PART I

PHILOSOPHY AND FUNDAMENTALS

COPYRIGHTED MATERIAL

1

INTRODUCTION TO QUALITY CONTROL AND THE TOTAL QUALITY SYSTEM

1-1 INTRODUCTION AND CHAPTER OBJECTIVES

Wa. . .ah, Wa. . .ah, Wa. . .ah. It was about 2 A.M. The resident physician had just delivered the newborn and the proud parents were ecstatic. Forgotten in an instant, as she held the infant close to her, was the pain and suffering of the mother. "Wouldn't it be nice if one could share this moment, right now, with family and loved ones who are far away?", thought the parents. As if through extrasensory perception, the physician understood this desire. In a moment, the digital camera that was already in place started streaming the video to the cell phones and Web addresses of those designated. Now, both parties could hear and see each other as they shared this unique and rare moment in a bond of togetherness. The developments of the twenty-first century and the advances in quality make this possible.

The objectives of this chapter are, first, to define quality as it relates to the manufacturing and service sector, to introduce the terminology related to quality, and to set up a framework

Fundamentals of Quality Control and Improvement, Third Edition, By Amitava Mitra
Copyright © 2008 John Wiley & Sons, Inc.

for the design and implementation of quality. Of importance will be the ability to identify the unique needs of the customer, which will assist in maintaining and growing market share. A study of activity-based product costing will be introduced along with the impact of quality improvement on various quality-related costs. The reader should be able to interpret the relationships among quality, productivity, long-term growth, and customer satisfaction.

1-2 EVOLUTION OF QUALITY CONTROL

The quality of goods produced and services rendered has been monitored, either directly or indirectly, since time immemorial. However, using a quantitative base involving statistical principles to control quality is a modern concept.

The ancient Egyptians demonstrated a commitment to quality in the construction of their pyramids. The Greeks set high standards in arts and crafts. The quality of Greek architecture of the fifth century B.C. was so envied that it profoundly affected the subsequent architectural constructions of Rome. Roman-built cities, churches, bridges, and roads inspire us even today.

During the Middle Ages and up to the nineteenth century, the production of goods and services was confined predominantly to a single person or a small group. The groups were often family-owned businesses, so the responsibility for controlling the quality of a product or service lay with that person or small group—Those also responsible for producing items conforming to those standards. This phase, comprising the time period up to 1900, has been labeled by Feigenbaum (1983) the *operator quality control period*. The entire product was manufactured by one person or by a very small group of persons. For this reason, the quality of the product could essentially be controlled by a person who was also the operator, and the volume of production was limited. The worker felt a sense of accomplishment, which lifted morale and motivated the worker to new heights of excellence. Controlling the quality of the product was thus embedded in the philosophy of the worker because pride in workmanship was widespread.

Starting in the early twentieth century and continuing to about 1920, a second phase evolved, called the *foreman quality control period* (Feigenbaum 1983). With the Industrial Revolution came the concept of mass production, which was based on the principle of specialization of labor. A person was responsible not for production of an entire product but rather, for only a portion of it. One drawback of this approach was the decrease in the workers' sense of accomplishment and pride in their work. However, most tasks were still not very complicated, and workers became skilled at the particular operations that they performed. People who performed similar operations were grouped together. A supervisor who directed that operation now had the task of ensuring that quality was achieved. Foremen or supervisors controlled the quality of the product, and they were also responsible for operations in their span of control.

The period from about 1920 to 1940 saw the next phase in the evolution of quality control. Feigenbaum (1983) calls this the *inspection quality control period*. Products and processes became more complicated, and production volume increased. As the number of workers reporting to a foreman grew in number, it became impossible for the foreman to keep close watch over individual operations. Inspectors were therefore designated to check the quality of a product after certain operations. Standards were set, and inspectors compared the quality of the item produced against those standards. In the event of discrepancies between a standard and a product, deficient items were set aside from those that met the standard. The nonconforming items were reworked if feasible, or were discarded.

During this period, the foundations of statistical aspects of quality control were being developed, although they did not gain wide usage in U.S. industry. In 1924, Walter A. Shewhart of Bell Telephone Laboratories proposed the use of statistical charts to control the variables of a product. These came to be known as *control charts* (sometimes referred to as *Shewhart control charts*). They play a fundamental role in statistical process control. In the late 1920s, H. F. Dodge and H. G. Romig, also from Bell Telephone Laboratories, pioneered work in the areas of acceptance sampling plans. These plans were to become substitutes for 100% inspection.

The 1930s saw the application of acceptance sampling plans in industry, both domestic and abroad. Walter Shewhart continued his efforts to promote to industry the fundamentals of statistical quality control. In 1929 he obtained the sponsorship of the American Society for Testing and Materials (ASTM), the American Society of Mechanical Engineers (ASME), the American Statistical Association (ASA), and the Institute of Mathematical Statistics (IMS) in creating the Joint Committee for the Development of Statistical Applications in Engineering and Manufacturing.

Interest in the field of quality control began to gain acceptance in England at this time. The British Standards Institution Standard 600 dealt with applications of statistical methods to industrial standardization and quality control. In the United States, J. Scanlon introduced the *Scanlon plan*, which dealt with improvement of the overall quality of worklife (Feigenbaum 1983). Furthermore, the U.S. Food, Drug, and Cosmetic Act of 1938 had jurisdiction over procedures and practices in the areas of processing, manufacturing, and packing.

The next phase in the evolution process, called the *statistical quality control phase* by Feigenbaum (1983), occurred between 1940 and 1960. Production requirements escalated during World War II. Since 100% inspection was often not feasible, the principles of sampling plans gained acceptance. The American Society for Quality Control (ASQC) was formed in 1946, subsequently renamed the American Society for Quality (ASQ). A set of sampling inspection plans for attributes called MIL-STD-105A was developed by the military in 1950. These plans underwent several subsequent modifications, becoming MIL-STD-105B, MIL-STD-105C, MIL-STD-105D, and MIL-STD-105E. Furthermore, in 1957, a set of sampling plans for variables called MIL-STD-414 was also developed by the military.

Although suffering widespread damage during World War II, Japan embraced the philosophy of statistical quality control wholeheartedly. When W. Edwards Deming visited Japan and lectured on these new ideas in 1950, Japanese engineers and top management became convinced of the importance of statistical quality control as a means of gaining a competitive edge in the world market. J. M. Juran, another pioneer in quality control, visited Japan in 1954 and further impressed on them the strategic role that management plays in the achievement of a quality program. The Japanese were quick to realize the profound effects that these principles would have on the future of business, and they made a strong commitment to a massive program of training and education.

Meanwhile, in the United States, developments in the area of sampling plans were taking place. In 1958, the Department of Defense (DOD) developed the Quality Control and Reliability Handbook H-107, which dealt with single-level continuous sampling procedures and tables for inspection by attributes. Revised in 1959, this book became the Quality Control and Reliability Handbook H-108, which also covered multilevel continuous sampling procedures as well as topics in life testing and reliability.

The next phase, *total quality control*, took place during the 1960s (Feigenbaum 1983). An important feature during this phase was the gradual involvement of several departments and management personnel in the quality control process. Previously, most of these activities were dealt with by people on the shop floor, by the production foreman, or by people from the inspection and quality control department. The commonly held attitude prior to this period was that quality control was the responsibility of the inspection department. The 1960s, however, saw some changes in this attitude. People began to realize that each department had an important role to play in the production of a quality item. The concept of *zero defects*, which centered around achieving productivity through worker involvement, emerged during this time. For critical products and assemblies – [e.g., missiles and rockets used in the space program by the National Aeronautics and Space Administration (NASA)] this concept proved to be very successful. Along similar lines, the use of **quality circles** was beginning to grow in Japan. This concept, which is based on the participative style of management, assumes that productivity will improve through an uplift of morale and motivation, achieved in turn, through consultation and discussion in informal subgroups.

The advent of the 1970s brought what Feigenbaum (1983) calls the *total quality control organizationwide phase*, which involved the participation of everyone in the company, from the operator to the first-line supervisor, manager, vice president, and even the chief executive officer. Quality was associated with every person. As this notion continued in the 1980s, it was termed by Feigenbaum (1983) the **total quality system**, which he defines as follows: "A quality system is the agreed on companywide and plantwide operating work structure, documented in effective, integrated technical and managerial procedures, for guiding the coordinated actions of the people, the machines, and the information of the company and plant in the best and most practical ways to assure customer quality satisfaction and economical costs of quality."

In Japan, the 1970s marked the expanded use of a graphical tool known as the **cause-and-effect diagram**. This tool was introduced in 1943 by K. Ishikawa and is sometimes called an **Ishikawa diagram**. It is also called a **fishbone diagram** because of its resemblance to a fish skeleton. This diagram helps identify possible reasons for a process to go out of control as well as possible effects on the process. It has become an important tool in the use of control charts because it aids in choosing the appropriate action to take in the event of a process being out of control. Also in this decade, G. Taguchi of Japan introduced the concept of quality improvement through statistically designed experiments. Expanded use of this technique has continued in the 1990s as companies have sought to improve the design phase.

In the 1980s, U.S. advertising campaigns placed quality control in the limelight. Consumers were bombarded with advertisements related to product quality, and frequent comparisons were made with those of competitors. These promotional efforts tried to point out certain product characteristics that were superior to those of similar products. Within the industry itself, an awareness of the importance of quality was beginning to evolve at all levels. Top management saw the critical need for the marriage of the quality philosophy to the production of goods and services in all phases, starting with the determination of customer needs and product design and continuing on to product assurance and customer service.

As computer use exploded during the 1980s, an abundance of quality control software programs came on the market. The notion of a total quality system increased the emphasis on vendor quality control, product design assurance, product and process quality audit, and related areas. Industrial giants such as the Ford Motor Company and General Motors Corporation adopted the quality philosophy and made strides in the implementation of statistical quality control methods. They, in turn, pressured other companies to use quality control techniques. For example, Ford demanded documentation of statistical process control from its vendors. Thus, smaller companies that had not used statistical quality control methods previously were forced to adopt these methods to maintain their contracts. The strategic importance of quality control and improvement was formally recognized in the United States through the **Malcolm Baldrige National Quality Award** in 1987.

The emphasis on customer satisfaction and continuous quality improvement globally created a need for a system of standards and guidelines that support the quality philosophy. The International Organization for Standardization (ISO) developed a set of standards, **ISO 9000–9004**, in the late 1980s. The American National Standards Institute (ANSI) and ASQC brought their standards in line with the ISO standards when they developed the ANSI/ASQC Q90–Q94 in 1987, which was subsequently revised in 1994 to ANSI/ASQC Q9000–Q9004, and further in 2000, to ANSI/ISO/ASQ Q9000–2000. The ISO 9000–9004 standards were also revised in 1994 and 2000.

Beginning with the last decade of the twentieth century and continuing on to the current century, the world has seen the evolution of an era of information technology. This is the major revolution since the Industrial Revolution of the late eighteenth century. The twenty-first century is undergoing its revolution in information technology digitally, using wireless technology. Such advances promote the maintenace and protection of information quality while delivering data in an effective manner. Further, advances in computational technology have made it feasible to solve, in a timely fashion, complex and/or large-scale problems to be used for decision making. Moreover, the Internet is part and parcel of our everyday lives. Among a multitude of uses, we make travel arrangements, purchase items, look up information on a variety of topics, and correspond. All of these activities are conducted on a real-time basis, thus raising expectations regarding what constitutes timely completion. On receiving an order through the Internet, service providers will be expected to conduct an error-free transaction, for example, either assemble the product or provide the service, receive payment, and provide an online tracking system for the customer to monitor. Thus, the current century will continue to experience a thrust in growth of quality assurance and improvement methods that can, using technology, assimilate data and analyze them in real time and with no tolerance for errors.

1-3 QUALITY

The notion of **quality** has been defined in different ways by various authors. Garvin (1984) divides the definition of quality into five categories: transcendent, product-based, user-based, manufacturing-based, and value-based. Furthermore, he identifies a framework of eight attributes that may be used to define quality: performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality. This frequently used definition is attributed to Crosby (1979): "Quality is conformance to requirements or specifications." A more general definition proposed by Juran (1974) is as follows: "Quality is fitness for use."

In this book we adopt, the latter definition and expand it to cover both the **manufacturing** and **service** sectors. The service sector accounts for a substantial segment of our present economy; it is a major constituent that is not to be neglected. Projections indicate that this proportion will expand even further in the future. Hence, quality may be defined as follows: The quality of a product or service is the fitness of that product or service for meeting or exceeding its intended use as required by the customer.

So, who is the driving force behind determining the level of quality that should be designed into a product or service? *The customer*! Therefore, as the needs of customers change, so should the level of quality. If, for example, customers prefer an automobile that gives adequate service for 15 years, then that is precisely what the notion of a quality product should be. Quality, in this sense, is not something that is held at a constant universal level. In this view, the term *quality* implies different levels of expectations for different groups of consumers. For instance, to some, a quality restaurant may be one that provides extraordinary cuisine served on the finest china with an ambience of soft music. However, to another group of consumers, the characteristics that comprise a quality restaurant may be quite different: excellent food served buffet style at moderate prices until the early morning hours.

Quality Characteristics

The preceding example demonstrates that one or more elements define the intended quality level of a product or service. These elements, known as **quality characteristics**, can be categorized in these groupings: **Structural characteristics** include such elements as the length of a part, the weight of a can, the strength of a beam, the viscosity of a fluid, and so on; **sensory characteristics** include the taste of good food, the smell of a sweet fragrance, and the beauty of a model, among others; **time-oriented characteristics** include such measures as a warranty, reliability, and maintainability; and **ethical characteristics** include honesty, courtesy, friendliness, and so on.

Variables and Attributes

Quality characteristics fall into two broad classes: variables and attributes. *Characteristics that are measurable and are expressed on a numerical scale* are called ***variables***. The waiting time in a bank before being served, expressed in minutes, is a variable, as are the density of a liquid in grams per cubic centimeter and the resistance of a coil in ohms.

Prior to defining an attribute, we should defined a nonconformity and a nonconforming unit. A *nonconformity* is a *quality characteristic that does not meet its stipulated specifications*. Let's say that the specification on the fill volume of soft drink bottles is 750 ± 3 milliliters (mL). If we have a bottle containing 745 mL, its fill volume is a nonconformity. A *nonconforming unit* has *one or more nonconformities such that the unit is unable to meet the intended standards and is unable to function as required*. An example of a nonconforming unit is a cast iron pipe whose internal diameter and weight both fail to satisfy specifications, thereby making the unit dysfunctional.

A quality characteristic is said to be an **attribute** if it is classified as *either conforming or nonconforming to a stipulated specification*. A quality characteristic that cannot be measured on a numerical scale is expressed as an attribute. For example, the smell of a cologne is characterized as either acceptable or is not; the color of a fabric is either acceptable or is not. However, there are some variables that are treated as attributes because it is simpler to measure them this way or because it is difficult to obtain data on them. Examples in this category are numerous. For instance, the diameter of a bearing is, in theory, a variable. However, if we measure the diameter using a go/no-go gage and classify it as either conforming or nonconforming (with respect to some established specifications), the characteristic is expressed as an attribute. The reasons for using a go/no-go gage, as opposed to a micrometer, could be economic; that is, the time needed to obtain a measurement using a go/no-go gage may be much shorter and consequently less expensive. Alternatively, an inspector may not have enough time to obtain measurements on a numerical scale using a micrometer, so such a classification of variables would not be feasible.

Defects

A **defect** is associated with a quality characteristic that does not meet certain standards. Furthermore, the severity of one of more defects in a product or service may cause it to be unacceptable (or defective). The modern term for *defect* is *nonconformity*, and the term for *defective* is *nonconforming item*. The American National Standards Institute, the International Organization for Standardization, and the American Society for Quality provide a definition of a defect in ANSI/ISO/ASQ Standard A8402 (ASQ 1994).

Standard or Specification

Since the definition of quality involves meeting the requirements of the customer, these requirements need to be documented. A **standard**, or a **specification**, refers to *a precise statement that formalizes the requirements of the customer; it may relate to a product, a process, or a service*. For example, the specifications for an axle might be 2 ± 0.1 centimeters (cm) for the inside diameter, 4 ± 0.2 cm for the outside diameter, and 10 ± 0.5 cm for the length. This means that for an axle to be acceptable to the customer, each of these dimensions must be within the values specified. Definitions given by the National Bureau of Standards (NBS, 2005) are as follows:

- *Specification:* a set of conditions and requirements, of specific and limited application, that provide a detailed description of the procedure, process, material, product, or service for use primarily in procurement and manufacturing. Standards may be referenced or included in a specification.
- *Standard:* a prescribed set of conditions and requirements, of general or broad application, established by authority or agreement, to be satisfied by a material, product, process, procedure, convention, test method; and/or the physical, functional, performance, or conformance characteristic thereof. A physical embodiment of a unit of measurement (for example, an object such as the standard kilogram or an apparatus such as the cesium beam clock).

Acceptable bounds on individual quality characteristics (say, 2 ± 0.1 cm for the inside diameter) are usually known as **specification limits**, whereas the document that addresses the requirements of all the quality characteristics is labeled the *standard*.

Three aspects are usually associated with the definition of quality: quality of design, quality of conformance, and quality of performance.

Quality of Design

Quality of design deals with the stringent conditions that a product or service must minimally possess to satisfy the requirements of the customer. *It implies that the product or service must be designed to meet at least minimally the needs of the consumer.* Generally speaking, the design should be the simplest and least expensive while still meeting customer's expectations. Quality of design is influenced by such factors as the type of product, cost, profit policy of the firm, demand for product, availability of parts and materials, and product safety. For example, suppose that the quality level of the yield strength of steel cables desired by the customer is 100 kg/cm^2 (kilograms per square centimeter). When designing such a cable, the parameters that influence the yield strength would be selected so as to satisfy this

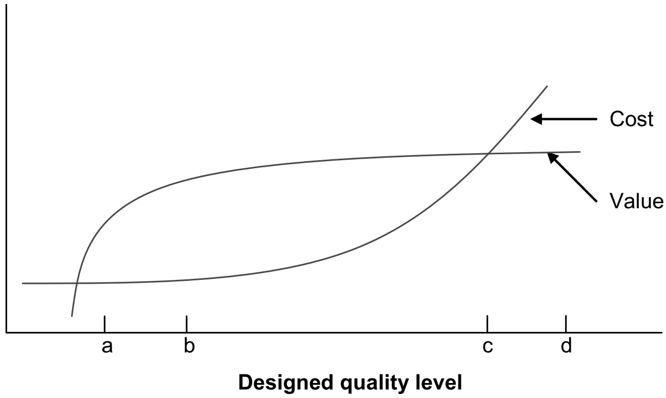

FIGURE 1-1 Cost and value as a function of designed quality.

requirement at least minimally. In practice, the product is typically overdesigned so that the desired conditions are exceeded. The choice of a safety factor (k) normally accomplishes this purpose. Thus, to design a product with a 25% stronger load characteristic over the specified weight, the value of k would equal 1.25, and the product will be designed for a yield strength of $100 \times 1.25 = 125\ \text{kg/cm}^2$.

In most situations, the effect of an increase in the design quality level is to increase the cost at an exponential rate. The value of the product, however, increases at a decreasing rate, with the rate of increase approaching zero beyond a certain designed quality level. Figure 1-1 shows the impact of the design quality level on the cost and value of the product or service. Sometimes, it might be of interest to choose a design quality level b, which maximizes the differences between value and cost given that the minimal customer requirements a are met. This is done with the idea of maximizing the return on investment. It may be observed from Figure 1-1 that for a designed quality level c, the cost and value are equal. For any level above c (say, d) the cost exceeds the value. This information is important when a suitable design level is being chosen.

Quality of Conformance

Quality of conformance implies that *a manufactured product or a service rendered must meet the standards selected in the design phase*. With respect to the manufacturing sector, this phase is concerned with the degree to which quality is controlled from the procurement of raw material to the shipment of finished goods. It consists of the three broad areas of defect prevention, defect finding, and defect analysis and rectification. As the name suggests, defect prevention deals with the means to deter the occurrence of defects and is usually achieved using statistical process control techniques. Locating defects is conducted through inspection, testing, and statistical analysis of data from the process. Finally, the causes behind the presence of defects are investigated, and corrective actions are taken.

Figure 1-2 shows how quality of design, conformance, and performance influence the quality of a product or service. The quality of design has an impact on the quality of conformance. Obviously, one must be able to produce what was designed. Thus, if the design specification for the length of iron pins is 20 ± 0.2 mm (millimeters), the question that must be addressed is how to design the tools, equipment, and operations such that the manufactured product will meet the design specifications. If such a system of production can be

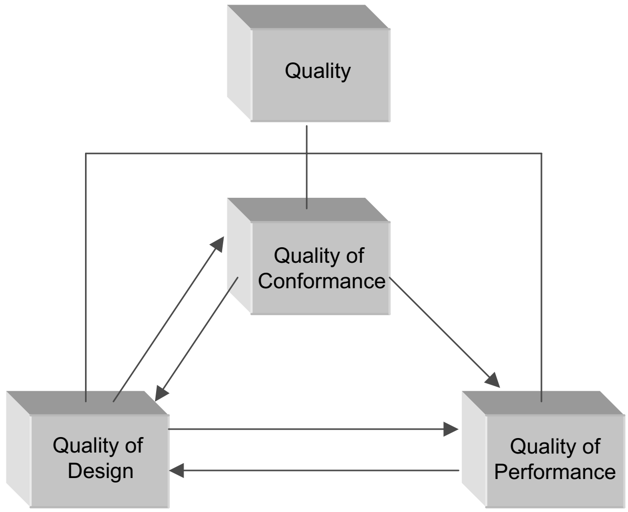

FIGURE 1-2 The three aspects of quality.

achieved, the conformance phase will be capable of meeting the stringent requirements of the design phase. On the other hand, if such a production system is not feasibly attained (e.g., if the process is only capable of producing pins with a specification of 20 ± 0.36 mm), the design phase is affected. This feedback suggests that the product be redesigned because the current design cannot be produced using the existing capability. Therefore, there should be a constant exchange of information between the design and manufacturing phases so that a feasible design can be achieved.

Quality of Performance

Quality of performance is concerned with *how well a product functions or service performs when put to use. It measures the degree to which the product or service satisfies the customer.* This is a function of both the quality of design and the quality of conformance. Remember that the final test of product or service acceptance always lies with the customers. Meeting or exceeding their expectations is the major goal. If a product does not function well enough to meet these expectations, or if a service does not live up to customer standards, adjustments need to be made in the design or conformance phase. This feedback from the performance to the design phase, as shown in Figure 1-2, may prompt a change in the design because the current design does not produce a product that performs adequately.

1-4 QUALITY CONTROL

Quality control may generally be defined as *a system that maintains a desired level of quality,* through feedback on product/service characteristics and implementation of remedial actions, in case of a deviation of such characteristics from a specified standard. This general area may be divided into three main subareas: off-line quality control, statistical process control, and acceptance sampling plans.

Off-Line Quality Control

Off-line quality control procedures deal with measures to select and choose controllable product and process parameters in such a way that the deviation between the product or process output and the standard will be minimized. Much of this task is accomplished through product and process design. The goal is to come up with a design within the constraints of resources and environmental parameters such that when production takes place, the output meets the standard. Thus, to the extent possible, the product and process parameters are set before production begins. Principles of experimental design and the Taguchi method, discussed in a later chapter, provide information on off-line process control procedures.

Statistical Process Control

Statistical process control involves comparing the output of a process or service with a standard and taking remedial actions in case of a discrepancy between the two. It also involves determining whether a process can produce a product that meets desired specifications or requirements.

For example, to control paperwork errors in an administrative department, information might be gathered daily on the number of errors. If the number observed exceeds a specified standard, then on identification of possible causes, action should be taken to reduce the number of errors. This may involve training the administrative staff, simplifying operations if the error is of an arithmetic nature, redesigning the form, or taking other appropriate measures.

Online statistical process control means that information is gathered about the product, process, or service while it is functional. When the output differs from a determined norm, corrective action is taken in that operational phase. It is preferable to take corrective action on a real-time basis for quality control problems. This approach attempts to bring the system to an acceptable state as soon as possible, thus minimizing either the number of unacceptable items produced or the time over which undesirable service is rendered. Chapters 6 to 9 cover the background and procedures of online statistical process control methods.

One question that may come to mind is: Shouldn't all procedures be controlled on an off-line basis? The answer is "yes," to the extent possible. The prevailing theme of quality control is that quality has to be designed into a product or service; it cannot be inspected into it. However, despite taking off-line quality control measures, there may be a need for online quality control, because variation in the manufacturing stage of a product or the delivery stage of a service is inevitable. Therefore, some rectifying measures are needed in this phase. Ideally, a combination of off-line and online quality control measures will lead to a desirable level of operation.

Acceptance Sampling Plans

Acceptance sampling plans involve inspection of a product or service. When 100% inspection of all items is not feasible, a decision has to be made as to how many items should be sampled or whether the batch should be sampled at all. The information obtained from the sample is used to decide whether to accept or reject the entire batch or lot. In the case of attributes, one parameter is the acceptable number of nonconforming items in the sample.

If the number of nonconforming items observed is less than or equal to this number, the batch is accepted. This is known as the *acceptance number*. In the case of variables, one parameter may be the proportion of items in the sample that are outside the specifications. This proportion would have to be less than or equal to a standard for the lot to be accepted. *A plan that determines the number of items to sample and the acceptance criteria of the lot, based on meeting certain stipulated conditions (such as the risk of rejecting a good lot or accepting a bad lot*), is known as *an acceptance sampling plan*.

Let's consider a case of attribute inspection where an item is classified as conforming or not conforming to a specified thickness of 12 ± 0.4 mm. Suppose that the items come in batches of 500 units. If an acceptance sampling plan with a sample size of 50 and an acceptance number of 3 is specified, the interpretation of the plan is as follows. Fifty items will be randomly selected by the inspector from the batch of 500 items. Each of the 50 items will then be inspected (say, with a go/no-go gage) and classified as conforming or not conforming. If the number of nonconforming items in the sample is 3 or less, the entire batch of 500 items is accepted. However, if the number of nonconforming items is greater than 3, the batch is rejected. Alternatively, the rejected batch may be screened; that is, each item is inspected and nonconforming ones are removed. Acceptance sampling plans for attributes and variables are discussed in Chapter 10.

1-5 QUALITY ASSURANCE

Quality is not just the responsibility of one person in the organization—this is the message. Everyone involved directly or indirectly in the production of an item or the performance of a service is responsible. Unfortunately, something that is viewed as everyone's responsibility can fall apart in the implementation phase and become no one's responsibility. This behavior can create an ineffective system where the quality assurances exist only on paper. Thus, what is needed is *a system that ensures that all procedures that have been designed and planned are followed*. This is precisely the role and purpose of the quality assurance function.

The objective of the quality assurance function is to have in place a formal system that continually surveys the effectiveness of the quality philosophy of the company. The quality assurance team thus audits the various departments and assists them in meeting their responsibilities for producing a quality product.

Quality assurance may be conducted, for example, at the product design level by surveying the procedures used in design. An audit may be carried out to determine the type of information that should be generated in the marketing department for use in designing the product. Is this information representative of the customer's requirements? If one of the customer's key needs in a food wrap is that it withstand a certain amount of force, is that information incorporated in the design? Do the data collected represent that information? How frequently are the data updated? Are the forms and procedures used to calculate the withstanding force adequate and proper? Are the measuring instruments calibrated and accurate? Does the design provide a safety margin? The answers to all of these questions and more will be sought by the quality assurance team. If discrepancies are found, the quality assurance team will advise the relevant department of the changes that should be adopted. This function acts as a watchdog over the entire system.

1-6 QUALITY CIRCLES AND QUALITY IMPROVEMENT TEAMS

A **quality circle** is typically *an informal group of people that consists of operators, supervisors, managers, and so on, who get together to improve ways to make a product or deliver a service*. The concept behind quality circles is that in most cases, the persons who are closest to an operation are in a better position to contribute ideas that will lead to an improvement in it. Thus, improvement-seeking ideas do not come only from managers but also from all other personnel who are involved in the particular activity. A quality circle tries to overcome barriers that may exist within the prevailing organizational structure so as to foster an open exchange of ideas.

A quality circle can be an effective productivity improvement tool because it generates new ideas and implements them. Key to its success is its participative style of management. The group members are actively involved in the decision-making process and therefore develop a positive attitude toward creating a better product or service. They identify with the idea of improvement and no longer feel that they are outsiders or that only management may dictate how things are done. Of course, whatever suggestions that a quality circle comes up with will be examined by management for feasibility. Thus, members of the management team must understand clearly the workings and advantages of the action proposed. Only then can they evaluate its feasibility objectively.

A **quality improvement team** is another means of identifying feasible solutions to quality control problems. Such teams are typically cross-functional in nature and involve people from various disciplines. It is not uncommon to have a quality improvement team with personnel from design and development, engineering, manufacturing, marketing, and servicing. A key advantage of such a team is that it promotes cross-disciplinary flow of information in real time as it solves the problem. When design changes are made, the feasibility of equipment and tools in meeting the new requirements must be analyzed. It is thus essential for information to flow between design, engineering, and manufacturing. Furthermore, the product must be analyzed from the perspective of meeting customer needs. Do the new design changes satisfy the unmet needs of customers? What are typical customer complaints regarding the product? Including personnel from marketing and servicing on these teams assists in answering these questions.

The formation and implementation of quality improvement teams is influenced by several factors. The first deals with selection of team members and its leader. Their knowledge and experience must be relevant to the problem being addressed. People from outside the operational and technical areas can also make meaningful contributions; the objective is to cover a broad base of areas that have an impact. Since the team leader has the primary responsibility for team facilitation and maintenance, he or she should be trained in accomplishing task concerns as well as people concerns, which deal with the needs and motivation of team members.

Team objectives should be clearly defined at the beginning of any quality improvement team project. These enable members to focus on the right problem. The team leader should prepare and distribute an agenda prior to each meeting. Assignments to individual members or subgroups must be clearly identified. Early in the process, the team leader should outline the approach, methods, and techniques to be used in addressing the problem. Team dynamics deals with interactions among members that promote creative thinking and is vital to the success of the project. The team leader plays an important role in creating this climate for creativity. He or she must remove barriers to idea generation and must encourage differing points of view and ideas. All team members should be encouraged to contribute their ideas or to build on others.

Regular feedback on the results and actions taken at meetings is important. It keeps the team on track, helps eliminate the personal bias of members, if any, and promotes group effort. Such reviews should ensure that all members have been assigned specific tasks; this should be documented in the minutes. Progress should be reviewed systematically, the objective being to come up with a set of action plans. This review is based on data collected from the process, which is analyzed through basic quality improvement tools (some of which are discussed in Chapters 3 and 5). Based on the results of the analysis, action plans can be proposed. In this way, team recommendations will not be based on intuition but on careful analysis.

1-7 CUSTOMER NEEDS AND MARKET SHARE

For the manufacturing or service sector, satisfying the customers—both internal and external—is fundamental to growth and improving market share. An important aspect of the *quality of design* phase deals with identification of customer needs and wants. These customer needs may be grouped into the three broad categories of *critical to quality*, *critical to delivery*, and *critical to cost*. Not all needs are of equal importance to the customer. Moreover, some are expressed while others are taken for granted.

Kano Model

Noriaki Kano, a Japanese consultant, developed a model relating design characteristics to customer satisfaction (Cohen 1995). Customer needs or expectations can be divided into three *prioritized* categories: *basic needs* (dissatisfiers); *performance needs* (satisfiers); and *excitement needs* (delighters). Basic needs are those that are taken for granted by the customer. Meeting these needs may not steeply increase customer satisfaction; but not meeting them will definitely cause dissatisfaction. For example, in a city public library, it is taken for granted that current editions of popular magazines will be available. Not having them will lead to dissatisfied consumers.

Performance needs are those that the consumer expects. Thus, the better these are met, the more satisfied the customer. Typically, customer satisfaction increases as a linear function of the degree to which such needs are met. Ease of checking out a book or video at a city library could be one such need. Excitement needs, also known as delighters, are those that surprise the customer unexpectedly. The consumer does not necessarily expect these and hence may not express them. So, when they are met, it increases customer satisfaction in an exponential manner. For example, if the city library offered free consultation on tax-form preparation, customers might be delighted beyond bounds.

Figure 1-3 shows the Kano model, relating the degree of meeting customer needs and customer satisfaction. Note the three curves associated with basic, performance, and excitement needs and their relative impact on increasing customer satisfaction. Basic and excitement needs are usually not identifiable from customer surveys. Satisfying basic needs may prevent customer loss but not necessarily promote growth. Survey data are typically used to address performance needs and the degree to which improvement in these needs is necessary in order to grow market share linearly, to a certain extent. Excitement needs, not generally expressed by consumers in surveys, demand a major source of attention for organizations seeking market share growth. These needs, if incorporated in the design phase, will distinguish the company from its competitors.

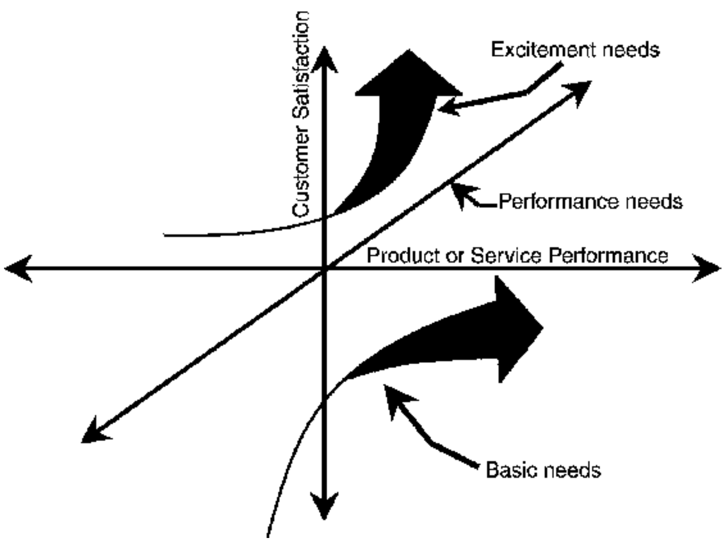

FIGURE 1-3 Kano model.

1-8 BENEFITS OF QUALITY CONTROL AND THE TOTAL QUALITY SYSTEM

The goal of most companies is to conduct business in such a manner that an acceptable rate of return is obtained by the shareholders. What must be considered in this setting is the short-term goal versus the long-term goal. If the goal is to show a certain rate of return this coming year, this may not be an appropriate strategy because the benefits of quality control may not be realized immediately. However, from a long-term perspective, a quality control system may lead to a rate of return that is not only better but is also sustainable.

One of the drawbacks of the manner in which many U.S. companies operate is that the output of managers is measured in short time frames. It is difficult for a manager to show a 5% increase in the rate of return, say, in the quarter after implementing a quality system. Top management may then doubt the benefits of quality control.

The advantages of a quality control system, however, become obvious in the long run. First and foremost is the improvement in the quality of products and services. Production improves because a well-defined structure for achieving production goals is present. Second, the system is continually evaluated and modified to meet the changing needs of the customer. Therefore, a mechanism exists for rapid modification of product or process design, manufacture, and service to meet customer requirements so that the company remains competitive. Third, a quality control system improves productivity, which is a goal of every organization. It reduces the production of scrap and rework, thereby increasing the number of usable products. Fourth, such a system reduces costs in the long run. The notion that improved productivity and cost reduction do not go hand in hand is a myth. On the contrary, this is precisely what a quality control system does achieve. With the production of few nonconforming items, total costs decrease, which may lead to a reduced selling price and thus increased competitiveness. Fifth, with improved productivity, the lead time for producing parts and subassemblies is reduced, which results in improved delivery dates. One again, quality control keeps customers satisfied. Meeting or exceeding their needs on a timely basis helps sustain a good relationship. Last, but not least, a quality control system maintains an "improvement" environment where everyone strives for improved quality and productivity. There is no end to this process—there is always room for improvement. A company that adopts this philosophy and uses a quality control system to help meet this objective is one that will stay competitive.

Total Quality System

Quality is everyone's responsibility. This means that comprehensive plans should be developed to show the precise responsibilities of the various units, procedures should be defined to check their conformance to the plans, and remedial measures should be suggested in the event of discrepancies between performance and standard. The quality assurance function, as defined earlier, monitors the system.

The **systems approach** to quality integrates the various functions and responsibilities of the various units and provides a mechanism to ensure that organizational goals are being met through the coordination of the goals of the individual units. The ISO, in conjunction with ANSI and ASQ, has developed standards ANSI/ISO/ASQ 9000–9004 (ASQ 2004) that describe quality systems.

In this book we focus on the analytical tools and techniques within the context of a total quality system. An overview of the chapter contents in the book follows. A foundation, along with appropriate terminology, is presented in this chapter. In Chapter 2 we introduce some quality philosophies developed by pioneers in the field. Further, similarities and differences between quality in the manufacturing and service sectors are delineated in this chapter. Quality management practices and their associated standards, developed by various organizations (ISO/ANSI/ASQ), which define acceptable norms, are the focus of Chapter 3, where the six sigma metric and methodology are discussed. Chapter 4 covers the fundamentals of statistical concepts and techniques used in quality control. In Chapter 5 we present some statistical techniques for quality analysis and improvement. The idea of process control through control charts, which is one of the primary quality control tools, is covered in Chapters 6 to 9. The fundamental principles of control charts are introduced in Chapter 6. Chapter 7 focuses on control charts for variables, while those for attributes are covered in Chapter 8. Statistical methods for determining whether a process is capable of producing items that conform to a standard are described in Chapter 9. These methods involve process capability analysis. The topics of acceptance sampling plans for attributes and variables are given in Chapter 10. Statistical methods dealing with life testing and reliability are covered in Chapter 11; these techniques concern the performance of a product over a period of time. Designing experiments for use in systematically analyzing and guiding process parameter settings is covered in Chapter 12. Some fundamental concepts of the Taguchi method of off-line quality control are also presented in Chapter 12. Since more than 70% of the gross national product comes from the service sector, techniques for monitoring quality that have been used primarily in the manufacturing sector are also warranted here. Such service-sector applications are integrated in the various chapters. Finally, computers play a fundamental role in quality control, and their use will expand even more in the years to come. The use of computer software (Minitab) for a variety of statistical techniques in quality control and improvement is integrated throughout.

1-9 QUALITY AND RELIABILITY

Reliability refers to the ability of a product to function effectively over a certain period of time. Reliability is related to the concept of quality of performance. Since the consumer has the ultimate say on the acceptability of a product or service, the better the performance over a given time frame, the higher the reliability and the greater the degree of customer satisfaction. Achieving desirable standards of reliability requires careful analysis in the product design phase. Analysis of data obtained on a timely basis during product performance keeps the design and production parameters updated so that the product may continue to perform in an acceptable manner. Reliability is built in through quality of design.

The product is often overdesigned so that it more than meets the performance requirements over a specified time frame. For example, consider the quality of a highway system where roads are expected to last a minimum time period under certain conditions of use. Conditions of use may include the rate at which the road system is used, the weight of vehicles, and such atmospheric conditions as the proportion of days that the temperature exceeds a certain value. Suppose that the performance specifications require the road system to last at least 20 years. In the design phase, to account for the variation in the uncontrollable parameters, the roads might be designed to last 25 years. This performance level may be achieved through properly selected materials and the thickness of the concrete and tar layers.

1-10 QUALITY IMPROVEMENT

Efforts to reduce both the variability of a process and the production of nonconforming items should be ongoing because quality improvement is a *never-ending* process. Whereas process control deals with identification and elimination of special causes (those for which an identifiable reason can be determined) that force a system to go out of control (e.g., tool wear, operator fatigue, poor raw materials), **quality improvement** relates to the detection and elimination of common causes. **Common causes** are inherent to the system and are always present. Their impact on the output may be uniform relative to that of special causes. An example of a common cause is the variability in a characteristic (say, a diameter) caused by the inherent capability of the particular equipment used (say, a milling machine). This means that all other factors held constant, the milling machine is unable to produce parts with exactly the same diameter. To reduce the inherent variability of that machine, an alternative might be to install a better or more sophisticated machine. **Special causes** are controllable mainly by the operator, but common causes need the attention of management. Therefore, quality improvement can take place only through the joint effort of the operator and management, with the emphasis primarily on the latter. For instance, a decision to replace the milling machine must be made by management. Another example could be the inherent variation in the time to process purchase orders. Once special causes have been eliminated, ways in which the average time or variability could be reduced could be through changes in the procedure/process, which requires management support. Eliminating or reducing the impact of some of the common causes results in improved process capability, as measured by less variation of the output.

Most quality control experts agree that common causes account for at least 90% of the quality problems in an organization. The late W. Edwards Deming, the noted authority on quality, strongly advocated this belief. He concluded that management alone is responsible for common-cause problems and, hence, only management can define and implement remedial actions for these problems. The operator has no control on nonconforming product or service in a majority of the instances. Therefore, if a company is interested in eliminating the root causes of such problems, management must initiate the problem-solving actions.

Quality improvement should be the objective of all companies and individuals. It improves the rate of return or profitability by increased productivity and by cost reduction.

It is consistent with the philosophy that a company should continually seek to expand its competitive edge. It supports the principle that no deviation from a standard is acceptable, which is akin to the principle of the loss function developed in the Taguchi methods (Taguchi 1986; Taguchi and Wu 1979). So even if the product is within the specification limits, an ongoing effort should be made to reduce its variability around the target value.

Let's say that the specifications for the weight of a package of sugar are 2.00 ± 0.02 kg. If the output from the process reveals that all packages weigh between 1.98 and 2.02 kg, the process is capable and all items will be acceptable. However, not all of the packages weigh exactly 2.00 kg, the target value; that is, there is some variability in the weights of the packages. The Taguchi philosophy states that any deviation from the target value of 2.00 kg is unacceptable with the loss being proportional to the deviation. Quality improvement is a logical result of this philosophy.

Quality function deployment techniques, which incorporate the needs and priorities of a customer in designing a product or service, are demonstrated in Chapter 3. Some methods for quality improvement are discussed in Chapter 5. These include such graphical techniques as Pareto analysis, histograms, and cause-and-effect or fishbone diagrams. Additional techniques discussed in Chapter 9 deal with process capability analysis. Quality improvement through design may also be achieved through experimental design techniques and the Taguchi method; these are discussed in Chapter 12.

1-11 PRODUCT AND SERVICE COSTING

In costing a product or service, the broad categories of direct and indirect costs come into play. **Direct costs**, such as direct labor and materials, are a function of the number of units of the manufactured product or the number of customers serviced. On the contrary, **indirect costs** do not change with each unit produced or each customer served, such as machine setup for the same product, depreciation of building, property taxes, and so on. Accounting methods that use a system that allocates indirect costs adequately to the particular product or service are highly desirable. This is true especially when multiple products are produced or types of services are performed. Indirect costs should be distributed to products or services based on cause-and-effect relations or actual use.

Traditional accounting methods can lead to misleading product/service costs where indirect costs are allocated based on direct labor or direct material. However, the actual use of the resource is not necessarily a function of the direct labor or direct material cost. In such cases, a better estimate of product costing is arrived at by using activities that measure the degree of use of the particular resource. This is known as *activity-based costing*. The implicit assumption in traditional financial/cost accounting methods is that indirect costs are a relatively small proportion of the unit cost. In the new century, as product/service options, product complexity, and volume continue to grow, the method of allocation of indirect costs becomes important, since use of indirect resources is not necessarily similar for all types of product/service.

Activity-Based Costing

Activities are tasks performed by a specialized group or department, say the purchasing unit in an organization, also known as an *activity* or *cost center*. The types of transactions that generate costs are identified as *cost-drivers*. For instance, the number of purchase orders processed is a cost-driver. Whether the purchase order is for one product item or 50, it uses the same amount of the purchasing department resource. Thus, allocation of the indirect costs associated with use of the purchasing department should incorporate the number of purchase orders, not the number of direct labor hours or direct material costs in making the product, as this represents a better picture of the resource use by the product/service.

Cost-drivers are typically categorized into four groups. **Unit-level costs** comprise those activities that are associated with each product/service unit. Direct labor and material, machining, and assembly costs are examples. **Batch-level costs** are based on activities that are performed once for each lot or batch of products and are not influenced by the number of units in the batch. A machine setup for an operation for a batch, or invoicing for a batch, are examples. Hence, the number of batches will influence the allocation of costs. The next level of cost driver is the **product/service-level cost** which is based on the type of product/service. In engineering design, if two products are being made, the resource spent on each product design will be an example of such a cost. Finally, there is the **production/service-sustaining cost level** which incorporates activities that use all other resources necessary to maintain operations. Building depreciation, insurance, and property taxes are examples in this category. These do not depend on the number of product/service units, batches, or product/service lines.

To determine the product/service unit cost, the following guidelines are used in activity-based costing. The direct costs are the unit-level costs that can be assigned to a product/service unit. Once the batch-level costs are identified, based on the number of batches used, the allocation to a product/service unit is computed by dividing by the number of units in a particular batch. Similarly, product/service level costs, once identified, based on the number of types of products/services, can be spread over all product/service units of a certain type to include toward computation of the unit cost. Finally, the production/service-sustaining costs, which cannot be linked directly to units, batches, or product/service lines, can be allocated in a sequential manner. First, they are assigned to product/service lines, then to batches, and eventually to product/service units. Another approach for this cost category is to allocate directly to units based on direct labor hours.

Thus, the essence of activity-based costing is based on the proper identification of cost-drivers, nonfinancial measures such as the number of purchase orders processed or the number of types of product made. Although the number of cost-drivers used might better identify product/service unit costs, the drawback lies in the cost of obtaining information. Further, some assumptions include that the unit batch cost is not dependent on the batch size or the type of product/service. In actuality, it could be that purchase order processing times, and thereby costs, vary based on the nature of the product/service. The benefits of activity-based costing are in decision making rather than decision control. It leads to better pricing and product/service mix decisions, especially in situations in multiproduct/service organizations. With product/service volumes that vary greatly between product/service types, it provides a better representation of the use of common resources in the organization.

Example 1-1 Two types of microchips (A and B) are being manufactured, with microchip B being slightly more complex. There are two sizes of microchip A, A1 and A2. For each type and each size, microchips are manufactured in batch sizes of 100,000. Table 1-1 shows the production volume and direct costs/batch, while Table 1-2 displays the overhead costs for the past year. Using the traditional costing method (unit-based costing) of allocating overhead rate based on direct labor costs, calculate the cost per batch of each type of microchip.

TABLE 1-1 Production Volume and Direct Costs per Batch of Microchips

	Microchip A		
	A1	A2	Microchip B
Number of batches produced	500	800	1200
Cost/batch			
Direct labor ($)	500	600	800
Direct material ($)	2500	3200	3800
Processing ($)	1500	2000	3000

TABLE 1-2 Overhead Cost of Plant

Category	Cost ($ millions)
Setup and testing	$2.20
Product-line costs	
Microchip A	5.50
Microchip B	9.30
Other plant costs	4.50
Total overhead costs	$21.50

TABLE 1-3 Overhead Rate Using Unit-Based Allocation

	Microchip			
	A1	A2	B	Total
Number of batches produced	500	800	1200	
Direct labor cost per batch ($)	500	600	800	
Total direct labor cost ($ millions)	0.25	0.48	0.96	1.69
Total overhead ($ millions)				21.50
Overhead rate (%)				1272.19

Calculate the cost per batch using the activity-based costing method and compare with the figures calculated previously.

Solution The unit-based allocation scheme is demonstrated first. The total direct labor cost is used, based on which the overhead rate is determined by using the ratio of the total overhead cost to the total direct labor cost. This common overhead rate is then applied to each microchip type and size to determine the overhead cost assignment. Subsequently, a unit cost is calculated. Table 1-3 shows the computation of the common overhead rate. Costs per batch of each microchip type and size are shown in Table 1-4 using the computed overhead rate in Table 1-3.

Next, the activity-based cost allocation scheme is used. The unit cost for each of the three activity-based cost drivers is calculated as follows:

- *Batch-related costs*: Setup and testing: $2.20 million ÷ 2500 batches = $880 per batch
- *Product line–related costs*: Microchip A: $5.50 million ÷ 1300 = $4231 per batch
  Microchip B: $9.30 million ÷ 1200 = $7750 per batch

TABLE 1-4 Cost per Batch Using Unit-Based Allocation

	Microchip		
Cost Component	A1	A2	B
Direct labor	$500	$600	$800
Direct material	2,500	3,200	3,800
Processing	1,500	2,000	3,000
Overhead (1272.19% of direct labor)	6,361	7,633	10,178
Total cost per batch	$10,861	$13,433	$17,778
Cost per microchip	$0.1086	$0.1343	$0.1778

TABLE 1-5 Cost per Batch Using Activity-Based Allocation

	Microchip		
Cost Component	A1	A2	B
Direct labor	$500	$600	$800
Direct material	2,500	3,200	3,800
Processing	1,500	2,000	3,000
Overhead			
Batch-related	880	880	880
Product-line related	4,231	4,231	7,750
Production-sustaining (266.27% of direct labor)	1,331	1,598	2,130
Total cost per batch	$10,942	$12,509	$18,360
Cost per microchip	$0.1094	$0.1251	$0.1836

- *Production-sustaining costs*: Overhead rate per direct labor dollar = \$4.50 million ÷ \$1.69 million = 266.27%

An assumption made in batch-related costs, in this example, is that setup and testing costs are quite similar for both types of microchips. Hence, the total setup and testing cost is averaged out over the total batches of both types of microchips. Using these computed values, Table 1-5 shows the costs per batch for each type and size of microchip using the activity-based allocation method.

From Tables 1-4 and 1-5, differences are observed between the two methods of costing in the cost per batch, and the corresponding cost per microchip, for each type and size of microchip. Some conclusions that can be drawn are as follows. The unit-based (traditional) costing method tends to over-cost the high-volume items within a product type. Also, since more complex products require more product-line costs, the activity-based costing method will make proportional allocations. However, the unit-based costing method, using direct labor as a measure of allocating overhead costs, will under-cost more complex products.

1-12 QUALITY COSTS

The value of a quality system is reflected in its ability to satisfy the customer. In this context, quality costs reflect the achievement or nonachievement of meeting product or service requirements, as determined from the perspective of the customer. These requirements may include design specifications of a product, operating instructions, government regulations, timely delivery, marketing procedures, and servicing commitments, among others.

The various components of quality costs are designated based on product/service conformance or nonconformance. The achievement of requirements, identified by product or service conformance, consists of a cost component, identified as prevention costs, while nonconformance consists of the cost components of appraisal and failure costs (Campanella 1999). To summarize, quality costs may be interpreted as the difference between the actual cost and the reduced cost if products and services were all conforming. The four major categories of quality costs are discussed here.

Prevention Costs

Prevention costs are incurred in planning, implementing, and maintaining a quality system to prevent poor quality in products and services. They include salaries and developmental costs for product design, process and equipment design, process control techniques (through such means as control charts), information systems design, and all other costs associated with making the product right the first time. Also, costs associated with education and training are included in this category. Other such costs include those associated with defect cause and removal, process changes, and the cost of a quality audit. Prevention costs increase with the introduction of a quality system and, initially, may be a significant proportion of the total quality costs. However, the rate of increase slows with time. Even though prevention costs increase, they are more than justified by reductions in total quality costs due to reductions in internal and external failure costs.

Appraisal Costs

Appraisal costs are those associated with measuring, evaluating, or auditing products, components, purchased materials, or services to determine their degree of conformance to the specified standards. Such costs include dealing with the inspection and testing of incoming materials as well as product inspection and testing at various phases of manufacturing and at final acceptance. Other costs in this category include the cost of calibrating and maintaining measuring instruments and equipment and the cost of materials and products consumed in a destructive test or devalued by reliability tests. Appraisal costs typically occur during or after production but before the product is released to the customer. Hence, they are associated with managing the outcome, whereas prevention costs are associated with managing the intent or goal. Appraisal costs normally decline with time as more nonconformities are prevented from occurring.

Internal Failure Costs

Internal failure costs are incurred when products, components, materials, and services fail to meet quality requirements prior to the transfer of ownership to the customer. These costs would disappear if there were no nonconformities in the product or service. Internal failure costs include scrap and rework costs for the materials, labor, and overhead associated with production. The cost of correcting nonconforming units, as in rework, can include such additional manufacturing operations as regrinding the outside diameter of an oversized part. If the outside diameter were undersized, it would not be feasible to use it in the finished product, and the part would become scrap. The costs involved in determining the cause of failure or in reinspecting or retesting reworked products are other examples from this category. The cost of lost production time due to nonconformities must also be considered (e.g., if poor quality of raw materials requires retooling of equipment). Furthermore, *downgrading costs,* the revenue lost because a flawed product has to be sold at a lower price, constitutes another component. As a total quality system is implemented and becomes effective with time, internal failure costs will decline. Less scrap and rework will result as problems are prevented.

External Failure Costs

External failure costs are incurred when a product does not perform satisfactorily after ownership is transferred to the customer or services offered are nonconforming. If no nonconforming units were produced, this cost would vanish. Such costs include those due to customer complaints, which include the costs of investigation and adjustments, and those associated with receipt, handling, repair, and replacement of nonconforming products. Warranty charges (failure of a product within the warranty time) and product liability costs (costs or awards as an outcome of product liability litigation) also fall under this category. A reduction in external failure costs occurs when a quality control system is implemented successfully.

Hidden Failure Costs

The measurable components of failure costs include those associated with scrap, rework, or warranty, which are easily tracked by accounting systems. A significant segment of the failure costs are "hidden." These include management and engineering time associated with cause identification and determination of remedial actions associated with failures. Line downtime, the necessity to carry increased inventory, the decrease in available capacity, and orders lost due to poor quality are examples of costs not easily tracked by accounting systems. Hence, what is typically reported as failure costs is but a minute portion of the true failure costs.

Quality Costs Data Requirements

Quality costs should be monitored carefully. Because indirect costs are as important as such direct costs as raw material and labor, well-defined accounting procedures should be set up to determine realistic quality cost estimates. Consider the case where quality cost data cross departmental lines. This occurs, for example, when a quality control supervisor in a staff position identifies the reason for scrap or rework, and a machine operator conducts an extra operation to rework those items. Similarly, should rework or scrap inspire a change in the product design, the redesign time is assigned to quality costs.

Figure 1-4 shows the data requirements at various management levels. Data are collected for each product line or project and distributed to each level of management. The needs are somewhat different at each level. Top management may prefer a summary of the total quality costs, broken down into each of the four categories, at the division or plant level. On the other hand, line management or supervisors may want a summary of the direct costs, which include labor and material costs, as it relates to their area.

This means that if a change is made in product or process design, it is possible for one or more quality cost categories to be affected. The time spent by the design engineer would be allocated, costwise, to prevention cost. On the other hand, if the design calls for new

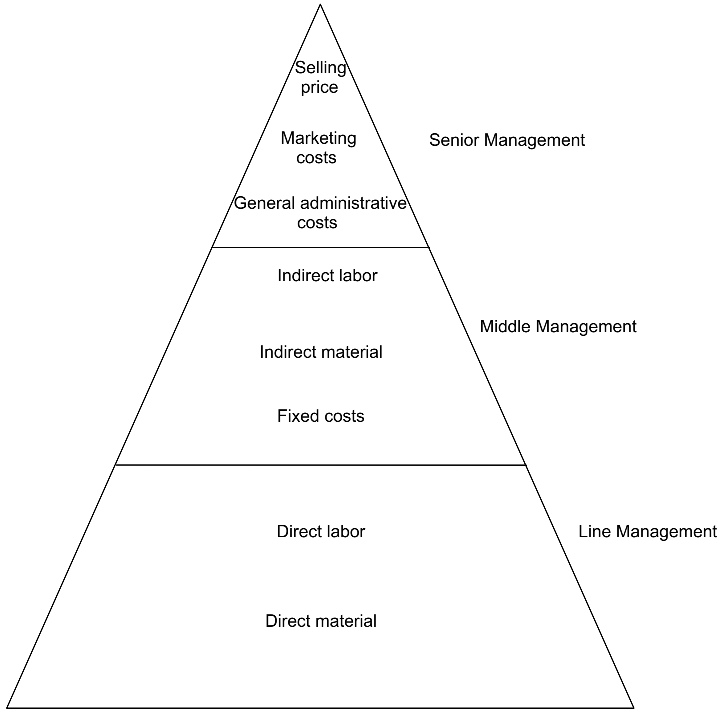

FIGURE 1-4 Quality costs data requirements at different management levels.

inspection equipment, that would be allocated to appraisal cost. Thus, a costwise breakdown into the four categories of prevention, appraisal, internal failure, and external failure is incorporated into the accounting system for the variety of functions performed by management and operators. Information from cost systems must be used to identify *root causes* associated with failures. Only when *remedial actions* are taken to prevent these from occurring will the true benefits of a cost system be reaped.

Process Cost Approach

In a conventional approach, the normal production costs associated with running a process (e. g., direct material, labor, and overhead costs) or providing a service (salaries and wages of personnel, shipment or delivery costs) may not be included in the quality costs of conformance (i.e., prevention). Costs of nonconformance typically include internal and external failure costs. It is possible that greater cost-saving opportunities might lie in reducing the cost of conformance. In this regard, the process-cost approach could be helpful by eliminating non-value-added activities or combining process steps, to reduce the cost of conformance. Such an approach may be effective where quality improvement efforts have reached maturation. It has the advantage of tackling costs associated with efficiency as well as quality and may reduce the “hidden” quality costs discussed previously.

Example 1-2 A company manufacturing a chemical compound has identified the following cost components (per kilogram): direct labor, \$2.00; material, \$5.00; energy, \$0.50; overhead, 30% of direct labor and material. The process is operating at a yield rate of 96%. A quality improvement team, through analysis, has been able to increase yield to 97%. Find the cost per kilogram of product before and after this improvement. On further study, the team analyzed the process and was able to eliminate several non-value-added steps. Direct labor and material costs were reduced by 25%. Calculate the cost per kilogram of product after these process changes are made. By what percentage have total costs been reduced? What is the percentage increase in capacity?

Solution The conformance costs include the process costs, comprising direct labor, material, energy, and overhead costs. Overhead costs are \$2.10/kg, leading to total conformance costs of \$9.60/kg. The total cost (conformance and nonconformance) is \$10/kg (9.60/0.96), implying a nonconformance cost of \$0.40/kg. By improving yield to 97%, the total cost/kg is \$9.90. Thus, the nonconformance cost has been reduced to \$0.30/kg. On elimination of non-value-added steps in the process, direct labor and material costs are \$5.25/kg. With overhead costs of \$1.58 (5.25×0.3), the process costs are \$7.33/kg. Since the yield rate is now 97%, the total cost of the product is \$7.56/kg, implying a nonconformance cost of \$0.23/kg. Total costs have been reduced by 24.4% [(10.00 − 7.56)/10.00]. Relative level in capacity $0.97/0.96 = 1.010$, indicating a 1% increase in capacity. The reduction in total costs, by analyzing the process, has made a major impact.

1-13 MEASURING QUALITY COSTS

The magnitude of quality costs is important to management because such indices as return on investment are calculated from it. However, for comparing quality costs over time, magnitude may not be the measure to use because conditions often change from one quarter to the next. The number of units produced may change, which affects the direct costs of labor and materials, so the total cost in dollars may not be comparable. To alleviate this situation, a measurement base that accounts for labor hours, manufacturing costs, sales dollars, or units produced could be used to produce an index. These ideas are discussed here.

1. *Labor-based index.* One commonly used index is the quality costs per direct-labor hour. The information required to compute this index is readily available, since the accounting department collects direct-labor data. This index should be used for short periods because over extended periods, the impact of automation on direct-labor hours may be significant. Another index lists quality costs per direct-labor dollar, thus eliminating the effect of inflation. This index may be most useful for line and middle management.
2. *Cost-based index.* This index is based on calculating the quality costs per dollar of manufacturing costs. Direct-labor, material, and overhead costs make up manufacturing costs, and the relevant information is readily available from accounting. This index is more stable than the labor base index because it is not significantly affected by price fluctuations or changes in the level of automation. For middle management, this might be an index of importance.
3. *Sales-based index.* For top management, quality costs per sales dollar may be an attractive index. It is not a good measure for short-term analysis, but for strategic decisions, top management focuses on long-term outlook. Sales lag behind production and are subject to seasonal variations (e.g., increased sales of toys during Christmas). These variations have an impact in the short run. However, they smooth out over longer periods of time. Furthermore, changes in selling price also affect this index.

4. *Unit-based index.* This index calculates the quality costs per unit of production. If the output of different production lines is similar, this index is valid. Otherwise, if a company produces a variety of products, the product lines would have to be weighted and a standardized product measure computed. For an organization producing refrigerators, washers, dryers, and electric ranges, for example, it may be difficult to calculate the weights based on a standard product. For example, if 1 electric range is the standard unit, is a refrigerator 1.5 standard units of a product and a washer 0.9 standard unit? The other indexes should be used in such cases.

For all of these indexes, a change in the denominator causes the value of the index to change, even if the quality costs do not change. If the cost of direct labor decreases, which may happen because of improvement in productivity, the labor-based index increases. Such increases should be interpreted cautiously because they can be misconstrued as increased quality costs.

A sample monthly quality cost report is shown in Table 1-6. Monthly costs are depicted for individual elements in each of the major quality cost categories of prevention, appraisal,

TABLE 1-6 Sample Monthly Quality Cost Report

Cost Categories	Amount	Percentage of Total
Prevention costs		
Quality planning	15,000	
Quality control engineering	30,000	
Employee training	10,000	
Total prevention costs	55,000	26.31
Appraisal costs		
Inspection	6,000	
Calibration and maintenance of test equipment	3,000	
Test	2,000	
Vendor control	4,000	
Product audit	5,000	
Total appraisal costs	20,000	9.57
Internal failure costs		
Retest and troubleshooting	10,000	
Rework	30,000	
Downgrading expense	3,000	
Scrap	16,000	
Total of internal failure costs	59,000	28.23
External failure costs		
Manufacturing failures	15,000	
Engineering failures	20,000	
Warranty charges	40,000	
Total external failure costs	75,000	35.89
Total quality cost	209,000	

Bases		Ratios	
Direct labor	800,000	Internal failure to labor	7.375%
Manufacturing cost	2,000,000	Internal failure to manufacturing	2.950%
Sales	3,800,000	Total quality costs to sales	5.500%

internal failure, and external failure. Observe that external failure and internal failure are the top two cost categories, comprising 35.89 and 28.23%, respectively, of the total cost. Comparisons of costs with different bases are also found in Table 1-6. Data on direct-labor cost, manufacturing cost that includes direct-labor, material, and overhead costs, and sales are shown in the table. Cost of goods sold includes manufacturing costs plus selling costs. Internal failure costs, for example, are 7.375% of direct-labor costs and 2.950% of manufacturing costs. Total quality costs are 5.5% of sales. From the information in the table, it seems that management needs to look into measures that will reduce internal and external failure costs, which dominate total quality costs. Perhaps better planning and design, and coordination with manufacturing, will reduce the external failure costs.

Impact of Quality Improvement on Quality Costs

The traditional notion of determining the optimal level of quality based on minimizing total quality costs is based on a static concept. It also does not incorporate the impact of quality improvement, an ideology that is an integral fabric of organizations, on the various quality cost functions. In fact, improving the level of quality of conformance and decreasing quality costs are not conflicting objectives. Rather, striving for improvements in both is complementary in nature and hence, can be achieved.

Minimization of total quality costs to determine the optimal operational level of quality using a traditional static concept is shown in Figure 1-5. In this case, prevention costs increase at an exponential rate with an improvement in the level of quality. Appraisal costs, however, may not increase rapidly with the level of quality. The combined prevention and appraisal cost function is dominated by the prevention costs, leading to the shape of the function in Figure 1-5. On the contrary, as the level of quality improves, a decline in the internal and external failure costs takes place, demonstrated by the nonlinear decay function. The total quality cost function, the sum of the prevention and appraisal costs and the internal failure and external failure costs, is also shown in Figure 1-5. The minimization of the total quality cost function leads to an optimal quality level (q_0).

We now discuss the more appropriate dynamic concept of analyzing quality costs and the manner in which the analysis is affected by the continuous quality improvement philosophy.

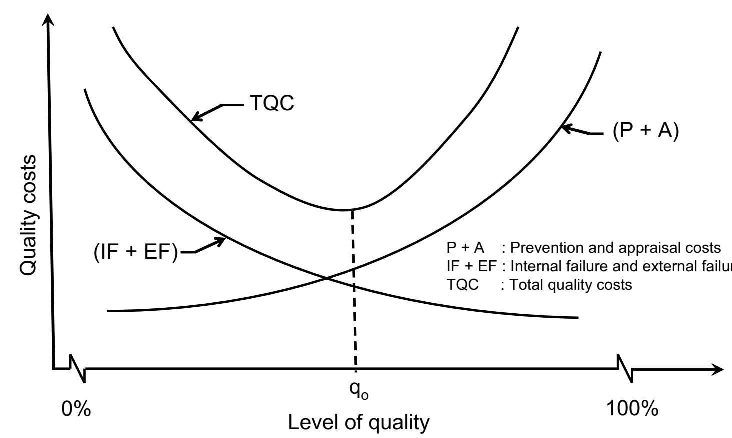

FIGURE 1-5 Quality costs versus level of quality.

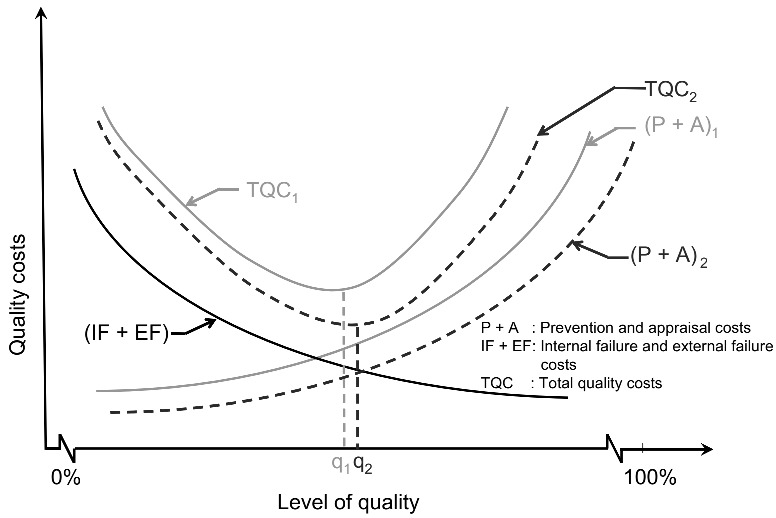

FIGURE 1-6 Dynamic concept of the impact of quality improvement.

First, with continuous improvement, not only is there a reduction in the unit cost of the product or service, but also a change in the shape of the prevention and appraisal cost function. Usually, the rate of increase of this function with the level of quality will be smaller than in the original situation. Ignoring, for the present, the other impacts of quality improvement, Figure 1-6 shows the shifted prevention and appraisal cost function. Note that the optimum level of quality desired improves (from q_1 to q_2). Rationalizing along these lines, the target level of quality to strive for, in the long run, should be total conformance.

Improvements in technology and advances in knowledge will initially affect the prevention and appraisal cost function, shifting it to the right with a reduction in slope. Although such advancements start out in *incremental steps* (i.e., the *Kaizen* concept of continuous improvement), after the achievement of a certain quality level, management must focus on *technological breakthroughs* to further improve quality. Such major innovations may lead to a reduction in the rate of change in the level of the prevention and appraisal cost function and consequently, a *change in the slope* of the prevention and appraisal cost function. The shape of the prevention and appraisal cost function changes from concave to convex after a certain level of quality (inflection point). Due to such a change, the shape of the total quality cost function will also change and will show a decreasing trend with the level of quality. Figure 1-7 demonstrates this impact. The target level of quality is 100% conformance.

Let us now discuss some of the other effects of continuous quality improvement that occur in a dynamic situation. Improvement in the performance of a product or service leads to improved customer satisfaction. As a result, market share improves. In a static situation, this increase in market share is not incorporated. Increased market share results in better overall company performance and return to stakeholders, necessitating a change to improved quality levels. An indirect impact of improved customer satisfaction is the ability of the manufacturer or service provider to charge a higher unit price, which leads to further improvement in profitability. In a static situation, the provider does not have the ability to increase unit price through quality improvement. To summarize, if we denote profitability as being proportional to the product of the market share and the difference between unit price and unit cost, quality

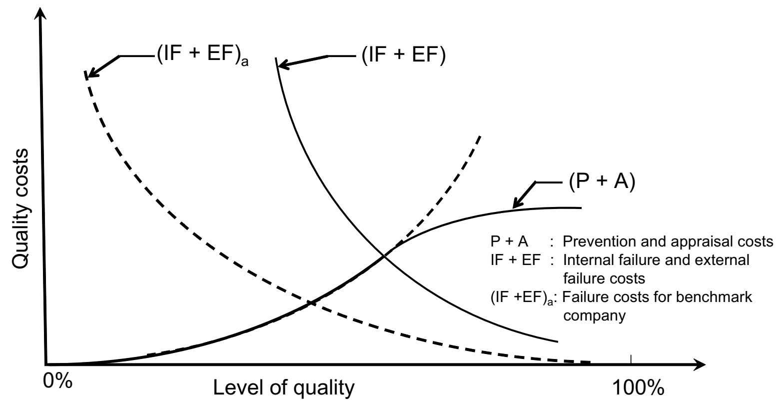

FIGURE 1-7 Target level of 100% conformance.

improvement affects all three components on a dynamic basis. It increases market share, decreases unit cost, and may also lead to increases in unit prices, thereby affecting profitability from three angles.

The focus of organizations should be on reduction of failure costs, internal and external. External failure is damaging. It leads to customer dissatisfaction, brand switching, and market share reduction. Although such opportunity costs are difficult to measure, they are significant. With an improvement in the level of quality, all other factors being constant, total failure costs should decrease. However, external failure costs are also influenced by the relative position of the organization relative to its competitors' offering. Thus, if a company's product lags significantly behind that of the benchmark or leader, the customer is likely not to be satisfied with the product, leading to increased external failure costs. Assuming that external failure costs are the more dominant of the two failure costs, Figure 1-7 also shows the total failure cost curve for the benchmark company in the industry. Whereas the prevention and appraisal cost function is influenced by actions and policies adopted by the company, the failure cost function is affected as well by the company and its competitors and by customer preferences. This demonstrates that managing external failure costs is much more encompassing. Even if the company maintains, internally, the same level of quality, external failure costs may go up, given the competitive environment of business. Further, customer preferences are dynamic in nature. It is not sufficient to improve only the manufacture of a chosen product. Keeping up with the needs and expectations of the customer is imperative.

1-14 MANAGEMENT OF QUALITY

Depending on the nature of the business (i.e., manufacturing, assembly, or service; range of product or service offerings; and degree of outsourcing), the management function of quality may employ appropriate models. Regardless, meeting and exceeding customer needs must be the central theme in all these models.

The first model describes the concept of *supply chain management*. Here, companies link to form partnerships with external organizations in order to leverage their strategic positioning as well as to improve operational efficiency. Consider Figure 1-8, which demonstrates a manufacturing or assembly situation conducted by the original equipment

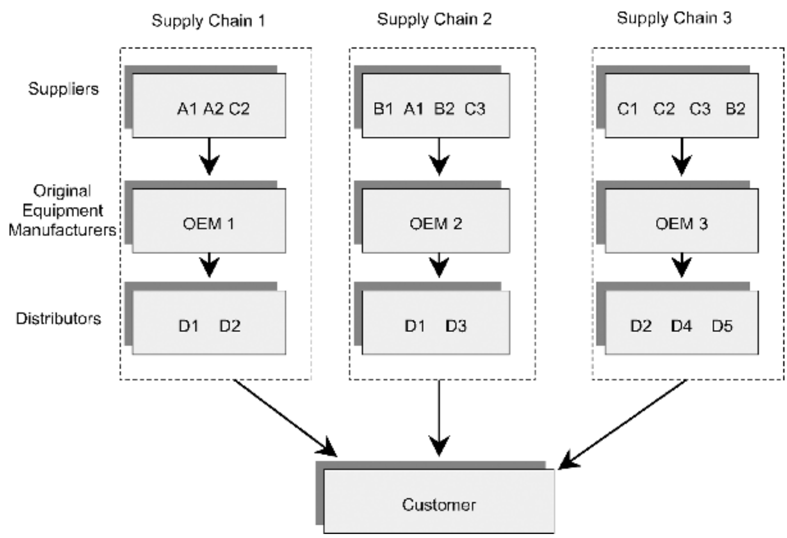

FIGURE 1-8 Supply chain configuration.

manufacturer (OEM). Based on the *core competencies* of the OEM, the OEM selects suppliers that can address their non-core competencies. Components or subassemblies could be obtained from suppliers which are not necessarily unique to a given OEM. The same supplier may serve multiple OEMs. Similarly, an OEM may market its products through one or more distributors, who also may not necessarily be unique to an OEM. The customer buys the products from the distributors. Thus, we have a situation in which supply chains rather than OEMs compete with each other. Quality and cost associated with the product are influenced by that of the suppliers, OEMs, and distributors considered collectively.

A second model describes the situation where the same suppliers, labeled in a tiered fashion that follows the process of assembly, feed all the OEMs. In this case, the OEMs are usually limited in number. Consider the automobile industry, where there are only a handful of OEMs: for example, Ford, General Motors, DaimlerChrysler, Toyota, Honda, and Hyundai. Since the same types of components are needed for each OEM, a tier 1 supplier producing a thermostatic control system to regulate engine temperature could conceivably supply all the OEMs. Similarly, at the tier 2 level, the components to produce the thermostatic control system could be manufactured by dedicated suppliers that focus on making only certain parts. Hence, parts produced by suppliers A and B in tier 2 are used to make a component or subassembly in tier 1. Information on individual parts and/or subassemblies could be monitored through a central "infomediary". The OEMs would draw parts and components using such information. As before, the customer buys from the distributors. Figure 1-9 shows such a tiered supply chain structure.

In considering the OEM as the organizational unit that attempts to maximize the performance of the associated supply chain, which involves its suppliers, distributors, customer representatives, and employees, an enterprise-wide concept could be incorporated. Data would be collected from the various facets of the organization in order to develop and monitor measures of quality and costs. Figure 1-10 shows the information needs for an enterprise-wide system. The quality of the product and/or service will be influenced by all of the contributing units, making management's task quite encompassing.

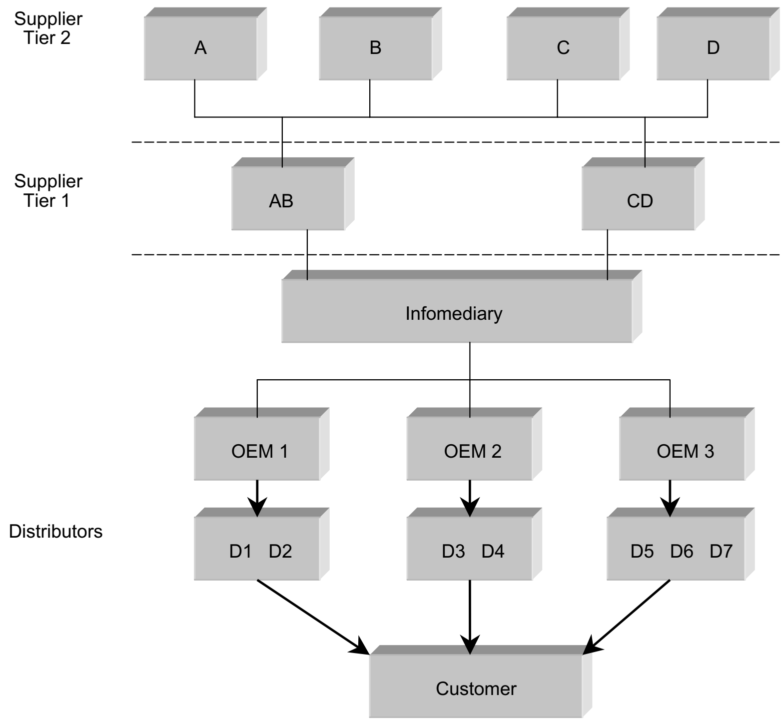

FIGURE 1-9 Tiered supply chain.

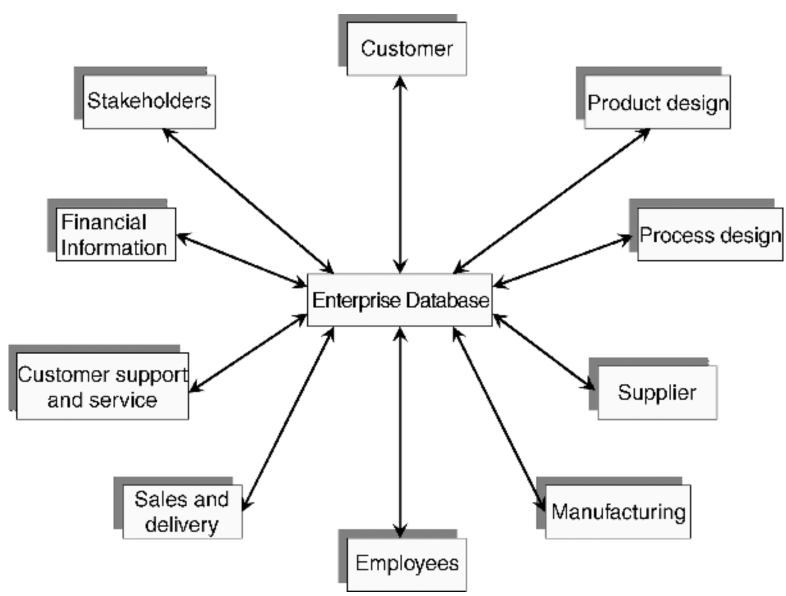

FIGURE 1-10 Enterprise-wide information needs.

1-15 QUALITY AND PRODUCTIVITY

A misconception that has existed among businesses (and is hopefully in the process of being debunked) is the notion that quality decreases productivity. On the contrary, the relationship between the two is positive: Quality *improves* productivity. Making a product right the first time lowers total costs and improves productivity. More time is available to produce defect-free output because items do not have to be reworked and extra items to replace scrap do not have to be produced. In fact, doing it right the first time increases the available capacity of the entire production line. As waste is reduced, valuable resources—people, equipment, material, time, and effort—can be utilized for added production of defect-free goods or services. The competitive position of the company is enhanced in the long run, with a concomitant improvement in profits.

Effect on Cost

As discussed previously, quality costs can be grouped into the categories of prevention, appraisal, internal failure, and external failure. Improved productivity may affect each of these costs differently.

1. *Prevention and appraisal costs.* With initial improvements in productivity, it is possible that prevention and appraisal costs will increase. As adequate process control procedures are installed, they contribute to prevention and appraisal costs. Furthermore, process improvement procedures may also increase costs in these two categories. These are thus called the *costs of conformance* to quality requirements. With time, a reduction in appraisal costs is usually observed. As process quality improves, it leads to efficient and simplified operations. This may yield further improvements in productivity.
2. *Internal and external failure costs.* A major impact of improved quality is a reduction in internal and external failure costs. In the long run, decreasing costs in these two categories usually offset the increase in prevention and appraisal costs. The total cost of quality thus decreases. Moreover, as less scrap and rework is produced, more time is available for productive output. The company's profitability increases. As external failures are reduced, customer satisfaction improves. Not only does this emphasis on quality reduce the tangible costs in this category (such as product warranty costs and liability suits), it also significantly affects intangible costs of customer dissatisfaction. Figure 1-11 shows how improved quality leads to reduced costs, improved productivity, increased customer satisfaction; and eventually, increased profits through improved competitive positioning.

As noted previously, management must focus on long-term profits rather than short-term gain. A reason cited frequently for not adopting a total quality system is management's emphasis on short-term profits. As is well known, short-term profits can be enhanced by postponing much-needed investment in process improvement equipment and methods, by reducing research and development, and/or by delaying preventive maintenance. These actions eventually hurt competitiveness and profitability.

Effect on Market

An improvement in quality can lead to increased market shares, improved competitive position, and increased profitability.

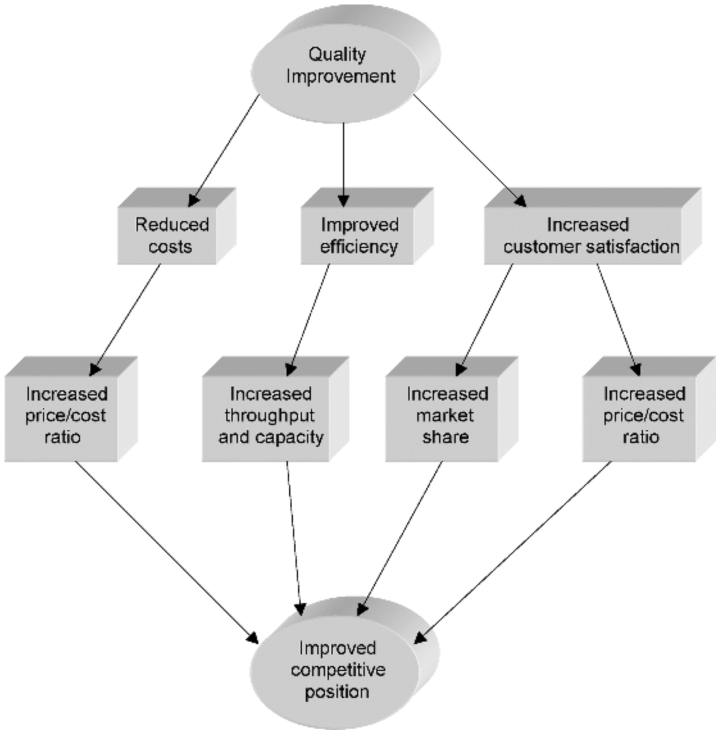

FIGURE 1-11 Impact of quality on competitive position.

1. *Market share.* With a reduction in external failure costs and improved performance of a product in its functional phase, a company is in a position to raise the satisfaction level of its customers, many of whom return to buy the product again. Satisfied customers spread the word about good quality, which leads to additional customers. Market share goes up as the quality level goes up.
2. *Competitive position.* All organizations want to stay competitive and to improve their market position, but simply improving quality or productivity may not be sufficient since competitors are doing the same. Organizations must monitor their relative position within the industry as well as the perception of customers. Efforts to improve quality are crucial in attaining these goals. Through process control and improvement and efficient resource utilization (reduced production of scrap and network), a firm can minimize its costs. So even if the selling price remains fixed, an improved price/ cost ratio is achieved. Alternatively, as quality improves, the firm may be able to charge a higher price for its product, although customer satisfaction and expectations ultimately determine price. In any event, an improved competitive position paves the way for increased profitability.

Example 1-3 Three independent operations are performed sequentially in the manufacture of a product. The first-pass yields (proportion conforming) for each operation are given by $p_1 = 0.90$, $p_2 = 0.95$, and $p_3 = 0.80$, respectively, as shown in Figure 1-12. The unit production costs for each operation are $u_1 = \$5$, $u_2 = \$10$, and $u_3 = \$15$, respectively.

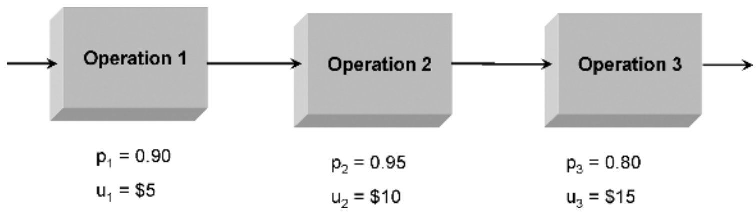

FIGURE 1-12 Operations sequence in manufacturing.

(a) What is the unit cost *per conforming product*?

Solution The first-pass yield (proportion conforming) at the completion of all three operations = (0.90)(0.95)(0.80) = 0.684. The total production cost of all three operations $30. Thus, if 1000 parts are manufactured at a cost of $30 each, only 684 of them are conforming. Thus, the unit cost per conforming product = $30/0.684 = $43.86. This is about a 46% increase over the unit production costs. As the level of quality is improved in the operations, the unit cost per conforming product may be reduced, its limiting value being $30, at which point the conformance rate for each operation is at 100%.

(b) Suppose, through quality improvement effort, the first-pass yield for each operation is improved to the following levels: $p_1 = 0.94$, $p_2 = 0.96$, $p_3 = 0.88$. Relative to part (a), determine how much improvement in *capacity* has taken place.

Solution The first-pass yield at completion of all three operations now = (0.94)(0.96)(0.88) = 0.794. Relative level in capacity = 0.794/0.684 = 1.161, compared to the previous operation level, indicating an increase in available production capacity of 16.1%.

(c) Management is contemplating a 100% inspection process after either operation 1 or 2. Assume that the inspection process is completely reliable [i.e., all units are identified correctly (conforming or not)]. Unit inspection costs after operations 1 and 2 are $0.10 and $0.20, respectively. Nonconforming parts are not forwarded to subsequent operations. Find the unit cost per conforming product for each plan for the improved process.

Solution

Plan 1: Inspection only following operation 1 In this plan, all units following operation 1 will undergo inspection. However, only the conforming parts will be forwarded to operation 2. Suppose that 1000 parts are input to operation 1. The total production and inspection costs for all the operations are as follows: (5 + 0.10)(1000) + (0.94)(1000)(10 + 15) = $28,600. The number of conforming product units = (1000)(0.94)(0.96)(0.88) = 794.112. Hence, the unit cost per conforming product = 28,600/794.112 = $36.02.

Plan 2: Inspection only following operation 2 Here, all units following operation will be forwarded to operation 2. After inspection on completion of operation 2, only the conforming units will be sent to operation 3. So the total production and inspection costs for all operations will be (1000)(5) + (1000)(10 + 0.20) + (0.94)(0.96)(1000)(15) = $28,736. This leads to a unit cost per conforming product = $28,736/794.112 = $36.19. Management should recommend plan 1 if unit cost per conforming product is used as the selection criterion.

1-16 TOTAL QUALITY ENVIRONMENTAL MANAGEMENT

In recent years we have witnessed the emergence of many national and regional standards in the environmental management field. Some companies, of course, have long felt a social responsibility to operate and maintain safe and adequate environmental conditions, regardless of whether outside standards required it. Xerox Corporation is an example of a large corporation that takes its social obligations toward the environment seriously. The company has undertaken a major effort to reduce pollution, waste, and energy consumption. The quality culture is reflected in Xerox's protection of the environment; their motto is to reuse, remanufacture, and recycle. Company goals are aimed at creating waste-free products in waste-free factories using a "Design for the Environment" program. To support their environmental management program, Xerox uses only recyclable and recycled thermoplastics and metals.

With the concern for protection of the environment that is mandated in regional and national standards, standards need to be developed in environmental management tools and systems. British Standards Institute's BSI 7750 standards on environmental management is one such example; the European Union's (EU) eco-label and Eco-Management and Auditing Scheme (EMAS) are other examples. Both of these rely on consensus standards for their operational effectiveness. Similarly, in the United States, technical environmental standards under the sponsorship of the American Society for Testing and Materials (now ASTM international) have been published that address the testing and monitoring associated with emission and effluent pollution controls.

The International Organization for Standardization (ISO) based in Geneva, Switzerland, has long taken the lead in providing quality management standards. Its ISO 9000 standards have become a benchmark for quality management practices. U.S. companies have adopted ISO 9000 standards and have found this particularly beneficial in doing business with or trading in the European Union. Technical Committee (TC) 207 of the ISO has developed standards in the field of environmental management tools and systems; their document, ISO 14000: *An International Environmental Management Standard*, deals with developing management systems for day-to-day operations that have an impact on the environment (Marcus and Willig 1997; Parry 2000; Welch 1998). ISO 14000 consists of six standards. Three of these are in the category of organizational evaluation, focusing on environmental and business management systems: the Environmental Management System (ISO 14001) Environmental Performance Evaluation (ISO 14031), and Environmental Auditing (ISO 14010) standards. The other three explore the product development process and consist of Life Cycle Assessment (ISO 14040), Environmental Labeling (ISO 14020), and Product Standards (ISO 14060).

Environmental management began as a regulation-based and compliance-driven system. It has subsequently evolved into a voluntary environmental stewardship process whereby companies have undertaken a continuous improvement philosophy to set goals that go beyond the protection levels required by regulations. The ISO 14000 standards promote this philosophy with the objective of developing uniform environmental management standards that do not create unnecessary trade barriers. These standards are therefore not product standards. Also, they do not specify performance or pollutant/effluent levels. Specifically excluded from the standards are test methods for pollutants and setting limit values for pollutants or effluents.

Environmental management systems and environmental auditing span a variety of issues, including top management commitment to continuous improvement, compliance and pollution prevention, creating and implementing environmental policies, setting appropriate targets and achieving them, integrating environmental considerations in operating procedures, training employees on their environmental obligations, and conducting audits of the environmental management system.

One of the major corporations taking a lead in adoption of environmental management systems is the Ford Motor Company. Not only are all its plants around the world certified in ISO 14001, they have achieved significant improvements in air pollution, utilization of energy resources, recycling, waste disposal, and water treatment. Major recycling efforts have kept solid waste out of landfills. Ford has promoted expansion of environmental consciousness by providing monetary incentives to suppliers who assist in their waste reduction effort.

Several benefits will accrue from the adoption of environmental management system standards. First and foremost is the worldwide focus on environmental management that the standards will help to achieve. This promotes a change in the corporate culture. At the commercial level, ISO 14000 will have an impact on creating uniformity in national rules and regulations, labels, and methods. They will minimize trade barriers and promote a policy that is consistent. Not only will the standard help in maintaining regulatory compliance, it will help create a structure for moving beyond compliance. Management commitment and the creation of a system that reflects the goal to maintain a self-imposed higher standard will pave the way for continuous improvement in environmental management.

1-17 PROFILE OF A COMPANY: THE BAMA COMPANIES, INC.*

The Bama Companies, Inc. is a privately held corporation that began in 1927 and has grown into a leading developer and manufacturer of frozen ready-to-use food products served worldwide by quick service and casual dining restaurant chains such as McDonald's and Pizza Hut. From four production facilities in Tulsa, Oklahoma and two in Beijing, China, Bama's 1100 employees generate over $200 million a year in revenues. The company's three main product categories—handheld pies, biscuits, and pizza crust—account for 92% of revenues. The company is a 2004 winner of the Malcolm Baldrige National Quality Award in the manufacturing category (NIST 2005).

Company History and Vision

Whereas overall sales in the frozen baked goods industry have remained flat since 1999, Bama's sales have grown 72%. At the Bejing plant, production leaped from 600,000 pies in 1993 to 90 million in 2004. In an industry dominated by companies several times its own size, Bama's agility, its unique approach to product innovation, and its System View pricing strategy (it has not raised prices for its handheld pies and biscuits since 1996) give it tremendous leverage in the marketplace.

The company is rooted in its original guiding principles; keep your eyes on quality and remember that people make a company. Yet the way that Bama applies these principles in today's competitive business environment is anything but traditional. The company's stated vision is to "Create and Deliver Loyalty, Prosperity and Fun for All, While Becoming a

* Adapted from the Baldrige National Quality Program, National Institute of Standards and Technology, U.S. Department of Commerce, Gaithersburg, MD, 2005, www.nist.gov.

Billion Dollar Company." Bama sees itself and its mission as "People Helping People Be Successful."

Eyes on Quality

In its endless quest for improvement, Bama uses a battery of advanced strategies and tools, including the Bama Quality Management System, based on the quality improvement philosophies of W. Edwards Deming and the company's own performance excellence model. The Bama Excellence System provides a framework for all decision making. A Principle Centered Bama Culture provides a context for creating and measuring excellence. Using six sigma methodologies since 2000, Bama has dramatically improved processes throughout the company. Total savings from six sigma improvements is over $17 million since 2001.

The Future Looks Bright

In 1999, Bama utilized a strategic planning process called Prometheus to develop a company Future Picture, a high-level view of the company as it wants to be in 2010. The future that Bama envisions includes billion-dollar sales, recognition of the company's world class quality, being first-choice supplier in all its target markets, and providing employees and other stakeholders with unparalleled personal and financial opportunities. To help achieve these goals but maintain its small company culture, the company focuses on five strategic outcomes: (1). people—create and deliver loyalty, prosperity, and fun; (2). learning and innovation; (3). continuous improvement; (4). being the customer's first choice; and (5). value-added growth.

Bama uses it centers of gravity (short-term action plans) and a balanced scorecard to assess progress toward meeting these outcomes. The plans and scorecard support the company's decision-making process at all levels and are posted throughout its facilities, allowing all employees to see at a glance how their unit is performing against goals. The senior management team reviews the information at weekly and monthly meetings.

Building long-term relationships with suppliers and customers also helps Bama stay at the top of its game. Most of its key suppliers have been partners for 10 years or more, two have worked with the Bama Companies for three decades. Relationships with customers are just as enduring. The McDonald's system has been a Bama customer for 37 years and Pizza Hut for 11 years. Through these long-term relationships, Bama understands its customers, their customers' markets, and what their customers need to succeed. The company has tailored its services to meet customer requirements in critical areas such as assured supply, precision manufacturing, and value pricing. Since 2001, Bama has achieved 98% on-time delivery of products to customers, with 99% of orders filled completely on the initial shipment. Customer satisfaction for the company's major national accounts has increased from 75% in 2001 to 100% in 2004, considerably higher than the food manufacturing benchmark of 85%.

Innovation and Quality Improvement

Bama's manufacturing capabilities and customer knowledge have positioned the company not just as a manufacturer and supplier, but also as a designer of innovative food products. Developing new and innovative products is a major reason for Bama's growing market share and sales growth rate and is also helping its customers increase their own market share. In recognition of the innovation Bama brings, Bama has received Pizza Hut's Innovator of the Year award in three consecutive years: 2001, 2002, and 2003.

To manage its innovation initiatives, the company developed a business opportunity management process to coordinate the activities required to get a product from the idea stage to market. As a result, from 2000 to 2004, sales from new and innovative products have grown from less than 0.5% of total sales to almost 25%; and sales per employee grew from $175,000 to $205,000. This exceeds the 2003 *Industry Week* benchmark by $40,000.

People Make the Company

Bama is committed to the success of everyone associated with its business: customers, employees, and the community. The company's *people assurance system* ensures that each employee is well trained, fully informed, and empowered, and centers on helping all employees develop their potential and achieve personal success. Bama encourages employees to seek a college education by providing tuition reimbursement.

Satisfaction and loyalty of their people is key, and the company shares its success with employees when certain financial measures are met. Since 2001, profit-sharing payments have averaged around $3000 per year for each employee. A promote-from-within philosophy offers every qualified employee opportunities for advancement and the opportunity to be considered for job openings. This commitment to employees is paying off. Bama's 14% employee turnover rate is well below the average rate of 20% in the Tulsa area.

Bama also is committed to its community. A full-time leader of community development directs all of Bama's charitable and volunteer efforts, and a volunteer coordinator matches community needs with corporate resources. Employees are given paid time off to volunteer to work on corporate-sponsored projects. The number of hours that Bama employees donated to organizations such as Meals on Wheels, Habitat for Humanity, domestic violence intervention services, emergency infant services, and others increased from 500 in 2000 to nearly 7000 in 2004. Bama is the third largest contributor to the Tulsa Area United Way (Manufacturing Division), contributing $150,000 in 2004 alone. In addition, the company contributes annually an average of 6% of its pretax income (over $2.6 million since 2000) to local organizations that provide essential social, educational, cultural, and health services.

SUMMARY

In this chapter we examine the detailed framework on which the concept of the total quality system is based. We introduce, some of the basic terminology and provide an overview of the design, conformance, and implementation phase of the quality concept. We trace the evolution of quality control and present specifics on the benefits of quality control, who is responsible for it, and how it is to be adopted. The importance of the various types of needs of the customer is discussed with emphasis on those that focus on increasing market share. Such concepts apply to the manufacturing and service sectors. In costing products and services, the concept of activity-based costing is demonstrated. The subject of quality costs is explored thoroughly and the trade-offs that take place among the cost categories upon successful implementation of a total quality system are presented. A critical consideration in the entire scheme is management of the quality function. With the quality of the end product or service being influenced by entities such as outside suppliers, neither monitoring of the quality function nor of informational needs is restricted to within the organization. An important outcome of improvement in quality is an increase in productivity, capacity, and market share, along with a decrease in costs. All of this leads to improved profitability.

KEY TERMS

acceptance sampling plans
attributes
cause-and-effect diagram
causes
  common or chance
  special or assignable
costing
  activity-based
costs
  batch-level
  product/service-level
  production/service-sustaining
  process
customer
  needs
  satisfaction
defect
fishbone diagram
inspection
Ishikawa diagram
Kano model
management of quality
market share
nonconforming unit
nonconformity
off-line quality control
product design
productivity
quality
  quality of conformance
  quality of design
  quality of performance
  responsibility for quality
quality assurance
quality characteristic
quality circles
quality control benefits
quality cost measurements
  cost-based index
  labor-based index
  sales-based index
  unit-based index
quality costs
  appraisal costs
  external failure costs
  hidden failure costs
  prevention costs
  internal failure costs
quality improvement
reliability
specification
  specification limits
standard
statistical process control
  online statistical process control
supply chain management
systems approach
total quality environmental management
total quality system
variables
zero-defects program

EXERCISES

Discussion Questions

1-1 Consider the following organizations. How would you define quality in each context? Specify attributes/variables that may measure quality. How do you integrate these measures? Discuss the ease or difficulties associated with obtaining values for the various measures.

(a) Call center for a company that sells computers
(b) Emergency services (i.e., ambulances) for a city or municipality
(c) Company making semiconductor chips
(d) Hospital
(e) Company that delivers mail/packages on a rapid basis
(f) Department store
(g) Bank
(h) Hydroelectric power plant

1-2 The senior management in an urban bank is committed to improving its services. Discuss the specifics of quality of design, conformance, and performance in this context. Elaborate on possible basic needs, performance needs, and excitement needs of the customer.

1-3 A travel agency is attempting to enter a market where several competitors currently exist. What are the various customer needs that they should address? How will quality be measured? As the company strives to improve its market share, discuss the impact on the various categories of quality costs.

1-4 Consider the hospitality industry. Describe special causes and common causes in this setting and discuss the role of quality control and quality improvement.

1-5 An OEM in the automobile industry is considering an improvement in its order-processing system with its tier 1 suppliers. Discuss appropriate measures of quality. What are some special and some common causes in this environment?

1-6 An intermodal logistics company uses trucks, trains, and ships to distribute goods to various locations. What might be the various quality costs in each of the categories of prevention, appraisal, internal failure, and external failure?

1-7 A quality improvement program has been instituted in an organization to reduce total quality costs. Discuss the impact of such a program on prevention, appraisal, and failure costs.

1-8 Classify each of the following into the cost categories of prevention, appraisal, internal failure, and external failure:
(a) Vendor selection
(b) Administrative salaries
(c) Downgraded product
(d) Setup for inspection
(e) Supplier control
(f) External certification
(g) Gage calibration
(h) Process audit

1-9 Discuss the indices for measuring quality costs. Give examples where each might be used.

1-10 Explain how it is feasible to increase productivity, reduce costs, and improve market share at the same time.

1-11 Explain why it is possible for external failure costs to go up even if the first-pass quality level of a product made by a company remains the same.

1-12 Discuss the impact of technological breakthrough on the prevention and appraisal cost and failure cost functions.

1-13 As natural resources become scarce, discuss the role of ISO 14000 in promoting good environmental management practices.

1-14 Discuss the processes through which supply chain quality may be monitored.

Problems

1-15 An assemble-to-order hardware company has two types of central processing units (CPUs), C1 and C2, and two types of display monitors, M1 and M2. Unit C2 is slightly more complex then C1, as is M2 compared to M1. The annual production volume and direct costs are shown in Table 1-7. Overhead costs for this past year are shown in Table 1-8. Assume that setup and testing costs are similar for both types of CPUs and monitors.

TABLE 1-7

	CPU		Monitor	
	C1	C2	M1	M2
Annual volume	10,000	15,000	18,000	20,000
Unit costs				
Direct labor ($)	80	140	120	200
Direct material ($)	60	100	80	120
Assembly ($)	40	60	60	100

TABLE 1-8

Category	Cost ($ millions)
Setup and testing	1.1
Product-line cost	
CPU C1	0.5
CPU C2	1.5
Monitor M1	0.8
Monitor M2	2.5
Other company costs	0.6

(a) Calculate the cost per unit of each product using the unit-based costing method by allocating overhead based on direct labor costs.
(b) Calculate the cost per unit of each product using the activity-based costing method.
(c) Discuss the unit costs calculated using these two methods.

1-16 For the hardware company in Exercise 1-15, suppose that setup and testing costs are different for CPUs and monitors. Annual costs for setup and testing are \$0.4 million and \$0.7 million, for CPUs and monitors, respectively. However, between two types of CPUs, these costs are basically similar, as is also the case for monitors.
(a) Calculate the cost per unit of each product using the activity-based costing method.
(b) Discuss these unit costs in relation to those in Exercise 1-15.

1-17 Consider the hardware company in Exercise 1-15. The company is contemplating outsourcing of its complex monitor M2. Assume that all other information remains as given in Exercise 1-15.
(a) What is the cost per unit of each product using activity-based costing assuming that M2 is not produced?
(b) A prospective supplier of monitor M2 has offered a unit price of \$480. Should the company outsource the monitor M2 to this supplier? Discuss.

1-18 A pharmaceutical company has obtained the following cost information (per 1000 tablets) based on the production of a drug in the past year: material, \$150; direct labor, \$100; energy, \$50; overhead, 40% of direct labor and material. Presently, the process yield rate is 94%.
(a) Find the cost per tablet of acceptable product.
(b) A team evaluating the entire process has suggested improvements that led to increasing the yield rate to 96%. What is the cost per tablet of conforming product and the percent increase in capacity?
(c) Process engineers have come up with an improved sequence of operations. Labor costs were reduced by 15% and energy costs by 20% from the original values. Find the cost per tablet of conforming product now, and calculate the percentage reduction in cost.

1-19 The following data (in \$/m^3) was obtained from a company that makes insulation for commercial buildings: direct labor, 20; direct materials, 30; indirect labor and materials, 30% of direct labor; fixed expenses, 25; administrative costs, 25; selling costs, 10.
(a) Assuming a 100% first-pass yield, what should the selling price (per m^3) be such that a 10% profit margin, over the cost of goods sold, will be obtained?
(b) Suppose that the first-pass yield is 94%. If the selling price is kept the same as calculated in part (a), what is the profit margin?
(c) Through process improvements, first-pass yield has been improved to 98%. However, the capital expenditures necessary for such improvements is \$150,000. If the selling price is kept the same as in part (a), what is the profit margin, ignoring additional capital expenditures?
(d) For the improved process in part (c), assuming that monthly demand is 5000 m^3, how long would it take for the company to break even on its added capital expenditures?
(e) Suppose that the company is able to sell product that does not meet first-pass quality criteria at a reduced price of \$120/m^3. For the improved process in part (d), what is the break-even time now to recover added capital expenditures?

1-20 In the production of a part for a printer, four sequential operations are involved. Unit processing costs for the operations are \$10, \$6, \$15, and \$20, respectively. The first-pass yield for each operation is 0.95, 0.90, 0.95, and 0.85, respectively. Unit inspection costs after each operation are \$0.50, \$2.00, \$3.00, and \$5.00, respectively.
(a) If no inspection is performed, what is the unit cost for an acceptable part?
(b) Assume that an inspection process is able to identify all parts correctly. Suppose that inspection is conducted only after the first and second operations. Nonconforming parts are not forwarded to the next operation. What is the unit cost per acceptable part?
(c) Suppose that inspection is conducted only after the third operation. Nonconforming parts are not forwarded to the next operation. What is the unit cost per acceptable part?
(d) Based on the unit costs computed in parts (b) and (c), discuss where, in general, inspections should be conducted.

1-21 Suppose that the prevention and appraisal cost functions are given by $C_p = 50q^2$ and $C_a = 10q$, respectively, where q represents the degree of quality level ($0 < q < 1$). The cost of reworking a unit is \$5, and the cost of a customer obtaining a nonconforming product is \$85. Assume that these cost functions are linear in $(1 - q)$. What is the desirable operational level of quality for this static situation? Discuss the appropriateness of the cost functions.

1-22 Suppose that the prevention cost function is as given in Exercise 1-21. However, the unit appraisal cost is \$2, with the cost function being linear in $1 - q$, implying a decrease in appraisal costs as quality improves. Further, the rework and external failure cost functions are given by $C_r = 5(1 - q)/q$ and $C_e = 85(1 - q)/q$, respectively. Construct the total cost function as a function of q and graph it for levels of q in the range 0.80 to 0.98. What is the desirable operational level of quality?

1-23 Consider Exercise 1-22. Suppose that market share is strongly influenced by the level of quality, with the revenue function given by $90q^2$. What is the net profit function? What is the minimum desirable quality level to break even?

REFERENCES

ASQ. (1994). *Quality Management and Quality Assurance Vocabulary*, ANSI/ISO/ASQ Standard A8402 Milwaukee, WI: American Society for Quality.

———(2000). *Quality Management Systems: Requirements*, ANSI/ISO/ASQ 9000 Milwaukee, WI: American Society for Quality.

———(2004). *Glossary and Tables for Statistical Quality Control*, 4th ed., Milwaukee, WI: American Society for Quality, Statistics Division.

Campanella, J., Ed. (1999). *Principles of Quality Costs: Principles, Implementation, and Use*, 3rd ed. Milwaukee, WI: American Society for Quality.

Cohen, L. (1995). *Quality Function Deployment: How to Make QFD Work for You*. Reading, MA: Addison-Wesley.

Crosby, P. B. (1979). *Quality Is Free*. New York: McGraw-Hill.

Feigenbaum, A. V. (1983). *Total Quality Control*. New York: McGraw-Hill.

Garvin, D. A. (1984). "What Does Product Quality Really Mean?" *Sloan Management Review*, 26 (1): 25–43.

Juran, J. M., Ed. (1974). *Quality Control Handbook*, 3rd ed. New York: McGraw-Hill.

Marcus, P. A., and J. T. Willig, Eds. (1997). *Moving Ahead with ISO 14000*. New York: Wiley.

NBS (2005). *Model State Laws and Regulations*, NBS Handbook 130. Gaithersburg, MD: U.S. Department of Commerce, National Bureau of Standards.

NIST (2005). *Malcolm Baldrige National Quality Award: Profiles of Winners*. Gaithersburg, MD: U.S. Department of Commerce, National Institute of Standards and Technology.

Parry, P. (2000). *The Bottom Line: How to Build a Business Case for ISO 14000*. Boca Raton, FL: St. Lucie Press.

Taguchi, G. (1986). *Introduction to Quality Engineering: Designing Quality into Products and Processes*. Tokyo, Japan: Asian Productivity Organization. Available in North America, U.K., and Western Europe from the American Supplier Institute, Inc., and UNIPUB/Kraus International Publications, White Plains, NY.

Taguchi, G. and Y. Wu (1979). *Introduction to Off-Line Quality Control*. Nagoya, Japan: Central Japan Quality Control Association.

Welch, T. E. (1998). *Moving Beyond Environmental Compliance*. Boca Raton FL: Lewis Publishers.