers want to produce a quality product or service; therefore, when management shows an interest in the quality, the operator responds.

Figure 15-19 illustrates the initial improvement that occurred after the introduction of the $\bar{X}$ and R charts in January. Owing to space limitations, only a representative number of subgroups for each month are shown in the figure. During January the subgroup ranges had less variation and tended to be centered at a slightly lower point. A reduction in the range variation occurred also.

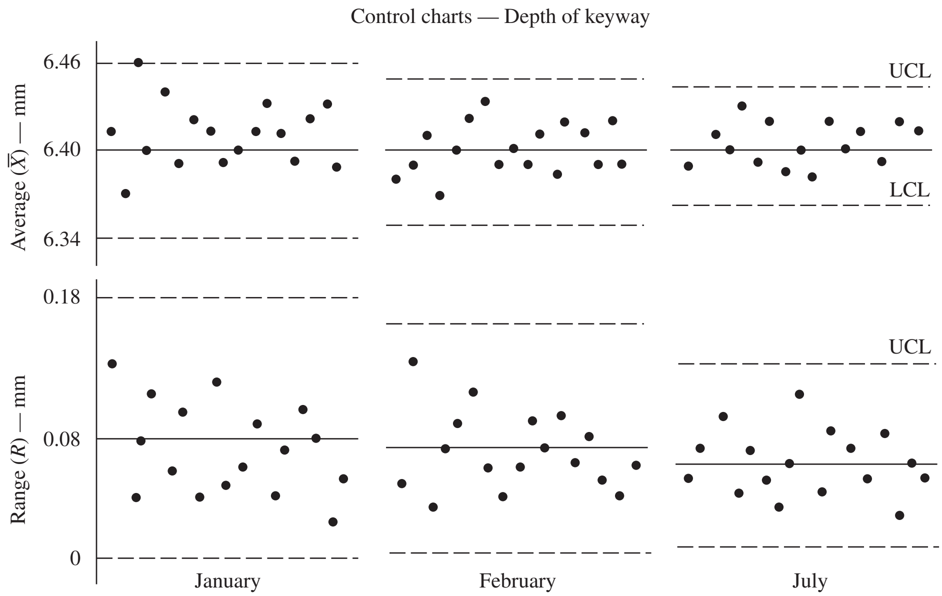


Figure 15-19 Continuing Use of Control Charts, Showing Improved Quality

Not all the improved performance in January was the result of operator effort. The first-line supervisor initiated a program of tool-wear control, which was a contributing factor.

At the end of January new central lines and control limits were calculated using the data from subgroups obtained during the month. It is a good idea, especially when a chart is being initiated, to calculate standard values periodically to see if any changes have occurred. This reevaluation can be done for every 25 or more subgroups, and the results can be compared to the previous values.

New control limits for the $\overline{X}$ and R charts and central line for the R chart were established for the month of February. The central line for the $\overline{X}$ chart was not changed because it is the nominal value. During the ensuing months, the maintenance department replaced a pair of worn gears, purchasing changed the material supplier, and tooling modified a workholding device. All these improvements were the result of investigations that tracked down the causes for out-of-control conditions or were ideas developed by a project team. The generation of ideas by many different personnel is the most essential ingredient for continuous quality improvement. Ideas from the operator, first-line supervisor, quality assurance, maintenance, manufacturing engineering, and industrial engineering should be evaluated. This evaluation or testing of an idea requires 25 or more subgroups. The control chart will tell if the idea is good, is poor, or has no effect on the process. Quality improvement occurs when the plotted points of the $\overline{X}$ chart converge on the central line, when the plotted points of the R chart trend downward, or when both actions occur. If a poor idea is tested, then the reverse occurs. Of course, if the idea is neutral, it will have no effect on the plotted point pattern.

To speed up the testing of ideas, the taking of subgroups can be compressed in time as long as the data represent the process by accounting for any hourly or day-to-day fluctuations. Only one idea should be tested at a time; otherwise, the results will be confounded.

At the end of June, the periodic evaluation of the past performance showed the need to revise the central lines and the control limits. The performance for the month of July and subsequent months showed a natural pattern of variation and no quality improvement. At that point, no further quality improvement would be possible without a substantial investment in new equipment or equipment modification.

Dr. Deming has stated that if he were a banker, he would not lend money to an organization unless statistical methods were used to prove that the money was necessary. This is precisely what the control chart can achieve, provided that all personnel use the chart as a method of quality improvement rather than a monitoring function.

When the objective for initiating the charts has been achieved, their use should be discontinued or the frequency of inspection be substantially reduced to a monitoring action by the operator. The median chart is an excellent chart for the monitoring activity. Efforts should then be directed toward the improvement of some other quality characteristic. If a project team was involved, it should be recognized and rewarded for its performance and disbanded.

The U.S. Postal Service at Royal Oak, Michigan used a variables control chart to reduce nonconformance in a sorting operation from 32% to less than 6%. This activity resulted in an annual savings of $700,000 and earned the responsible team the 1999 RIT/USA Today Quality Cup for government.

State of Control

When the assignable causes have been eliminated from the process to the extent that the points plotted on the control chart remain within the control limits, the process is in a state of control. No higher degree of uniformity can be attained with the existing process. However, greater uniformity can be attained through a change in the basic process resulting from quality improvement ideas.

When a process is in control, there occurs a natural pattern of variation, which is illustrated by the control chart in Figure 15-20. This natural pattern of variation has (1) about 34% of the plotted points on an imaginary band between one standard deviation on both sides of the central line, (2) about 13.5% of the plotted points in an imaginary band between one and two standard deviations on both sides of the central line, and (3) about 2.5% of the plotted points in an imaginary band between two and three standard deviations on both sides of the central line. The points are located back and forth across the central line in a random manner, with no points beyond the control limits. The natural pattern of the points, or subgroup average values, forms its own frequency distribution. If all the points were stacked up at one end, they would form a normal curve.

When a process is in control, only chance causes of variation are present. Small variations in machine performance, operator performance, and material characteristics are expected and are considered to be part of a stable process.

When a process is in control, certain practical advantages accrue to the producer and consumer:

1. Individual units of the product will be more uniform, or, stated another way, there will be less variation.

2. Because the product is more uniform, fewer samples are needed to judge the quality. Therefore, the cost of inspection can be reduced to a minimum. This advantage is extremely important when 100% conformance to specifications is not essential.

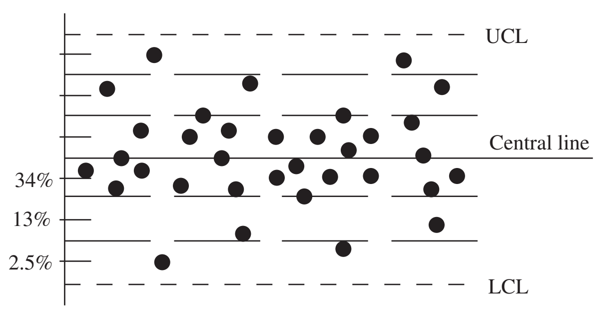


Figure 15-20 Natural Pattern of Variation of a Control Chart

3. The process capability, or spread of the process, is easily attained from 6σ. With a knowledge of the process capability, a number of reliable decisions relative to specifications can be made, such as the product specifications; the amount of rework or scrap when there is insufficient tolerance; and whether to produce the product to tight specifications and permit interchangeability of components or to produce the product to loose specifications and use selective matching of components.

4. The percentage of product that falls within any pair of values can be predicted with the highest degree of assurance. For example, this advantage can be very important when adjusting filling machines to obtain different percentage of items below, between, or above particular values.

5. It permits the customer to use the supplier's data and, therefore, to test only a few subgroups as a check on the supplier's records. The $\overline{X}$ and R charts are used as statistical evidence of process control.

6. The operator is performing satisfactorily from a quality viewpoint. Further improvement in the process can be achieved only by changing the input factors: materials, equipment, environment, and operators. These changes require action by management.

When only chance causes of variation are present, the process is stable and predictable over time, as shown in Figure 15-21(a). We know that future variation as shown by the dotted curve will be the same unless there has been a change in the process due to an assignable cause.

Out-of-Control Process

Figure 15-21(b) illustrates the effect of assignable causes of variation over time. The unnatural, unstable nature of the variation makes it impossible to predict future variation. The assignable causes must be found and corrected before a natural stable process can continue.

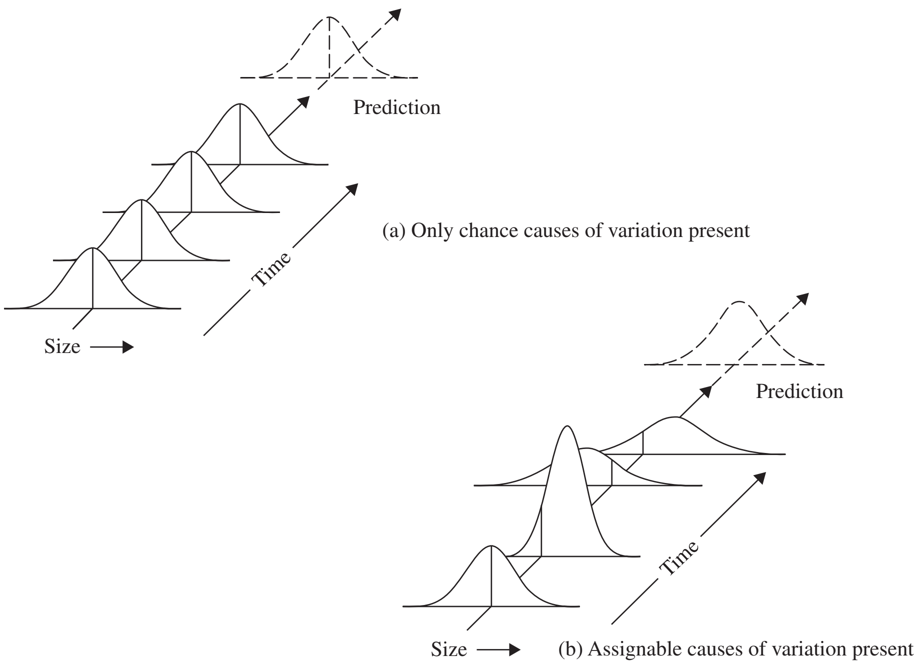


Figure 15-21 Stable and Unstable Variation

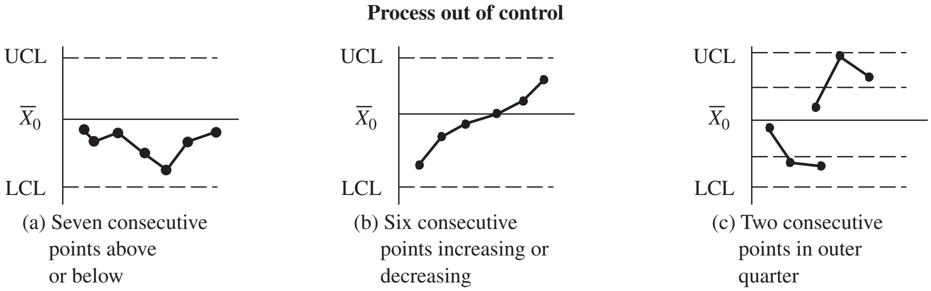


Figure 15-22 Some Unnatural Runs—Process Out of COntrol

The term *out of control* is usually thought of as being undesirable; however, there are situations where this condition is desirable. It is best to think of the term *out of control* as a change in the process due to an assignable cause.

A process can also be considered out of control even when the points fall inside the 3σ limits. This situation, as shown in Figure 15-22, occurs when unnatural runs of variation are present in the process. It is not natural for seven or more consecutive points to be above or below the central line as shown at (a). Another unnatural run occurs at (b), where six points in a row are steadily increasing or decreasing. At (c), the space is divided into four equal bands of 1.5σ. The process is out of control when there are two successive points at 1.5σ beyond.[4]

There are some common questions to ask when investigating an out-of-control process:

1. Are there differences in the measurement accuracy of the instruments used?
2. Are there differences in the methods used by different operators?
3. Is the process affected by the environment? If so, have there been any changes?
4. Is the process affected by tool wear?
5. Were any untrained workers involved in the process?
6. Has there been any change in the source of the raw materials?
7. Is the process affected by operator fatigue?
8. Has there been any change in maintenance procedures?
9. Is the equipment being adjusted too frequently?
10. Did samples come from different shifts, operators, or machines?

It is advisable to develop a checklist for each process using these common questions as a guide.

Process Capability

Control limits are established as a function of the averages—in other words, control limits are for averages. Specifications, on the other hand, are the permissible variation in the size of the part and are, therefore, for individual values. The specification or tolerance limits are established by design engineers to meet a particular

[4] For more information, see A. M. Hurwitz and M. Mather, "A Very Simple Set of Process Control Rules," *Quality Engineering* 5, no. 1 (1992–1993): 21–29.

function. Figure 15-23 shows that the location of the specifications is optional and is not related to any of the other features in the figure. The control limits, process spread (process capability), distribution of averages, and distribution of individual values are interdependent. They are determined by the process, whereas the specifications have an optional location. Control charts cannot determine if the process is meeting specifications.

The true process capability cannot be determined until the $\overline{X}$ and R charts have achieved the optimal quality improvement without a substantial investment for new equipment or equipment modification. When the process is in statistical control, process capability is equal to 6σ, where $\sigma = R_0/d_2$ and d_2 is a factor from Appendix Table A. In the example problem, it is

$$6\sigma = 6(R_0/d_2) = 6(0.079/2.059) = 0.230$$

It is frequently necessary to obtain the process capability by a quick method rather than by using the $\overline{X}$ and R charts. This method assumes the process is stable or in statistical control, which may or may not be the case. The procedure is as follows:

1. Take 25 subgroups of size 4, for a total of 100 measurements.
2. Calculate the range, R, for each subgroup.
3. Calculate the average range: $\overline{R} = \Sigma R/g$.
4. Calculate the estimate of the population standard deviation:

$$\sigma = \overline{R}/d_2$$

where d_2 is obtained from Appendix Table A and is 2.059 for $n = 4$.

5. The process capability will equal 6σ.

Remember that this technique does not give the true process capability and should be used only if circumstances require its use. Also, more than 25 subgroups can be used to improve accuracy.

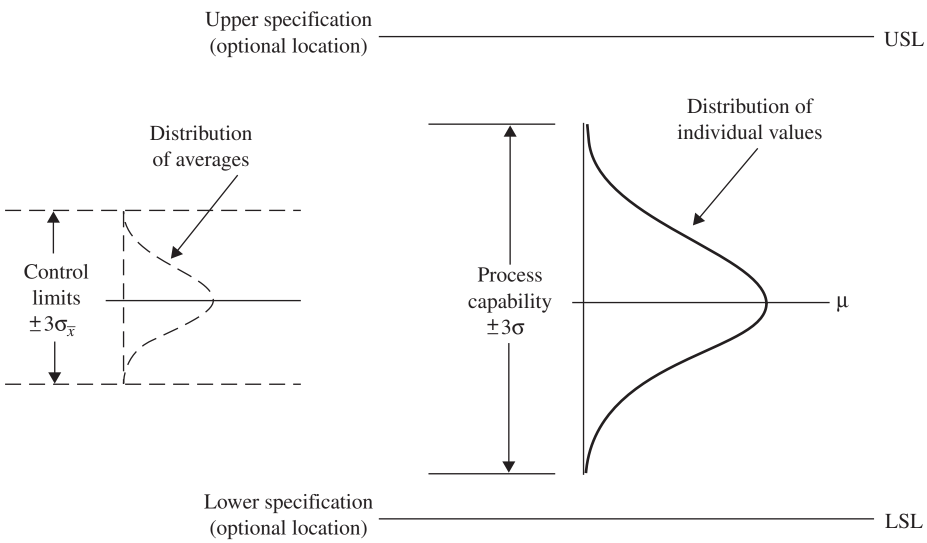


Figure 15-23 Relationship of Limits, Specifications, and Distribution

The relationship of process capability and specifications is shown in Figure 15-24. Tolerance is the difference between the upper specification limit (USL) and the lower specification limit (LSL). Process capability and the tolerance are combined to form a capability index, defined as

$$C_p = \frac{\text{USL} - \text{LSL}}{6\sigma}$$

where USL − LSL = upper specification − lower specification, or tolerance
C_p = capability index
6σ = process capability

If the capability index is greater than 1.00, the process is capable of meeting the specifications; if the index is less than 1.00, the process is not capable of meeting the specifications. Because processes are continually shifting back and forth, a C_p value of 1.33 has become a de facto standard, and some organizations are using a 2.00 value. Using the capability index concept, we can measure quality, provided the process is centered. The larger the capability index, the better the quality. We should strive to make the capability index as large as possible. This result is accomplished by having realistic specifications and continual striving to improve the process capability.

The capability index does not measure process performance in terms of the nominal or target value. This measure is accomplished using C_{pk}, which is

$$C_{pk} = \frac{\text{Min}\left\{\left(\text{USL} - \overline{X}\right) \text{ or } \left(\overline{X} - \text{LSL}\right)\right\}}{3\sigma}$$

A C_{pk} value of 1.00 is the de facto standard, with some organizations using a value of 1.33. Figure 15-25 illustrates C_p and C_{pk} values for processes that are centered and also off center by 1σ.

Comments concerning C_p and C_{pk} are as follows:

1. The C_p value does not change as the process center changes.
2. $C_p = C_{pk}$ when the process is centered.

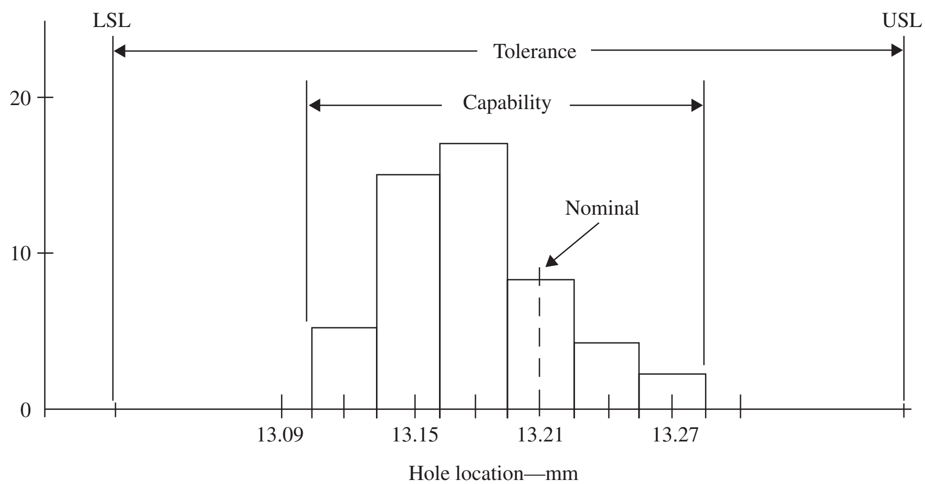


Figure 15-24 Relationship of Process Capability to Tolerance

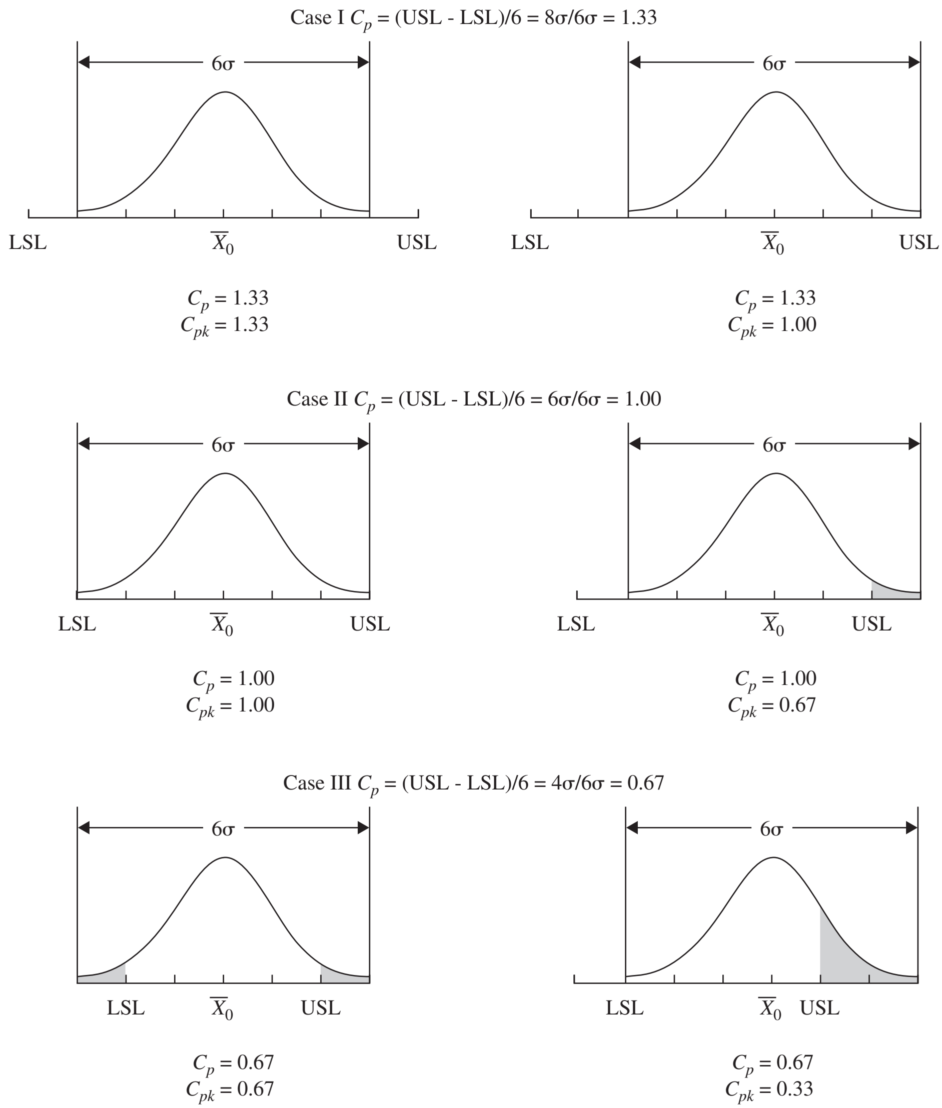


Figure 15-25 C_p and C_{pk} Values for Three Different Situations

3. C_{pk} is always equal to or less than C_p.
4. A C_{pk} value greater than 1.00 indicates the process conforms to specifications.
5. A C_{pk} value less than 1.00 indicates that the process does not conform to specifications.
6. A C_p value less than 1.00 indicates that the process is not capable.
7. A C_{pk} value of zero indicates the average is equal to one of the specification limits.
8. A negative C_{pk} value indicates that the average is outside the specifications.

Quality professionals will use these eight items to improve the process. For example, if a C_p value is less than one, then corrective action must occur. Initially 100% inspection is necessary to eliminate noncomformities. One solution would be to increase the tolerance of the specifications. Another would be to work on the process to reduce the standard deviation or variability.

Process Performance

Process capability indices C_p and C_{pk} are calculated using standard deviation from control charts as $\sigma = R/d_2$. This standard deviation is a measure of variation within the subgroups. It is expected that subgroup size is selected such that there is no opportunity for any assignable causes to occur and therefore, only random or "inherent" variation is present within the subgroups. Thus, $\sigma = R/d_2$ represents random variation only and σ is called "within standard deviation". Capability indices C_p and C_{pk} calculated using the within standard deviation are referred to as "Process Capability Within". Strictly speaking, this is the best or potential capability of the process that can be expected.

In reality, there are some assignable causes present. These are investigated and corrective action is taken so that these causes do not reoccur. In addition to C_p and C_{pk}, SPC manual from Automotive Industry Action Group (AIAG) suggests process performance indices P_p and P_{pk}. These indices are calculated using standard deviation using the formula:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{(n-1)}}$$

This is sometimes referred to as "overall" standard deviation. Overall standard deviation includes not only random variation but also variation between the subgroups and also variation due to the assignable causes, if any. P_p and P_{pk} are called process performance indices and can be considered as more realistic representation of what the customers will experience.

Different Control Charts for Variables

Although most of the quality control activity for variables is concerned with the and R charts, there are other charts that find application in some situations. These charts are described in Table 15-5.

Control Charts for Attributes

An attribute, as defined in quality, refers to those quality characteristics that conform to specifications or do not conform to specifications. There are two types:

1. Where measurements are not possible, for example, visually inspected items such as color, missing parts, scratches, and damage.
2. Where measurements can be made but are not made because of time, cost, or need. In other words, although the diameter of a hole can be measured with an inside micrometer, it may be more convenient to use a "go–no go" gauge and determine if it conforms or does not conform to specifications.

Where an attribute does not conform to specifications, various descriptive terms are used. A *nonconformity* is a departure of a quality characteristic from its intended level or state that occurs with a severity sufficient to

TABLE 15-5

Different Control Charts for Variables

Type	*Central Line*	*Central Limits*	*Comments*
$\overline{X}$ and s	$\overline{\overline{X}}$	$LCL_{\bar{x}} = \overline{\overline{X}} - A_3\bar{s}$ $LCL_{\bar{x}} = X - A_3 s$	Use when more sensitivity is desired than R; when $n > 10$; and when data are collected automatically
	$\bar{s}$	$UCL_s = B_4 s$ $LCL_s = B_3\bar{s}$	
Moving average, M $\overline{X}$ and moving range, MR	$\overline{\overline{X}}$	$UCL_{\bar{x}} = \overline{\overline{X}} + A_2\overline{R}$ $LCL_{\bar{x}} = \overline{\overline{X}} - A_2\overline{R}$	Use when only one observation is possible at a time. Data needn't be normal.
	$\overline{R}$	$UCL_R = D_4\overline{R}$ $LCL_R = D_3\overline{R}$	
X and moving R	$\overline{X}$	$UCL_x = \overline{X} + 2.660\overline{R}$ $LCL_x = \overline{X} - 2.660\overline{R}$	Use when only one observation is possible at a time and the data are normal. Equation are based on a moving range of two.
	$\overline{R}$	$UCL_R = 3.276\overline{R}$ $LCL_R = (0)\overline{R}$	
Median and Range	Md_{md}	$UCL_{Md} = Md_{Md} + A_5 R_{Md}$ $LCL_{Md} = Md_{Md} - A_5 R_{Md}$	Use when process is in a maintenance mode. Benefits are less arithmetic and simplicity.
	R_{md}	$UCL_R = D_6 R_{Md}$ $LCL_R = D_5 R_{Md}$	

cause an associated product or service not to meet a specification requirement. The definition of a defect is similar, except it is concerned with satisfying intended normal or reasonably foreseeable usage requirements. Defect is appropriate for use when evaluation is in terms of usage, and nonconformity is appropriate for conformance to specifications.

The term *nonconforming unit* is used to describe a unit of product or service containing at least one nonconformity. Defective is analogous to defect and is appropriate for use when a unit of product or service is evaluated in terms of usage rather than conformance to specifications.

In this section we are using the terms *nonconformity* and *nonconforming unit*. This practice avoids the confusion and misunderstanding that occurs with *defect* and *defective* in product-liability lawsuits.

Variable control charts are an excellent means for controlling quality and subsequently improving it; however, they do have limitations. One obvious limitation is that these charts cannot be used for quality characteristics that are attributes. The converse is not true, because a variable can be changed to an attribute by stating that it conforms or does not conform to specifications. In other words, nonconformities such as missing parts, incorrect color, and so on, are not measurable, and a variable control chart is not applicable.

Another limitation concerns the fact that there are many variables in a manufacturing entity. Even a small manufacturing plant could have as many as 1,000 variable quality characteristics. Because $\overline{X}$ and R charts are needed for each characteristic, 1,000 charts would be required. Clearly, this would be too expensive and impractical. A control chart for attributes can minimize this limitation by providing overall quality information at a fraction of the cost.

There are two different groups of control charts for attributes. One group of charts is for nonconforming units. A proportion, p, chart shows the proportion nonconforming in a sample or subgroup. The proportion is expressed as a fraction or a percent. Another chart in the group is for number nonconforming, np.

Another group of charts is for nonconformities. A c chart shows the count of nonconformities in an inspected unit such as an automobile, bolt of cloth, or roll of paper. Another closely-related chart is the u chart, which is for the count of nonconformities per unit.

Much of the information on control charts for attributes is similar to that already given in Variable Control Charts. Also see the information on State of Control.

Objectives of the Chart

The objectives of attribute charts are to

1. Determine the average quality level. Knowledge of the quality average is essential as a benchmark. This information provides the process capability in terms of attributes.

2. Bring to the attention of management any changes in the average. Changes, either increasing or decreasing, become significant once the average quality is known.

3. Improve the product quality. In this regard, an attribute chart can motivate operating and management personnel to initiate ideas for quality improvement. The chart will tell whether the idea is an appropriate or inappropriate one. A continual and relentless effort must be made to improve the quality.

4. Evaluate the quality performance of operating and management personnel. Supervisors should be evaluated by a chart for nonconforming units. One chart should be used to evaluate the chief executive officer (CEO). Other functional areas, such as engineering, sales, finance, etc., may find a chart for nonconformities more applicable for evaluation purposes.

5. Suggest places to use $\overline{X}$ and R charts. Even though the cost of computing and charting $\overline{X}$ and R charts is more than that of charts for attributes, they are much more sensitive to variations and are more helpful in diagnosing causes. In other words, the attribute chart suggests the source of difficulty, and $\overline{X}$ and R charts find the cause.

6. Determine acceptance criteria of a product before shipment to the customer. Knowledge of attributes provides management with information on whether or not to release an order.

Use of the Chart

The general procedures that apply to variable control charts also apply to the p chart. The first step in the procedure is to determine the use of the control chart. The p chart is used for data that consist of the proportion of the number of occurrences of an event to the total number of occurrences. It is used in quality control to report the proportion nonconforming in a product, quality characteristic, or group of quality characteristics. As such, the proportion nonconforming is the ratio of the number nonconforming in a sample or subgroup to the total number in the sample or subgroup. In symbolic terms, the equation is

$$p = \frac{np}{n}$$

where p = proportion (fraction or percent) nonconforming in the sample or subgroup
n = number in the sample or subgroup
np = number nonconforming in the sample or subgroup

The p chart is an extremely versatile control chart. It can be used to control one quality characteristic, as is done with $\overline{X}$ and R charts; to control a group of quality characteristics of the same type or of the same part; or to control the entire product. The p chart can be established to measure the quality produced by a work center, by a department, by a shift, or by an entire plant. It is frequently used to report the performance of an operator, group of operators, or management as a means of evaluating their quality performance.

A hierarchy of utilization exists so that data collected for one chart can also be used on a more all-inclusive chart. The use for the chart or charts will be based on securing the greatest benefit for a minimum of cost.

Subgroup Size

The second step is to determine the size of the subgroup. The subgroup size of the p chart can be either variable or constant. A constant subgroup size is preferred; however, there may be many situations, such as changes in mix and 100% automated inspection, where the subgroup size changes.

If a part has a proportion nonconforming, p, of 0.001 and a subgroup size, n, of 1000, then the average number nonconforming, np, would be one per subgroup. This situation would not make a good chart, since a large number of values, posted to the chart, would be zero. If a part has a proportion nonconforming of 0.15 and a subgroup size of 50, the average number of nonconforming units would be 7.5, which would make a good chart.

Therefore, the selection of the subgroup size requires some preliminary observations to obtain a rough idea of the proportion nonconforming and some judgment as to the average number of nonconforming units that will make an adequate graphical chart. A minimum size of 50 is suggested as a starting point. Inspection can either be by audit or on-line. Audits are usually done in a laboratory under optimal conditions. On-line provides immediate feedback for corrective action.

Data Collection

The third step requires data to be collected for at least 25 subgroups, or the data may be obtained from historical records. Perhaps the best source is from a check sheet designed by a project team. Table 15-6 gives the inspection results from the motor department for the blower motor in an electric hair dryer. For each subgroup,

TABLE 15-6

Inspection Results of Hair Dryer Blower Motor, Motor Department, May

Subgroup Number	Number Inspected n	Number Nonconforming np	Proportion Nonconforming p
1	300	12	0.040
2	300	3	0.010
3	300	9	0.030
.	.	.	.
.	.	.	.
.	.	.	.
19	300	16	0.053
20	300	2	0.007
21	300	5	0.017
22	300	6	0.020
23	300	0	0.0
24	300	3	0.010
25	300	2	0.007
Total	7500	138	

the proportion nonconforming is calculated. The quality technician reported that subgroup 19 had an abnormally large number of nonconforming units, owing to faulty contacts.

Trial Central Lines and Control Limits

The fourth step is the calculation of the trial central line and control limits. The average proportion nonconforming, $\overline{p}$, is the central line and the control limits are established at 3σ. The equations are

$$\overline{p} = \Sigma np/\Sigma n$$

$$\text{UCL} = \overline{p} + 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}} \qquad \text{LCL} = \overline{p} - 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$$

where $\overline{p}$ = average proportion nonconforming for many subgroups
n = number inspected in a subgroup

Calculations for the central line and the trial control limits using the data on the electric hair dryer are as follows:

$$\overline{p} = \Sigma np/\Sigma n = 1.38/7500 = 0.018$$

$$\text{UCL} = \overline{p} + 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}} \qquad \text{LCL} = \overline{p} - 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$$

$$= 0.018 + 3\sqrt{\frac{0.018(1-0.018)}{300}} \qquad = 0.018 - 3\sqrt{\frac{0.018(1-0.018)}{300}}$$

$$= 0.041 \qquad = -0.005 \text{ or } 0.0$$

Calculations for the lower control limit resulted in a negative value, which is a theoretical result. In practice, a negative proportion nonconforming would be impossible. Therefore, the lower control limit value of -0.005 is changed to zero.

When the lower control limit is positive, it may in some cases be changed to zero. If the p chart is to be viewed by operating personnel, it would be difficult to explain why a proportion nonconforming that is below the lower control limit is out of control. In other words, performance of exceptionally good quality would be classified as out of control. To avoid the need to explain this situation to operating personnel, the lower control limit is left off the chart. When the p chart is to be used by quality control personnel and by management, a positive lower control limit is left unchanged. In this manner, exceptionally good performance (below the lower control limit) will be treated as an out-of-control situation and be investigated for an assignable cause. It is hoped that the assignable cause will indicate how the situation can be repeated.

The central line, $\overline{p}$, and the control limits are shown in Figure 15-26; the proportion nonconforming, p, from Table 15-6 is also posted to that chart. This chart is used to determine if the process is stable and is not posted. Like the $\overline{X}$ and R charts, the central line and control limits were determined from the data.

Revised Central Line and Control Limits

The fifth step is completed by discarding any out-of-control points that have assignable causes and recalculating the central line and control limits. The equations are the same except p_0, the standard or reference value, is substituted for $\overline{p}$.

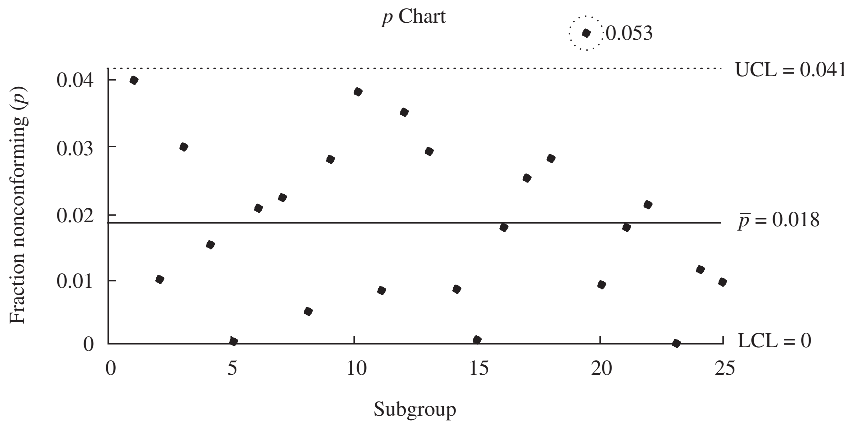


Figure 15-26 *p* Chart to illustrate the Trial Central Line and Control LimitsUsing the Data of Table 15-6

Most industrial processes, however, are not in control when first analyzed, and this fact is illustrated in Figure 15-26 by subgroup 19, which is above the upper control limit and, therefore, is out of control. Because subgroup 19 has an assignable cause, it can be discarded from the data, and a new $\overline{p}$ can be computed with all of the subgroups except 19. The value of p_0 is 0.017, which makes the UCL = 0.039 and the LCL = − 0.005, or 0.0.

The revised control limits and the central line are shown in Figure 15-27. This chart, without the plotted points, is posted in an appropriate place and the proportion nonconforming, *p*, for each subgroup is plotted as it occurs.

Achieving the Objective

Whereas the first five steps are planning, the last step involves action and leads to the achievement of the objective. The revised control limits were based on data collected in May. Some representative values of inspection results for the month of June are shown in Figure 15-27. Analysis of the June results shows that the quality improved. This improvement is expected, because the posting of a quality control chart usually results in improved quality. Using the June data, a better estimate of the proportion nonconforming is obtained. The new value (p_0 = 0.014) is used to obtain the UCL of 0.036.

During the latter part of June and the entire month of July, various quality improvement ideas generated by a project team are tested. These ideas are new shellac, change in wire size, stronger spring, $\overline{X}$ and *R* charts

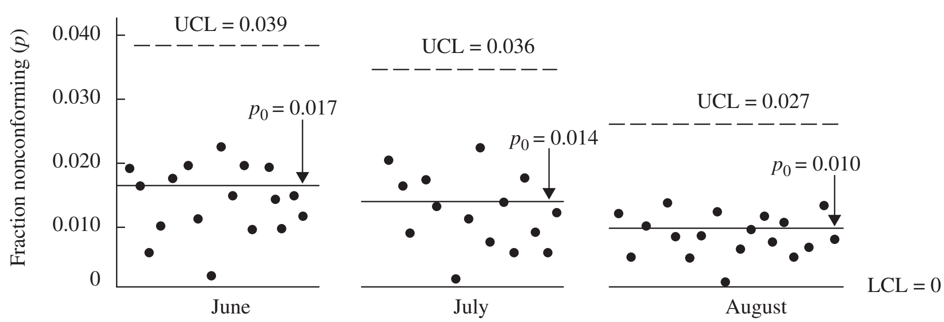


Figure 15-27 Continuing Use of the *p* Chart for Representative Values of the Proportion Nonconforming, *p*

on the armature, and so on. In testing ideas, there are three criteria: a minimum of 25 subgroups are required, the 25 subgroups can be compressed in time as long as no sampling bias occurs, and only one idea can be tested at a time. The control chart will tell whether the idea improves the quality, reduces the quality, or has no effect on the quality. The control chart should be located in a conspicuous place so operating personnel can view it.

Data from July are used to determine the central line and control limits for August. The pattern of variation for August indicates that no further improvement resulted. However, a 41% improvement occurred from June (0.017) to August (0.010). At this point, considerable improvement was obtained from testing the ideas of the project team. Although this improvement is very good, the relentless pursuit of quality improvement must continue—1 out of every 100 is still a nonconforming unit. Perhaps a detailed failure analysis or technical assistance from product engineering will lead to additional ideas that can be evaluated. A new project team may help.

Quality improvement is never finished. Efforts may be redirected to other areas based on need and/or resources available.

Like $\overline{X}$ and R charts, the p chart is most effective if it is posted where operating and quality control personnel can view it. Also, like $\overline{X}$ and R charts, the control limits are three standard deviations from the central value. Therefore, approximately 99% of the plotted points will fall between the upper and lower control limits.

A control chart for subgroup values of p will aid in disclosing the occasional presence of assignable causes of variation in the process. The elimination of these assignable causes will lower p_0 and, therefore, have a positive effect on spoilage, production efficiency, and cost per unit. A p chart will also indicate long-range trends in the quality, which will help to evaluate changes in personnel, methods, equipment, tooling, materials, and inspection techniques.

TABLE 15-7

Different Types of Control Charts for Attributes*

Type	*Central Line*	*Control Limits*	*Comments*
p	$\overline{p}$	$UCL=\overline{p}+3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$ $LCL=\overline{p}-3\sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$	Use for nonconforming units with constant or variable sample size.
np	$\overline{np}$	$UCL=\overline{np}+3\sqrt{\overline{np}(1-\overline{p})}$ $LCL=\overline{np}-3\sqrt{\overline{np}(1-\overline{p})}$	Use for nonconforming units, where *np* is the number nonconforming. The sample size must be constant.
c	$\overline{c}$	$UCL=\overline{c}+3\sqrt{\overline{c}}$ $UCL=\overline{c}-3\sqrt{\overline{c}}$	Use for nonconformities within a unit where *c* is the count of nonconformities. The sample size is one inspected unit, i.e., a case of 24 cans.
u	$\overline{u}$	$UCL=\overline{u}+3\sqrt{\frac{\overline{u}}{n}}$ $LCL=\overline{u}+3\sqrt{\frac{\overline{u}}{n}}$	Use for nonconformities within a unit where *u* is the count of nonconformities per unit. The sample size can vary.

*For more information see *Quality Control*, 6th ed., by Dale H. Besterfield (Upper Saddle River, NJ: Prentice Hall, 2001).

The process capability is the central line for all attribute charts. Management is responsible for the capability. If the value of the central line is not satisfactory, then management must initiate the procedures and provide the resources to take the necessary corrective action. As long as operating personnel (operators, first-line supervisors, and maintenance workers) are keeping the plotted points within the control limits, they are doing what the process is capable of doing. When the plotted point is outside the control limit, operating personnel are usually responsible.

A plotted point below the lower control limit is due to exceptionally good quality. It should be investigated to determine the assignable cause, so that if it is not due to an inspection error, it can be repeated.

Additional types of charts for attributes are shown in Table 15-7, with comments concerning their utilization.

Measurement System Analysis (MSA)[5]

Importance of Measurement

Measurement "converts" unknown existing information into a useable value. It helps us take decisions. For example, when doctors measure blood pressure, they often want to decide about the medication or line of treatment. When a cricket umpire decides whether the batsman is out or not, the decision affects the outcome of the match. When a manufactured part is inspected, it is decided whether it should be accepted or rejected. Measurement decisions are associated with risks, as there is a possibility of measurement error. When a good part is rejected, it is called a producer's risk or α-risk. On the other hand, when a bad part is accepted, it is a consumers' risk or β-risk.

In all of these cases, the impact of wrong measurement on decisions is quite evident. We often do not realize the way our decisions depend on the results of the measurement system. We also do not realize the consequences of incorrect results of a measurement system. Many of us, may have more than a clock in our houses and each one showing different time! For the domestic application of time measurement, the criticality is quite less. But imagine its criticality in project like satellite launching at Indian Space Research Organization (ISRO) or NASA! Least count of our wrist watches is normally one second. It is rather adequate for day-to-day activity. The time clocks or event meters, which are used in sports, would require much higher accuracy and precision and the wrist watch is not an acceptable measurement system. In fact, digital frame capture technology has taken over the conventional time measurement instruments now. Thus, we need to use a measurement system that is appropriate for the objective and is able to discern the "process variation" to take correct decisions.

Where Do We Use Measurement Systems?

Measurement systems are used for the following purposes:

- Product classification and/or acceptance.
- Process adjustment.
- Process control.
- Analysis of process variation and assessment of process capability.

Measurement systems are not limited to manufacturing and shop-floor environment. Table 15.8 shows some examples that shall help us understand the wide variety of measurement systems available.

In improvement projects, it is essential that the measurement system is assessed before evaluating the process capability. The procedures used for variable and attribute data are different. However, measurement

[5] This subtopic on MSA is adapted with permission from "Six Sigma for Business Excellence" by Hemant Urdhwareshe, Pearson Education India.

TABLE 15-8
Examples of Measurement Systems

Type of Measuring System	*Type of Data*	*Consequences of Measurement Variation*
Watches keep time.	Variable	We may miss appointments, trains, buses, etc.
Stop watches of various types to decide winner in sports, process evaluation.	Variable	Wrong participant may be declared as a winner.
Measuring tape of a tailor.	Variable	Clothes may not fit well.
Engineering graduation examination, MBA entrance examination.	Variable	Students may be graded wrongly. Deserving candidates may not be selected for MBA.
Interview.	Discrete binary (selected or not selected)	Inappropriate candidate may get selected or appropriate candidate may get rejected.
Cricket umpire.	Discrete binary (out or not out)	Batsman will be given out when he is actually not and vice-versa.
Blood pressure (BP) measurement.	Variable	Medicines can be wrongly prescribed.
Stress test for heart fitness.	Discrete binary (test positive or negative)	Patients suffering from heart ailments may be declared fit and vice-versa.
Counting parts for inventory.	Discrete	Wrong purchase order may be issued, production disruption may happen, incorrect profits (or losses) may appear, etc.
Fuel gauge in a car.	Variable continuous	We may get stuck travelling as it may show wrong indication of fuel.

system analysis should be performed on both types. Before we study these procedures, let us take a look at some of the basic terms used in MSA.

Measurement Terminology

Accuracy is the degree of conformity of a measured quantity to its actual or true value. For example, a watch showing time equal to standard time can be considered accurate.

Precision is the degree to which further measurements show the same or similar results. Figure 15.28 clarifies the difference between accuracy and precision.

Bias is the difference between measurement and master value. To estimate bias, a “same part” needs to be measured number of times. The difference between the average of these measurements and the true value is called bias.

Calibration helps in minimizing the bias during usage. For example, if a person wants to know his or her own weight, he or she can take a few readings. Suppose average of 5 such readings is 55 kg. He or she then goes to a lab where the weighing scales are regularly calibrated. He finds his weight as 56.5 kg in the lab. The bias of the weighing scale is $56.5 - 55 = 1.5$ kg.

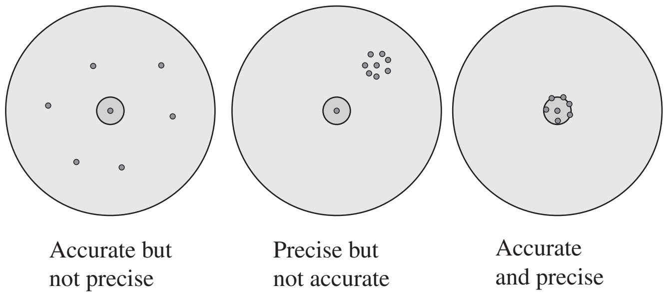


Figure 15-28 Accuracy and Precision

Repeatability is the inherent variation due to the measuring equipment. If the same appraiser measures the same part a number of times, the closeness in the readings is a measure of repeatability. Traditionally, this is referred to as "Within Appraiser Variation". It is also known as equipment variation (EV).

Linearity is the change in the bias over operating range. It is a systematic error component of the measurement system. In many measuring systems, error tends to increase with the larger measurements. For example, pressure gauge, dial gauge, weighing scales, etc.

Stability is the measurement variation over time. We should calibrate a gauge or an instrument to ensure its stability. This is sometimes also called drift. Periodic calibration of measuring equipment is performed to assess stability.

Reproducibility is a variation in the average of measurements made by different appraisers using the *same measuring instrument when measuring identical characteristic on the same part*. Reproducibility has been traditionally, referred to as "Between Appraiser" or appraiser variation (AV).

Process and Measurement Variation

The objective in number of situations is to measure process variation (PV). But what we measure in reality is a total of process as well as measurement variation. Ideally, we do not want any measurement variation! However, this is not possible. Thus, it is desirable that measurement variation is a very small portion of observed variation. Measurement variation can be seen as a component of observed variation, as shown in the Figure 15.29.

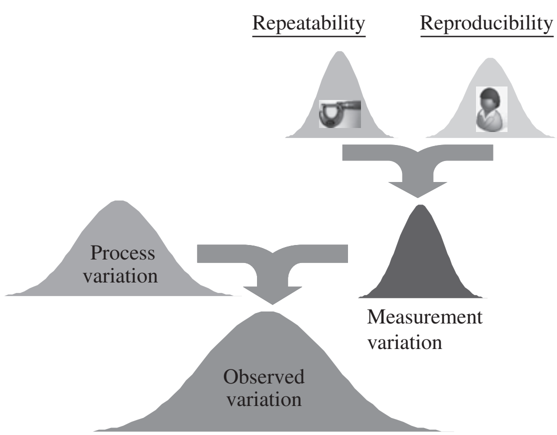


Figure 15-29 Measurement, Process and Observed Variation
(Reproduced with permission from Institute of Quality and Reliability, Pune)

In a typical measurement system analysis (MSA), we use statistical methods to estimate how much of the total variation (TV) is due to the measurement system. An ideal measurement system should not have any variation. However, it is impossible and we have to be satisfied with a measurement system that has variation less than 10% of the process variation. As portion of variation due to measurement system increases, value or utility of the measurement system goes on decreasing. If this proportion is more than 30%, the measurement system is unacceptable.

Repeatability and Reproducibility (R & R)

- Let σ_m be the standard deviation of the measurement variation and $\sigma_{Observed}$ be the standard deviation of the total observed variation.
- Ratio of the measurement variation to the process variation, that is, $\sigma_m/\sigma_{Observed}$ is called gauge repeatability and reproducibility (GRR). GRR is usually expressed in percent.

It is customary to quantify R&R value as "ratio of measurement standard deviation with total standard deviation" in percentage. This analysis method is called "% Study Variation Method". MSA manual published by AIAG specifies the following norms.

- If GRR is less than 10%, measurement system is acceptable.
- If GRR is between 10 to 30%, equipment may be accepted based upon the importance of application, cost of measurement device, cost of repair etc.
- Measurement system is not acceptable for GRR beyond 30%.

In a typical measurement system study, GRR is estimated. The stability bias and linearity errors are to be addressed during the selection and calibration of the instrument.

Please note that in the % study variation method, we are using ratios of standard deviations. The other alternative to this is percent contribution method. In this method, we compare ratios of variances. It is easy to understand the norms. For example, when GRR is 10%, the ratio $\sigma_m/\sigma_{Observed}$ is 0.1. Thus, $\frac{\sigma_m^2}{\sigma_{\text{observed}}^2} = \left(\frac{\sigma_m}{\sigma_{\text{observed}}}\right)^2 = 0.1^2 = 0.01$ or 1%. Norms for both the methods are summarized in Table 15-9.

TABLE 15-9

Acceptance Norms for R & R with Study Variation Method	*Acceptance Norms for R & R with %Variance Contribution Method*	*Decision Guidelines*
<10%	<1%	Acceptable measurement system.
Between 10 and 30%	Between 1 and 9%	May be acceptable based upon importance of application, cost of measurement device, cost of repair, etc.
>30%	>10%	Unacceptable measurement system. Every effort should be made to improve the system.

Often, when the process variation is very small, we may like to compare the measurement variation with the tolerance of the component being measured. This is called **precision to tolerance ratio or P/T Ratio**. Precision is the 6σ band that includes 99.73 of the measurements. This is compared with the tolerance. Thus, P/T Ratio = $\frac{6 \times \sigma_m}{Tolerance}$ The AIAG acceptance norms for P/T ratio are same as those for study variation method shown in Table 15-6.

NUMBER OF DISTINCT CATEGORIES (NDC)

Another norm used in the variable measurement systems is number of distinct categories NDC. This number represents the number of groups within our process data that the measurement system can discern or discriminate.

$$\text{NDC} = \frac{\sigma_p}{\sigma_m} \times 1.41$$ where sigmap is process standard deviation.

Imagine that we measured ten different parts, and NDC = 4. This means that some of those ten parts are not different enough to be discerned as being different by the measurement system. If we want to distinguish a higher number of distinct categories, we need a more precise gauge. AIAG MSA manual suggests that when the number of categories is less than 2, the measurement system is of no value for controlling the process, since one part cannot be distinguished from the another. When the number of categories is 2, the data can be divided into two groups, say high and low. When the number of categories is 3, the data can be divided into 3 groups, say low, middle and high. As per the AIAG recommendations, NDC must be 5 or more for an acceptable measurement system.

PROCEDURE FOR GAUGE R & R STUDY FOR MEASUREMENT SYSTEMS

1. Decide the part and the measuring equipment.
2. Establish and document method of measurement.
3. Train appraisers (operators) for measurement.
4. Select 2 or 3 "Appraisers".
5. Select 5 to 10 parts. The parts selected should represent process variation.
6. Each part must be measured, by each appraiser at least twice, preferably thrice.
7. Measurements must be taken in random order without ducking other readings so that each measurement can be considered as "independent".
8. Record, analyze and interpret the results.

COLLECTING DATA

Typically, in a Gauge R & R Study 10 parts are measured by three appraisers. Each appraiser measures each part thrice. Thus, we have 9 measurements of each part with total 90 measurements. The data structure will be as shown in Figure 15-30. When we compare the measurement of same part by same appraiser, we get an estimate of repeatability. We may call this measurement variation "within" appraiser. If we compare average measurements by each appraiser for the same part, we can estimate variation "between" appraisers, i.e., reproducibility.

ANALYSIS OF DATA

After collecting the data, we can analyze it by one of the two methods.

1. Control chart method.
2. ANOVA method.

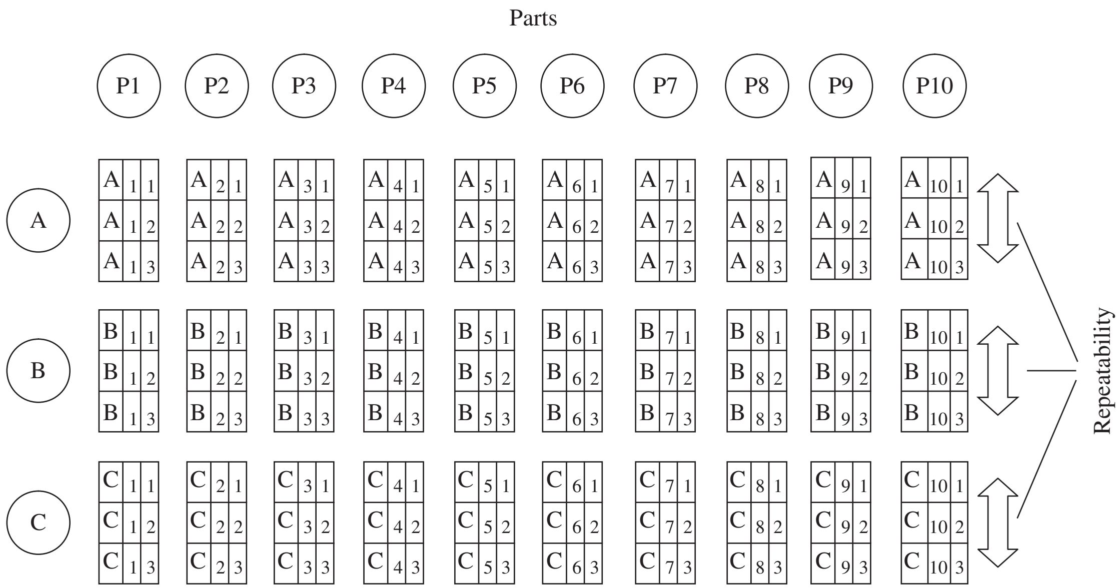


Figure 15-30 Typical Crossed R & R Study Data Structure. Three Appraisers Measure 10 Parts Three Times Each With Total 90 Measurements*

We will briefly discuss only the control chart method using the example from measurement system analysis (MSA) manual by Automotive Industry Action Group (AIAG). Refer Figure 15.31 for the discussion. In this procedure, the averages and the ranges are calculated for each appraiser for each part. The magnitude of range values will relate to the repeatability or equipment variation (EV). If we calculate the average of all these range values, we will get "R-double-bar". We can covert this into standard deviation $\sigma_{\text{repeatability}}$ using statistical constant K1. The value of K1 depends upon the number of trials (3 here) by each appraiser for each part. For three trials, K1=0.5908. Similarly, we can calculate the range of averages, of nine part measurements for each of the 10 parts. This is range of parts variation R_{part}. We can use constant K3 to convert this range value to standard deviation σ_p. For ten parts, value of K3 is 0.3146. Based on these two values, we can also calculate standard deviation due to reproducibility, that is, variation between appraisers. An illustration of this procedure is shown in Figure 15-31. For complete details of the procedure, refer the AIAG MSA manual. %GRR in this example is 26.67%. This is between 10 and 30% and therefore is marginally acceptable. The precision to tolerance (P/T) ratio is calculated using tolerance of 5 units. We can conditionally accept the equipment with improvement actions planned. The number of distinct categories and precision to tolerance ratio can also be calculated.

Measurement Systems Analysis for Attribute Data

Quite often, we have to use measurement system for attribute data. Simplest example is the decision of the cricket umpire to decide whether a batsman is out or not. Typical examples of attribute data include.

- Crack Testing result, i.e., crack or no crack.
- Leak Test.
- Visual Inspection.

* Data collection in R&R study (reproduced with permission from the institute of quality and reliability, India, www.world-class-quality.com).

Std.Dev. Multiplier	6

MSA AIAG Example

Appraiser A	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6	Part 7	Part 8	Part 9	Part 10		
Reading 1	0.29	–0.56	1.34	0.47	–0.8	0.02	0.59	–0.31	2.26	–1.36		
Reading 2	0.41	–0.68	1.17	0.5	–0.92	–0.11	0.75	–0.2	1.99	–1.25		
Reading 3	0.64	–0.58	1.27	0.64	–0.84	–0.21	0.66	–0.17	2.01	–1.31		
Average	0.4467	–0.6067	1.2600	0.5367	–0.8533	–0.1000	0.6667	–0.2267	2.0867	–1.3067	X-bar$_a$	0.1903
Range	0.3500	0.1200	0.1700	0.1700	0.1200	0.2300	0.1600	0.1400	0.2700	0.1100	R-bar$_a$	0.1840

Appraiser B	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6	Part 7	Part 8	Part 9	Part 10		
Reading 1	0.08	–0.47	1.19	0.01	–0.56	–0.2	0.47	–0.63	1.8	–1.68		
Reading 2	0.25	–1.22	0.94	1.03	–1.2	0.22	0.55	0.08	2.12	–1.62		
Reading 3	0.07	–0.68	1.34	0.2	–1.28	0.06	0.83	–0.34	2.19	–1.5		
Average	0.1333	–0.7900	1.1567	0.4133	–1.0133	0.0267	0.6167	–0.2967	2.0367	–1.6000	X-bar$_b$	0.0683
Range	0.1800	0.7500	0.4000	1.0200	0.7200	0.4200	0.3600	0.7100	0.3900	0.1800	R-bar$_b$	0.5130

Appraiser C	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6	Part 7	Part 8	Part 9	Part 10		
Reading 1	0.04	–1.38	0.88	0.14	–1.46	–0.29	0.02	–0.46	1.77	–1.49		
Reading 2	–0.11	–1.13	1.09	0.2	–1.07	–0.67	0.01	–0.56	1.45	–1.77		
Reading 3	–0.15	–0.96	0.67	0.11	–1.45	–0.49	0.21	–0.49	1.87	–2.16		
Average	–0.0733	–1.1567	0.8800	0.1500	–1.3267	–0.4833	0.0800	–0.5033	1.6967	–1.8067	X-bar$_c$	–0.2543
Range	0.1900	0.4200	0.4200	0.0900	0.3900	0.3800	0.2000	0.1000	0.4200	0.6700	R-bar$_c$	0.3280

Part Averages	0.1689	–0.8511	1.0989	0.3667	–1.0644	–0.1856	0.4544	–0.3422	1.9400	–1.5711	X-double-bar	0.0014
	Difference between max and min of part averages–>										R-part	3.5111
	Average of ranges by each appraiser										R-double bar	0.3417
	Difference between max and min of each appraiser average										X-bar-Diff	0.4447

Trials	K1
2	0.8862
3	0.5908

Repeatability or Equipment Variation EV (R–double bar xK1)	0.20186
Part Variation PV (R–part x K3)	1.10460
$AV=\sqrt{(\overline{X}_{Diff} \text{ x } K_2)^2-(EV^2/(nr))}$ Reproducibility or Appraiser Variation	0.22967
Gauge Repeatability and Reproducibility or GRR	0.30577
Total Variation TV	1.14613

Parts	K3
5	0.403
10	0.3146

Appraisers	K2
2	0.7071
3	0.5231

%EV (100x(EV/TV))	17.612
%AV (100x(AV/TV))	20.038
%GRR (100x(GRR/TV))	26.678
%PV(100x(PV/TV))	96.376
NDC	5
Precision to Tolerance (P/T) Ratio	0.367

Figure 15-31 Illustration of R & R Study Calculations
(Reproduced with permission from the Institute of Quality and Reliability, Pune, www.world-class-quality.com)

TABLE 15-10
Attribute Agreement Analysis Layout

		APPRAISER A		APPRAISER B		APPRAISER C	
Part	*True Standard*	*Trial # 1*	*Trial #2*	*Trial #1*	*Trial #2*	*Trial #1*	*Trial #2*
1	G	G	G	NG	G	G	G
2	G	NG	G	G	G	G	G
3	NG	NG	NG	NG	NG	NG	NG
4	G	G	G	G	NG	G	G
5	NG	NG	NG	NG	NG	NG	NG
6	NG	NG	NG	NG	NG	NG	NG
7	G	G	G	NG	G	G	G
8	NG	NG	NG	NG	NG	NG	NG
9	G	G	G	G	G	G	G
10	NG	NG	NG	NG	NG	NG	NG
11	G	G	G	NG	G	G	G
12	NG	NG	NG	NG	NG	NG	NG
13	NG	NG	NG	NG	NG	NG	NG
14	G	NG	G	NG	G	G	G
15	NG	NG	NG	NG	G	NG	NG
16	G	G	NG	G	G	G	NG
17	G	G	G	G	G	G	G
18	NG	NG	NG	NG	G	NG	NG
19	NG	NG	NG	NG	NG	NG	NG
20	G	G	G	NG	G	G	G

*Reproduced with permission from sigma XL.

Attribute agreement analysis is used to assess such measurement systems. In this procedure, at least ten good parts and ten bad parts should be inspected by 3 appraisers. We should also know evaluation of each part by an "expert" or "master". The collected data may look as shown in Table 15-10 here.

Once the evaluation is completed, we can analyze the data for the following:

- Agreement within appraisers.
- Agreement between appraisers.
- Agreement between appraisers and "true standard".

A measure called Cohen's Kappa is used to decide whether measurement system is acceptable or not. Its value can range between 0 to 1. Value 1 shows a perfect agreement while, as value 0 indicates that the agreement is no better than a chance. For more details of the procedure, refer to MSA manual by AIAG. Kappa value of >0.75 is considered acceptable as per AIAG MSA manual. Detailed calculations of Kohen's Kappa are beyond the scope of this book.

Scatter Diagrams

The simplest way to determine if a cause-and-effect relationship exists between two variables is to plot a scatter diagram. Figure 15-32 shows the relationship between automotive speed and gas mileage. The figure

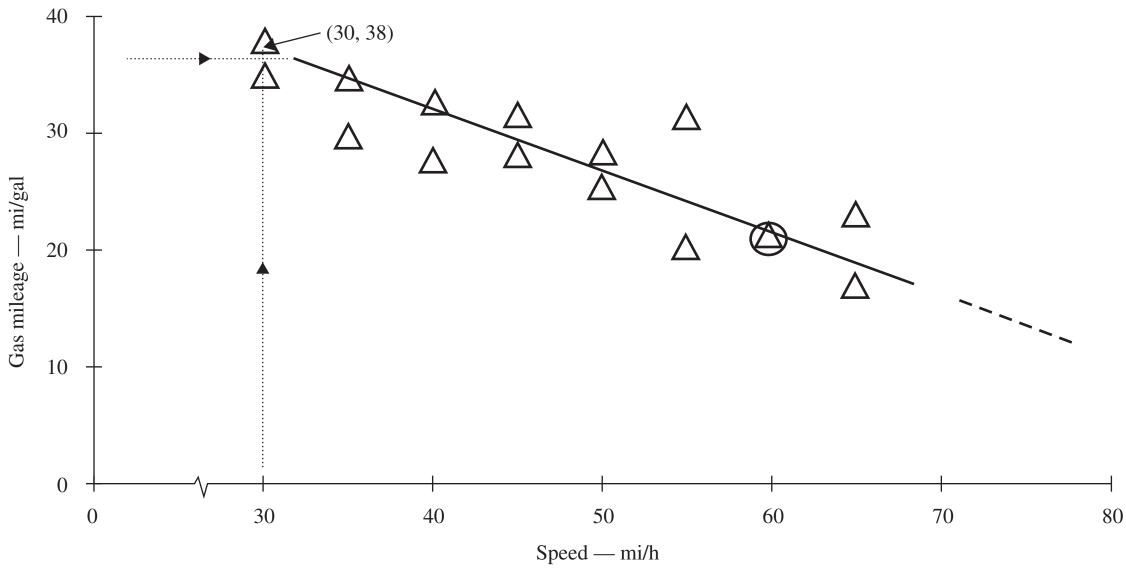


Figure 15-32 Scatter Diagram

shows that as speed increases, gas mileage decreases. Automotive speed is plotted on the *x*-axis and is the independent variable. The independent variable is usually controllable. Gas mileage is on the *y*-axis and is the dependent, or response, variable. Other examples of relationships are as follows:

Cutting speed and tool life.

Temperature and lipstick hardness.

Striking pressure and electrical current.

Temperature and percent foam in soft drinks.

Yield and concentration.

Training and errors.

Breakdowns and equipment age.

Accidents and years with the organization.

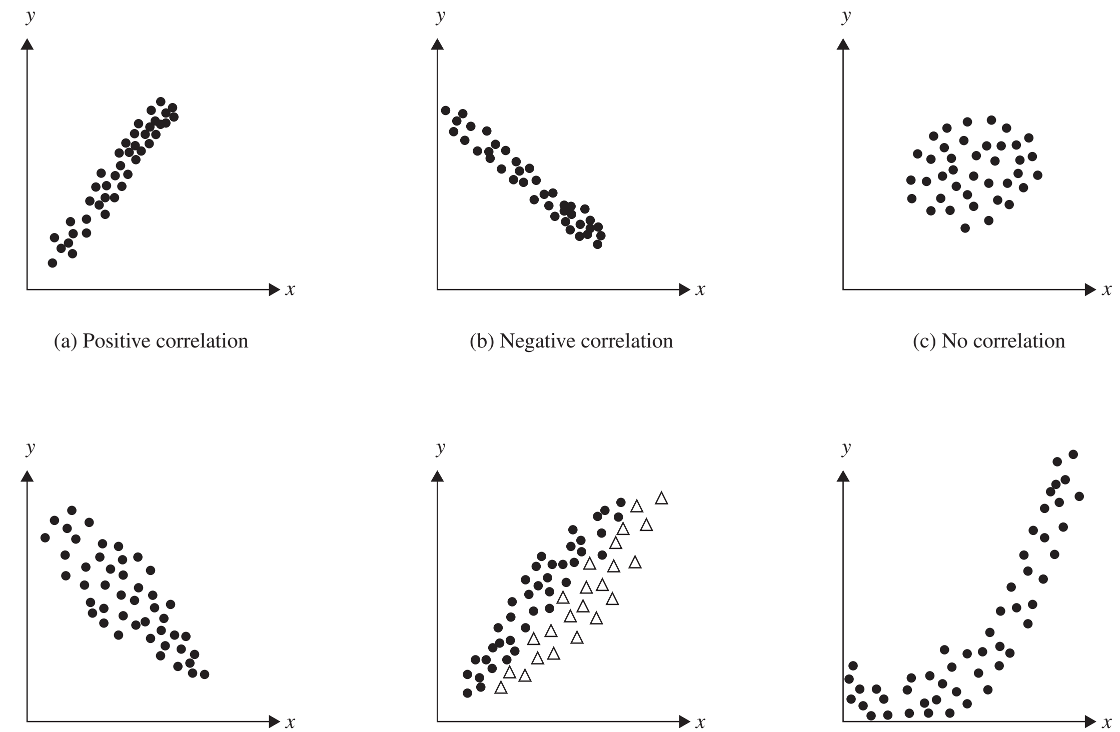
There are a few simple steps for constructing a scatter diagram. Data are collected as ordered pairs (x, y). The automotive speed (cause) is controlled and the gas mileage (effect) is measured. Table 15-11 shows resulting x, y paired data. The horizontal and vertical scales are constructed with the higher values on the right for the *x*-axis and on the top for the *y*-axis. After the scales are labeled, the data are plotted. Using dotted lines, the technique of plotting sample number 1 (30, 38) is illustrated in Figure 15-32. The *x*-value is 30, and the *y*-value is 38. Sample numbers 2 through 16 are plotted, and the scatter diagram is complete. If two points are identical, the technique illustrated at 60 mi/h can be used.

Once the scatter diagram is complete, the relationship or correlation between the two variables can be evaluated. Figure 15-33 shows different patterns and their interpretation. At (a), there is a positive correlation between the two variables, because as *x* increases, *y* increases. At (b), there is a negative correlation between

TABLE 15-11

Data on Automotive Speed vs. Gas Mileage

Sample Number	*Speed (mi/h)*	*Mileage (mi/gal)*	*Sample Number*	*Speed (mi/h)*	*Mileage (mi/gal)*
1	30	38	9	50	26
2	30	35	10	50	29
3	35	35	11	55	32
4	35	30	12	55	21
5	40	33	13	60	22
6	40	28	14	60	22
7	45	32	15	65	18
8	45	29	16	65	24



(a) Positive correlation (b) Negative correlation (c) No correlation

(d) Negative correlation may exist (e) Correlation by stratification (f) Curvilinear relationship

Figure 15-33 Different Scatter Diagram Patterns

the two variables, because as x increases, y decreases. At (c), there is no correlation, and this pattern is sometimes referred to as a shotgun pattern. The patterns described in (a), (b), and (c) are easy to understand; however, those described in (d), (e), and (f) are more difficult. At (d), there may or may not be a relationship between the two variables. There appears to be a negative relationship between x and y, but it is not too strong. Further statistical analysis is needed to evaluate this pattern. At (e), we have stratified the data to represent different causes for the same effect. Some examples are gas mileage with the wind versus against the wind, two different suppliers of material, and two different machines. One cause is plotted with a small solid circle, and the other cause is plotted with an open triangle. When the data are separated, we see that there is a strong correlation. At (f), we have a curvilinear relationship rather than a linear one.

When all the plotted points fall on a straight line, we have a perfect correlation. Because of variations in the experiment and measurement error, this perfect situation will rarely, if ever, occur.

It is sometimes desirable to fit a straight line to the data in order to write a prediction equation. For example, we may wish to estimate the gas mileage at 42 mi/h. A line can be placed on the scatter diagram by sight or mathematically using least squares analysis. In either approach, the idea is to make the deviation of the points on each side of the line equal. Where the line is extended beyond the data, a dashed line is used, because there are no data in that area.

TQM Exemplary Organization[6]

Founded in 1900, Granite Rock Company employs 400 people and produces rock, sand, and gravel aggregates; ready-mix concrete; asphalt; road treatments; and recycled road-base material. It also retails building materials made by other manufacturers and runs a highway-paving operation.

Since 1980, the regional supplier to commercial and residential builders and highway construction companies has increased its market share significantly. Productivity also has increased, with revenue earned per employee rising to about 30% above the national industry average. Most of the improvement has been realized since 1985, when Granite Rock started its Total Quality Program. The program stresses customer satisfaction with teams carrying out quality improvement projects. In 1991, nearly all workers took part in at least one of the company's 100-plus quality teams.

In 1991, Granite Rock employees averaged 37 hours of training at an average cost of $1,697 per employee, 13 times more than the construction-industry average. Many employees are trained in statistical process control, root-cause analysis, and other quality-assurance and problem-solving methods.

Applying statistical process control to all product lines has helped the company reduce variable costs and produce materials that exceed customer specifications and industry- and government-set standards. For example, Granite Rock's concrete products consistently exceed the industry performance specifications by 100 times. Granite Rock's record for delivering concrete on time has risen from less than 70% in 1988 to 93.5% in 1991. The reliability of several key processes has reached the six-sigma level which is a nonconforming rate of 3.4 per million.

Charts for each product line help executives assess Granite Rock's performance relative to competitors on key product and service attributes, ranked according to customer priorities. Ultimate customer satisfaction is assured through a system where customers can choose not to pay for a product or service that doesn't meet

[6] Malcolm Baldrige National Quality Award, 1992 Small Business Category Recipient, NIST/Baldrige Home-page, Internet.

expectations; however, dissatisfaction is rare. Costs incurred in resolving complaints are equivalent to 0.2% of sales, as compared with the industry average of 2%.

Summary

We have seen some basic and simple but quite a useful tools to solve problems. These tools include pareto charts, cause and effects diagrams, checksheets and histograms, process flow diagrams, run charts, control charts and scatter plots. Pareto chart is useful to identify a vital few causes or elements and how to prioritize. Process flow charts are useful to visualize the trouble spots and improvement opportunities for the process, if any. Histograms and checksheets can make variation visible. Scatter plots can be plotted when it is required to understand whether two variables are related to each other or not.

Mean, median, and mode are measures of central tendency, while range and standard deviation are measures of dispersion or variation.

Statistical control charts are powerful to assess stability of processes and to detect presence of assignable cause(s), if any. Control charts for subgroups such as $\overline{X}$-R and $\overline{X}$-s are more sensitive and therefore, preferred over control charts for individuals. Control charts for attributes data include charts for defectives and charts for defects.

It is necessary to validate the measurement system(s) for the critical characteristics. Statistical procedures are available to analyze and quantify measurement system uncertainty. Measurement system is considered acceptable, if R&R is less than 10% of the process variation. In case of attribute data, agreement analysis can be performed. Cohen's kappa value indicates extent of agreement within and between appraisers.

Process capability index C_p quantifies, relationship between specification limits and standard deviation. C_{pk} considers additionally effect of centring.

Exercises

1. A major record-of-the-month club collected data on the reasons for returned shipments during a quarter. Results are: wrong selection, 50,000; refused, 195,000; wrong address, 68,000; order canceled, 5,000; and other, 15,000. Construct a Pareto diagram.

2. Form a project team of six or seven people, elect a leader, and construct a cause-and-effect diagram for bad coffee from a 22-cup coffee maker used in the office.

3. Design a check sheet for the maintenance of a piece of equipment such as a gas furnace, laboratory scale, or typewriter.

4. Construct a flow diagram for the manufacture of a product or the providing of a service.

5. An organization that fills bottles of shampoo tries to maintain a specific weight of the product. The table gives the weight of 110 bottles that were checked at random intervals. Make a tally of these weights and construct a frequency histogram. (Weight is in kilograms.)

6.00	5.98	6.01	6.01	5.97	5.99	5.98	6.01	5.99	5.98	5.96
5.98	5.99	5.99	6.03	5.99	6.01	5.98	5.99	5.97	6.01	5.98
5.97	6.01	6.00	5.96	6.00	5.97	5.95	5.99	5.99	6.01	5.98
6.01	6.03	6.01	5.99	5.99	6.02	6.00	5.98	6.01	5.98	5.99
6.00	5.98	6.05	6.00	6.00	5.98	5.99	6.00	5.97	6.00	6.00
6.00	5.98	6.00	5.94	5.99	6.02	6.00	5.98	6.02	6.01	6.00
5.97	6.01	6.04	6.02	6.01	5.97	5.99	6.02	5.99	6.02	5.99
6.02	5.99	6.01	5.98	5.99	6.00	6.02	5.99	6.02	5.95	6.02
5.96	5.99	6.00	6.00	6.01	5.99	5.96	6.01	6.00	6.01	5.98
6.00	5.99	5.98	5.99	6.03	5.99	6.02	5.98	6.02	6.02	5.97

6. Determine the average, median, mode, range, and standard deviation for each group of numbers.

   (a) 50, 45, 55, 55, 45, 50, 55, 45, 55
   (b) 89, 87, 88, 83, 86, 82, 84
   (c) 11, 17, 14, 12, 12, 14, 14, 15, 17, 17
   (d) 16, 25, 18, 17, 16, 21, 14
   (e) 45, 39, 42, 42, 43

7. Control charts for $\overline{X}$ and R are to be established on a certain dimension part, measured in millimeters. Data were collected in subgroup sizes of 6 and are given below. Determine the trial central line and control limits. Assume assignable causes and revise the central line and limits.

Subgroup Number	$\overline{X}$	R	***Subgroup Number***	$\overline{X}$	R
1	20.35	0.34	14	20.41	0.36
2	20.40	0.36	15	20.45	0.34
3	20.36	0.32	16	20.34	0.36
4	20.65	0.36	17	20.36	0.37
5	20.20	0.36	18	20.42	0.73
6	20.40	0.35	19	20.50	0.38
7	20.43	0.31	20	20.31	0.35
8	20.37	0.34	21	20.39	0.38
9	20.48	0.30	22	20.39	0.33
10	20.42	0.37	23	20.40	0.32
11	20.39	0.29	24	20.41	0.34
12	20.38	0.30	25	20.40	0.30
13	20.40	0.33			

8. The following table gives the average and range in kilograms for tensile tests on an improved plastic cord. The subgroup size is 4. Determine the trial central line and control limits. If any points are out of control, assume assignable causes, and determine the revised limits and central line.

Subgroup Number	$\overline{X}$	*R*	*Subgroup Number*	$\overline{X}$	*R*
1	476	32	14	482	22
2	466	24	15	506	23
3	484	32	16	496	23
4	466	26	17	478	25
5	470	24	18	484	24
6	494	24	19	506	23
7	486	28	20	476	25
8	496	23	21	485	29
9	488	24	22	490	25
10	482	26	23	463	22
11	498	25	24	469	27
12	464	24	25	474	22
13	484	24			

9. Assume that the data in Exercise 7 are for a subgroup size of 4. Determine the process capability.

10. Determine the process capability for Exercise 8.

11. Determine the capability index before ($\sigma_0 = 0.038$) and after ($\sigma_0 = 0.030$) improvement for the chapter example problem using specifications of 6.40 ± 0.15 mm.

12. What is the C_{pk} value after improvement for Exercise 11 when the process center is 6.40? When the process center is 6.30? Explain.

13. The Get-Well Hospital has completed a quality improvement project on the time to admit a patient using $\overline{X}$ and R charts. They now wish to monitor the activity using median and range charts. Determine the central line and control limits with the latest data in minutes, as given here.

Subgroup Number	*Observation*			*Subgroup Number*	*Observation*		
	X_1	X_2	X_3		X_1	X_2	X_3
1	6.0	5.8	6.1	13	6.1	6.9	7.4
2	5.2	6.4	6.9	14	6.2	5.2	6.8
3	5.5	5.8	5.2	15	4.9	6.6	6.6
4	5.0	5.7	6.5	16	7.0	6.4	6.1

Subgroup Number	Observation X_1	X_2	X_3	Subgroup Number	Observation X_1	X_2	X_3
5	6.7	6.5	5.5	17	5.4	6.5	6.7
6	5.8	5.2	5.0	18	6.6	7.0	6.8
7	5.6	5.1	5.2	19	4.7	6.2	7.1
8	6.0	5.8	6.0	20	6.7	5.4	6.7
9	5.5	4.9	5.7	21	6.8	6.5	5.2
10	4.3	6.4	6.3	22	5.9	6.4	6.0
11	6.2	6.9	5.0	23	6.7	6.3	4.6
12	6.7	7.1	6.2	24	7.4	6.8	6.3

14. The viscosity of a liquid is checked every half hour during one three-shift day. What does the run chart indicate? Data are 39, 42, 38, 37, 41, 40, 36, 35, 37, 36, 39, 34, 38, 36, 32, 37, 35, 34, 33, 35, 32, 38, 34, 37, 35, 35, 34, 31, 33, 35, 32, 36, 31, 29, 33, 32, 31, 30, 32, and 29.

15. Determine the trial central line and control limits for a p chart using the following data, which are for the payment of dental insurance claims. Plot the values on graph paper and determine if the process is stable. If there are any out-of-control points, assume an assignable cause and determine the revised central line and control limits.

Subgroup Number	Number Inspected	Number Noncon-forming	Subgroup Number	Number Inspected	Number Noncon-forming
1	300	3	14	300	6
2	300	6	15	300	7
3	300	4	16	300	4
4	300	6	17	300	5
5	300	20	18	300	7
6	300	2	19	300	5
7	300	6	20	300	0
8	300	7	21	300	2
9	300	3	22	300	3
10	300	0	23	300	6
11	300	6	24	300	1
12	300	9	25	300	8
13	300	5			

16. Determine the trial limits and revised control limits for a u chart using the data in the table for the surface finish of rolls of white paper. Assume any out-of-control points have assignable causes.

Lot Number	Sample Size	Total Nonconformities	Lot Number	Sample Size	Total Nonconformities
1	10	45	15	10	48
2	10	51	16	11	35
3	10	36	17	10	39
4	9	48	18	10	29
5	10	42	19	10	37
6	10	5	20	10	33
7	10	33	21	10	15
8	8	27	22	10	33
9	8	31	23	11	27
10	8	22	24	10	23
11	12	25	25	10	25
12	12	35	26	10	41
13	12	32	27	9	37
14	10	43	28	10	28

17. An np chart is to be established on a painting process that is in statistical control. If 35 pieces are to be inspected every 4 hours, and the fraction nonconforming is 0.06, determine the central line and control limits.

18. A quality technician has collected data on the count of rivet nonconformities in four-meters travel trailers. After 30 trailers, the total count of nonconformities is 316. Trial control limits have been determined and a comparison with the data shows no out-of-control points. What is the recommendation for the central line and the revised control limits for a count of nonconformities chart?

19. By means of a scatter diagram, determine if a relationship exists between product temperatures and percent foam for a soft drink.

Day	Product Temperature °F	Foam %	Day	Product Temperature °F	Foam %
1	36	15	11	44	32
2	38	19	12	42	33
3	37	21	13	38	20
4	44	30	14	41	27
5	46	36	15	45	35

Day	Product Temperature °F	Foam %	Day	Product Temperature °F	Foam %
6	39	20	16	49	38
7	41	25	17	50	40
8	47	36	18	48	42
9	39	22	19	46	40
10	40	23	20	41	30

20. Approximately what area is covered under the normal distribution curve between +/– 3 standard deviations?

(a) 95.40%
(b) 88.00%
(c) 99.73%
(d) 68.0 %

21. To calculate a performance index Pp, which single of the two should be known:
I Specification limits
II Standard deviation
III Bias
IV The process mean

(a) I and II only.
(b) I and III only.
(c) II and III only.
(d) II and IV only.

22. In an MSA, R&R is 38% and reproducibility component is predominant. Which of the following actions is most appropriate?

(a) Procure a better equipment.
(b) Calibrate the gauge immediately.
(c) Train the operators.
(d) Conduct a stability study to confirm that gauge performance is sustainable.

23. Which of the following statements cannot be true?

(a) Cp=1.2, Cpk=1.01
(b) Cp=2.3, Cpk=2.3
(c) Cp=1.5, Cpk=1,75,
(d) Cp=0.5, Cpk=0.1

24. A quality engineer to chart number of parts rejected every day. Daily production rate fluctuates between 1000 to 1200 parts. The engineer should use

(a) X-bar and range charts
(b) U-charts

(c) C-charts
(d) p-charts

25. A process is monitored using X-bar and Range chart with subgroup size of 5. The chart for averages shows control limits at 105 and 95. The process standard deviation for individuals is:

(a) 1.66
(b) 3.72
(c) 5
(d) 2.88

26. When a measuring instrument is calibrated, our objective is to reduce

(a) Accuracy
(b) Bias
(c) Repeatability
(d) Reproducibility

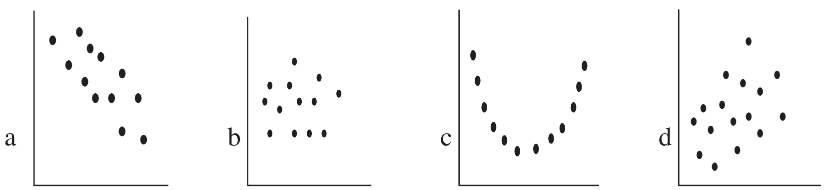
27. In R and R study, measurement variation due to equipment is called

(a) Bias
(b) Reproducibility
(c) Linearity
(d) Repeatability

28. The primary objective of control charts is

(a) To evaluate process mean and spread with reference to specification limits.
(b) To assess the process for stability.
(c) to stop the process when defect is observed.
(d) To ensure that the process is set correctly at the mean of specifications.

29. Which of the following is has strongest linear correlation?



16

Taguchi's Quality Engineering

Chapter Objectives

- Introduction to Taguchi's philosophy and loss function
- The structure of orthogonal arrays, linear graphs and interaction tables
- Understanding the application examples of designed experiments with orthogonal arrays
- Introduction to the signal-to-noise ratios with an application example
- Studying the parameter design using orthogonal arrays and signal-to-noise ratios
- Application examples with calculations and interpretation from the industry
- Brief overview of tolerance design to minimize variation like calculation method and application examples from the industry

Introduction

The significant portion of the body of knowledge associated with quality sciences was developed in the U.K. as design of experiments (DOE) (1), in the U.S. as statistical quality control (SQC) and in Japan as total quality control (TQC). More recently, Dr. Genichi Taguchi, a mechanical engineer who has won four Deming Awards, has added to this body of knowledge. In particular, he introduced the loss function concept, which combines cost, target, and variation into one metric with specifications being of secondary importance. Furthermore, he developed the concept of robustness, which means that noise factors are taken into account to ensure that the system functions correctly. Noise factors are uncontrollable variables that can cause significant variability in the process or the product.

Loss Function

Taguchi has defined quality as the loss imparted to society from the time a product is shipped. Societal losses include failure to meet customer requirements, failure to meet ideal performance, and harmful side effects. Many practitioners have included the losses due to production, such as raw material, energy, and labor consumed on unusable products or toxic by-products.

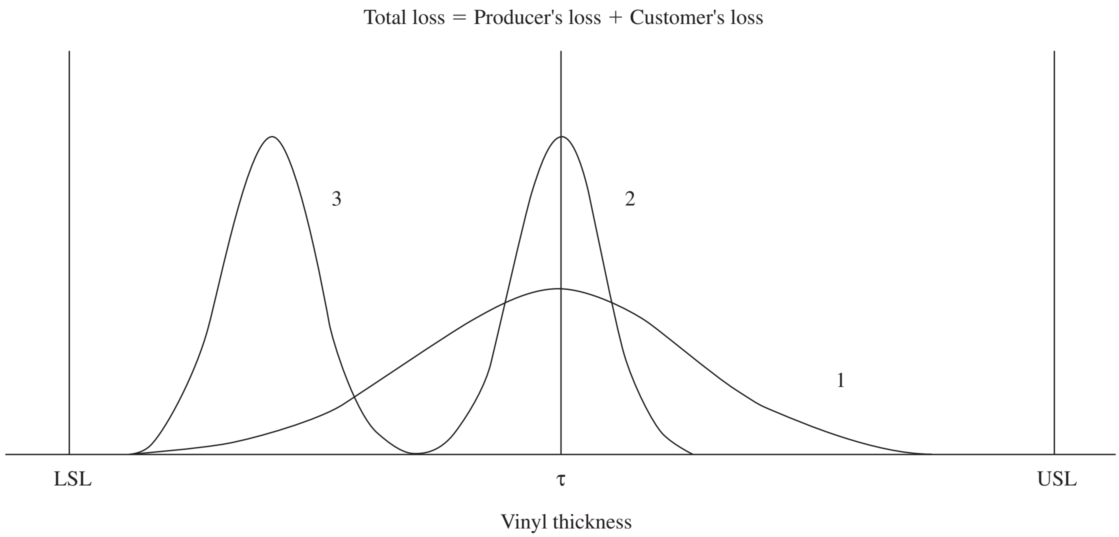


Figure 16-1 Loss to Society
Reproduced, with permission, from Taguchi Methods: Introduction to *Quality Engineering* (Allen Park, Mich.: American Supplier Institute, Inc, 1991).

The loss-to-society concept can be illustrated by an example associated with the production of large vinyl covers to protect materials from the elements. Figure 16-1 shows three stages in the evolution of vinyl thickness. At (1), the process is just capable of meeting the specifications (USL and LSL); however, it is on the target *tau*, τ.[1] After considerable effort, the production process was improved by reducing the variability about the target, as shown at (2). In an effort to reduce its production costs, the organization decided to shift the target closer to the LSL, as shown at (3). This action resulted in a substantial improvement by lowering the cost to the organization; however, the vinyl covers were not as strong as before. When farmers used the covers to protect wheat from the elements, they tore and a substantial loss occurred to the farmers. In addition, the cost of wheat increased as a result of supply-and-demand factors, thereby causing an increase in wheat prices and a further loss to society. The company's reputation suffered, which created a loss of market share with its unfavorable loss aspects.

Assuming the target is correct, losses of concern are those caused by a product's critical performance characteristics deviating from the target. The importance of concentrating on "hitting the target" is documented by Sony. In spite of the fact that the design and specifications were identical, U.S. customers preferred the color density of shipped TV sets produced by Sony–Japan over those produced by Sony–USA. Investigation of this situation revealed that the frequency distributions were markedly different, as shown in Figure 16-2. Even though Sony–Japan had 0.3% outside the specifications, the distribution was normal and centered on the target. The distribution of the Sony–USA was uniform between the specifications with no values outside specifications. It was clear that customers perceived quality as meeting the target (Japan) rather than just meeting the specifications (USA). Ford Motor Company had a similar experience with transmissions.

Out of specification is the common measure of quality loss. Although this concept may be appropriate for accounting, it is a poor concept for all other areas. It implies that all products that meet specifications are

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[1] Taguchi uses the symbol *m* for the target.

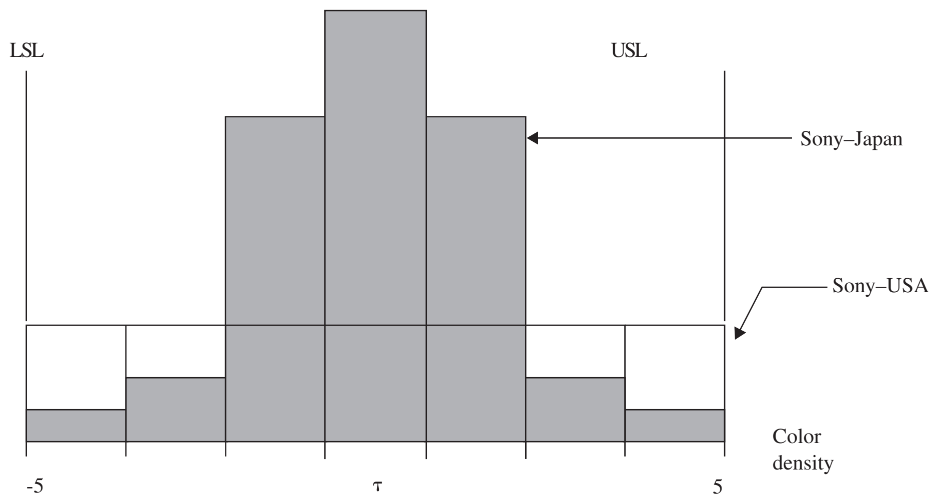


Figure 16-2 Distribution of Color Density for Sony-USA and Sony-Japan
Source: The Asahi, April 17, 1979.

good, whereas those that do not are bad. From the customer's point of view, the product that barely meets specification is as good (or bad) as the product that is barely out of specification. It appears the wrong measuring system is being used. The loss function corrects for the deficiency described above by combining cost, target, and variation into one metric.

Nominal-the-Best

Although Taguchi developed more than 68 loss functions, many situations are approximated by the quadratic function which is called the nominal-the-best type. Figure 16-3(a) shows the step function that describes the Sony–USA situation. When the value for the performance characteristic, y, is within specifications the loss is \$0, and when it is outside the specifications the loss is \$$A$. The quadratic function is shown at 16-3(b) and describes the Sony–Japan situation. In this situation loss occurs as soon as the performance characteristic, y, departs from the target, τ.

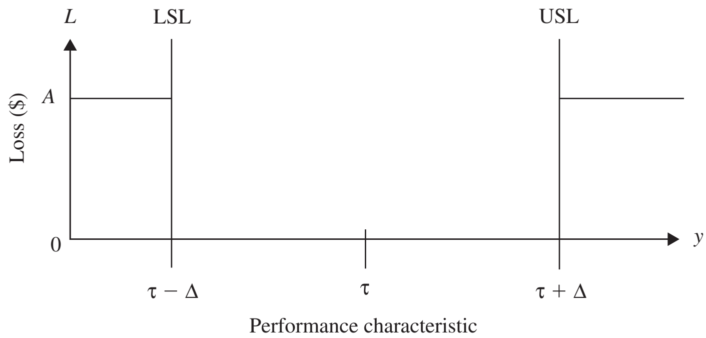
The quadratic loss function is described by the equation

$$L = k(y - \tau)^2$$

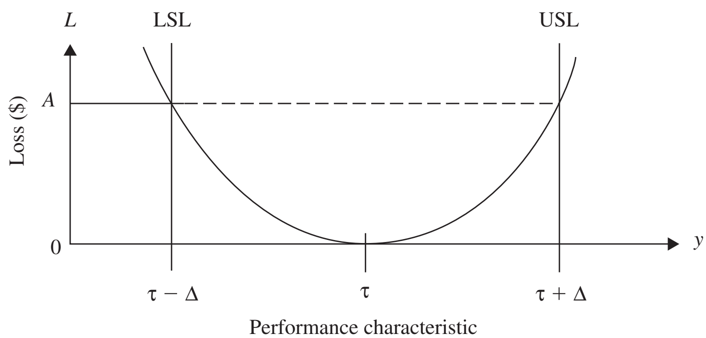
where L = cost incurred as quality deviates from the target
y = performance characteristic
τ = target
k = quality loss coefficient

The loss coefficient is determined by setting $\Delta = (y - \tau)$, the deviation from the target. When Δ is at the USL or LSL, the loss to the customer of repairing or discarding the product is \$$A$. Thus,

$$k = A/(y - \tau)^2 = A/\Delta^2$$



(a) Step function (Sony − USA)



(b) Quadratic function (Sony − Japan)

Figure 16-3 **Step and Quadratic Loss Functions**

EXAMPLE PROBLEM

If the specifications are 10 ± 3 for a particular quality characteristic and the average repair cost is \$230, determine the loss function. Determine the loss at $y = 12$.

$$k = A/\Delta^2 = 230/3^2 = 25.6$$

Thus, $L = 25.6\,(y - 10)^2$ and at $y = 12$,

$$\begin{aligned} L &= 25.6(y - 10)^2 \\ &= 25.6(12 - 10)^2 \\ &= \$102.40 \end{aligned}$$

Average Loss

The loss described here assumes that the quality characteristic is static. In reality, one cannot always hit the target, τ. It is varying due to noise, and the loss function must reflect the variation of many pieces rather than just one piece. Noise factors are classified as external and internal, with internal being further classified as unit-to-unit and deterioration.

A refrigerator temperature control will serve as an example to help clarify the noise concept. External noise is due to the actions of the user, such as the number of times the door is opened and closed, amount of food inside, the initial temperature, and so forth. Unit-to-unit internal noise is due to variation during production such as seal tightness, control sensor variations and so forth. Although this type of noise is inevitable, every effort should be made to keep it to a minimum. Noise due to deterioration is caused by leakage of refrigerant, mechanical wear of compressor parts, and so forth. This type of noise is primarily a function of the design. Noise factors cause deviation from the target, which causes a loss to society.

Figure 16-4 shows the nominal-the-best loss function with the distribution of the noise factors. An equation can be derived by summing the individual loss values and dividing by their number to give

$$\bar{L} = k\,[\sigma^2 + (\bar{y} - \tau)^2]$$

where $\bar{L}$ = the average or expected loss.

Because the population standard deviation, σ, will rarely be known, the sample standard deviation, s, will need to be substituted. This action will make the value somewhat larger; however, the average loss is a very conservative value.

The loss can be lowered by first reducing the variation, σ, and then adjusting the average, $\bar{y}$ to bring it on target, τ. The loss function "speaks the language of things," which is engineering's measure, and money, which is management's measure. Examples where the nominal-the-best loss function would be applicable are the performance characteristics of color density, voltage, dimensions, and so forth.

EXAMPLE PROBLEM

Compute the average loss for a process that produces steel shafts. The target value is 6.40 mm and the coefficient is 9500. Eight samples give 6.36, 6.40, 6.38, 6.39, 6.43, 6.39, 6.46, and 6.42.

$$s = 0.0315945 \qquad \bar{y} = 6.40375$$

$$\begin{aligned}\bar{L} &= k\left[s^2 + (\bar{y} - \tau)^2\right]\\ &= 9500\left[0.0315945^2 + (6.40375 - 6.40)^2\right]\\ &= \$9.62\end{aligned}$$

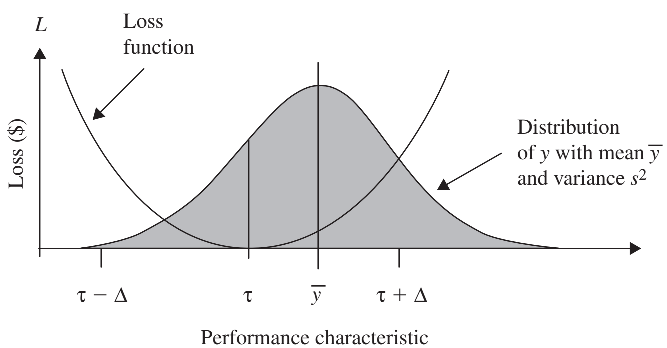


Figure 16-4 Average or Expected Loss
Reproduced, with permission, from Madhav S. Phadke, *Quality Engineering Using Robust Design* (Englewood Cliffs, NJ.: Prentice Hall, 1989).

Other Loss Functions

There are two other loss functions that are quite common, smaller-the-better and larger-the-better. Figure 16-5 illustrates the concepts.

As shown in the figure, the target value for smaller-the-better is 0, and there are no negative values for the performance characteristic. Examples of performance characteristics are radiation leakage from a microwave appliance, response time for a computer, pollution from an automobile, out of round for a hole, etc.

In the larger-the-better situation, shown in Figure 16-5(b), the target value is ∞, which gives a zero loss. There are no negative values and the worst case is at $y = 0$. Actually, larger-the-better is the reciprocal of smaller-the-better, and because of the difficulty of working with ∞, some practitioners prefer to work with the reciprocal. Thus, a larger-the-better performance characteristic of meters/second becomes a smaller-the-better performance characteristic of seconds/meter. Examples of performance characteristics are bond strength of adhesives, welding strength, automobile gasoline consumption and so forth.

Summary of the Equations

Table 16-1 gives a summary of the equations for the three common loss functions. It also shows the relationship of the loss function to the mean squared deviation (MSD).

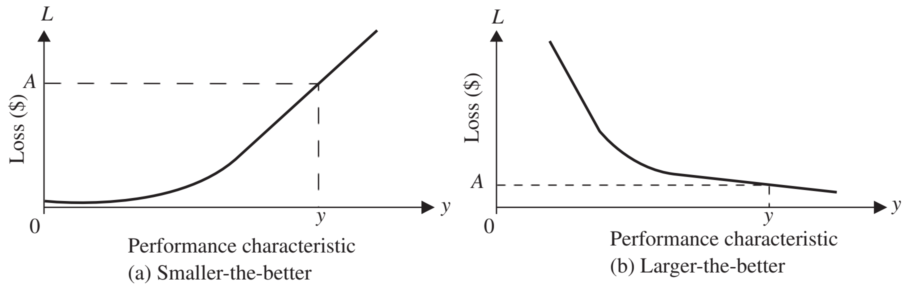


Figure 16-5 Smaller the-Better and Larger-the-Better Loss Functions

TABLE 16-1
Summary of the Equations for the Three Common Loss Functions

Nominal-the-best	$L = k\,(y - \tau)^2$	where $k = A/\Delta^2$
	$\bar{L} = k\,(\text{MSD})$	where $\text{MSD} = [\Sigma(y - \tau)^2]/n$
	$\bar{L} = k[\sigma^2 + (\bar{y} - \tau)^2]$	
Smaller-the-better	$L = ky^2$	where $k = A/y^2$
	$\bar{L} = k\,(\text{MSD})$	where $\text{MSD} = [\Sigma\, y^2]/n$
	$\bar{L} = k[\bar{y}^2 + \sigma^2]$	
Larger-the-better	$L = k(1/y^2)$	where $k = Ay^2$
	$\bar{L} = k\,(\text{MSD})$	where $\text{MSD} = [\Sigma\,(1/y^2)]/n$
	$\bar{L} = k[\Sigma(1/y^2)]/n$	

These three common loss functions will cover most situations. After selecting one of the loss functions, one point on the curve needs to be determined in order to obtain the coefficient. It is helpful to work with accounting to obtain this one point. Knowing the coefficient, the equation is complete and can be used to justify the use of resources and as a benchmark to measure improvement. It is much easier to use the loss function to obtain cost information than to develop an elaborate quality cost system. Cost data are usually quite conservative; therefore, it is not necessary for the loss function to be perfect for it to be effective.

Sometimes the loss function curves are modified for particular situations. For example, larger-the-better can be represented by one-half the nominal-the-best curve. Another situation occurs where the performance characteristic is weld strength. In such a case the larger-the-better curve can terminate at the strength of the parent metal rather than ∞. If the three common loss functions do not seem to be representative of a particular situation, then individual points can be plotted.

Orthogonal Arrays[2]

Orthogonal arrays (OA) are a simplified method of putting together an experiment. The original development of the concept was by Sir R. A. Fischer of England in the 1930s. Taguchi added three OAs to the list in 1956, and the National Institute of Science and Technology (NIST) of the United States added three.

An orthogonal array is shown in Table 16-2. The 8 in the designation OA8 represents the number of rows, which is also the number of treatment conditions (TC) and the degrees of freedom. Across the top of the orthogonal array is the maximum number of factors that can be used, which in this case is seven. The levels are designated by 1 and 2. If more levels occur in the array, then 3, 4, 5, and so forth, are used. Other schemes such as $-$, 0, and + can be used.

The orthogonal property of the OA is not compromised by changing the rows or the columns. Taguchi changed the rows from a traditional design so that TC 1 was composed of all level 1s and, if the team desired, could thereby represent the existing conditions. Also, the columns were switched so that the least amount of

TABLE 16-2

Orthogonal Array (OA8)*

TC	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

*Taguchi uses a more elaborate system of identification for the orthogonal arrays. It is the authors' opinions that a simple system using OA is more than satisfactory.

[2] Orthogonal arrays, interaction tables, and linear graphs in this chapter are reproduced, with permission, from *Taguchi Methods: Introduction to Quality Engineering* (Allen Park, Mich.: American Supplier Institute, Inc., 1991).

change occurs in the columns on the left. This arrangement can provide the team with the capability to assign factors with long setup times to those columns. Orthogonal arrays can handle dummy factors and can be modified. Refer to the bibliography for these techniques.

To determine the appropriate orthogonal array, use the following procedure:

1. Define the number of factors and their levels.
2. Determine the degrees of freedom.
3. Select an orthogonal array.
4. Consider any interactions.

The project team completes the first step.

Degrees of Freedom

The number of degrees of freedom is a very important value because it determines the minimum number of treatment conditions. It is equal to the sum of

(Number of levels - 1) for each factor.

(Number of levels - 1)(number of levels - 1) for each interaction.

One for the average.

An example problem will illustrate the concept.

EXAMPLE PROBLEM

Given four two-level factors, *A, B, C, D*, and two suspected interactions, *BC* and *CD*, determine the degrees of freedom, df. What is the answer if the factors are three-level?

$$\text{df} = 4(2 - 1) + 2(2 - 1)(2 - 1) + 1 = 7$$
$$\text{df} = 4(3 - 1) + 2(3 - 1)(3 - 1) + 1 = 17$$

At least seven treatment conditions are needed for the two-level, and 17 conditions are needed for the three-level. As can be seen by the example, the number of levels has considerable influence on the number of treatment conditions. Although a three-level design provides a great deal more information about the process, it can be costly in terms of the number of treatment conditions.

The maximum degrees of freedom is equal to

$$\text{df} = l^f$$

where l = number of levels
f = number of factors

For the example problem with two levels, df = 2^4 = 16. Table 16-3 shows the maximum degrees of freedom.

In the example problem, it was assumed that four of the two-factor interactions (*AB, AC, AD*, and *BD*), four of the three-factor interactions (*ABC, ABD, ACD*, and *BCD*), and the four-factor interaction (*ABCD*) would not occur. Interactions are discussed later in the chapter.

TABLE 16-3
Maximum Degrees of Freedom for a Four-Factor, Two-Level Experimental Design

Design Space				*df*
A	*B*	*C*	*D*	4
AB	*AC*	*AD*	*BC*	6
BD	CD			
ABC	*ABD*	*ACD*	*BCD*	4
ABCD				1
Average				1
			Sum	16

Selecting the Orthogonal Array

Once the degrees of freedom are known, the next step, selecting the orthogonal array (OA), is easy. The number of treatment conditions is equal to the number of rows in the OA and must be equal to or greater than the degrees of freedom. Table 16-4 shows the orthogonal arrays that are available, up to OA36. Thus, if the number of degrees of freedom is 13, then the next available OA is OA16. The second column of the table has the number of rows and is redundant with the designation in the first column. The third column gives the maximum number of factors that can be used, and the last four columns give the maximum number of columns available at each level.

Analysis of the table shows that there is a geometric progression for the two-level arrays of OA4, OA8, OA16, OA32, . . . , which is 2^2, 2^3, 2^4, 2^5, . . . , and for the three-level arrays of OA9, OA27, OA81, . . . , which is 3^2, 3^3, 3^4, ... Orthogonal arrays can be modified. Refer to the references for more information.

Interaction Table

Confounding is the inability to distinguish among the effects of one factor from another factor and/or interaction. In order to prevent confounding, one must know which columns to use for the factors. This knowledge is provided by an interaction table, which is shown in Table 16-6. The orthogonal array (OA8) is repeated in Table 16-5 for the convenience of the reader.

Let's assume that factor *A* is assigned to column 1 and factor *B* to column 2. If there is an interaction between factors *A* and *B*, then column 3 is used for the interaction, *AB*. Another factor, say, *C*, would need to be assigned to column 4. If there is an interaction between factor *A* (column 1) and factor *C* (column 4), then interaction *AC* will occur in column 5. The columns that are reserved for interactions are used so that calculations can be made to determine whether there is a strong interaction. If there are no interactions, then all the columns can be used for factors. The actual experiment is conducted using the columns designated for the factors, and these columns are referred to as the design matrix. All the columns are referred to as the design space.

Linear Graphs

Taguchi developed a simpler method of working with interactions using linear graphs. Two are shown in Figure 16-6 for OA8. They make it easier to assign factors and interactions to the various columns of an

TABLE 16-4
Orthogonal Array Information

OA	*Number of Rows*	*Maximum Number of Factors*	MAXIMUM NUMBER OF COLUMNS *2-Level*	*3-Level*	*4-Level*	*5-Level*
OA2	4	3	3	—	—	—
OA8	8	7	7	—	—	—
OA9	9	4	—	4	—	—
OA12	12	11	11	—	—	—
OA16	16	15	15	—	—	—
OA16[1]	16	5	—	—	5	—
OA18	18	8	1	7	—	—
OA25	25	6	—	—	—	6
OA27	27	13	—	13	—	—
OA32	32	31	31	—	—	—
OA32[1]	32	10	1	—	9	—
OA36	36	23	11	12	—	—
OA36[1]	36	16	3	13	—	—
⋮	⋮	⋮	⋮	⋮	⋮	⋮

Adapted, with permission, from Madhav S. Phadke, *Quality Engineering Using Robust Design* (Englewood Cliffs, NJ: Prentice Hall, 1989).

TABLE 16-5
Orthogonal Array OA8

TC	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

TABLE 16-6
Interaction Table for OA8

Column	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1	(1)	3	2	5	4	7	6
2		(2)	1	6	7	4	5
3			(3)	7	6	5	4
4				(4)	1	2	3
5					(5)	3	2
6						(6)	1
7							(7)

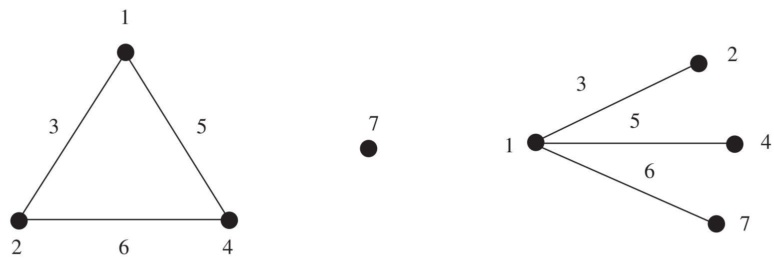


Figure 16-6 Linear Graphs for OA8

array. Factors are assigned to the points. If there is an interaction between two factors, then it is assigned to the line segment between the two points. For example, using the linear graph on the left in the figure, if factor *B* is assigned to column 2 and factor *C* is assigned to column 4, then interaction *BC* is assigned to column 6. If there is no interaction, then column 6 can be used for a factor.

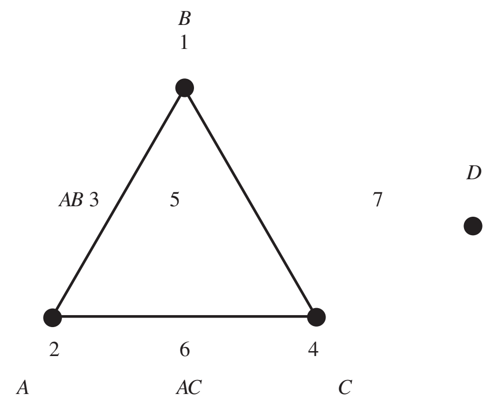
The linear graph on the right would be used when one factor has three two-level interactions. Three-level orthogonal arrays must use two columns for interactions, because one column is for the linear interaction and one column is for the quadratic interaction. The linear graphs—and, for that matter, the interaction tables—are not designed for three or more factor interactions, which rarely occur. Linear graphs can be modified; refer to the references for modification techniques. Use of the linear graphs requires some trial-and-error activity, and a number of solutions may be possible, as shown by the example problem.

EXAMPLE PROBLEM

An experimental design has four two-level factors (*A, B, C, D*) where only main effects are possible for factor *D* and there is no *BC* interaction. Thus, only interactions *AB* and *AC* are possible, and they can be assigned the line segments 3 and 5, 3 and 6, or 5 and 6, with their apex for factor *A*. Factors *B* and *C* are then assigned to the adjacent points. Column 7 or a line segment that does not have an interaction is used for factor *D*. A number of solutions are possible; one is shown here. The one chosen might well be a function of the setup time when the experiment is run. Column 5 is not used, so it is given the symbol *UX* for unexplained, and calculations for this column should show no effect (very small variation).

Orthogonal Array OA8

	B	*A*	*AB*	*C*	*UX*	*AC*	*D*
TC	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2



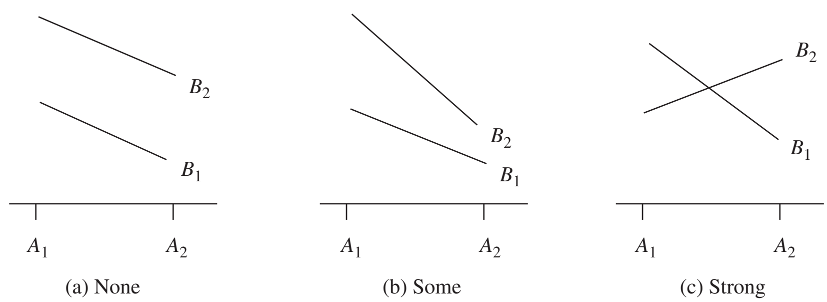


Figure 16-7 **Interaction Between Two Factors**

Interactions

The fourth step in the procedure is to consider interactions. Figure 16-7 shows the graphical relationship between two factors. At (a) there is no interaction because the lines are parallel; at (b) there is some interaction; and at (c) there is a strong interaction. The graph is constructed by plotting the points A_1B_1, A_1B_2, A_2B_1, and A_2B_2 drawing lines B_1 and B_2. Taguchi's approach to interactions are given in the following list.

1. Interactions use degrees of freedom; therefore, more treatment conditions are needed or fewer factors can be used.

2. Orthogonal arrays are used in parameter design to obtain optimal factor/levels for robustness and cost in order to improve product and process performance. On the other hand, statistics are applied in pure and applied research to find relationships and a mathematical model. The emphasis is different—one engineering and the other mathematical.

3. Interactions are primarily between control factors and noise factors. Control and noise factors are discussed later.

4. As long as interactions are relatively mild, main effect analysis will give the optimal results and good reproducibility.

5. OA12 (two-level) and OA18 (three-level) are recommended so that if interactions are present, they are dispersed among all the factors.

6. Engineers should strive to develop a design that uses main effects only.

7. Control factors that will not interact should be selected. For example, the dimensions length and width will frequently interact, whereas the area may provide the same information and save two degrees of freedom.

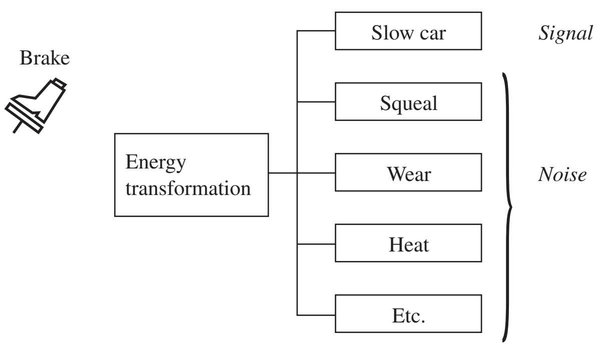
8. Energy-related outputs, such as braking distance, should be selected whenever possible. This concept is discussed in the next section.

9. An unsuccessful confirmation run may indicate an interaction.

The appendix gives the common orthogonal arrays with their interaction tables and linear graphs. OA12 and OA18 do not have linear graphs, because the effect of any interactions are dispersed within the array.

Signal-to-Noise (S/N) Ratio

Another of Taguchi's contributions is the signal-to-noise (S/N) ratio. It was developed as a proactive equivalent to the reactive loss function. Figure 16-8 illustrates the concept of the S/N ratio. When a person puts his/her foot on the brake pedal of a car, energy is transformed with the intent to slow the car, which is the signal.



$$S/N = \frac{\textit{Amt. of energy for intended function}}{\textit{Amt. of energy wasted}} = \frac{\textit{Signal}}{\textit{Noise}}$$

Figure 16-8 **Concept of Signal-to-Noise (S/N) Ratio**

However, some of the energy is wasted by squeal, pad wear, heat, and so forth. The figure emphasizes that energy is neither created nor destroyed. At the bottom of the figure the concept is written in the form of a ratio.

Signal factors ($\bar{y}$) are set by the designer or operator to obtain the intended value of the response variable. Noise factors (s^2) are not controlled or are very expensive or difficult to control. Both the average, $\bar{y}$, and the variance, s^2, need to be controlled with a single figure of merit. In elementary form, S/N is $\bar{y}$/s, which is the inverse of the coefficient of variation and a unitless value. Squaring and taking the log transformation gives

$$S/N_N = \log_{10}(\bar{y}^2/s^2)$$

Adjusting for small sample sizes and changing from Bels to decibels by multiplying by ten yields

$$S/N_N = 10\log_{10}\left[(\bar{y}^2/s^2) - (1/n)\right]$$

which is the nominal-the-best S/N_N ratio. The average and sample standard deviation are squared to eliminate any negative averages and to use the variance, which is an unbiased measure of the dispersion. By taking the log transformation, the calculated value becomes a relative one.

The S/N units are decibels (dB), which are tenths of a Bel and are a very common unit in electrical engineering. Why use decibels? If someone says that the voltage is 6 volts too low, does it indicate a problem? Of course, it depends if you are describing a 745,000-volt power line or the battery in your car. It makes more sense to say that your car battery voltage is 50% low or is only half of the target value of 12 volts. A useful system for describing this condition is logarithms. Another advantage of using decibels as the unit of measure is that they are a relative measure. For example, the difference between 74 dB and 71 dB is the same as the difference between 7 dB and 10 dB. Both are twice as good or bad. Decibels also are not affected by different units. Temperature in Celsius or in Kelvin will give different answers but the same amount of change. Table 16-7 shows some linear and percent changes for the decibel change. The percent change is found by subtracting the linear change from 1.000, dividing by 1.000, and multiplying by 100. Thus, a 2.0-dB change is

$$\frac{(1.59 - 1.000)}{1.000}100 = 59\%$$

TABLE 16-7
Decibel, Linear, and Percent Change

dB Change (log)	*Linear Change (nonlog) 10^8*	*Percent Change*
0.001	1.00	0
0.5	1.12	12
1.0	1.26	26
1.5	1.41	41
2.0	1.59	59
3.0	2.00	100
6.0	4.00	300
10.0	10.00	900

There are many different S/N ratios. Six basic ones are

1. Nominal-the-best
2. Target-the-best
3. Smaller-the-better
4. Larger-the-better
5. Classified attribute
6. Dynamic

We will discuss those ratios that parallel the loss function.

Nominal-the-Best

The equation for nominal-the-best was given in the initial discussion. It is used wherever there is a nominal or target value and a variation about that value, such as dimensions, voltage, weight, and so forth. The target (τ) is finite but not zero. For robust (optimal) design, the S/N ratio should be maximized. The nominal-the-best S/N value is a maximum when the average is large and the variance is small. When the average is off target on the high side, the S/N_N value can give more favorable information; when off target on the low side, the value can give less favorable information. Taguchi's approach is to reduce variation and then bring the average on target. Another S/N_T ratio, called target-the-best, eliminates these problems provided the target is known.[3]

EXAMPLE PROBLEM

Determine the S/N ratio for a process that has a temperature average of 21°C and a sample standard deviation of 2°C for four observations.

$$\begin{aligned} S/N_N &= 10 \log_{10}\left[\left(\bar{y}^2/s^2\right) - \left(1/n\right)\right] \\ &= 10 \log_{10}\left[\left(21^2/2^2\right) - \left(1/4\right)\right] \\ &= 20.41 \text{ dB} \end{aligned}$$

The adjustment for the small sample size in the example problem has little effect on the answer. If it had not been used, the answer would have been 20.42 dB.

Smaller-the-Better

The S/N_S ratio for smaller-the-better is used for situations where the target value (τ) is zero, such as computer response time, automotive emissions, or corrosion. The equation is

$$S/N_S = -10 \log_{10}[\text{MSD}] = -10 \log_{10}\left[\left(\Sigma y^2\right)/n\right]$$

[3] Thomas B. Barker, *Engineering Quality by Design* (New York: Marcel Dekker, 1990).

The negative sign is used to ensure that the largest value gives the optimum value for the response variable and, therefore, robust design. Mean standard deviation (MSD) is given to show the relationship to the loss function.

EXAMPLE PROBLEM

A bread-stuffing producer is comparing the calorie content of the original process with a new process. Which has the lower content and what is the difference? Results are

Original	130	135	128	127
Light	115	112	120	113

$$\begin{aligned} \mathrm{S/N}_S &= -10 \log_{10}\left[\left(\Sigma y^2\right)/n\right] \\ &= -10 \log_{10}\left[\left(130^2 + 135^2 + 128^2 + 127^2\right)/4\right] \\ &= -42.28 \text{ dB} \end{aligned}$$

$$\begin{aligned} \mathrm{S/N}_S &= -10 \log_{10}\left[\left(\Sigma y^2\right)/n\right] \\ &= -10 \log_{10}\left[\left(115^2 + 112^2 + 120^2 + 113^2\right)/4\right] \\ &= -41.22 \text{ dB} \end{aligned}$$

$$\Delta = \left|-41.22 - (-42.28)\right| = 1.06 \text{ dB}$$

Light is lower in calories by 26%.

Larger-the-Better

The third S/N ratio is larger-the-better. It is used where the largest value is desired, such as weld strength, gasoline mileage, or yield. From a mathematical viewpoint, the target value is 00. Like the loss function, it is the reciprocal of smaller-the-better. The equation is

$$\mathrm{S/N}_L = -10 \log_{10}[\mathrm{MSD}] = -10 \log_{10}\left[\Sigma\left(1/y^2\right)/n\right]$$

EXAMPLE PROBLEM

Using the existing design, the lives of three AA batteries are 20, 22, and 21 hours. An experimental design produces batteries with values of 17, 21, and 25 hours. Which is the better design and by how much? What is your next step?

$$\begin{aligned} S/N_L &= -10\log_{10}\left[\Sigma(1/y^2)/n\right] \\ &= -10\log_{10}\left[\left(\frac{1}{20^2}+\frac{1}{22^2}+\frac{1}{21^2}\right)\Big/3\right] \\ &= 26.42 \text{ dB} \end{aligned}$$

$$\begin{aligned} S/N_L &= -10\log_{10}\left[\Sigma(1/y^2)/n\right] \\ &= -10\log_{10}\left[\left(\frac{1}{17^2}+\frac{1}{21^2}+\frac{1}{25^2}\right)\Big/3\right] \\ &= 26.12 \text{ dB} \end{aligned}$$

$$\Delta = |26.42 - 26.12| = 0.3 \text{ dB}$$

The new design is 7% better. It is suggested that more data be collected.

Although signal-to-noise ratios have achieved good results, they have not been accepted by many in the statistical community. The controversy has focused more attention on variation or noise, whereas in the past the entire focus was on the average or signal. It is our opinion that with computer programs, it is quite easy to use three metrics—average, variance, and signal-to-noise. Also, note that the advantages of the log transformation can be used with the average and the variance.

Parameter Design

Introduction

There are three product-development stages: product design, process design, and production. These stages are shown in Table 16-8, along with the three previously discussed sources of variation or noise: environmental variables, product deterioration, and production variations. Only at the product design stage are countermeasures possible against all the sources of variation.

TABLE 16-8
Product Development Stages

Product Development Stages	SOURCES OF VARIATION (NOISE)		
	Environmental Variables	*Product Deterioration*	*Production Variations*
Product design	0	0	0
Process design	X	X	0
Production	X	X	0

0—Countermeasures possible; X—Countermeasures impossible

Adapted, with permission, from Raghu N. Kackar, "Taguchi's Quality Philosophy: Analysis and Commentary," *Quality Progress* (December 1986): 21–29.

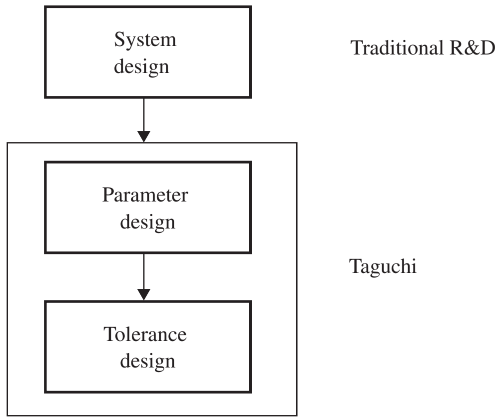


Figure 16-9 Robust Design is the Cornerstone of Taguchi's philosophy

The cornerstone of Taguchi's philosophy is robust design. Figure 16-9 illustrates the three design components: system design, parameter design, and tolerance design, with robust design encompassing the latter two. System design is composed of traditional research and development. Until recently, Japan spent approximately 40%, 40%, and 20% and the United States spent 70%, 2%, and 28%, respectively, of their time and money on the three design components.

System design is the development of the prototype. It uses engineering and scientific knowledge to define initial setting of product and process parameters. Knowledge of customer requirements is important at this stage.

Parameter design is the selection of the optimal conditions (parameters), so that the product is least sensitive to noise variables. The idea is to start with inferior-grade, low-cost components and raw materials. Nothing is more foolish than research using high-priced materials and components. Variability is reduced by identifying control and noise factors and treating them separately in order to innovate and develop a product that is high in quality and low in cost. The concept uses OAs, response tables, and the metrics of S/N ratios, variances, and averages to obtain the appropriate parameters.

An excellent example of robust design is provided by the Ina Tile Company. Figure 16-10 shows a cross section of an 80-meter-long kiln for baking tiles. The kiln, purchased from West Germany, had quality problems because the tiles at the center were baked at a lower temperature than the outer tiles, which resulted in nonuniform dimensions. One hundred percent inspection was used to screen for improper dimensions; however, this activity was very expensive. The kiln could be redesigned to give uniform dimensions, but the redesign would be very expensive and there was no guarantee that it would correct the problem. It was decided to run an experiment using an OA8 design with seven variables at two levels. The results showed that by increasing the lime content of the clay from 1% to 5%, the excessive dimensional variation was eliminated. Lime is an inexpensive material in the content of the clay. It was also found that an expensive material in the process could be reduced.

Parameter Design Example

An example of an improved product at the design stage is illustrated by the development of a paper feeder for a copy machine. It is important that the prototype, as illustrated by the schematic in Figure 16-11, be constructed so that experiments can be run on the factors. The first step for the project team is to determine the performance characteristic from the customer's viewpoint, which most likely will be "no

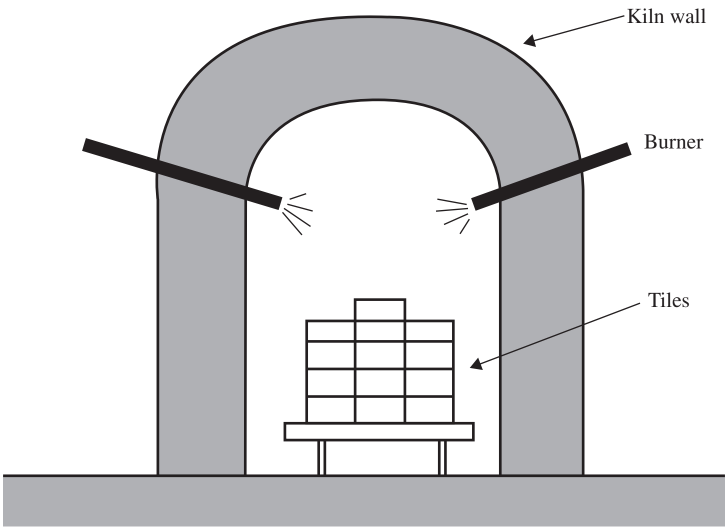


Figure 16-10 Ina Tile Company
Reproduced, with permission, from Medhav S. Phadke, *Quality Engineering* Using Robust Design (Englewood Cliffs, NJ: Prentice Hall, 1989).

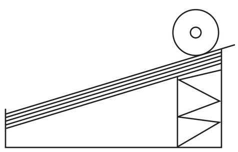


Figure 16-11 Parameter Design Concept Using a Paper Feed Device

multisheets and no misses." Next, the factors and their levels for the control factors are determined. The team decides to use a three-level design with four control factors. They are factor A—spring tension with the levels low, medium, and high; factor B—roller diameter with the levels small, medium, and large; factor C—speed with the levels slow, medium, and fast; and factor D—roller durometer with the levels soft, medium, and hard. The third step is for the team to determine the noise or uncontrollable factors that can, however, be controlled in an experiment. Note that uncontrollable factors can also be very expensive to control. The team identifies three noise factors and decides to experiment using two levels. They are factor K—paper weight with the levels 12 and 20 lb; factor L—moisture with the levels 30% RH and 80% RH; and factor M—number of sheets with the levels 1 and 100. Not all sources of noise can be included because of lack of knowledge. Additional information on the inclusion of noise factors is given later.

The experimental design that results from the preceding example is shown in Figure 16-12. Basically there are two arrays: the control factor array, which is also called the inner, or controllable, array, and the noise array, which is also called the outer, or uncontrollable (except in the experiment), array. An OA9 with its nine treatment conditions is used for the inner array, and an OA4 with its four treatment conditions is used for the outer array. Treatment condition 1 is set up with all level 1s, and four runs are made—one for each of the noise treatment conditions. These four runs produce four results y_1, y_2, y_3, and y_4, which are

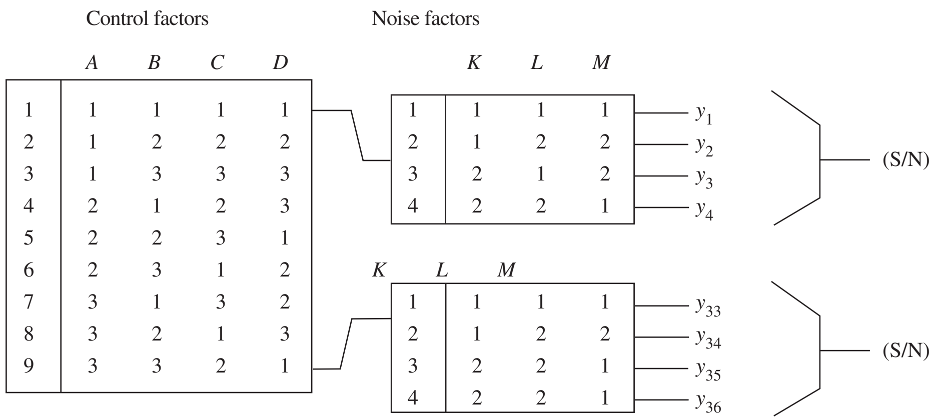


Figure 16-12 Parameter Design Concept
Adapted, with permission, from Raghu N. Kackar, "Taguchi's Quality Philosophy: Analysis and Commentary." *Quality Progress* (December 1986): 21-29.

combined to produce the S/N_1 ratio for TC 1 of the control factors. This process is repeated for the other nine treatment conditions of the control factors. The results are then used in a response table to determine the strong factors and their levels.

A number of case studies will be used to illustrate the approach. Each case builds on the preceding ones.

Case I: Iron Casting

This case illustrates the basic technique using a two-level, smaller-the-better performance characteristic with the maximum number of factors. Wirco Castings, Inc., designed an experiment to evaluate the percent of casting that required finish grinding, with the objective of reducing this labor-intensive operation. It was decided there were seven factors that influenced the grinding operation, and they are shown in Table 16-9, along with their levels. Noise factors were not considered to be important, so they were not included in this experiment.

TABLE 16-9
Factors and Levels for Iron Casting Design

Factors	*Level 1*	*Level 2*
A. Sand compact	A_1 = 55 mm	A_2 = 49 mm
B. Iron temperature	B_1 = FT	B_2 = Chill
C. Clay addition	C_1 = 6.5 lb	C_2 = 16 lb
D. Mold hardness	D_1 = 1000 lb/in.^{2}	D_2 = 750 lb/in.^{2}
E. Mulling time	E_1 = 4 min	E_2 = 1.7 min
F. Seacoal addition	F_1 = 6.7 lb	F_2 = 15 lb
G. Sand addition	G_1 = 0	G_2 = 150 lb

DESIGN AND RESULTS

An OA8 was used for the design, as shown in Table 16-10 with the treatment condition results. Each treatment condition was run and produced 16 molds with 4 cavities per mold, for a total of 64 castings per TC.

The effect of each factor and its levels are calculated here:

$$A_1 = (89 + 55 + 38 + 44)/4 = 56.5 \qquad A_2 = (83 + 16 + 66 + 55)/4 = 55.0$$
$$B_1 = (89 + 55 + 83 + 16)/4 = 60.8 \qquad B_2 = (38 + 44 + 66 + 55)/4 = 50.8$$
$$C_1 = (89 + 55 + 66 + 55)/4 = 66.3 \qquad C_2 = (38 + 44 + 83 + 16)/4 = 45.3$$
$$D_1 = (89 + 38 + 83 + 66)/4 = 69.0 \qquad D_2 = (55 + 44 + 16 + 66)/4 = 42.5$$
$$E_1 = (89 + 38 + 16 + 55)/4 = 49.5 \qquad E_2 = (55 + 44 + 83 + 66)/4 = 62.0$$
$$F_1 = (89 + 44 + 83 + 55)/4 = 67.8 \qquad F_2 = (55 + 38 + 16 + 66)/4 = 43.8$$
$$G_1 = (89 + 44 + 16 + 66)/4 = 53.8 \qquad G_2 = (55 + 38 + 83 + 55)/4 = 56.8$$

Calculations for level 2 can be simplified by subtracting level 1 from the total.

RESPONSE TABLE AND GRAPH

Values from the preceding calculations are placed in a *response table*, as shown in Table 16-11. The absolute difference, Δ, between level 1 and level 2 is calculated and placed in the table. A *response graph*, as shown by Figure 16-13, can also be constructed to aid in visualizing the strong effects. This graph is Paretoized, with the largest difference on the left and the smallest difference on the right.

TABLE 16-10
Orthogonal Array and Results for Iron Castings

TC	*A* *1*	*B* *2*	*C* *3*	*D* *4*	*E* *5*	*F* *6*	*G* *7*	*Results* *%*
1	1	1	1	1	1	1	1	89
2	1	1	1	2	2	2	2	55
3	1	2	2	1	1	2	2	38
4	1	2	2	2	2	1	1	44
5	2	1	2	1	2	1	2	83
6	2	1	2	2	1	2	1	16
7	2	2	1	1	2	2	1	66
8	2	2	1	2	1	1	2	55

TABLE 16-11
Response Table for Iron Casting

	A	*B*	*C*	*D*	*E*	*F*	*G*
Level 1	56.5	60.8	66.3	69.0	49.5	67.8	53.8
Level 2	55.0	50.8	45.3	42.5	62.0	43.8	57.8
Δ	1.5	10.0	21.0	26.5	12.5	24.0	4.0

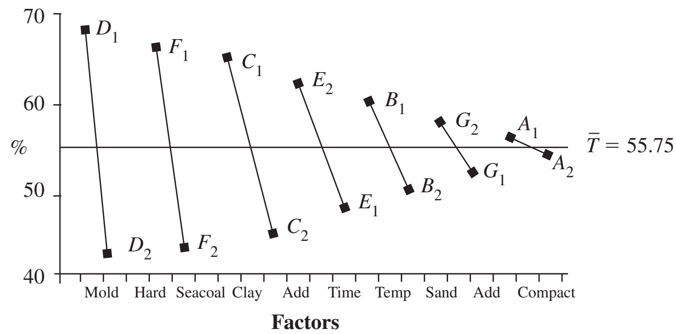


Figure 16-13 Response Graph for Iron Casting

A simple rule is used as a guideline to analyze which of the factors has a strong effect on the process and which is merely a natural variation. Take the largest difference, which in this case is 26.5, and divide in half, to give 13.3. All differences equal to or above 13.3 are considered to be strong effects. Because this experiment is a smaller-the-better performance, the strong factors and their levels are D_2, F_2, and C_2.

CONFIRMATION RUN

The next step is to predict the outcome of the confirmation run using the equation

$$\hat{\mu} = \bar{T} - (\bar{T} - D_2) - (\bar{T} - F_2) - (\bar{T} - C_2) = D_2 + F_2 + C_2 - (N-1)\bar{T}$$

where $\hat{\mu}$ = estimate of the response for y
$\bar{T}$ = overall average of the response data

Calculations are

$$\bar{T} = \Sigma y/n = (89 + 55 + 38 + 44 + 83 + 16 + 66 + 55)$$

$$\begin{aligned}\hat{\mu} &= D_2 + F_2 + C_2 - (N-1)\bar{T} \\ &= 42.5 + 43.8 + 45.3 - (3-1)55.8 \\ &= 20.0\%\end{aligned}$$

A fundamental part of the Taguchi approach is the confirmation run. For this experiment the factors and their levels are D_2, F_2, C_2, E_1, B_1, G_2, and A_1, and the result from the confirmation run was 19.2%, which is very close to the predicted value. TC 6 also had good results at 16%, using most of the same factors and their levels. Thus, the experiment is a success, and the new parameters are the strong effects of D_2, F_2, and C_2. The levels of the other four factors might not make any difference. If the confirmation run does not show good producibility, like this case, then (1) the factor levels may have been set too close, (2) an important factor was missing, or (3) interactions were present due to the improper selection of control factors.

As a result of this experiment, less finish grinding was needed, thereby reducing the workforce from six to five people. In addition, the parameter changes resulted in a reduction in scrap from 8% to 4% and in smoother castings.

Although the S/N ratio and variance have good additivity, the percent nonconforming should not be outside the range of 20% to 80%. Fortunately, in this experiment, the data were within that range. If such had not been the case, an omega transformation would have been made on each of the eight results. For information on the omega transformation, see the references.

Case II: Grille[4]

This case is a two-level design with a smaller-the-better performance characteristic and interactions. Automotive grille opening panels were shipped to Chrysler by a supplier and assembled in the car prior to painting. Surface imperfections in the finish (pops) caused a first run capability of 77% conforming, and the condition was not detected prior to painting. A joint supplier/customer team, using the problem-solving techniques of flow process and cause-and-effect diagrams, decided on a two-level design with nine control variables and five potential interactions, as shown in Table 16-12.

Five potential interactions were possible: *AB, AC, AD, BF*, and *FH*.

Because there are 15 degrees of freedom, an OA16 was needed. A modified linear graph was used to determine the experimental design, which is shown in Table 16-13. No factor or interaction was assigned to column 15, so it is labeled unexplained, *UX*.

The experiment was run with two repetitions per TC and a response table calculated as shown in Table 16-14. Using the one-half guideline, the factors *E, A*, and *C* and the interactions *FH, AC*, and *BF*, are the strong effects. It is also noted that *UX* has a strong effect.

TABLE 16-12

Factors and Levels for Grille

	Variable	*Level 1*	*Level 2*
A	Mold pressure	Low	High
B	Mold temp.	Low	High
C	Mold cycle	Low	High
D	Cut pattern	Method I	Method II
E	Priming	Method I	Method II
F	Viscosity	Low	High
G	Weight	Low	High
H	Mat'l thickness	Process I	Process II
I	Glass type	Type I	Type II

[4] Adapted, with permission, from P. I. Hsieh and D. E. Goodwin, "Sheet Molded Compound Process Improvement," *Fourth Symposium on Taguchi Methods* (Allen Park, Mich.: American Supplier Institute, Inc., 1986).

Table 16-13
Experimental Design Using an OA16 and Results for Grille

1 A	2 B	3 AB	4 F	5 G	6 BF	7 E	8 C	9 AC	10 H	11 I	12 D	13 AD	14 FH	15 UX	R1	R2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	56	10
1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	17	2
1	1	1	2	2	2	2	1	1	1	1	2	2	2	2	2	1
1	1	1	2	2	2	2	2	2	2	2	1	1	1	1	4	3
1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	3	1
1	2	2	1	1	2	2	2	2	1	1	2	2	1	1	4	13
1	2	2	2	2	1	1	1	1	2	2	2	2	1	1	50	49
1	2	2	2	2	1	1	2	2	1	1	1	1	2	2	2	3
2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	3
2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	0	3
2	1	2	2	1	2	1	1	2	1	2	2	1	2	1	3	2
2	1	2	2	1	2	1	2	1	2	1	1	2	1	2	12	2
2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	3	4
2	2	1	1	2	2	1	2	1	1	2	2	1	1	2	4	10
2	2	1	2	1	1	2	1	2	2	1	2	1	1	2	0	5
2	2	1	2	1	1	2	2	1	1	2	1	2	2	1	0	8

The interactions are plotted to determine the level for those factors involved in the interactions. Using the results in Table 16-13, the calculations are

$$A_1C_1 = (56 + 10 + 2 + 1 + 3 + 1 + 50 + 49)/8 = 21.5$$
$$A_1C_2 = (17 + 2 + 4 + 3 + 4 + 13 + 2 + 3)/8 = 6.0$$
$$A_2C_1 = (1 + 3 + 3 + 2 + 3 + 4 + 0 + 8)/8 = 3.0$$
$$A_2C_2 = (0 + 3 + 12 + 2 + 4 + 10 + 0 + 8)/8 = 4.9$$

$$B_1F_1 = (56 + 10 + 17 + 2 + 1 + 3 + 0 + 3)/8 = 11.5$$
$$B_1F_2 = (2 + 1 + 4 + 3 + 3 + 2 + 12 + 2)/8 = 3.6$$
$$B_2F_1 = (3 + 1 + 4 + 13 + 3 + 4 + 4 + 10)/8 = 5.3$$
$$B_2F_2 = (50 + 49 + 2 + 3 + 0 + 5 + 0 + 8)/8 = 14.6$$

$$F_1H_1 = (56 + 10 + 4 + 13 + 1 + 3 + 4 + 10)/8 = 12.6$$
$$F_1H_2 = (17 + 2 + 3 + 1 + 0 + 3 + 3 + 4)/8 = 4.1$$
$$F_2H_1 = (2 + 1 + 2 + 3 + 3 + 2 + 0 + 8)/8 = 2.6$$
$$F_2H_2 = (4 + 3 + 50 + 49 + 12 + 2 + 0 + 5)/8 = 15.6$$

These values are plotted in Figure 16-14. Analysis of the *AC* interaction shows that A_2 and C_1 give the best interaction results; however, C_2 gives the best results from a factor viewpoint, as seen in Table 16-14. If we

Table 16-14
Response Table for Grille

Factor	*Level 1*	*Level 2*	*Difference*
E	14.31	3.19	11.12
A	13.75	3.75	10.00
C	12.06	5.44	6.62
D	7.19	10.31	3.12
B	7.56	9.94	2.38
I	7.50	10.00	2.50
H	7.62	9.88	2.26
F	8.38	9.12	0.74
G	8.62	8.88	0.26
FH	14.12	3.38	10.74
AC	13.19	4.31	8.88
BF	13.06	4.44	8.62
AD	6.81	10.69	3.88
AB	8.06	9.44	1.38
UX	13.25	4.25	9.00

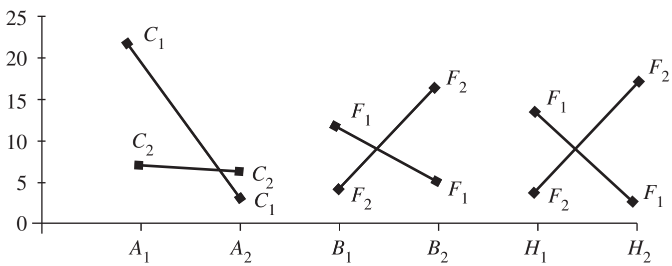


Figure 16-14 **Interaction Graphs for Grille**

use C_1, the gain will be 1.7 (4.6 − 2.9) from the interaction, but there will be a loss of 6.7 (12.1 − 5.4) from the factor. Thus, A_2 and C_2 will give the optimum results. For the *BF* interaction, the best values are at B_1 and F_2, although B_2 and F_1 are close. The decision may be based on some criterion other than "pops." The level chosen for F influences the choice of the level for H. Thus, if F_2 is chosen, then H_1 would be used; if F_1 is chosen, then H_2 would be used. The preceding analysis could just as well have started with the *FH* interaction rather than the *BF* interaction.

The confirmation run gave a first-time capability of 96%, for a savings of \$900,000 per year. Future experiments are planned to find the reason for *UX* being too high.

Case III: Tube[5]

This case is a three-level control array and a two-level noise array, with a larger-the-better performance characteristic using the average and a signal-to-noise ratio. The experiment involves the joining of a small flexible tube to a rigid plastic connector, with the objectives of minimum assembly effort and maximum pull-off force in pounds; the focus is on the latter. A project team determines the control factors and their levels, and they are listed in Table 16-15.

An OA9 is used for the four control factors, and an OA4 is used for the three noise factors. The layout, along with the results of the experiment, are shown in Table 16-16. For TC 1, there are four observations for the three

TABLE 16-15

Factors and Levels for Tube

Control Factors	*Levels*		
A. Interference	Low	Med.	High
B. Wall thickness	Thin	Med.	Thick
C. Insertion depth	Shal.	Med.	High
D. % adhesive	Low	Med.	High

Noise Factors	*Levels*	
E. Time	24 h	120 h
F. Temp.	72°F	150°F
G. RH	25%	75%

TABLE 16-16

OA9 and OA4 Layout with Experimental Results for Tube

TC	*A*	*B*	*C*	*D*	E_1 F_1 G_1	E_1 F_2 G_2	E_2 F_1 G_2	E_2 F_2 G_1	S/N_L	$\overline{y}$
1	1	1	1	1	15.6	19.9	19.6	20.0	25.3	18.8
2	1	2	2	2	15.0	19.6	19.8	24.2	25.5	19.7
3	1	3	3	3	16.3	15.6	18.2	23.3	25.0	18.4
4	2	1	2	3	18.3	18.6	18.9	23.2	25.8	19.8
5	2	2	3	1	19.7	25.1	21.4	27.5	27.2	23.4
6	2	3	1	2	16.2	19.8	19.6	22.5	25.6	19.5
7	3	1	3	2	16.4	23.6	18.6	24.3	26.0	20.7
8	3	2	1	3	14.2	16.8	19.6	23.3	24.9	18.5
9	3	3	2	1	16.1	17.3	22.7	22.6	25.6	19.7

[5] Adapted, with permission, from Diane M. Byrne and Shin Taguchi, "The Taguchi Approach to Parameter Design," *Quality Progress* (December 1987): 19–26.

noise factors. These observations are 15.6, 19.9, 19.6, and 20.0; their average is 18.8.lb, and their signal-to-noise ratio for larger-the-better is 25.3 lb. The process is repeated for the other eight treatment conditions.

The response table is shown in Table 16-17 for S/N and $\bar{y}$, along with the maximum difference between the levels. A better evaluation of the factors and their levels can be seen in the response graph given in Figure 16-15. For factor *A*, interference, level 2 (medium) is obviously the best one for both S/N and $\bar{y}$; for factor *B*, wall thickness, level 2 (medium) is best for $\bar{y}$, but there does not appear to be a clear choice for the S/for factor *C*, insertion depth, level 3 (deep) is best for both S/N and $\bar{y}$; and for factor *D*, percent adhesive, level 1 (low) is best for both S/N and $\bar{y}$.

TABLE 16-17

S/N and $\bar{y}$ Response Table for Tube

S/N_L			Δ
$A_1 = 25.3$	$A_2 = 26.2$	$A_3 = 25.5$	0.9
$B_1 = 25.7$	$B_2 = 25.9$	$B_3 = 25.4$	0.5
$C_1 = 25.3$	$C_2 = 25.6$	$C_3 = 26.1$	0.8
$D_1 = 26.0$	$D_2 = 25.7$	$D_3 = 25.2$	0.8
$\bar{y}$			Δ
$A_1 = 18.9$	$A_2 = 20.9$	$A_3 = 19.6$	2.0
$B_1 = 19.8$	$B_2 = 20.5$	$B_3 = 19.2$	1.3
$C_1 = 18.9$	$C_2 = 19.7$	$C_3 = 20.8$	1.9
$D_1 = 20.6$	$D_2 = 20.0$	$D_3 = 18.9$	1.7

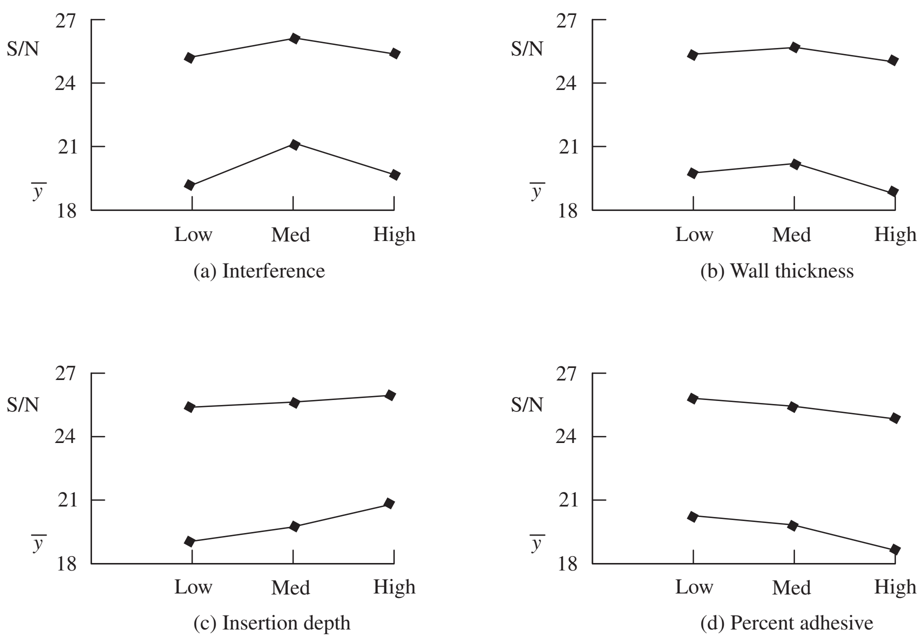


Figure 16-15 **Response Graph for S/N and $\bar{y}$ for Tube**

A summary of results is shown in Table 16-18; it includes cost and ease of assembly, as well as information on the noise factors. For factor B, wall thickness, level 1 (thin wall thickness) was selected for its lower cost and ease of assembly as well as for the fact that the S/N did not show any difference. It should be noted that these factors and their levels are least sensitive to the three noise factors; therefore, it is a robust design. The predicted equation was

$$\overline{T} = \Sigma y/n = (18.8 + 19.7 + \ldots + 19.7)/8 = 19.7$$

$$\hat{\mu} = \overline{T} + (A_2 - \overline{T}) + (B_1 - \overline{T}) + (C_3 - \overline{T}) + (D_1 - \overline{T}) = A_2 + B_1 + C_3 + D_1 + (N - 1)\overline{T}$$

$$= 20.9 + 19.8 + 20.8 + 20.6 - (4 - 1)19.7$$

$$= 23.0$$

The S/N ratio could also have been used for the prediction. Results of the confirmation run were very close to the predicted value and also close to TC 5, which is the same combination except for the difference in the B level. The actual combination was not run during the experiment, this tendency is often the case with highly-fractionalized experiments. In addition, the operators were quite pleased with the ease of assembly.

Treating Noise

Before continuing to the next case, let's discuss ways to treat noise. There are three techniques:

1. *Repetition*. When the process is very noisy, it is necessary to run only a few repetitions.

2. *Strongest*. When there is one strong noise factor, then two levels for that factor will be sufficient. For example: If temperature is a strong noise factor, it would be set at, say, 20° and 40°, and there would be two runs for each TC.

TABLE 16-18
Summary of Results

Factors	*Levels*	*Assembly Effort*	*Pull-off Force*	*Cost Rating*	*Overall Rating*
Interference	1. Low	8.1	18.9	Least	—
(A)	2. Medium	8.3	20.9	—	X
	3. High	8.7	19.6	Most	—
Wall	1. Thin	7.8	19.8	Least	X
Thickness (B)	2. Medium	8.3	20.5	—	—
	3. Thick	8.4	19.2	Most	—
Insertion	1. Shallow	7.7	18.9	Least	—
Depth (C)	2. Medium	8.3	19.7	—	X
	3. Deep	9.1	20.8	Most	—
Percent	1. Low	8.3	20.6	Least	X
Adhesive (D)	2. Medium	8.4	20.0	—	—
	3. High	8.4	18.9	Most	—
Conditioning	1. 24 h		18.0		
Time (E)	2. 120 h		21.6		
Conditioning	1. 75°F		18.1		
Temp. (F)	2. 150°F		21.5		
Conditioning	1. 25%		19.9		
R.H. (G)	2. 75%		19.7		

3. *Compounded*. When neither repetition nor strongest is applicable, then compounded is used. It requires an initial experiment for noise using a prototype or some units from production. The objective is to determine the extremes. Table 16-19 shows an OA4 with results for three noise factors and the response table next to it. The two extreme noise situations are

$$N_1 = U_1, V_2, \text{and } W_2$$
$$N_2 = U_2, V_1, \text{and } W_1$$

Each of these techniques can be used to minimize the number of runs while maintaining the concept of the noise array.

Case IV: Metal Stamping[6]

This case is a two-level design with a noise array and a nominal-the-best performance characteristic that is the distance from the center of the hole to the edge of a metal stamping. The target value is 0.40 in. Three control factors and their levels and three noise factors and their levels are determined by the team and are shown in Table 16-20. The experiment is run using an OA4 for the control array and a OA4 for the noise array. This layout along with the results are shown in Table 16-21.

TABLE 16-19
Compounded Noise Example for Three Noise Factors

TC	*U*	*V*	*W*	*y*
1	1	1	1	50
2	1	2	2	10
3	2	1	2	45
4	2	2	1	40

Level	*U*	*V*	*W*
1	30.0	47.5	45.0
2	42.5	25.0	27.5
Δ	12.5	22.5	17.5

TABLE 16-20
Control and Noise Factors with Their Levels for Metal Stamping

Control Factors	*Level 1*	*Level 2*
A. Roller Height	Sm	Lg
B. Material Supplier	SAE	SQC
C. Feed Adjustment	I	II
Noise Factors	***Level 1***	***Level 2***
U. Amount of Oil	Sm	Lg
V. Material Thickness	Low	High
W. Material Hardness	Low	High

[6] Adapted, with permission, from *Taguchi Methods: Introduction to Quality Engineering* (Allen Park, Mich.: American supplier Institute, Inc., 1991).

Table 16-21

Experimental Design with Results for Metal Stamping

TC	A 1	B 2	C 3	U_1 V_1 W_1	U_2 V_2 W_1	U_2 V_1 W_2	U_1 V_2 W_2	$\bar{y}$	S/N_N
1	1	1	1	0.37	0.38	0.36	0.37	0.370	33.12
2	1	2	2	0.35	0.39	0.40	0.33	0.368	20.92
3	2	1	2	0.45	0.44	0.44	0.46	0.448	33.39
4	2	2	1	0.41	0.52	0.46	0.42	0.443	19.13

Level	A	B	C
1	27.02	33.26	26.12
2	26.27	20.03	27.15
Δ	0.75	13.23	1.03

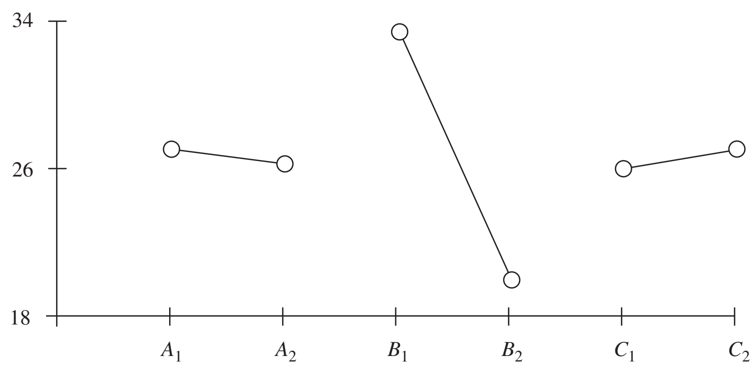


Figure 16-16 Response Table and Response Graph for the S/N Ratio

The nominal-the-best strategy is to identify two types of control factors:

1. Those that affect variation and that are to be minimized. They are determined first using the S/N ratio.
2. Those that affect the average and are called adjustment or signal factors. They are used to adjust the average, $\bar{y}$, to the target, τ.

Figure 16-16 shows the response table and response graph for the S/N ratio. A strong effect is given by factor B, with level 1 the appropriate level. Thus variation is minimized by using either level of factors A and C and factor B_1. Figure 16-17 shows the response table and response graph for the average, $\bar{y}$. A strong effect is given by factor A, which is the roller height. Thus the adjustment factor becomes the roller height, and it is adjusted to obtain the target value of 0.400. This adjustment or signal factor can make the design very robust by providing this additional capability for the process or the product. An excellent example of this concept for a product is the zero-adjustment feature of a bathroom scale.

Regular analysis for the average, as used in this case, is appropriate when there is a small change in the average. If you like the log transform concept, then 10 log $\bar{y}$ could be used. Sensitivity analysis, Sm, is used when there is a large change in the average, which is true in research. The equation is

$$Sm \text{ (dB)} = 10 \log_{10} (T^2/n)$$

Level	A	B	C
1	0.369	0.409	0.412
2	0.446	0.411	0.408
Δ	0.077	0.002	0.004

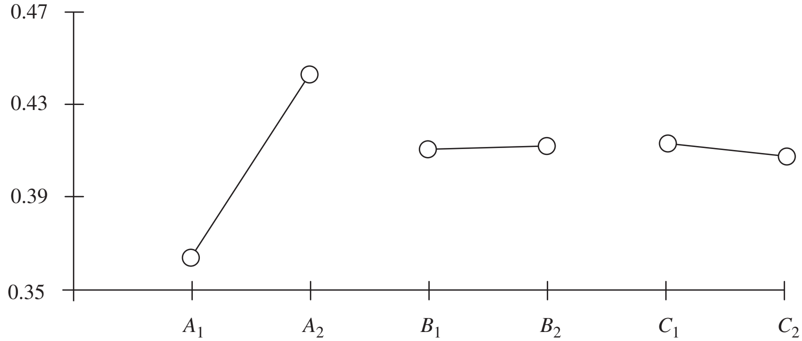


Figure 16-17 Response Table and Response Graph for the Average

The expression T^2/n is the sum of squares for the average, SS_{avg}, which is a common measure used in traditional design of experiments.

Regular analysis for the S/N ratio, such as used in this case, is appropriate when variability in relation to the average, $\bar{y}$, is measured in terms of a plus or minus percentage of $\bar{y}$. However, when variability in relation to the average is measured in terms of plus or minus absolute units and negative values are possible, then use the equation

$$\text{S/N}_N = -10 \log_{10} s^2$$

This situation occurs in few cases.

Tolerance Design

Tolerance design is the process of determining the statistical tolerance around the target. During the parameter-design stage, low-cost tolerancing should be used. Only when the values are beyond the low-cost tolerancing limits is this concept implemented. Tolerance design is the selective tightening of tolerances and/or upgrading to eliminate excessive variation. It uses analysis of variance (ANOVA) to determine which factors contribute to the total variability and the loss function to obtain a trade-off between quality and cost.

Percent Contribution

In order to determine the percent contribution of the factors to the total variability, the iron casting case is used as the learning vehicle. The first step is to calculate the sum of squares for each of the factors and the total:

$$SS_A = \Sigma(A^2/n) - T^2/n = \left(\frac{226^2}{4} + \frac{220^2}{4}\right) - \frac{446^2}{8} = 4.5$$

$$SS_B = \Sigma(B^2/n) - T^2/n = \left(\frac{243^2}{4} + \frac{203^2}{4}\right) - \frac{446^2}{8} = 200$$

$$SS_C = \Sigma(C^2/n) - T^2/n = \left(\frac{265^2}{4} + \frac{181^2}{4}\right) - \frac{446^2}{8} = 882$$

$$SS_D = \Sigma(D^2/n) - T^2/n = \left(\frac{276^2}{4} + \frac{370^2}{4}\right) - \frac{446^2}{8} = 28{,}405$$

$$SS_E = \Sigma(E^2/n) - T^2/n = \left(\frac{198^2}{4} + \frac{248^2}{4}\right) - \frac{446^2}{8} = 313$$

$$SS_F = \Sigma(F^2/n) - T^2/n = \left(\frac{271^2}{4} + \frac{175^2}{4}\right) - \frac{446^2}{8} = 1152$$

$$SS_G = \Sigma(G^2/n) - T^2/n = \left(\frac{215^2}{4} + \frac{231^2}{4}\right) - \frac{446^2}{8} = 32$$

$$SS_{\text{Total}} = \Sigma y^2 - T^2/n = (89^2 + 55^2 + \cdots + 55^2) - 446^2/8 = 3987.5$$

These values are placed in an ANOVA table, as shown in Table 16-22, along with their degrees of freedom, which for a two-level is 1 (2 − 1). This information is given in the first three columns. Note that the smaller the difference in the response table, the smaller the *SS*. The fourth column is the mean square (*MS*) column for each factor, and its equation is

$$MS = \frac{SS}{\text{df}}$$

Because the number of degrees of freedom is 1, the *MS* value is the same as the *SS* value. If this were a three-level design, the number of degrees of freedom would have been 2: one for the linear component and one for the quadratic component, as shown in Table 16-24.

TABLE 16-22
ANOVA for the Iron Casting Case

Source	*df*	*SS*	*MS*	*F*
A	1	4.5	4.5	
B	1	200.0	200.0	
C	1	882.0	882.0	
D	1	1404.5	1404.5	
E	1	312.5	312.5	
F	1	1152.0	1152.0	
G	1	32.0	32.0	
Total	7	3987.5	3987.5	

The last column in the table, labeled F, has not been completed. This value is determined by the equation

$$F = \frac{MS_{\text{factor}}}{MS_{\text{error}}}$$

We do not have a value for MS_{error}. If the treatment conditions had been repeated, a value for the error could have been obtained. Regardless, a pooling-up technique can be used to obtain an estimate.

The pooling-up technique maximizes the number of significant factors. In other words, a factor can be classified as significant when, in truth, it is not. This action is referred to as the alpha error, or risk. Opposite to the alpha error is the beta error, or risk, which can classify a factor as being nonsignificant when, in truth, it is significant. The F-test, developed by Fischer, is used to determine significance at a designated alpha risk, which is usually 0.05.

The pooling-up procedure is to F-test the factor with the smallest SS against the next largest. If not significant, the SS is pooled and tested against the next largest. The process is continued until a factor is significant or one-half the total number of degrees of freedom is used.

Calculations for the first step using factors A and G and the iron casting case are

$$F = \frac{MS_G}{MS_e} = \frac{SS_G/\text{df}}{SS_A/\text{df}} = \frac{32/1}{4.5/1} = 7.11, \text{ thus, n.s.}$$

An F table for an alpha value of 0.05 and 1 degree of freedom for both the numerator and the denominator gives a critical value of 161. Because the calculated value is less than the critical value, the factor is not significant (n.s.). The next step is to pool the SS for the factors G and A and test against the next factor. Calculations are

$$F = \frac{MS_B}{MS_e} = \frac{SS_B/\text{df}}{SS_{B,G}/\text{df}} = \frac{200/1}{36.5/2} = 10.93 \text{ n.s.}$$

From an F table, the critical value for 1 and 2 degrees of freedom is 18.5, which is greater than the calculated value, so factor B is also not significant. Factor B is now pooled with the other two factors to obtain SS of 236.5 and MS of 78.8. However, since one-half the total degrees of freedom was obtained, the pooling process is complete.

The F column for the ANOVA is completed and shown in Table 16-23. F values in the column are compared with the critical F, which is obtained from the F table and shown at the bottom of the table. Three of the factors are significant at an alpha of 0.05 and one factor is nonsignificant. Two additional columns, labeled SS', which is the pure SS after the error is subtracted, and %, which is the percent contribution, are shown in the table. Calculations for SS' are

$$SS'_C = SS_C - \left(MS_e * \text{df}_C\right) = 882.0 - 78.8(1) = 803.2$$

$$SS'_D = SS_D - \left(MS_e * \text{df}_D\right) = 1404.5 - 78.8(1) = 1325.7$$

$$SS'_E = SS_E - \left(MS_e * \text{df}_E\right) = 312.5 - 78.8(1) = 233.7$$

$$SS'_F = SS_F - \left(MS_e * \text{df}_F\right) = 1152.0 - 78.8(1) = 1073.2$$

$$SS'_e = SS_e - \left(MS_e * \text{df}_{C,D,E,F}\right) = 236.5 + 78.8(4) = 551.7$$

TABLE 16-23
Percent Contribution for the Iron Casting Case

Source	*df*	*SS*	*MS*	*F*	*SS*	*%*
A	[1]	4.5				
B	[1]	200.0				
C	1	882.0	882.0	11.2*	803.2	20.1
D	1	1404.5	1404.5	17.8*	1325.7	33.2
E	1	312.5	312.5	4.0 n.s.	233.7	5.9
F	1	1152.0	1152.0	14.6*	1073.2	26.9
G	[1]	32.0				
Pooled *e*	3	236.5	78.8		551.7	13.8
Total	7	3987.5			3987.5	99.9

*Significance at 95% confidence, $F(0.05; 1, 3) = 10.1$.

TABLE 16-24
Percent Contribution for the Tube Case

Source		*SS*	*df*	*MS*	*F*	*SS*¿	*%*
Intr.	(L)	[0.73500]	[1]				
	(Q)	5.28125	1	5.28125	15.2149*	4.93419	25.9
Tube	(L)	[0.48167]	[1]				
	(Q)	2.20500	1	2.20500	6.3525	1.85789	9.8
Ins. dp.	(L)	5.46260	1	5.46260	15.7374	5.11549	26.9
	(Q)	[0.07031]	[1]				
% Adh.	(L)	4.68167	1	4.68167	13.4876	4.33456	22.8
	(Q)	[0.10125]	[1]				
e		0.0	0				
Pooled *e*		1.38843	4	0.34711		2.77687	14.6
Total		19.01875	8			19.01875	100.0

*$F_{1,4}$ ($\alpha = 0.05$) = 7.7088.

Values for the percent contribution for each factor are obtained by dividing by the total and are shown in the last column. The percent contribution for the error is 13.8, which is satisfactory. If the percent contribution for the error is a high value, say, 40% or more, then some important factors were omitted, conditions were not precisely controlled, or measurement error was excessive.

Tables 16-24 and 16-25 provide further illustration of the percent contribution technique for two of the cases discussed in this chapter.

Table 16-25
Percent Contribution for the Grille Case

Source	*df*	*SS*	*MS*	*F*	*SS'*	%
A	1	800.000	800.000	11.728**	731.788	11.04
B	[1]	[45.125]				
AB	[1]	[15.125]				
F	[1]	[4.500]				
G	[1]	[0.500]				
BF	1	595.125	595.1215	8.725**	526.913	7.95
E	1	990.125	990.125	14.515**	921.913	13.91
C	1	351.125	351.125	5.148**	282.913	4.27
AC	1	630.125	630.125	9.128**	561.913	8.48
H	[1]	[40.500]				
I	[1]	[50.000]				
D	[1]	[78.125]				
AD	1	120.125	120.125	1.761	51.913	0.78
FH	1	924.500	924.500	13.553**	856.288	12.92
UX	1	648.000	648.000	9.500**	579.788	8.75
e	16	1335.000	83.438			
Pooled *e*	23	1568.873	68.212		2114.571	31.9
Total	31	6628.000			6628.000	100.0

*Significance at 95% confidence, $F(0.05; 1, 23) = 4.28$.
**Significance at 99% confidence, $F(0.01; 1, 23) = 7.88$.

Case I: TV Power Circuit[7]

A TV power circuit specification is 115 ± 15 volts. If the circuit goes out of this range, the customer will need to correct the problem at an average cost for all TV sets of $45.00. The problem can be corrected by recalibration at the end of the production line for a cost of $1.60. Using the loss function, the customer's loss is

$$L = k(y - \tau)^2$$
$$A_0 = k(\Delta_0)^2$$
$$k = A_0/\Delta_0^2$$

The manufacturer's loss function is

$$L = k(y - \tau)^2$$

[7] Adapted, with permission, from *Quality Engineering: Dynamic Characteristics and Measurement Engineering* (Allen Park, Mich.: American Supplier Institute, 1990).

Substituting gives

$$A = \frac{A_0}{\Delta_0^2}(\Delta)^2$$

Thus,

$$\begin{aligned}\Delta &= \Delta_0\sqrt{\frac{A}{A_0}}\\ &= 15\sqrt{\frac{1.60}{45.00}}\\ &= 2.6 \text{ or about } 3\text{ V}\end{aligned}$$

The tolerance is ± 3 V, and the specifications are 112 V to 118 V. If the TV circuit is outside the specifications, it is recalibrated at a cost of $1.60.

Case II: Butterfly[8]

The plastic butterfly for the carburetor of a small engine has experienced a rash of complaints due to breakage. A larger-the-better loss function showed a loss of $39.00 at an average strength of 105 lb/in.^{2} and a standard deviation of 30 lb/in.^{2} for the defective items. Four factors of the plastic-molding process are identified by the project team, along with the experiment goal of $\overline{y}$ = 160 1b/in^2 and s = 16 lb/in.^{2} Table 16-26 shows the factors, range of interest, and the low-cost tolerancing. A new temperature-control system was recently installed on the machine, and its tolerance is ± 0.1%.

The parameter design resulted in a feed rate (*FR*) of 1200, a first rpm (*1R*) of 480, a second rpm (*2R*) of 950, and a temperature (*T*) of 360. A confirmation run was made using an OA9 with the low-cost tolerances as the outer levels and the parameter as the nominal. In other words, the three levels were 960, 1200, and 1440 for *FR*; 432, 480, and 528 for *IR*; 855, 950, and 1045 for *2R*; and 360, 360, and 360 for *T*. The results were $\overline{y}$ = 168.5 lb/in.^{2} and s = 28.4 lb/in.^{2}, which was a substantial improvement, but the goal of s = 16 was not met. From the confirmation run, the percent contribution was calculated,

Feed rate	17.9%
First rpm	65.5%
Second rpm	9.4%
Residual (error)	7.3%
Total	100.1%

Table 16-26

Factors, Range of Interest, and Low-cost Tolerancing for Butterfly

Factor	*Range of Interest*	*Low-cost Tolerance*
A. Feed rate (*FR*)	1000–1400 g/min	± 20%
B. First rpm (*1R*)	400–480 rev/min	± 10%
C. Second rpm (*2R*)	850–950 rev/min	± 10%
D. Temp. (*T*)	320–400°F	± 0.1%

[8] Adapted, with permission, from Thomas B. Baker, "Quality Engineering by Design: Taguchi's Philosophy." *Quality Progress* (December 1986): 32-42

Temperature did not contribute to the percent contribution, so it is not included.

The next step is the rational (selective) reduction in tolerances by the project team. Variances are additive and standard deviations are not; therefore, calculations are made using variance. We have a variance of 806.6 (28.4^2) and need 256.0 (16^2). Thus, the variance needs to be reduced by 256.0/806.6, or 0.317 of its current value. Using this value, the factors, and the percent contribution, we can write the equation

$$0.317 = \left[(FR)^2 0.179 + (IR)^2 0.655 + (2R)^2 0.094 + e^2(0.073)\right]$$

where $e^2 = 1$ and is the residual or error.

The solution to the equation is by trial and error. After deliberation, the project team decides that the feed rate can be reduced by 33% of its original value; the calculations are

$$0.317 = (0.33)^2 0.179 + \ldots$$
$$(0.33)^2 0.179 = 0.020$$
$$0.317 - 0.020 = 0.297 \text{ left}$$

The project team decides that the first rpm can be reduced by 50% of its original value; the calculations are

$$0.297 = \ldots + (0.50)^2 0.655 + \ldots$$
$$(0.50)^2 0.655 = 0.164$$
$$0.297 - 0.164 = 0.133 \text{ left}$$

The remaining factor is the second rpm. Removing the residual of 7.3%, the result is 0.060(0.133 − 0.073). The calculations are

$$(2R)^2\, 0.094 = 0.060$$
$$2R = 0.80$$

New tolerances are shown in Table 16-27. If these need modification, the preceding process can be repeated with different values.

Levels for the final run are

$$\begin{aligned} &FR \quad 6.6\% \text{ of } 1200 = 80\ (1120, 1200, 1280)\\ &1R \quad 5.05\% \text{ of } 480 = 24\ (456, 480, 504)\\ &2R \quad 8.0\% \text{ of } 950 = 76\ (874, 950, 1026) \end{aligned}$$

Using an OA9 and these levels, the results were $\bar{y} = 179.9$, $s = 12.1$, and S/N = 45.0, which is almost 200% better than the original. The appropriate parameter settings and realistic tolerance settings are now known.

TABLE 16-27
New Tolerances for Butterfly

Factor	*Old*		*New*
FR	±20%	20(0.33)	±6.6%
1R	±10%	10(0.50)	±5.0%
2R	±10%	10(0.80)	±8.0%

From the loss function graph, the average loss is \$2.00 per engine, for a savings of \$370,000 for 10,000 engines. Statistical process control (SPC) is used to maintain the target and variation.

Noise can be based on (1) percent of the parameter, as in this case, (2) experience, or (3) standard deviation (Taguchi recommends 1σ for a two-level and 1.22σ for a three-level). A two-level design would occur when the tolerance is unilateral or one-directional or only the upper and lower specifications are used without the nominal or target. It should be noted that the rational reduction concept was not developed by Taguchi.

Case III: Control Circuit[9]

This case concerns the tolerance design of a control circuit after the parameter design has determined the factors and their target or nominal values. The design team decides to establish the tolerance levels at $\pm 1\sigma$. Table 16-28 shows the 12 factors with their nominal and tolerance specifications.

The design team established a target for the performance characteristic of 570 cycles and functional limits of ± 150 cycles, with the loss at the limit of \$100.00. Using these values, the average loss equation is

$$\overline{L} = 0.004444\left[\sigma^2 + (y - 570)^2\right]$$

The experiment was run using an OA16, which is shown in Table 16-29 along with the results. Note that three of the columns are unexplained or classified as error. From the results, the percent contribution is determined using the ANOVA and pooling-up technique, as shown in Table 16-30. Note the error includes the last three columns plus the pooling of factors *E, H*, and *J*. The error percent contribution is very low at 1.3%.

TABLE 16-28
Factors and Levels for the Tolerance Design of the Control Circuit

Factors	*Units*	*Level 1* $-\sigma$	*Target or Nominal*	*Level 2* $+\sigma$
Resistor *A*	kilohms	2.09	2.20	2.31
Resistor *B*	ohms	446.5	4.700	493.5
Capacitor *C*	microfarads	0.65	0.68	0.71
Resistor *D*	kilohms	95.0	100.0	105.0
Capacitor *E*	microfarads	8.0	10.0	12.0
Transistor *F*	hfe	90.0	180.0	270.0
Resistor *G*	kilohms	9.5	10.0	10.5
Resistor *H*	kilohms	1.43	1.50	1.57
Resistor *I*	kilohms	9.5	10.0	10.5
Resistor *J*	kilohms	9.5	10.0	10.5
Transistor *K*	hfe	90.0	180.0	270.0
Voltage *L*	volts	6.2	6.5	6.8

[9] Source: Robert Moesta, American Supplier, Inc.

Table 16-29
OA16 with Results for Control Circuit

TC	A	B	C	D	E	F	G	H	I	J	K	L	e	e	e	Data
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	523
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	430
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2	674
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1	572
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	609
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1	534
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1	578
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2	527
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	605
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	707
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1	541
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2	669
13	2	2	1	1	2	2	1	1	2	2	1	1	1	2	1	430
14	2	2	1	1	2	2	1	2	1	1	2	2	2	1	2	480
15	2	2	1	2	1	1	2	1	2	2	1	2	2	1	2	578
16	2	2	1	2	1	1	2	2	1	1	2	1	1	2	1	668

The mean squared deviation for the total is calculated from the percent contribution table using the equation

$$MSD_{\mathrm{T}} = \frac{SS_{\mathrm{T}}}{\mathrm{df}_{\mathrm{T}}} = \frac{105,361.5}{15} = 7024.1$$

This amount is then apportioned to each of the factors based on its percent contribution and placed in the *MSD* column of Table 16-31. Using the loss function equation, $L = k(MSD)$, the quality loss for each factor is determined and placed in the loss column of the table. Calculations for factor *A* are

$$\begin{aligned} MSD_A &= MSD_{\mathrm{T}}\left(\%_A/100\right) = 7024.1(3.1/100) = 217.7 \\ L_A &= k\left(MSD_A\right) = 0.004444(217.7) = \$0.97 \end{aligned}$$

Calculations are repeated for the other factors and placed in the table. The total quality loss is \$31.22, shown at the bottom of the table.

The next step in the process is to evaluate the upgrade performance of the factors. With electronic components, a higher quality component is obtained by reducing the tolerance. For example, factor *A*, a resistor, changes from a 5% tolerance to a 1% tolerance, and Δ in the loss function equation is 5/1 = 5. Thus, Δ^2 is 25. This information is shown in Table 16-32. Also shown are the upgraded *MSD*, new loss, and quality gain; for factor *A* the calculations are

$$\begin{aligned} MSD'_A &= MSD_A/\Delta^2 = 217.7/25 = 8.7 \\ L'_A &= k\left(MSD'_A\right) = 0.004444(8.7) = \$0.04 \\ \mathrm{Gain}_A &= \$0.97 - \$0.04 = \$0.93 \end{aligned}$$

TABLE 16-30

Percent Contribution for Control Circuit

Source	*df*	*SS*	*MS*	*SS′*	*%*
A	1	3,335.1	3,335.1	3,247.1	3.1
B	1	6,280.6	6,280.6	6,192.6	5.9
C	1	10,764.1	10,764.1	10,676.1	10.1
D	1	14,945.1	14,945.1	14,857.1	14.1
E	[1]	27.6			
F	1	715.6	715.6	627.6	0.6
G	1	36,960.1	36,960.1	36,875.1	35.0
H	[1]	150.0			
I	1	29,842.6	29,842.6	29,754.6	28.2
J	[1]	27.6			
K	1	1,580.1	1,580.1	1,492.1	1.4
L	1	410.1	410.1	322.1	0.3
e	[3]	322.8			
e (pooled)	6	528.1	88.0	1320.3	1.3
Total	15	105,361.5		105,361.5	100.0

Table 16-31

Quality Loss by Factor

Factor	*Type*	*%*	*MSD*	*Loss—$*
A	Resistor	3.1	217.7	0.97
B	Resistor	5.9	414.4	1.84
C	Capacitor	10.1	709.4	3.15
D	Resistor	14.1	990.4	4.40
E	Capacitor	0.0		
F	Transistor	0.6	42.1	0.19
G	Resistor	35.0	2458.4	10.93
H	Resistor	0.0		
I	Resistor	28.2	1980.8	8.80
J	Resistor	0.0		
K	Transistor	1.4	98.3	0.44
L	Voltage	0.3	21.1	0.09
e	Error	1.3	91.3	0.41
Total		100.0		$31.22

TABLE 16-32
Upgrade Performance

Factor	*Type*	*Loss—$*	*Upgrade Effect*	*Upgrade Factor*	*Upgraded MSD′*	*New Loss—$*	*Quality Gain—$*
A	Resistor	0.97	5%-1%	25	8.7	0.04	0.93
B	Resistor	1.84	5%-1%	25	16.6	0.07	1.77
C	Capacitor	3.15	5%-1%	25	28.4	0.13	3.02
D	Resistor	4.40	5%-1%	25	39.6	0.18	4.22
E	Capacitor						
F	Transistor	0.19	12%-3%	16	2.6	0.01	0.18
G	Resistor	10.93	5%-1%	25	98.3	0.44	10.49
H	Resistor						
I	Resistor	8.80	5%-1%	25	72.2	0.35	8.45
J	Resistor						
K	Transistor	0.44	12%-1%	16	6.1	0.03	0.41
L	Voltage	0.09					
e	Error	0.41					
Total		31.22					

The final step in the process is to make the upgrade decision by comparing the quality gain to the upgrade cost to obtain the net gain. As shown in Table 16-33, a resistor upgrade is inexpensive and a transistor upgrade is expensive; this information affects the final decision. For factor *A* the net gain calculations are

$$\begin{aligned}\text{Net gain} &= \text{quality gain} - \text{upgrade cost}\\ &= \$0.93 - \$0.06\\ &= \$0.87\end{aligned}$$

Of course, because $0.87 is saved per unit, the upgrade decision is "yes."

As a result of this tolerance design, there was a substantial improvement in cost and performance. Upgrade costs were $1.30 and the net gain was $27.57 per unit. The C_{pk} went from 0.6 to 2.2.

Dr. Taguchi's Latest Thinking[10]

Dr. Taguchi strongly thinks that engineering theory is of little value unless it is applied for the benefit of the society. While discussing quality and productivity, he strongly recommends that the improvement efforts should be prioritized on R&D, rather than reducing defects on the production line. For example, 75% of the

[10] *Taguchi's Quality Engineering Handbook*, Genichi Taguchi, Subir Chowdhury and Yuin Wu, published in 2005, by John Wiley and Sons, Inc and ASI Consulting Group.

TABLE 16-33

Upgrade Decision for Control Circuit

Factor	*Type*	*Quality Gain—$*	*Upgrade Cost—$*	*Net Gain—$*	*Make Upgrade?*
A	Resistor	0.93	0.06	0.87	Yes
B	Resistor	11.77	0.06	1.71	Yes
C	Capacitor	3.02	1.00	2.02	Yes
D	Resistor	4.22	0.06	4.16	Yes
E	Capacitor				No
F	Transistor	0.18	2.00	(1.82)	No
G	Resistor	10.49	0.06	10.41	Yes
H	Resistor				No
I	Resistor	8.45	0.06	8.40	Yes
J	Resistor				No
K	Transistor	0.41	1.00	(0.59)	No
L	Voltage				No
e	Error				
Total			1.30	27.57	

gasoline fuel is wasted in the automobiles contributing to enormous economic loss. Thus, efforts should be focussed on improving the fuel efficiency of the engines. If the fuel efficiency is doubled, global pollution levels would drop by 50%. He suggests differential taxation to preserve natural resources. For example, rather than regulating pollution, it should be taxed. Higher consumption of natural resources should be taxed at higher rates to stimulate recycling. For land leading to lower productivity such as housing, taxation should be higher, as compared to the land used in the larger benefits of the society.

Recently, Taguchi has expanded quality engineering application to fields such as medical treatment/efficacy experimentation and also software technology.

In software technology, two types of signal factors have been discussed by him—active and passive. When software is designed using a system with computers, software is considered as active signal factor of the user. When we conduct inspection, diagnosis or prediction using research data, the entire group of data is considered as a set of passive signal factors.

In case of active noise factors, he recommends a special approach of using orthogonal arrays for software testing with bug or no bug as a response. In case of passive noise factors, wherein there are many quality characteristics, Taguchi suggests "Mahalanobis-Taguchi System" (MTS). MTS uses concept of Mahalanobis Distance (MD) for reducing the complexity. In this procedure, a sufficiently large sample of "normal" items (characteristics) is selected. MD is then calculated by performing certain calculations which include "standardizing" of the responses of characteristics, finding correlation coefficients for all pairs and its inverse matrix. According to Taguchi, for "normal" items, the value of MD is approximately 1, while the items which are not "normal" have value much larger than 1. Taguchi further suggests, logarithmic transformation to convert the value of MD into decibels. This transformed value of MD is used with orthogonal arrays for optimization using SN Ratios. Mathematical treatment of MTS is complex and beyond the scope of this text.

TQM Exemplary Organization[11]

Based at Armstrong's corporate headquarters in Lancaster, Pa., their Building Products Operations, BPO, employs about 2,400 people, 85% of whom work at the operation's seven manufacturing plants in six states. BPO makes and markets hundreds of products for both home and commercial interiors and industry. The world's largest manufacturer of acoustical ceilings, BPO accounted for nearly one-fourth of Armstrong's sales in 1994.

Within BPO, overall responsibility rests with its ten-member Quality Leadership Team, (QLT) composed of senior executives and headed by the BPO President. The QLT places its emphasis on leadership and fully shares its responsibility for identifying and realizing improvement opportunities with the entire organization.

The QLT performs fact-based assessments of how well it stacks up against its competitors in each of BPO's eight market segments. Then, the team defines BPO's "full potential" in each segment. Drawing on this and other information, such as the results of customer surveys, the QLT sets goals and devises action plans so that BPO will grow to reach its full potential. Along with organization-wide goals, each of the eight functional units develops and deploys action plans to every BPO employee. Relevant BPO goals and supporting process objectives are incorporated into the various incentive plans that now cover more than 93% of hourly and salaried workers.

In each of the past five years, over half of the BPO workforce has participated on the more than 250 improvement teams operating at any given time. The objectives of teams range from correcting specific operational problems at one plant to improving key business processes that enhance the entire organization. At each plant, the Quality Improvement Team, led by the facility's top manager, monitors the progress of all team efforts and reports on the results to the QLT. All Quality Improvement Teams are required to develop specific action plans and set goals that will have a measurable impact on one or more of BPO's five "key business drivers"—customer satisfaction, sales growth, operating profit, asset management, and high performance organization (human resources capabilities).

Across eight market categories in 1994, at least 97% of customers gave BPO an overall rating of good or better. As it pursues increasingly ambitious levels of customer satisfaction, BPO also is reducing operating costs. Scrap rates, for example, have been cut by 38% since 1991. Manufacturing output per employee has jumped 39% over the same span, exceeding company goals.

Over the past few years, BPO has made substantial investments to optimize its information gathering and analytical capabilities. It also has stepped up its benchmarking studies, conducting 89 in 1994, or more than twice the number performed during the previous year. The principal return on these efforts, according to the company, has been an ever-improving understanding of the dynamics of BPO's markets, competitors' performance, and its own business results. At all seven manufacturing plants, employees are organized into natural work teams or business unit teams whose individual members can perform a variety of jobs. As of 1995, six plants pay workers for mastering new skills and knowledge. Six plants also offer gain sharing, which links

[11] Malcolm Baldrige National Quality Award, 1995 Manufacturing Category Recipient, NIST/Baldrige Homepage.

measures of safety, customer satisfaction, process effectiveness, and other aspects of performance areas to a portion of each employee's compensation.

In 1985, the company established a supplier quality management process that has entailed assessing the quality systems of 135 suppliers. Overall, notices of nonconformance sent to suppliers have been declining, falling 32% from 1992 to 1994. Over the same span, on-time delivery has improved from 93% in 1992, when the arrival time window for carriers was four hours, to 97.3% in 1994, even though BPO had reduced the window to 30 minutes.

Since 1991, BPO's "cost of quality"—the company's composite indicator of the price it pays as a result of waste and nonconformance—has dropped by 37%, contributing \$16 million in additional operating profit in 1994 alone. In 1994 overall, BPO reduced operating costs by a company record \$40 million, while maintaining or increasing its share in each of its markets. Employees shared in those accomplishments. BPO set industry safety records—employees worked more than 3 million hours without a lost time injury—and the company made its highest-ever gain sharing and incentive payouts.

Summary

Taguchi defines Quality, as Loss to the society after the product is shipped. Quality Loss can be modelled using the quadratic loss function. Taguchi added the concept of orthogonal arrays to Fisher's experimental structures. He further created linear graphs and interaction tables for selection of appropriate design for a particular objective.

The objective in Fisher's experimental design was to optimize the mean response. Taguchi added additional objective of reducing variation while optimizing the mean. He called it robust design. For analysis and optimization, he added a metric SN Ratio. SN ratios are defined for six different type of characteristics. These are nominal-the-best, target-the-best, smaller-the-better, larger the better, classified attribute and dynamic. Quality engineering strategy consists of system design, parameter design and tolerance design.

Exercises

1. The specifications of a steel shaft are 6.40 ± 0.10 mm. The device sometimes fails when the shaft exceeds the specification. When failure occurs, repair or replacement is necessary at an average cost of \$95.00.

   (a) What is the loss coefficient k?
   (b) What is the loss function equation?
   (c) What is the loss at 6.45 mm?

2. The specifications for an electronic device are 24 ± 0.4 A and the average repair cost is \$32.00.

   (a) Determine the loss function.
   (b) Determine the loss at 24.6 A.

3. Determine the average loss for the information in Exercise 2 if 13 samples give 24.2, 24.0, 24.1, 23.8, 24.3, 24.2, 23.9, 23.8, 24.0, 23.6, 23.8, 23.9, and 23.7.

4. For an out-of-round condition (smaller-the-better) of a steel shaft, the true indicator readings (TIR) for eight shafts are 0.05, 0.04, 0.04, 0.03, 0.04, 0.02, 0.04, and 0.03 mm.

   (a) If the average loss at 0.03 is \$15.00, what is the loss function?
   (b) What is the loss at 0.05?
   (c) What is the average loss?

5. When the tensile strength of a plastic part is 120 lb/in.^{2}, there is an average loss of \$34.00 due to breakage. Determine the average loss for sample tests of 130, 132, 130, 132, and 131.

6. A new process is proposed for the manufacture of steel shafts, as given in the example problem on page 566. Data are 6.38, 6.40, 6.41, 6.38, 6.39, 6.36, 6.37.

   (a) What is the expected loss?
   (b) Is the new process better than the process of the example?
   (c) What future improvements might be tried? Hint: Compare average with target and the standard deviations of both processes.

7. Given three two-level factors and three suspected two-factor interactions, determine the degrees of freedom and the OA.

8. If a three-factor interaction was also suspected in Exercise 7, what are the degrees of freedom and the OA? What type of OA is this design?

9. What are the degrees of freedom and OA if the factors in Exercise 7 are three-level? Why does a three-level design require so much more design space?

10. An experimental design has five two-level factors (*A, B, C, D, E*), where only main effects are possible for factor *C* and there are no suspected *AB* and three-factor or higher interactions. Using a linear graph, assign the factors and their interactions to the columns of the OA.

11. Using a linear graph, assign the factors and their interactions to the columns of the OA determined in Exercise 7.

12. Using a linear graph, assign the factors and their interactions to the columns of the OA determined in Exercise 9.

13. A new process has been developed and the temperature results are 21°C for the average and 0.8°C for the sample standard deviation ($n = 5$).

    (a) What is the S/N ratio for nominal-the-best?
    (b) How much improvement has occurred? Compare to the example problem answer of 20.41 dB on page 578.
    (c) If you change the units of the example problem and this exercise, will you get the same results? Prove your conclusion.

14. Suppose the results of the new process for the bread stuffing example problem are 125, 132, 138, 137, 128, and 131. What conclusions can be drawn?

15. The yield on a new chemical process for five days is 61, 63, 58, 57, and 60 and the old process had recent yields of 54, 56, 52, 56, 53, 51, 54, 53, and 52. Is the new process better? If so, how much better?

16. The results for a larger-the-better experimental design that was run in random order with seven factors are as follows:

TC	*A* 1	*B* 2	*C* 3	*D* 4	*E* 5	*F* 6	*G* 7	*R1*	*R2*
1	1	1	1	1	1	1	1	19	25
2	1	1	1	2	2	2	2	20	24
3	1	2	2	1	1	2	2	24	22
4	1	2	2	2	2	1	1	22	25
5	2	1	2	1	2	1	2	26	20
6	2	1	2	2	1	2	1	25	26
7	2	2	1	1	2	2	1	25	20
8	2	2	1	2	1	1	2	25	21

(a) Determine the response table, response graph, strong effects, and prediction for the average and the S/N ratio.
(b) If the confirmation run is 27.82, what can you say about the experiment? If the confirmation run is 27.05, what can you say about the experiment?

17. The results of a nominal-the-best experimental design are as follows:

TC	*A* 1	*B* 2	*C* 3	*N1*	*N2*	$\bar{y}$	*S/N*
1	1	1	1	1.75	1.84	1.80	29.01
2	1	2	2	1.34	2.13	1.74	9.84
3	2	1	2	2.67	2.43	2.55	23.54
4	2	2	1	2.23	2.73	2.48	16.92

(a) Determine the response table, response graph, and strong effects.
(b) Analyze your results in terms of adjustment factors and variation factors.

18. The results for a smaller-the-better saturated experimental design using an OA16 with 15 factors where the factors $A, B, \ldots, O$ are located in columns 1, 2, …, 15, respectively, are as follows:

R1	*R2*	*R3*	*R4*
0.49	0.54	0.46	0.45
0.55	0.60	0.57	0.58
0.07	0.09	0.11	0.08
0.16	0.16	0.19	0.19
0.13	0.22	0.20	0.23
0.16	0.17	0.13	0.12
0.24	0.22	0.19	0.25
0.13	0.19	0.19	0.19
0.08	0.10	0.14	0.18
0.07	0.04	0.19	0.18
0.48	0.49	0.44	0.41
0.54	0.53	0.53	0.54
0.13	0.17	0.21	0.17
0.28	0.26	0.26	0.30
0.34	0.32	0.30	0.41
0.58	0.62	0.59	0.54

(a) Determine the response table, response graph, strong effects, and prediction for the average and the S/N ratio.
(b) If the results of the confirmation run are 0.13, 0.07, 0.06, 0.08, what can you say about the experiment?

19. The results of a larger-the-better experimental design with an outer array for noise are as follows:

TC	*A*	*B*	*C*	*D*	*N1*	*N2*
1	1	1	1	1	7.9	11.9
2	1	2	2	2	7.3	12.1
3	1	3	3	3	8.6	10.5
4	2	1	2	3	10.6	11.2
5	2	2	3	1	12.0	13.7
6	2	3	1	2	8.5	11.9
7	3	1	3	2	8.7	10.9
8	3	2	1	3	6.5	11.9
9	3	3	2	1	8.4	15.0

(a) Determine the response table, response graph, strong effects, and prediction for the S/N ratio.
(b) What value for the confirmation run would you consider satisfactory?

20. The results of a smaller-the-better experimental design are as follows:

TC	*B* *1*	*A* *2*	*AB* *3*	*C* *4*	*UX* *5*	*AC* *6*	*D* *7*	*S/N*
1	1	1	1	1	1	1	1	32.1
2	1	1	1	2	2	2	2	33.6
3	1	2	2	1	1	2	2	32.8
4	1	2	2	2	2	1	1	31.7
5	2	1	2	1	2	1	2	31.2
6	2	1	2	2	1	2	1	33.7
7	2	2	1	1	2	2	1	32.3
8	2	2	1	2	1	1	2	33.6

(a) Determine the response table, response graph, and strong effects.
(b) Explain the results.

21. Determine the percent contributions of Exercise 16.

22. Determine the percent contributions of Exercise 20.

23. The confirmation run for the experimental design of an electronic device gave the following percent contributions for unpooled factors from an OA12 design. Also given is the upgrade effect and the upgrade cost.

Factor	*Type*	*df*	*%*	*Ungrade Effect*	*Upgrade Cost—$*
A	Capacitor	1	41.0	5%-1%	1.81
B	Resistor	1	12.4	5%-1%	0.15
C	Transistor	1	32.1	12%-3%	3.92
D	Resistor	1	20.9	5%-1%	0.15
e	Error	7	5.6		
		11			

If the total *SS* is 1301.2 and $k = 0.05$, determine the net gain per unit from upgrading.

24. A four-factor experiment gives the following percent contributions for the confirmation run: *A* (43%), *B* (9%), *C* (28%), *D* (13%), and residual (7%). If the variance is currently 225 and the desired value is 100, determine two possible reduction schemes.

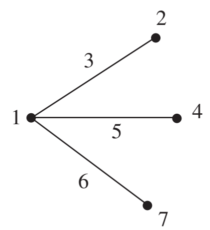
25. Design and conduct a Taguchi experiment for

    (a) Growth of a house plant
    (b) Flight of a paper airplane
    (c) Baking brownies, chocolate-chip cookies, and so forth
    (d) Making coffee, popcorn, etc.
    (e) Any organization listed in Chapter 1, Exercise 5

26. For robust design, we should

    (a) Minimize SN ratios
    (b) Maximize standard deviation
    (c) Maximize SN ratios
    (d) Maximize mean

27. Linear graph for L8 array is shown. How may maximum factors can be evaluated if we wish to evaluate interactions?



    (a) 3
    (b) 4
    (c) 7
    (d) 5

28. In an experiment, there are three factors A, B and C with levels 2, 3 and 4 respectively. The degrees of freedom for interaction AB and BC are:

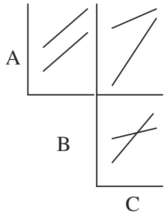
    (a) 6 and 12, respectively
    (b) 5 and 7, respectively
    (c) 2 and 6,
    (d) 3 and 5, respectively

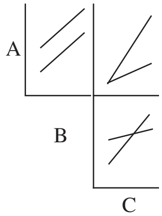
29. In ANOVA, Sum of squares of a factor is 25 and the factor has 4 levels. The mean-square or error is 1.5 with 6 degrees of freedom for error. From this information we conclude that the factor is

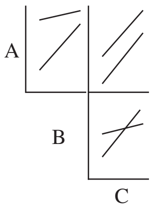
    (a) Significant at 95% confidence level
    (b) Significant at 99% confidence level

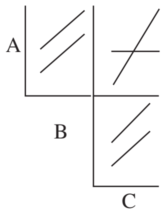
(c) Not significant at 95%
(d) Not significant at 90%

30. Which of the following figures shows presence of interaction between factors A and B?

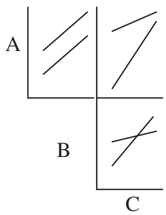
(a)


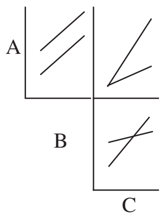
(b)


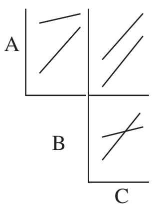
(c)


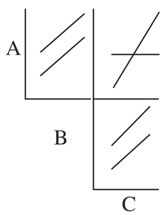
(d)


31. Which of the following figures shows absence of interaction between factors A and C?

(a)


(b)


(c)


(d)


Appendix

TABLE A Control Chart Factors
TABLE B Critical Values of t Distribution
TABLE C–1 Critical Values of F Distribution ($\alpha = 0.1$)
TABLE C–2 Critical Values of F Distribution ($\alpha = 0.05$)
TABLE C–3 Critical Values of F Distribution ($\alpha = 0.01$)
TABLE D Orthogonal Arrays

TABLE A

Factors for Computing Central Lines and 3 σ Control Limits for Variables Charts

Sample Size	CHART FOR AVERAGES		CHART FOR STANDARD DEVIATIONS		
	Factors for Control Limits		Factor for Central Line	Factors for Control Limits	
n	A_2	A_3	C_4	B_3	B_4
2	1.880	2.659	0.7979	0	3.267
3	1.023	1.954	0.8862	0	2.568
4	0.729	1.628	0.9213	0	2.266
5	0.577	1.427	0.9400	0	2.089
6	0.483	1.287	0.9515	0.030	1.970
7	0.419	1.182	0.9594	0.118	1.882
8	0.373	1.099	0.9650	0.185	1.815

Sample Size	CHART FOR RANGES					Chart for Medians
	Factor for Central Line	Factors for Control Limits				
n	d_2	D_3	D_4	D_5	D_6	A_5
2	1.128	0	3.267	0	3.865	2.224
3	1.693	0	2.574	0	2.745	1.265
4	2.059	0	2.282	0	2.375	0.829
5	2.326	0	2.114	0	2.179	0.712
6	2.534	0	2.004	0	2.055	0.562
7	2.704	0.076	1.924	0.078	1.967	0.520
8	2.847	0.136	1.864	0.139	1.901	0.441

TABLE B
Critical Values, $t_{\alpha,v}$, of t Distribution

	α							
v	0.25	0.10	0.05	0.025	0.01	0.005	0.001	0.0005
1	1.000	3.078	6.314	12.706	21.821	63.657	318.31	636.62
2	0.816	1.886	2.920	4.303	6.965	9.925	22.326	31.598
3	0.765	1.638	2.353	3.182	4.541	5.841	10.213	12.924
4	0.741	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.727	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.718	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	0.711	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.706	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.703	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.700	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0.697	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.695	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.694	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.692	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	0.691	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0.690	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.689	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.688	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.688	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0.687	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	0.686	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	0.686	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.685	1.319	1.714	2.069	2.500	2.807	3.485	3.767
24	0.685	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0.684	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	0.684	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.684	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.683	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.683	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0.683	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	0.681	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0.679	1.296	1.671	2.000	2.390	2.660	3.232	3.460
∞	0.674	1.282	1.645	1.960	2.326	2.576	3.090	3.291

TABLE C–1

Critical Values, F_{α, v_1, v_2}, of *F* Distribution (α = 0.1)

	V_1 (NUMERATOR)												
v_2	*1*	*2*	*3*	*4*	*6*	*8*	*10*	*12*	*15*	*20*	*50*	*100*	∞
1	4052	4999	5403	5625	5859	5981	6056	6106	6157	6209	6300	6330	6366
2	98.5	99.0	99.2	99.2	99.3	99.4	99.4	99.4	99.4	99.4	99.5	99.5	99.5
3	34.1	30.8	29.5	28.7	27.9	27.5	27.2	27.1	26.9	26.7	26.4	26.2	26.1
4	21.2	18.0	16.7	16.0	15.2	14.8	14.5	14.4	14.2	14.0	13.7	13.6	13.5
5	16.3	13.3	12.1	11.4	10.7	10.3	10.1	9.89	9.72	9.55	9.24	9.13	9.02
6	13.7	10.9	9.78	9.15	8.47	8.10	7.87	7.72	7.56	7.40	7.09	6.99	6.88
7	12.2	9.55	8.45	7.85	7.19	6.84	6.62	6.47	6.31	6.16	5.86	5.75	5.65
8	11.3	8.65	7.59	7.01	6.37	6.03	5.81	5.67	5.52	5.36	5.07	4.96	4.86
9	10.6	8.02	6.99	6.42	5.80	5.47	5.26	5.11	4.96	4.81	4.52	4.42	4.31
10	10.0	7.56	6.55	5.99	5.39	5.06	4.85	4.71	4.56	4.41	4.12	4.01	3.91
11	9.65	7.21	6.22	5.67	5.07	4.74	4.54	4.40	4.25	4.10	3.81	3.71	3.60
12	9.33	6.93	5.95	5.41	4.82	4.50	4.30	4.16	4.01	3.86	3.57	3.47	3.36
13	9.07	6.70	5.74	5.21	4.62	4.30	4.10	3.96	3.82	3.66	3.38	3.27	3.17
14	8.86	6.51	5.56	5.04	4.46	4.14	3.94	3.80	3.66	3.51	3.22	3.11	3.00
15	8.68	6.36	5.42	4.89	4.32	4.00	3.80	3.67	3.52	3.37	3.08	2.98	2.87
16	8.53	6.23	5.29	4.77	4.20	3.89	3.69	3.55	3.41	3.26	2.97	2.86	2.75
17	8.40	6.11	5.18	4.67	4.10	3.79	3.59	3.46	3.31	3.16	2.87	2.76	2.65
18	8.29	6.01	5.09	4.58	4.01	3.71	3.51	3.37	3.23	3.08	2.78	2.68	2.57
19	8.18	5.93	5.01	4.50	3.94	3.63	3.43	3.30	3.15	3.00	2.71	2.60	2.49
20	8.10	5.85	4.94	4.43	3.87	3.56	3.37	3.23	3.09	2.94	2.64	2.54	2.42
22	7.95	5.72	4.82	4.31	3.76	3.45	3.26	3.12	2.98	2.83	2.53	2.42	2.31
24	7.82	5.61	4.72	4.22	3.67	3.36	3.17	3.03	2.89	2.74	2.44	2.33	2.21
26	7.72	5.53	4.64	4.14	3.59	3.29	3.09	2.96	2.81	2.66	2.36	2.25	2.13
28	7.64	5.45	4.57	4.07	3.53	3.23	3.03	2.90	2.75	2.60	2.30	2.19	2.06
30	7.56	5.39	4.51	4.02	3.47	3.17	2.98	2.84	2.70	2.55	2.25	2.13	2.01
40	7.31	5.18	4.31	3.83	3.29	2.99	2.80	2.66	2.52	2.37	2.06	1.94	1.80
60	7.08	4.98	4.13	3.65	3.12	2.82	2.63	2.50	2.35	2.20	1.88	1.75	1.60
120	6.85	4.79	3.95	3.48	2.96	2.66	2.47	2.34	2.19	2.03	1.70	1.56	1.38
200	6.76	4.71	3.88	3.41	2.89	2.60	2.41	2.27	2.13	1.97	1.63	1.48	1.28
∞	6.63	4.61	3.78	3.32	2.80	2.51	2.32	2.18	2.04	1.88	1.52	1.36	1.00

TABLE C–2
Critical Values, F_{α, v_1, v_2}, of F Distribution ($\alpha = 0.05$)

	V_1 (NUMERATOR)												
v_2	1	2	3	4	6	8	10	12	15	20	50	100	∞
1	161	200	216	225	234	239	242	244	246	248	252	253	254
2	18.5	19.0	19.2	19.2	19.3	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.5
3	10.1	9.55	9.28	9.12	8.94	8.85	8.79	8.74	8.70	8.66	8.58	8.55	8.53
4	7.71	6.94	6.59	6.39	6.16	6.04	5.96	5.91	5.86	5.80	5.70	5.66	5.63
5	6.61	5.79	5.41	5.19	4.95	4.82	4.74	4.68	4.62	4.56	4.44	4.41	4.36
6	5.99	5.14	4.76	4.53	4.28	4.15	4.06	4.00	3.94	3.87	3.75	3.71	3.67
7	5.59	4.74	4.35	4.12	3.87	3.73	3.64	3.57	3.51	3.44	3.32	3.27	3.23
8	5.32	4.46	4.07	3.84	3.58	3.44	3.35	3.28	3.22	3.15	3.02	2.97	2.93
9	5.12	4.26	3.86	3.63	3.37	3.23	3.14	3.07	3.01	2.94	2.80	2.76	2.71
10	4.96	4.10	3.71	3.48	3.22	3.07	2.98	2.91	2.85	2.77	2.64	2.59	2.54
11	4.84	3.98	3.59	3.36	3.09	2.95	2.85	2.79	2.72	2.65	2.51	2.46	2.40
12	4.75	3.89	3.49	3.26	3.00	2.85	2.75	2.69	2.62	2.54	2.40	2.35	2.30
13	4.67	3.81	3.41	3.18	2.92	2.77	2.67	2.60	2.53	2.46	2.31	2.26	2.21
14	4.60	3.74	3.34	3.11	2.85	2.70	2.60	2.53	2.46	2.39	2.24	2.19	2.13
15	4.54	3.68	3.29	3.06	2.79	2.64	2.54	2.48	2.40	2.33	2.18	2.12	2.07
16	4.49	3.63	3.24	3.01	2.74	2.59	2.49	2.42	2.35	2.28	2.12	2.07	2.01
17	4.45	3.59	3.20	2.96	2.70	2.55	2.45	2.38	2.31	2.23	2.08	2.02	1.96
18	4.41	3.55	3.16	2.93	2.66	2.51	2.41	2.34	2.27	2.19	2.04	1.98	1.92
19	4.38	3.52	3.13	2.90	2.63	2.48	2.38	2.31	2.23	2.16	2.00	1.94	1.88
20	4.35	3.49	3.10	2.87	2.60	2.45	2.35	2.28	2.20	2.12	1.97	1.91	1.84
22	4.30	3.44	3.05	2.82	2.55	2.40	2.30	2.23	2.15	2.07	1.91	1.85	1.78
24	4.26	3.40	3.01	2.78	2.51	2.36	2.25	2.18	2.11	2.03	1.86	1.80	1.73
26	4.23	3.37	2.98	2.74	2.47	2.32	2.22	2.15	2.07	1.99	1.82	1.76	1.69
28	4.20	3.34	2.95	2.71	2.45	2.29	2.19	2.12	2.04	1.96	1.79	1.73	1.65
30	4.17	3.32	2.92	2.69	2.42	2.27	2.16	2.09	2.01	1.93	1.76	1.70	1.62
40	4.08	3.23	2.84	2.61	2.34	2.18	2.08	2.00	1.92	1.84	1.66	1.59	1.51
60	4.00	3.15	2.76	2.53	2.25	2.10	1.99	1.92	1.84	1.75	1.56	1.48	1.39
120	3.92	3.07	2.68	2.45	2.17	2.02	1.91	1.83	1.75	1.66	1.46	1.37	1.25
200	3.89	3.04	2.65	2.42	2.14	1.98	1.88	1.80	1.72	1.62	1.41	1.32	1.19
∞	3.84	3.00	2.60	2.37	2.10	1.94	1.83	1.75	1.67	1.57	1.35	1.24	1.00

TABLE C–3

Critical Values, F_{α,v_1,v_2}, of *F* Distribution ($\alpha = 0.01$)

v_2	v_1 (NUMERATOR) 1	2	3	4	6	8	10	12	15	20	50	100	∞
1	39.9	49.5	53.6	55.8	58.2	59.4	60.2	60.7	61.2	61.7	62.7	63.0	63.3
2	8.53	9.00	9.16	9.24	9.33	9.37	9.39	9.41	9.42	9.44	9.47	9.48	9.49
3	5.54	5.46	5.39	5.34	5.28	5.25	5.23	5.22	5.20	5.18	5.15	5.14	5.13
4	4.54	4.32	4.19	4.11	4.01	3.95	3.92	3.90	3.87	3.84	3.80	3.78	3.76
5	4.06	3.78	3.62	3.52	3.40	3.34	3.30	3.27	3.24	3.21	3.15	3.13	3.10
6	3.78	3.46	3.29	3.18	3.05	2.98	2.94	2.90	2.87	2.84	2.77	2.75	2.72
7	3.59	3.26	3.07	2.96	2.83	2.75	2.70	2.67	2.63	2.59	2.52	2.50	2.47
8	3.46	3.11	2.92	2.81	2.67	2.59	2.54	2.50	2.46	2.42	2.35	2.32	2.29
9	3.36	3.01	2.81	2.69	2.55	2.47	2.42	2.38	2.34	2.30	2.22	2.19	2.16
10	3.28	2.92	2.73	2.61	2.46	2.38	2.32	2.28	2.24	2.20	2.12	2.09	2.06
11	3.23	2.86	2.66	2.54	2.39	2.30	2.25	2.21	2.17	2.12	2.04	2.00	1.97
12	3.18	2.81	2.61	2.48	2.33	2.24	2.19	2.15	2.10	2.06	1.97	1.94	1.90
13	3.14	2.76	2.56	2.43	2.28	2.20	2.14	2.10	2.05	2.01	1.92	1.88	1.85
14	3.10	2.73	2.52	2.39	2.24	2.15	2.10	2.05	2.01	1.96	1.87	1.83	1.80
15	3.07	2.70	2.49	2.36	2.21	2.12	2.06	2.02	1.97	1.92	1.83	1.79	1.76
16	3.05	2.67	2.46	2.33	2.18	2.09	2.03	1.99	1.94	1.89	1.79	1.76	1.72
17	3.03	2.64	2.44	2.31	2.15	2.06	2.00	1.96	1.91	1.86	1.76	1.73	1.69
18	3.01	2.62	2.42	2.29	2.13	2.04	1.98	1.93	1.89	1.84	1.74	1.70	1.66
19	2.99	2.61	2.40	2.27	2.11	2.02	1.96	1.91	1.86	1.81	1.71	1.67	1.63
20	2.97	2.59	2.38	2.25	2.09	2.00	1.94	1.89	1.84	1.79	1.69	1.65	1.61
22	2.95	2.56	2.35	2.22	2.06	1.97	1.90	1.86	1.81	1.76	1.65	1.61	1.57
24	2.93	2.54	2.33	2.19	2.04	1.94	1.88	1.83	1.78	1.73	1.62	1.58	1.53
26	2.91	2.52	2.31	2.17	2.01	1.92	1.86	1.81	1.76	1.71	1.59	1.55	1.50
28	2.89	2.50	2.29	2.16	2.00	1.90	1.84	1.79	1.74	1.69	1.37	1.53	1.48
30	2.88	2.49	2.28	2.14	1.98	1.88	1.82	1.77	1.72	1.67	1.55	1.51	1.46
40	2.84	2.44	2.23	2.09	1.93	1.83	1.76	1.71	1.66	1.61	1.48	1.43	1.38
60	2.79	2.39	2.18	2.04	1.87	1.77	1.71	1.66	1.60	1.54	1.41	1.36	1.29
120	2.75	2.35	2.13	1.99	1.82	1.72	1.65	1.60	1.55	1.48	1.34	1.27	1.19
200	2.73	2.33	2.11	1.97	1.80	1.70	1.63	1.57	1.52	1.46	1.31	1.24	1.14
∞	2.71	2.30	2.08	1.94	1.77	1.67	1.60	1.55	1.49	1.42	1.26	1.18	1.00

TABLE D

Orthogonal Arrays, Interaction Tables, and Linear Graphs

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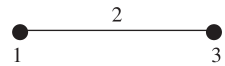
Orthogonal Array (OA4)

	COLUMN		
TC	***1***	***2***	***3***
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1



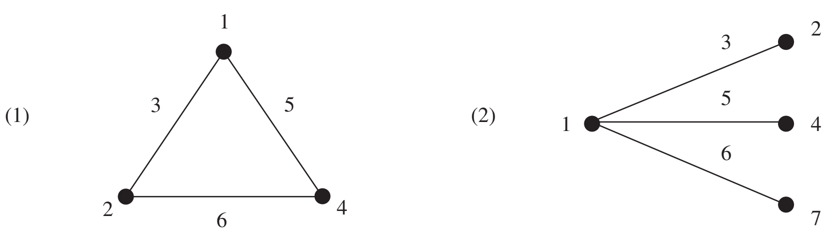
Linear graph for OA4

Orthogonal Array (OA8)

	COLUMN						
TC	***1***	***2***	***3***	***4***	***5***	***6***	***7***
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

Interaction Table for OA8

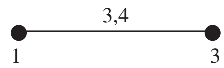
	COLUMN						
Column	***1***	***2***	***3***	***4***	***5***	***6***	***7***
1	(1)	3	2	5	4	7	6
2		(2)	1	6	7	4	5
3			(3)	7	6	5	4
4				(4)	1	2	3
5					(5)	3	2
6						(6)	1
7							(7)



Linear graphs for OA8

Orthogonal Array (OA9)

	COLUMN			
TC	***1***	***2***	***3***	***4***
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1



Linear graph for OA9

Orthogonal Array (OA12)

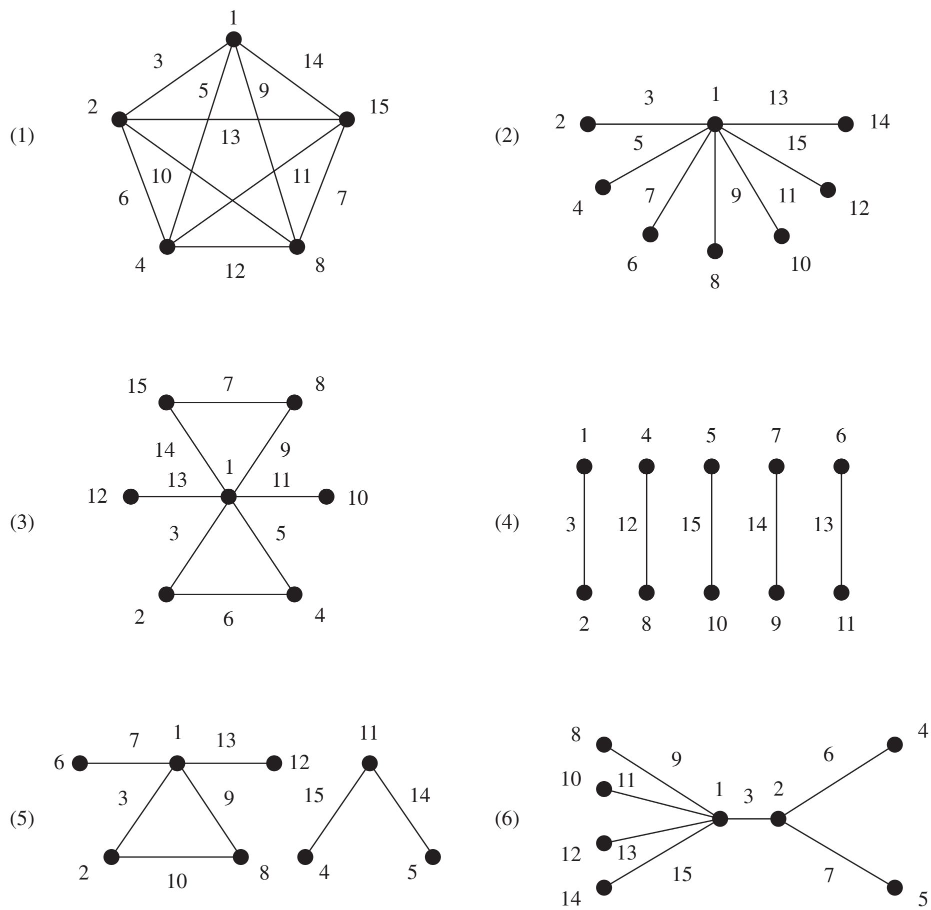
	COLUMN										
TC	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***
1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	2	2	2	2	2	2
3	1	1	2	2	2	1	1	1	2	2	2
4	1	2	1	2	2	1	2	2	1	1	2
5	1	2	2	1	2	2	1	2	1	2	1
6	1	2	2	2	1	2	2	1	2	1	1
7	2	1	2	2	1	1	2	2	1	2	1
8	2	1	2	1	2	2	2	1	1	1	2
9	2	1	1	2	2	2	1	2	2	1	1
10	2	2	2	1	1	1	1	2	2	1	2
11	2	2	1	2	1	2	1	1	1	2	2
12	2	2	1	1	2	1	2	1	2	2	1

Orthogonal Array (OA16)

	COLUMN														
TC	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1

Interaction Table for OA16

	COLUMN														
Column	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***
1	(1)	3	2	5	4	7	6	9	8	11	10	13	12	13	14
2		(2)	1	6	7	4	5	10	11	8	9	14	15	12	13
3			(3)	7	6	5	4	11	10	9	8	15	14	13	12
4				(4)	1	2	3	12	13	14	15	8	9	10	11
5					(5)	3	2	13	12	15	14	9	8	11	10
6						(6)	1	14	15	12	13	10	11	8	9
7							(7)	15	14	13	12	11	10	9	8
8								(8)	1	2	3	4	5	6	7
9									(9)	3	2	5	4	7	6
10										(10)	1	6	7	4	5
11											(11)	7	6	5	4
12												(12)	1	2	3
13													(13)	3	2
14														(14)	1
15															(15)



Linear graphs for OA16

Orthogonal Array (OA18)

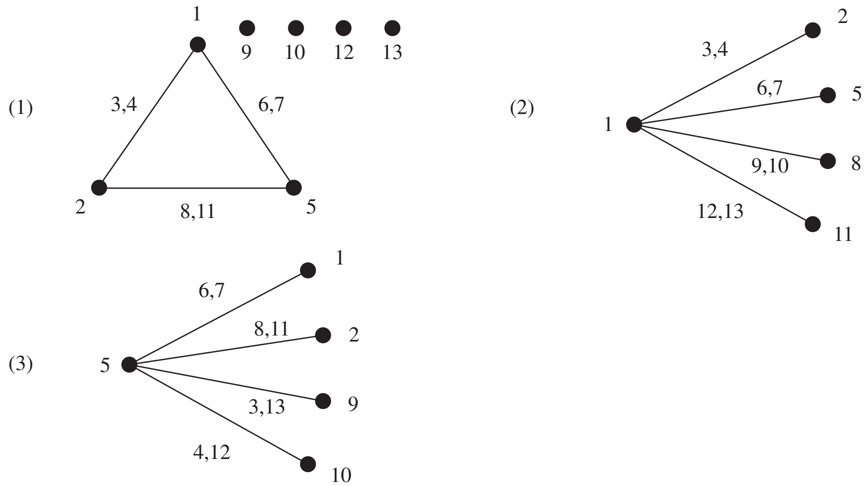
	COLUMN							
TC	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	3	3	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	3	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	3	1	3	2
14	2	2	2	3	1	2	1	3
15	2	2	3	1	2	3	2	1
16	2	3	1	3	2	3	1	2
17	2	3	2	1	3	1	2	3
18	2	3	3	2	1	2	3	1

Orthogonal Array (OA27)

	COLUMN												
TC	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

Interaction Table for OA27

	COLUMN											
Column	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***
1	3 4	2 4	2 3	6 7	5 7	5 6	9 10	8 10	8 9	12 13	11 13	11 12
2		1 4	1 3	8 11	9 12	10 13	5 11	6 12	7 13	5 8	6 9	7 10
3			1 2	9 13	10 11	8 12	7 12	8 13	6 11	6 10	7 8	5 9
4				10 12	8 13	9 11	6 13	7 11	5 12	7 9	5 10	6 8
5					1 7	1 6	2 11	3 13	4 12	2 8	4 10	3 9
6						1 5	4 3	2 12	3 11	3 10	2 9	4 8
7							3 12	4 11	2 13	4 9	3 8	2 10
8								1 10	1 9	2 5	3 7	4 6
9									1 8	4 7	2 6	3 5
10										3 6	4 7	2 7
11											1 13	1 12
12												1 11



Linear graphs for OA27

References

ANDERSON, DAVID, *Management Information Systems*, New Jersey: Prentice Hall, Inc., 2000.

ASQ/AIAG TASK FORCE, *Fundamental Statistical Process Control*. Troy, MI: Automobile Industry Action Group, 1991.

ASQ QUALITY COST COMMITTEE, *Guide for Reducing Quality Costs*, 2nd ed. Milwaukee, WI: American Society for Quality, Inc., 1987.

ASQ QUALITY COST COMMITTEE, *Principles of Quality Costs*. Milwaukee, WI: American Society for Quality, Inc., 1986.

BESTERFIELD, DALE H., *Quality Control*, 6th ed. Upper Saddle River, NJ: Prentice Hall, 2001.

BOSSERT, JAMES L., *Quality Function Deployment: A Practioner's Approach*. Milwaukee, WI: ASQ Quality Press, 1991.

BRASSARD, MICHAEL, *The Memory Jogger Plus +. Featuring the Seven Management and Planning Tools*. Methuen, MA: GOAL/QPC, 1996.

CAMP, ROBERT C., *Benchmarking: The Search for Industry Best Practices That Lead to Superior Practice*. Milwaukee, WI: ASQ Quality Press, 1989.

CASCIO, JOSEPH, WODSIDE, GAYLE, and MITCHELL, PHILLIP, *ISO 14000 Guide. The New International Environmental Management Standards*. New York: McGraw-Hill, 1996.

CHASE, G. W., *Implementing TQM in a Construction Company*. Washington D.C.: Associated General Contractors of America, 1993.

CHRYSLER/FORD/GENERAL MOTORS SUPPLIER QUALITY REQUIREMENTS TASK FORCE. *Quality System Requirements QS-9000*. Troy, MI: Automobile Industry Action Group, 1994.

CHRYSLER/FORD/GENERAL MOTORS TASK FORCE, *Potential Failure Mode and Effects Analysis (FMEA)*. Troy, MI: Automobile Industry Action Group, 1995.

COVEY, STEPHEN R., *The 7 Habits of Highly Effective People*. New York, NY: Simon & Schuster, 1989.

CROSBY, PHILIP B., *Quality Without Tears*. New York: McGraw-Hill Book Company, 1984.

DEMING, W. EDWARDS, *Quality, Productivity, and Competitive Position*. Cambridge, MA: Massachusetts Institute of Technology, 1982.

DUNCAN, ACHESON J., *Quality Control and Industrial Statistics*, 5th ed. Homewood, IL: Richard D. Irwin, 1986.

FEIGENBAUM, A. V., *Total Quality Control*. New York: McGraw-Hill Book Company, 1961.

FISHER, DONALD C., *The Simplified Baldrige Award Organization Assessment*. New York: The Lincoln-Bradley Publishing Group, 1993.

GATES, BILL, *The Road Ahead*, New York: Viking Penquin, 1995.

GOETSCH, DAVID L., and STANLEY B. DAVIS, *ISO 14000 Environmental Management*, New Jersey, Prentice Hall, Inc., 2001.

GOODEN, RANDALL L., *Product Liability Prevention, Mil*waukee, WI: ASQ Quality Press, 2000.

HICKS, CHARLES R., *Fundamental Concepts in the Design of Experiments*. New York: Holt, Rinehart and Winston, 1973.

ISHIKAWA, K., *What Is Total Quality Control?* Englewood Cliffs, NJ: Prentice Hall, Inc., 1985.

Jordan, JAMES A. JR and FREDERICK J. MICHEL, *The Lean Company—Making the Right Choices*, Dearborn, MI, Society of Manufacturing Engineering, 2001.

JURAN, JOSEPH M., Editor, *Quality Control Handbook*, 4th ed. New York: McGraw-Hill Book Company, 1980.

KNOUSE, STEPHEN B., Editor, *Human Resources Management Perspectives on TQM Concepts and Practices*. Milwaukee, WI: ASQ Quality Press, 1996.

LEBOW, ROB, *A Journey into the Heroic Environment*. Rocklin, CA: Prima Publishing, 1990.

MARTIN, E. WAINRIGHT, et. al., *Managing Information Technology*, New Jersey: Prentice Hall, 1999.

NAKAJIMA, SEIICHI, *Total Productivity Maintenance*, Portland, OR: Productivity Press Inc., 1988.

PEACE, STUART GLEN, *Taguchi Methods: A Hands-On Approach*. New York: Addison-Wesley Publishing Company, Inc., 1992.

PEACH, ROBERT W., Editor, *The ISO 9000 Handbook*. Fairfax, VA: CEEM Information Services, 1992.

SCHMIDT, WARREN H., AND JEROME P. FINNIGAN, *The Race Without a Finish Line*. San Francisco, CA: Jossey-Bass Publishers, 1992.

SCHOLTES, PETER R., *The Team Handbook*. Madison, WI: Joiner Associates, Inc., 1988.

SCHOLTES, PETER R., *The Team Handbook. How to Use Teams to Improve Quality*. Madison, WI: Joiner Associates, Inc., 1992.

TAGUCHI, G., *Introduction to Quality Engineering*. Tokyo: Asian Productivity Organization, 1986.

WHEELER, DONALD J., *Understanding Industrial Experimentation*. Knoxville, TN: Statistical Process Controls, Inc., 1988.

WIERSEMA, FRED, *Customer Intimacy*, Santa Monica, CA: Knowledge Exchange, 1996.

WINCHELL, WILLIAM, *TQM: Getting Started and Achieving Results with Total Quality Management*. Dearborn, MI: Society of Manufacturing Engineers, 1992.

MODEL QUESTION PAPER – I

M.B.A DEGREE EXAMINATION

TOTAL QUALITY MANAGEMENT

Time : Three hours | Maximum : 100 marks

Answer ALL Questions

PART A – (10 × 2 = 20 marks)

Q.1 What is quality policy?

Q.2 What is quality control?

Q.3 Define quality circle.

Q.4 List the phases of implementation of Taguchi methods.

Q.5 List the control charts for attributes.

Q.6 Define tero-technology.

Q.7 How is the voice of the customer heard?

Q.8 List the phases of bench marking.

Q.9 Define quality culture.

Q.10 Define employee empowerment.

PART B – (5 × 6 = 80 Marks)

Q.11 **(a)** Explain the factors that influence end-user perceptions.

(Or)

(b) Explain the cost of quality.

Q.12 **(a)** Explain Juran's quality trilogy process in detail.

(Or)

(b) Elaborate on the following:

Q.13 **(a)** Using a neat flow diagram, explain the process of selecting the appropriate control chart.

(Or)

(b) Elaborate on the principles of reengineering using appropriate examples.

Q.14 **(a)** Explain the seven new management tools.

(Or)

(b) Prepare the format of an FMEA table and explain the components with the example of your choice.

Q.15 **(a)** Explain the types of quality audits.

(Or)

(b) List the elements of ISO 9000 series requirements.

MODEL QUESTION PAPER – II

M.B.A DEGREE EXAMINATION

TOTAL QUALITY MANAGEMENT

Time : Three hours Maximum : 100 Marks

Answer ALL Questions

Part A – (10 × 2 = 20 Marks)

Q.1 What is Appraisal Costs of Quality?

Q.2 Explain the term. Return on Quality (ROQ).

Q.3 What is Taguchi loss function?

Q.4 Define Cost of quality (COQ).

Q.5 What is Process capability?

Q.6 What is Infant mortality period?

Q.7 What is an Affinity diagram?

Q.8 Define Life cycle cost.

Q.9 Define Empowerment.

Q.10 What is Statistical thinking?

PART B – (5 × 6 = 80 Marks)

Q.11 **(a)** Explain in detail the obstacles to be faced in implementing TQM in an organization.

(Or)

(b) Bring out the dimensions of product and service quality. Also explain why the service quality is more difficult to define than product quality.

Q.12 **(a)** Compare and contrast Deming's Juran's and Croby's perspectives of quality management. What are the major similarities and differences between their perspectives?

(Or)

(b) Enumerate in detail the various principles of quality management.

Q.13 **(a)** Explain in detail the methodology to implement Business Process Re-engineering.

(Or)

(b) **i)** AAA Inc., produces meter sticks that have a target length of 100 centimeters with upper and lower specification limits of 100.05 and 99.95 centimeters respectively. Their existing process produces meter sticks with an average length of 99.97 centimeters and a standard deviation of 0.015 centimeters. They are considering the purchase of a new machine that can hold a process output average exactly to target with a standard deviation of 0.02. Which machine will provide a better process capability index?

ii) Suppose a product is designed to function for 1,00,000 hours with a 1% chance of failure. Suppose that there are six of these in use at a facility. Find the average number of failures per hour and the MTTF.

Q.14 **(a)** **i)** Explain the matrices involved in Quality Function Deployment (QFD) process.

ii) Define key customer requirement for a product of your choice. Next, define key technical-requirements for the same product. Create a matrix showing the relationships between technical and customer requirements using the QFD format.

(Or)

(b) What is FMEA? Explain in detail the different types of FMEA. Also highlight the scales used in FMEA.

Q.15 **(a)** Describe the purpose and the intent of the ISO 9000:2000 program. What are the advantages of becoming an ISO 9000:2000 certified companies? Are there any disadvantages?

(Or)

(b) List and briefly explain the principles of leaderships.

MODEL QUESTION PAPER – III

M.B.A. DEGREE EXAMINATION

BA 1656 – QUALITY MANAGEMENT

Time : Three Hours | Maximum : 80 Marks

PART A – (5 × 5 = 25 Marks)

Answer any FIVE questions
All question carry equal marks

Q.1 What is Total Quality?

Q.2 What is Pareto Priniciple?

Q.3 What is Juran Trilogy?

Q.4 What is the purpose of Design of Experiments?

Q.5 Name the three Ms for effective TPM.

Q.6 Define Life cycle cost.

Q.7 Define the 'Voice of the customer'.

Q.8 Define 'Robust design'.

Q.9 What are the benefits of QMS?

Q.10 List any three appropriate reasons for implementing ISO 9000.

PART – B

Q.11 **(a)** Explain in detail the various principles of Quality Management.

(Or)

(b) Explain in detail the concept of Cost of Quality. Bring out the various components of cost of quality with the interrelationship among them in minimizing the total Cost of Quality.

Q.12 **(a)** In details explain the W. Edwards Deming's philosophy of quality Management.

(Or)

(b) Write a note on importance and applicability of 5-S practice and 8D methodologies.

Q.13 **(a)** **i)** A Products is made up of 20 components in a series. Ten of the components have a 1/10,000 chance of failure. Five have a 3/10,000 chance for failure. Four have a 4/10,000 chance for failure. One component has a 1/100 chance for failure. What is the overall reliability of the products?

(Or)

(b) Explain in detail the six sigma concepts of process capability. Also bring out the methodologies adopted in six sigma practices.

Q.14 **(a)** **i)** Explain the purpose and methodology of construction of a cause –and-effect (Ishikawa) diagram with an example.

ii) Suppose a product is designed to function for 100,000 hours with a 1% chance of failure. Suppose that there are six of these in use at a facility. Find the average number of failures per hour and the MTTF.

(Or)

(b) Define key customer requirements for an automobile windshield. Next, define key technical requirements. Create a matrix showing the relationships between technical and customer requirements using the QFD format.

Q.15 **(a)** Describe ISO 9000: 2000 and state its scope and applications.

(Or)

(b) **i)** What is meant by employees empowerment? What is the relationship between employee empowerment and team work?

ii) Describe the principle attributes of Hersey and Blanchard's situational leadership model. Is this model of leadership appropriate for a quality-minded company?

MODEL QUESTION PAPER – IV

M.B.A DEGREE EXAMINATION

QUALITY MANAGEMENT

Time : Three hours | Maximum : 100 marks

Answer ALL Questions

PART A – (10 × 2 = 20 marks)

Q.1 Define total quality management.

Q.2 Who is the customer?

Q.3 Explain briefly the reinvention strategy

Q.4 Given four level factors and two suspected two factors interactions, determine the degrees of freedom

Q.5 What are the sources of variation that present in every process

Q.6 Write the principles of BPR

Q.7 How solicited, measurable and routine data are collected for customer information?

Q.8 What is the use of tree diagram?

Q.9 What are the inputs for design and development (clause 7.3.2)?

Q.10 What are the ingredients for an effective recognition and reward system?

PART B – (5 × 16 = 80 marks)

Q.11 **(a)** Explain TQM frame work using an appropriate model that is suitable for Indian manufacturing Industries/Service industries.

(Or)

(b) **i)** Explain how Kano model translates customer needs into requirements.

ii) Explain how a survey and focus group help in collecting customer feedback.

Q.12 **(a)** **i)** Juran divided quality management into three parts, known as Juran's quality trilogy. Briefly explain the three parts of the trilogy.

ii) Explain briefly the concept of quality circle.

(Or)

(b) Discuss with a case study the contributions of ishikawa.

Q.13 **(a)** The following table gives the average and range in kilograms for tensile tests on an improved plastic cord. The subgroup size is 4. Determine the trial central line and control limits of $\overline{X}$ and R charts. If any points are out of control, assume assignable causes, and determine the revised limits and central line

Subgroup number	$\bar{X}$	R	Subgroup number	$\bar{X}$	R
1	476	32	14	482	22
2	466	24	15	506	23
3	484	32	16	496	23
4	466	26	17	478	25
5	470	24	18	484	24
6	494	24	19	506	23
7	486	28	20	476	25
8	496	23	21	485	29
9	488	24	22	490	25
10	482	26	23	463	22
11	498	25	24	469	27
12	464	24	25	474	22
13	484	24			

(Or)

(b) **i)** Given the component reliabilities indicated below, calculate the probability of survival of the assembly.

Component	A	B	C	D	E	F
Reliability	0.999	0.98	0.99	0.87	0.92	0.84

ii) A sample of 10 electronic components were tested. The time to failure for first four component to fail were 1900, 2650, 2810, and 2820 hours respectively. The test was terminated at 3000 hours. There was no replacement of failed units and the remaining six units were functioning properly at the time of termination. Determine the MTTF.

iii) What are the objective of TPM?

iv) What are the six big losses?

Q.14 **(a)** Explain the benchmarking process for an automotive industry in India.

(Or)

(b) Explain the steps followed in conducting design FMEA

Q.15 **(a)** Write short notes on the following:

i) Quality manual, ii) Control of records, iii) Customers focus iv) Design and development review

(Or)

(b) Examine the role of leaders in transformation or changing the organization. What principle reasons, you think, might be responsible for many leaders not being able to succeed in managing change (in the context to TQM)?

Solutions to the Model Question Paper I

Q.1 The quality policy is a guide for everyone in the organization as to how they should provide products and service to the customers. It should be written by the CEO with feedback from the work force and be approved by the quality council. Common characteristics are

- Quality is first among equals.
- Meet the needs of the internal and external customers.
- Equal or exceed the competition.
- Continually improve the quality.
- Include business and production practices.
- Utilize the entire work force.

Q.2 The control and prevention of quality problems associated with information technology will be similar to any product or service. A number of solutions have already been mentioned in this chapter. Like any product or service, many errors or glitches will go unnoticed for years.

Many of the TQM principles and practices, and tools and techniques in this textbook will provide additional solutions. In particular, ISO 9000, Quality by Design, FMEA, and SPC will be most effective.

Q.3 It is the driver for the TQM engine. In a typical organization the council is composed of the chief executive officer (CEO); the senior managers of the functional areas, such as design, marketing, finance, production, and quality; and a coordinator or consultant. If there is a union, consideration should be given to having a representative on the council. Some organizations, such as Friendly Ice Cream of Wilbaham, MA, include front-line representatives from every area. A coordinator is necessary to assume some of the added duties that a quality improvement activity requires. The individual selected for the coordinator's position should be a bright young person with executive potential. That person will report to the CEO.

The responsibility of the coordinator is to build two-way trust, propose team needs to the council, share council expectations with the team, and brief the council of team progress. In addition, the coordinator will ensure that the teams are empowered and know their responsibilities. The coordinator's activities are to assist the team leaders, share lessons learned among teams, and have regular leaders' meetings.

In smaller organizations where managers may be responsible for more than one functional area, the number of members will be smaller. Also, a consultant would most likely be employed rather than a coordinator.

Q.4 **Parameter Design** There are three product-development stages: product design, process design, and production. These stages are shown in Table 20–8, along with the three previously discussed sources of variation or noise: environmental variables, product deterioration, and production variations. Only at the product design stage are countermeasures possible against all the sources of variation. AQ:1

Tolerance Design Tolerance design is the process of determining the statistical tolerance around the target. During the parameter-design stage, low-cost tolerancing should be used. Only when the values are beyond the low-cost tolerancing limits is this concept implemented. Tolerance design is the selective tightening of tolerances and/or upgrading to eliminate excessive variation. It uses analysis of variance (ANOVA) to determine which factors contribute to the total variability and the loss function to obtain a trade-off between quality and cost.

Q.5 **i)** ***p* Chart** shows the proportion nonconforming in a sample or subgroup.

ii) ***np* Chart** shows the number nonconforming.

iii) ***u* Chart** is for the count of nonconformities per unit.
iv) ***c* Chart** shows the count of nonconformities in an inspected unit.

Q.6 Multidisciplinary approach to obtaining maximum economic benefit from physical assets

Q.7 Comment card, Focus group, Questionnaire, Toll-free telephone lines, Customer visits, Report cards, Internet employee feedback, Mass customization, American customer satisfaction index.

Q.8 Organizations that benchmark, adapt the process to best fit their own needs and culture. Although the number of steps in the process may vary from organization to organization, the following six steps contain the core techniques.

1. Decide what to benchmark.
2. Understand current performance.
3. Plan.
4. Study others.
5. Learn from the data.
6. Use the findings.

Q.9 TABLE 1
New and Old Cultures

Quality Element	*Previous State*	*TQM*
Definition	Product-oriented	Customer-oriented
Priorities	Second to service and cost	First among equals of service and cost
Decisions	Short-term	Long-term
Emphasis	Detection	Prevention
Errors	Operations	System
Responsibility	Quality control	Everyone
Problem Solving	Managers	Teams
Procurement	Price	Life-cycle costs, partnership
Manager's Role	Plan, assign, control, and enforce	Delegate, coach, facilitate, and mentor

Q.10 Empowerment is an environment in which people have the ability, the confidence, and the commitment to take the responsibility and ownership to improve the process and initiate the necessary steps to satisfy customer requirements within well-defined boundaries in order to achieve organizational values and goals.

AQ:2

Author Query:

AQ:1 Please check this x-reference for Table 20.8 and provide modified text.
AQ:2 Please provide solutions for Part-B Questions.

Solutions to the Model Question Paper II

Q.1 These are the costs incurred while conducting inspection, tests, and several other planned evaluations with the purpose of determining whether the product (or service) confirms to its stated requirements. Appraisal cost also includes various activities related to quality system audit, cost of legal compliance, supplier surveillance, product quality audits, costs for calibration of testing equipment, etc. Thus, cost of maintaining the inspection and test equipment is a part of appraisal cost. Examples include:

- Design reviews
- Software testing
- Set-up inspection
- Performance testing by customer
- Calibration of gauges
- Calibration of testing facility
- Receiving inspection of purchased parts

Q.2 The benefits of TQM are improved quality, employee participation, teamwork, working relationships, customer satisfaction, employee satisfaction, productivity, communication, profitability, and market share.

Q.3 Taguchi has defined quality as the loss imparted to society from the time a product is shipped. Societal losses include failure to meet customer requirements, failure to meet ideal performance, and harmful side effects. Many practitioners have included the losses due to production, such as raw material, energy, and labor consumed on unusable products or toxic by-products.

AQ:1

The loss-to-society concept can be illustrated by an example associated with the production of large vinyl covers to protect materials from the elements. Figure 20-1 shows three stages in the evolution of vinyl thickness. At (1), the process is just capable of meeting the specifications (USL and LSL); however, it is on the target *tau*, τ. After considerable effort, the production process was improved by reducing the variability about the target, as shown at (2). In an effort to reduce its production costs, the organization decided to shift the target closer to the LSL, as shown at (3). This action resulted in a substantial improvement by lowering the cost to the organization; however, the vinyl covers were not as strong as before. When farmers used the covers to protect wheat from the elements, they tore and a substantial loss occurred to the farmers. In addition, the cost of wheat increased as a result of supply-and-demand factors, thereby causing an increase in wheat prices and a further loss to society. The company's reputation suffered, which created a loss of market share with its unfavorable loss aspects.

Q.4 "Cost of quality" is an approach to measure and track financial impact of various quality activities. Until 1950s, the concept did not expl icitly extend to the quality function and the activities related to inspection, testing and audits were merely categorized as "overheads". In the 1950s, Dr. Armand Feigenbaum suggested to consider reporting systems focusing on quality costs. Dr. Joseph Juran also started emphasizing the need to speak of the language of upper management which is money. As the upper management best understands the language of money, reporting cost of quality can help in prioritizing appropriate improvement activities to minimize overall costs.

Q.5 **Process Capability** $C_p = 6\sigma$

$$\sigma = R_0 / d_2$$

Q.6 **Infant Mortality period** $R_t = e^{-t\lambda} = e^{-\frac{t}{\theta}}$

Q.7 These cost were not only limited to factory operations but also extended to support functions. Big chunk of the cost was on account of poor quality. Cost of poor quality is often compared with the tip of an iceberg. Figure 1 shows that the warranty costs and scrap costs are clearly visible but significant portion of the financial impact of poor quality is hidden like an iceberg.

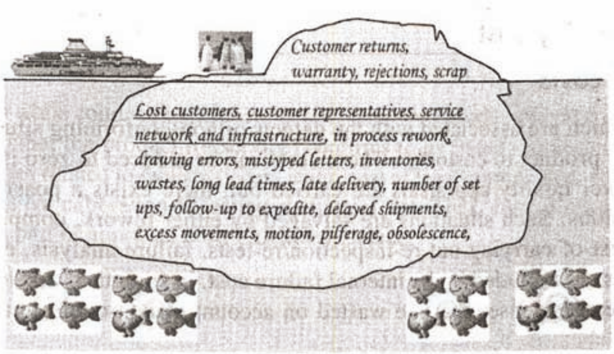


Figure 1 **Iceberg of Cost of Poor Quality**
(Reproduced with permission from the institute of Quality and Reliability, Pune, WWW.world-class-quality.com)

Q.8 The cost of product is not only limited to factory operation but also extended to support functions.

Q.9 Empowerment is an environment in which people have the ability, the confidence, and the commitment to take the responsibility and ownership to improve the process and initiate the necessary steps to satisfy customer requirements within well-defined boundaries in order to achieve organizational values and goals.

Q.10 Before a description of the next SPC tool, it is necessary to have a background in statistical fundamentals *Statistics* is defined as the science that deals with the collection, tabulation, analysis, interpretation and presentation of quantitative date. Each division is dependent of the accuracy and completeness of the preceding one. Data may be collected by a technician measuring the tensile strength of a plastic part or by an operator using a check sheet. It may be tabulated by simple paper-and-pencil techniques or by the use of a computer. Analysis may involve a cursory visual examination or exhaustive calculations. The final results are interpreted and presented to assist in the making of decisions concerning quality.

AQ:2

Author Query:

AQ:1 Check x-reference for Figure and provide updated text.
AQ:2 Please provide solutions for Part-B Questions.