
Total Quality Management

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Notes for students of 2010 Batch 8th Semester (2nd Term 4th year) Examination.

These topics are being provided after search from different books and internet articles. For better exam preparation you can consult suggested books and online resources.

Best of Luck.

Final List of Topics.

1. Introduction, Definition, characteristics of quality.
 2. Short note
 - a. 5S
 - b. Charts with examples
 - c. Kaizen
 - d. Six sigma
 3. Quality of Design, quality of conformance and quality of performance
 4. Statistical Process control
 5. Differentiate QC & QA
 6. Quality tools
 - a. Histograms
 - b. Pareto analysis
 - c. X-bar , R chart
 - d. Check sheet
 7. Quality Circles
 8. Problems (Numericals)
-

Quality Assurance vs Quality Control

Quality Assurance is **process oriented** and focuses on defect *prevention*; while quality control is **product oriented** and focuses on defect *identification*.

Comparison chart

 Edit	Quality Assurance	Quality Control
Definition	QA is a set of activities for ensuring quality in the processes by which products are developed.	QC is a set of activities for ensuring quality in products. The activities focus on identifying defects in the actual products produced.
Focus on	QA aims to prevent defects with a focus on the process used to make the product. It is a proactive quality process.	QC aims to identify (and correct) defects in the finished product. Quality control, therefore, is a reactive process.
Goal	The goal of QA is to improve development and test processes so that defects do not arise when the product is being developed.	The goal of QC is to identify defects after a product is developed and before it's released.
How	Establish a good quality management system and the assessment of its adequacy. Periodic conformance audits of the operations of the system.	Finding & eliminating sources of quality problems through tools & equipment so that customer's requirements are continually met.
What	Prevention of quality problems through planned and systematic activities including documentation.	The activities or techniques used to achieve and maintain the product quality, process and service.
Responsibility	Everyone on the team involved in developing the product is responsible for quality assurance.	Quality control is usually the responsibility of a specific team that tests the product for defects.
Example	Verification is an example of QA	Validation/Software Testing is an example of QC
Statistical Techniques	Statistical Tools & Techniques can be applied in both QA & QC. When they are applied to processes (process inputs & operational parameters), they are called Statistical Process Control (SPC); & it becomes the part of QA.	When statistical tools & techniques are applied to finished products (process outputs), they are called as Statistical Quality Control (SQC) & comes under QC.
As a tool	QA is a managerial tool	QC is a corrective tool

Differences between Quality Assurance and Quality Control

Definitions of QA and QC

- - **Quality Assurance (QA)** refers to the process used to create the deliverables, and can be performed by a [manager](#), client, or even a third-party reviewer. Examples of quality assurance include process checklists, project audits and methodology and standards development.
 - **Quality Control (QC)** refers to quality related activities associated with the creation of project deliverables. Quality control is used to verify that deliverables are of acceptable quality and that they are complete and correct. Examples of quality control activities include inspection, deliverable peer reviews and the testing process.
- Quality control is about adherence to requirements. Quality assurance is generic and does not concern the specific requirements of the product being developed.
- Quality assurance activities are determined before production work begins and these activities are performed while the product is being developed. **Incontrast**, Quality control activities are performed **after** the product is developed.

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 maintenance 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 define 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 or 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

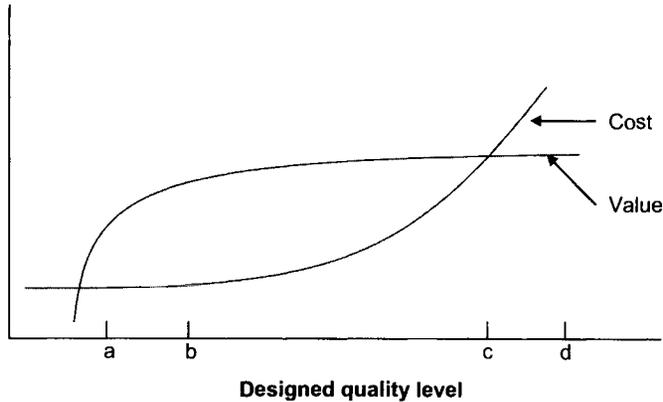


FIGURE 1-1 Cost and value as a function of designed quality.

requirement at least minimally. In practice, the product is typically oversized 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 $20 \pm 0.2 \text{ mm}$ (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

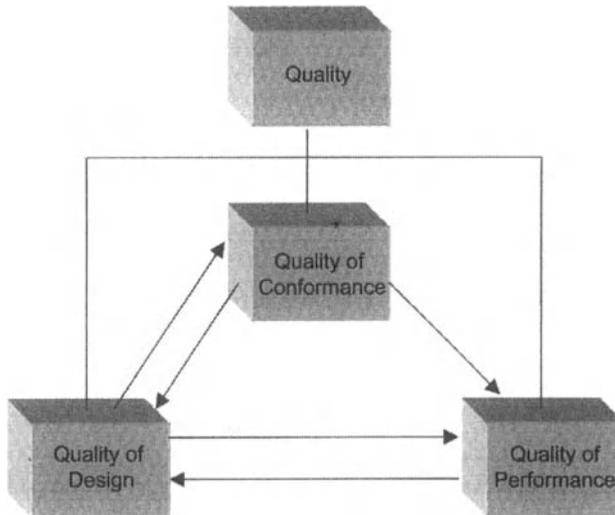


FIGURE 1-2 The three aspects of quality.

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.

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

6. *Corrective action.* Open communication and active discussion of problems creates feasible solutions. Furthermore, such discussion also exposes other problems not identified previously and thus determines procedures to eliminate them. Attempts to resolve problems should be made as they arise. For those problems without immediately identifiable remedies, discussion is postponed to subsequent meetings. The entire process creates a stimulating environment of problem identification and correction.
7. *Ad hoc committee for the zero-defects program.* The concept of **zero defects** must be communicated clearly to all employees; everyone must understand that the achievement of such a goal is the company's objective. This committee gives credibility to the quality program and demonstrates the commitment of top management.
8. *Supervisor training.* All levels of management must be made aware of the steps of the quality improvement program. Also, they must be trained so they can explain the program to employees. This ensures propagation of the quality concepts from the chief executive officers to the hourly worker.
9. *Zero-defects day.* The philosophy of zero defects should be established companywide and should originate on one day. This ensures a uniform understanding of the concept for everyone. Management has the responsibility of explaining the program to the employees, and they should describe the day as signifying a "new attitude." Management must foster this type of quality culture in the organization.
10. *Goal setting.* Employees, in conjunction with their supervisors, should set specific measurable goals. These could be 30-, 60-, or 90-day goals. This process creates a favorable attitude for people ultimately to achieve their own goals.
11. *Error-cause removal.* The employees are asked to identify reasons that prevent them from meeting the zero-defects goal—not to make suggestions but to list the problems. It is the task of the appropriate functional group to come up with procedures for removing these problems. Reporting problems should be done quickly. An environment of mutual trust is necessary so that both groups work together to eliminate the problems.
12. *Recognition.* Award programs should be based on recognition rather than money and should identify those employees who have either met or exceeded their goals or have excelled in other ways. Such programs will encourage the participation of everyone in the quality program.
13. *Quality councils.* Chairpersons, team leaders, and professionals associated with the quality program should meet on a regular basis to keep everyone up to date on progress. These meetings create new ideas for further improvement of quality.
14. *Do it over again.* The entire process of quality improvement is continuous. It repeats again and again as the quality philosophy becomes ingrained.

2-6 JOSEPH M. JURAN'S PHILOSOPHY

Joseph M. Juran founded the Juran Institute, which offers consulting and management training in quality. Juran has worked as an engineer, labor arbitrator, and corporate director in the private sector and as a government administrator and a university professor in the public sector. He has authored many books on the subjects of quality planning, control, management, and improvement (Juran 1986, 1988a,b, 1989; Juran and Gryna 1993).

Like Deming, Juran visited Japan in the early 1950s to conduct training courses in quality management. He eventually repeated these seminars in over 40 countries on all continents. In the 1980s, Juran met the explosive demand for his services with offerings through the Juran

Institute. His books and videotapes have been translated into many languages, and he has trained thousands of managers and specialists. Juran believes that management has to adopt a unified approach to quality. Quality is defined as “fitness for use.” The focus here is on the needs of the customer.

Certain nonuniformities deter the development of a unified process. One is the existence of multiple functions—such as marketing, product design and development, manufacture, and procurement—where each function believes itself to be unique and special. Second, the presence of hierarchical levels in the organizational structure creates groups of people who have different responsibilities. These groups vary in their background and may have different levels of exposure to the concepts of quality management. Third, a variety of product lines that differ in their markets and production processes can cause a lack of unity.

Juran proposes a universal way of thinking about quality, which he calls the **quality trilogy**: quality planning, quality control, and quality improvement. This concept fits all functions, levels of management, and product lines.

Quality Trilogy Process

The quality trilogy process starts with quality planning at various levels of the organization, each of which has a distinct goal. At the upper management level, planning is termed *strategic quality management*. Broad quality goals are established. A structured approach is selected in which management chooses a plan of action and allocates resources to achieve the goals. Planning at the middle management level is termed *operational quality management*. Departmental goals consistent with the strategic goals are established. At the workforce level, planning involves a clear assignment to each worker. Each worker is made aware of how his or her individual goal contributes to departmental goals.

After the planning phase, quality control takes over. Here, the goal is to run the process effectively such that the plans are enacted. If there are deficiencies in the planning process, the process may operate at a high level of chronic waste. Quality control will try to prevent the waste from getting worse. If unusual symptoms are detected sporadically, quality control will attempt to identify the cause behind this abnormal variation. Upon identifying the cause, remedial action will be taken to bring the process back to control.

The next phase of the trilogy process is **quality improvement**, which deals with the continuous improvement of the product and the process. This phase is also called the **quality breakthrough sequence**. Such improvements usually require action on the part of upper and middle management, who deal with such actions as creating a new design, changing methods or procedures of manufacturing, and investing in new equipment.

Table 2-4 shows an outline of the various steps involved in the quality planning, quality control, and quality improvement phases. Readers should consult the listed references for an elaborate treatment of the details of each phase.

Quality Planning

1. *Establish quality goals.* Goals, as established by the organization, are desired outcomes to be accomplished in a specified time period. The time period may be short-term or long-term.
2. *Identify customers.* Juran has a concept similar to Deming's extended process. Juran's includes vendors and customers. He stresses the importance of identifying the customer, that could be internal or external. In cases where the output from one department flows to another, the customer is considered internal.

TABLE 2-4 Universal Process for Managing Quality

Quality Planning	Quality Control	Quality Improvement
Establish quality goals	Choose control subjects	Prove the need
Identify customers	Choose units of measure	Identify projects
Discover customer needs	Set goals	Organize project teams
Develop product features	Create a sensor	Diagnose the causes
Develop process features	Measure actual performance	Provide remedies, prove that the remedies are effective
Establish process controls, transfer to operations	Interpret the difference	Deal with resistance to change
	Take action on the difference	Control to hold the gains

Source: Adapted from J.M. Juran and F.M. Gryna, *Quality Planning and Analysis*, 3rd ed., McGraw-Hill, New York, 1993. Reproduced with permission of The McGraw-Hill Companies.

3. *Discover customer needs.* Long-term survival of the company is contingent upon meeting or exceeding the needs of the customer. Conducting analysis and research, surveying clients and nonclients, and keeping abreast of the dynamic customer needs are a few examples of activities in this category.
4. *Develop product features.* With customer satisfaction as the utmost objective, the product or service should be designed to meet the customer requirements. As customer needs change, the product should be redesigned to conform to these changes.
5. *Develop process features.* While a product is designed based on a knowledge of customer needs, this step deals with the manufacturing process of that product. Methods must be developed, and adequate equipment must be available to make the product match its design specifications. For service organizations, effective and efficient processes that meet or exceed customer requirements are critical.
6. *Establish process controls, transfer to operations.* For manufacturing operations, bounds should be established on process variables for individual operations, that assist in making an acceptable product. Similarly, in the service setting, norms on operations such as time to complete a transaction must be adopted.

Quality Control

1. *Choose control subjects.* Product characteristics that are to be controlled in order to make the product conform to the design requirements should be chosen. For instance, a wheel's control characteristics may be the hub diameter and the outside diameter. Selection is done by prioritizing the important characteristics that influence the operation or appearance of the product and hence impact the customer.
2. *Choose units of measure.* Based on the quality characteristics that have been selected for control, appropriate units of measure should be chosen. For example, if the hub diameter is being controlled, the unit of measurement might be millimeters.
3. *Set goals.* Operational goals are created such that the product or service meets or exceeds customer requirements. For instance, a standard of performance for the hub diameter could be 20 ± 0.2 mm. A hub with a diameter in this range would be compatible in final assembly and would also contribute to making a product that will satisfy the customer.

4. *Create a sensor.* To collect information on the identified quality characteristics, automated equipment or individuals, who serve as auditors or inspectors, are integrated into the system. Databases that automatically track measurements on the quality characteristic (diameter of hub or processing time of purchase order) could also serve as sensors.
5. *Measure actual performance.* This phase of quality control is concerned with the measurement of the actual process output. Measurements are taken on the previously selected control subjects (or quality characteristics). Such measurements will provide information on the operational level of the process.
6. *Interpret the difference.* This involves comparing the performance of the process with the established goals. If the process is stable and capable, then any differences between the actual and the standard may not be significant.
7. *Take action on the difference.* In the event that a discrepancy is found between the actual output of the process and the established goal, remedial action needs to be taken. It is usually management's responsibility to suggest a remedial course of action.

Quality Improvement

1. *Prove the need.* Juran's breakthrough sequence tackles the chronic problems that exist because of a change in the current process; this task requires management involvement. First, however, management has to be convinced of the need for this improvement. Problems such as rework and scrap could be converted to dollar figures to draw management's attention. It would also help to look at problems as cost savings opportunities.
2. *Identify projects.* Because of the limited availability of resources, not all problems can be addressed simultaneously. Therefore, problems should be prioritized. A Pareto analysis is often used to identify vital problems. Juran's quality improvement process works on a project-by-project basis. A problem area is identified as a project, and a concerted effort is made to eliminate the problem.
3. *Organize project teams.* The organizational structure must be clearly established so projects can be run smoothly. Authority and responsibility are assigned at all levels of management to facilitate this. Top management deals with strategic responsibilities, and lower management deals with the operational aspects of the actions. Furthermore, the structure should establish precise responsibilities for the following levels: guidance of overall improvement program, guidance for each individual project, and diagnosis and analysis for each project.
4. *Diagnose the causes.* This is often the most difficult step in the whole process. It involves data gathering and analysis to determine the cause of a problem. The symptoms surrounding the defects are studied, and the investigator then hypothesizes causes for the symptoms. Finally, an analysis is conducted to establish the validity of the hypotheses. Juran defines a **diagnostic arm** as a person or group of persons brought together to determine the causes of the problem. The organization needs to enlist the right people and to ensure that the required tools and resources are available. This is accomplished through a **steering arm**.
5. *Provide remedies, prove that the remedies are effective.* Here, remedial actions are developed to alleviate the chronic problems. Remedies may deal with problems that are

controllable by management or those that are controllable by operations. Changes in methods or equipment should be considered by management and may require substantial financial investment. Frequently, the return on investment is analyzed. This is also the real test of the effectiveness of the remedies proposed. Can the suggested actions be implemented, and do they have the beneficial effect that has been hypothesized?

6. *Deal with resistance to change.* The breakthrough process requires overcoming resistance to change. Changes may be technological or social in nature. The proposed procedure may require new equipment, and operators may have to be trained. Management commitment is vital to the effective implementation of the changes. By the same token, social changes, which deal with human habits, beliefs, and traditions, require patience, understanding, and the participation of everyone involved.
7. *Control to hold the gains.* Once the remedial actions have been implemented and gains have been realized, there must be a control system to sustain this new level of achievement. In other words, if the proportion of nonconforming items has been reduced to 2%, we must make sure that the process does not revert to the former nonconformance rate. A control mechanism is necessary, for example, audits may be performed in certain departments. Such control provides a basis for further process improvement as the whole cycle is repeated.

2-7 THE THREE PHILOSOPHIES COMPARED

We have now briefly examined the quality philosophies of three experts: Deming, Crosby, and Juran. All three philosophies have the goal of developing an integrated total quality system with a continual drive for improvement. Although there are many similarities in these approaches, some differences do exist. A good discussion of these three philosophies may be found in an article by Lowe and Mazzeo (1986).

Definition of Quality

Let's consider how each expert defines **quality**. Deming's definition deals with a predictable uniformity of the product. His emphasis on the use of statistical process control charts is reflected in this definition. Deming's concern about the quality of the product is reflected in the quality of the process, which is the focal point of his philosophy. Thus, his definition of quality does not emphasize the customer as much as do Crosby's and Juran's. Crosby defines quality as conformance to requirements. Here, requirements are based on customer needs. Crosby's performance standard of zero defects implies that the set requirements should be met every time. Juran's definition of quality—fitness of a product for its intended use—seems to incorporate the customer the most. His definition explicitly relates to meeting the needs of the customer.

Management Commitment

All three philosophies stress the importance of top management commitment. Deming's first and second points (creating a constancy of purpose toward improvement and adopting the new philosophy) define the tasks of management. In fact, his 14 points are all aimed at management, implying that management's undivided attention is necessary to create a total

characteristics of critical parts that will help in achieving the product designed. The next level may address the design of a process in order to make parts with the characteristics identified. Finally, the QFD process identifies production requirements for operating the process under specified conditions. Use of quality function deployment in such a multi-phased environment requires a significant commitment of time and resources. However, the advantages—the spirit of teamwork, cross-functional understanding, and an enhanced product design—offset this commitment.

3-4 BENCHMARKING AND PERFORMANCE EVALUATION

The goal of continuous improvement forces an organization to look for ways to improve operations. Be it a manufacturing or service organization, the company must be aware of the best practices in its industry and its relative position in the industry. Such information will set the priorities for areas that need improvement.

Organizations benefit from innovation. Innovative approaches cut costs, reduce lead time, improve productivity, save capital and human resources, and ultimately, lead to increased revenue. They constitute the breakthroughs that push product or process to new levels of excellence. However, breakthroughs do not happen very often. Visionary ideas are few and far between. Still, when improvements come, they are dramatic and memorable. The development of the computer chip is a prime example. Its ability to store enormous amounts of information in a fraction of the space that was previously required has revolutionized our lives. Figure 3-8 shows the impact of innovation on a chosen quality measure over time. At times a and b innovations occur as a result of which steep increases in quality from x to y and y to z are observed.

Continuous improvement, on the other hand, leads to a slow but steady increase in the quality measure. Figure 3-8 shows that for certain periods of time, a process with continuous improvement performs better than one that depends only on innovation. Of course, once an innovation takes place, the immense improvement in the quality measure initially outperforms the small improvements that occur on a gradual basis. This can be useful in

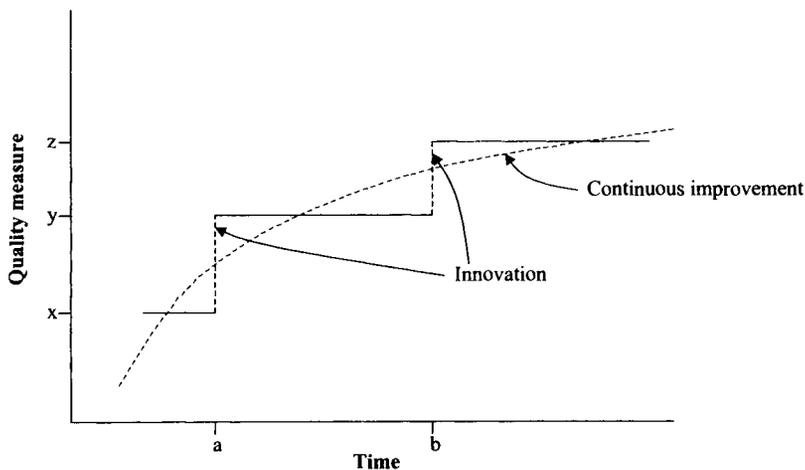


FIGURE 3-8 Impact of innovation and continuous improvement.

gaining market share, but it is also a high-risk strategy because innovations are rare. A company must carefully assess how risk averse it is. If its aversion to risk is high, continuous improvement is its best strategy. A process that is guaranteed to improve gradually is always a wise investment.

One way to promote continuous improvement is through innovative adaptation of the best practices in the industry. To improve its operations, an organization can incorporate information on the companies perceived to be the leaders in the field. Depending on the relative position of the company with respect to the industry leader, gains will be incremental or dramatic. Incorporating such adaptations on an ongoing basis provides a framework for continuous improvement.

Benchmarking

As discussed earlier, the practice of identifying best practices in industry and thereby setting goals to emulate them is known as **benchmarking**. Companies cannot afford to stagnate; this guarantees a loss of market share to the competition. Continuous improvement is a mandate for survival, and such fast-paced improvement is facilitated by benchmarking. This practice enables an organization to accelerate its rate of improvement. While innovation allows an organization to “leapfrog” its competitors, it does not occur frequently and thus cannot be counted on. Benchmarking, on the other hand, is doable. To adopt the best, adapt it innovatively, and thus reap improvements is a strategy for success.

Specific steps for benchmarking vary from company to company, but the fundamental approach is the same. One company’s benchmarking may not work at another organization because of different operating concerns. Successful benchmarking reflects the culture of the organization, works within the existing infrastructure, and is harmonious with the leadership philosophy. Motorola, Inc., winner of the Malcolm Baldrige Award for 1988, uses a five-step benchmarking model: (1) Decide what to benchmark; (2) select companies to benchmark; (3) obtain data and collect information; (4) analyze data and form action plans; and (5) recalibrate and start the process again.

AT&T, which has two Baldrige winners among its operating units, uses a nine-step model: (1) Decide what to benchmark; (2) develop a benchmarking plan; (3) select a method to collect data; (4) collect data; (5) select companies to benchmark; (6) collect data during a site visit; (7) compare processes, identify gaps, and make recommendations; (8) implement recommendations; and (9) recalibrate benchmarks.

A primary advantage of the benchmarking practice is that it promotes a thorough understanding of the company’s own processes—the company’s current profile is well understood. Intensive studies of existing practices often lead to identification of non-value-added activities and plans for process improvement. Second, benchmarking enables comparisons of performance measures in different dimensions, each with the best practices for that particular measure. It is not merely a comparison of the organization with a selected company, but a comparison with several companies that are the best for the measure chosen. Some common performance measures are return on assets, cycle time, percentage of on-time delivery, percentage of damaged goods, proportion of defects, and time spent on administrative functions. The spider chart shown in Figure 3-9 is used to compare multiple performance measures and gaps between the host company and industry benchmark practices. Six performance measures are being considered here. The scales are standardized: say, between 0 and 1, 0 being at the center and 1 at the outer circumference, which represents the most desired value. Best practices for each performance measure are indicated, along with

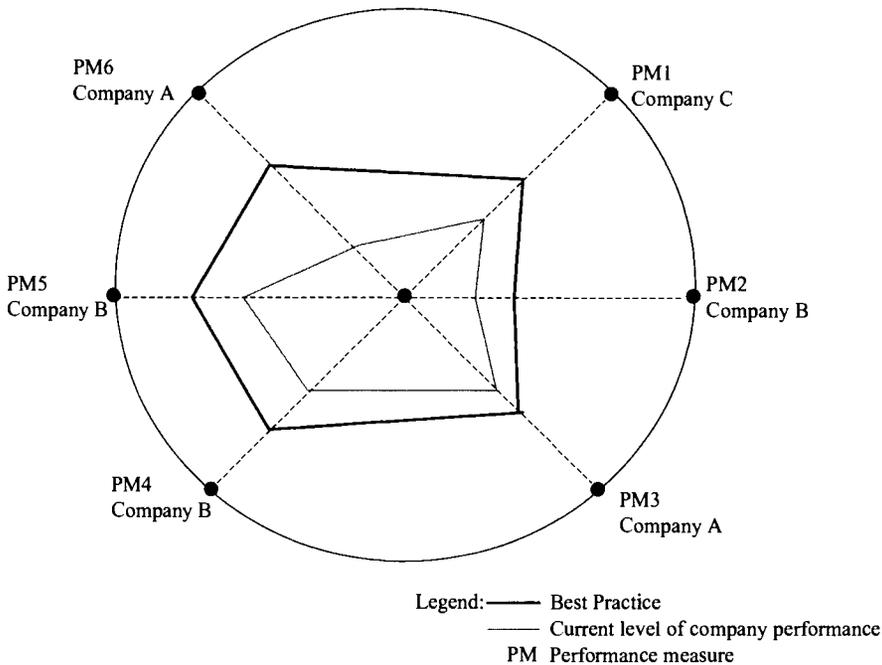


FIGURE 3-9 Spider chart for gap analysis.

the companies that achieve them. The current performance level of the company performing the benchmarking is also indicated in the figure. The difference between the company's level and that of the best practice for that performance measure is identified as the gap. The analysis that focuses on methods and processes to reduce this gap and thereby improve the company's competitive position is known as **gap analysis**.

Another advantage of benchmarking is its focus on performance measures and processes, not on the product. Thus, benchmarking is not restricted to the confines of the industry in which the company resides. It extends beyond these boundaries and identifies organizations in other industries that are superior with respect to the measure chosen. It is usually difficult to obtain data from direct competitors. However, companies outside the industry are more likely to share such information. It then becomes the task of management to find ways to adapt those best practices innovatively within their own environment.

In the United States, one of the pioneers of benchmarking is Xerox Corporation. It embarked on this process because its market share eroded rapidly in the late 1970s to Japanese competition. Engineers from Xerox took competitors' products apart and looked at them component by component. When they found a better design, they sought ways to adapt it to their own products or, even better, to improve on it. Similarly, managers from Xerox began studying the best management practices in the market; this included companies both within and outside the industry. As Xerox explored ways to improve its warehousing operations, it found a benchmark outside its own industry: L. L. Bean, Inc., the outdoor sporting goods retailer.

L. L. Bean has a reputation of high customer satisfaction; the attributes that support this reputation are its ability to fill customer orders quickly and efficiently with minimal errors and to deliver undamaged merchandise. The backbone behind this successful operation is an effective management system aided by state-of-the-art operations planning that addresses

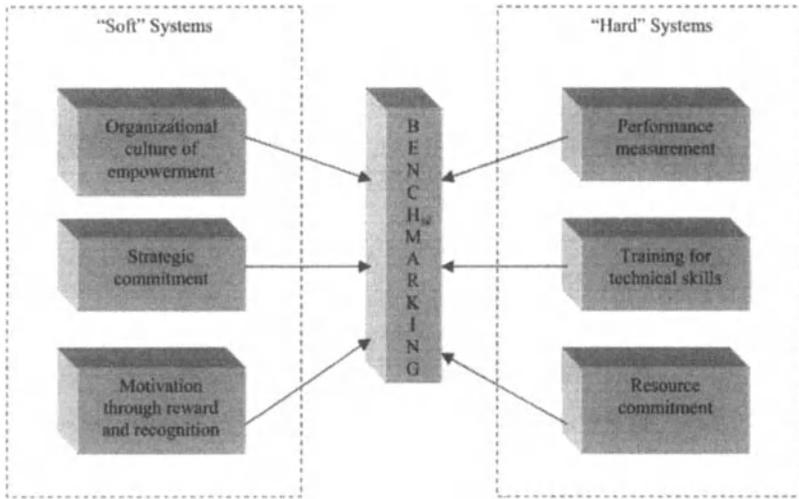


FIGURE 3-10 Role of benchmarking in implementing best practices.

warehouse layout, workflow design, and scheduling. Furthermore, the operations side of the process is backed by an organizational culture of empowerment, management commitment through effective education and training, and a motivational reward system of incentive bonuses.

Figure 3-10 demonstrates how benchmarking brings the “soft” and “hard” systems together. Benchmarking is not merely identification of the best practices. Rather, it seeks to determine how such practices can be adapted to the organization. The real value of benchmarking is accomplished only when the company has integrated the identified best practices successfully into its operation. To be successful in this task, soft and hard systems must mesh. The emerging organizational culture should empower employees to make decisions based on the new practice.

For benchmarking to succeed, management must demonstrate its strategic commitment to continuous improvement and must also motivate employees through an adequate reward and recognition system that promotes learning and innovative adaptation. When dealing with hard systems, resources must be made available to allow release time from other activities, access to information on best practices, and installation of new information systems to manage the information acquired. Technical skills, required for benchmarking such as flowcharting and process mapping, should be provided to team members through training sessions. The team must also identify performance measures for which the benchmarking will take place. Examples of such measures are return on investment, profitability, cycle time, and defect rate.

Several factors influence the adoption of benchmarking; **change management** is one of them. Figure 3-11 illustrates factors that influence benchmarking and the subsequent outcomes that derive from it. In the current environment of global competition, change is a given. Rather than react haphazardly to change, benchmarking provides an effective way to manage it. Benchmarking provides a road map for adapting best practices, a major component of change management. These are process-oriented changes. In addition, benchmarking facilitates cultural changes in an organization. These deal with overcoming resistance to change. This is a people-oriented approach, the objective being to demonstrate that change is not a threat but an opportunity.

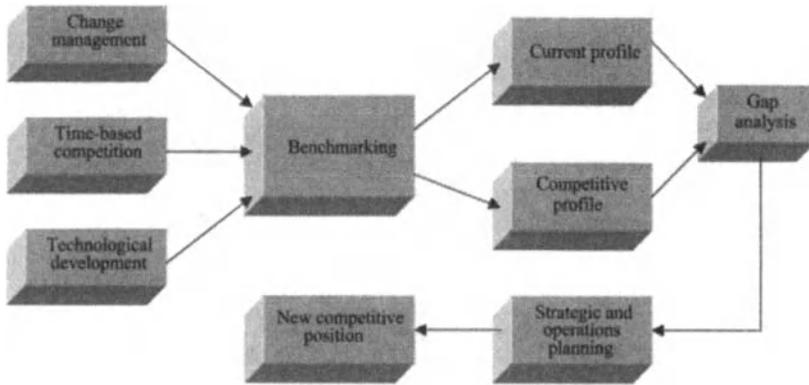


FIGURE 3-11 Influences on benchmarking and its outcomes.

The ability to reduce process time and create a model of quick response is important to all organizations. The concept of **time-based competition** is linked to reductions in **cycle time**, which can be defined as the interval between the beginning and ending of a process, which may consist of a sequence of activities. From the customer's point of view, cycle time is the elapsed time between placing an order and having it fulfilled satisfactorially. Reducing cycle time is strongly correlated with performance measures such as cost, market share, and customer satisfaction. Detailed flowcharting of the process can identify bottlenecks, decision loops, and non-value-added activities. Reducing decision and inspection points, creating electronic media systems for dynamic flow of information, standardizing procedures and reporting forms, and consolidating purchases are examples of tactics that reduce cycle time. Motorola, Inc., for example, reduced its corporate auditing process over a three-year period from an average of seven weeks to five days.

Technological development is another impetus for benchmarking. Consider the microelectronics industry. Its development pace is so rapid that a company has no choice but to benchmark. Falling behind the competition in this industry means going out of business. In this situation, benchmarking is critical to survival.

Quality Auditing

The effectiveness of management control programs may be examined through a practice known as quality auditing. One reason that management control programs are implemented is to prevent problems. Despite such control, however, problems can and do occur, so, **quality audits** are undertaken to identify problems.

In any quality audit, three parties are involved. The party that requests the audit is known as the *client*, the party that conducts the audit is the *auditor*, and the party being audited is the *auditee*. Auditors can be of two types, internal or external. An *internal auditor* is an employee of the auditee. *External auditors* are not members of the auditee's organization. An external auditor may be a single individual or a member of an independent auditing organization.

Quality audits fulfill two major purposes. The first purpose, performed in the **suitability quality audit**, deals with an in-depth evaluation of the quality program against a reference standard, usually predetermined by the client. Reference standards are set by several organizations, including the American National Standards Institute/American Society for Quality (ANSI/ASQ), International Organization for Standardization (ISO), and British

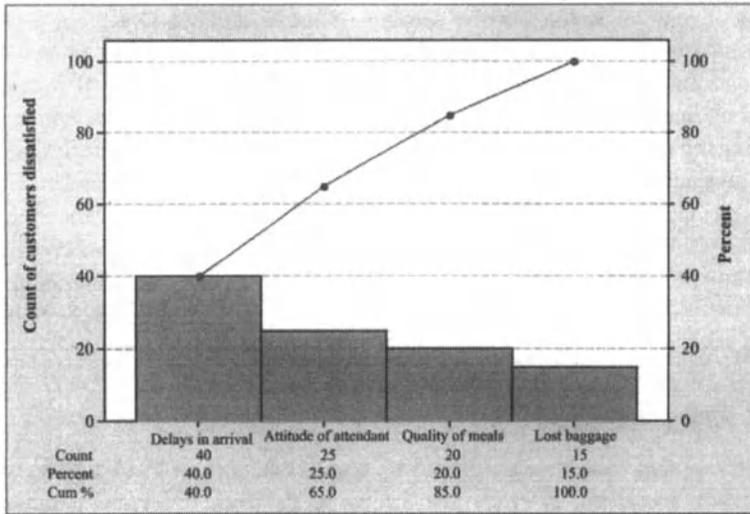


FIGURE 3-12 Pareto diagram for dissatisfied airline customers.

Flowcharts

Flowcharts, which show the sequence of events in a process, are used for manufacturing and service operations. They are often used to diagram operational procedures to simplify a system, as they can identify bottlenecks, redundant steps, and non-value-added activities. A realistic flowchart can be constructed by using the knowledge of the personnel who are directly involved in the particular process. Valuable process information is usually gained through the construction of flowcharts. Figure 3-13 shows a flowchart for patients reporting to the emergency department in a hospital. The chart identifies where delays can occur: for

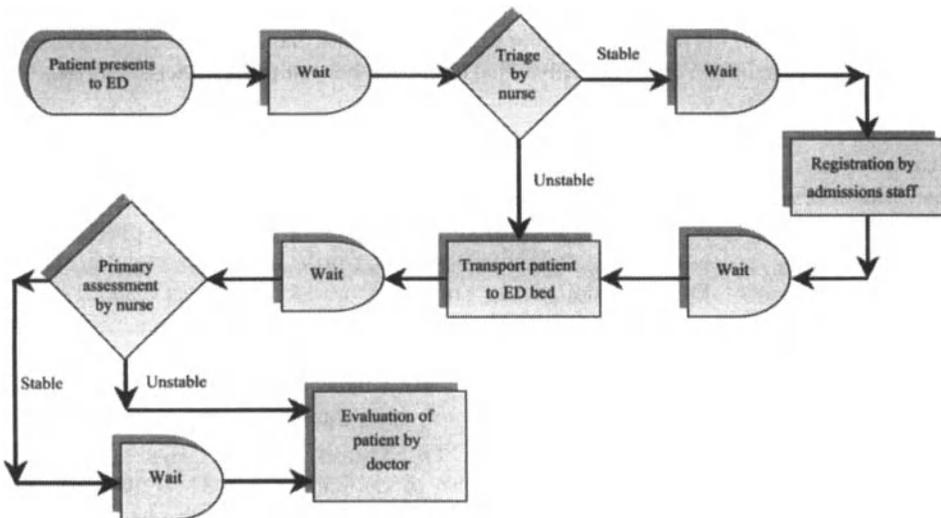


FIGURE 3-13 Flowchart for patients in an emergency department (ED).

example, in several steps that involve waiting. A more detailed flowchart would allow pinpointing of key problem areas that contribute to lengthening waiting time.

Further, certain procedures could be modified or process operations could be combined to reduce waiting time. A detailed version of the flowchart is the *process map*, which identifies the following for each operation in a process: process inputs (e.g., material, equipment, personnel, measurement gage), process outputs (these could be the final results of the product or service), and process or product parameters (classified into the categories of controllable, procedural, or noise). Noise parameters are uncontrollable and could represent the in-flow rate of patients or the absenteeism of employees. Through discussion and data analysis, some of the parameters could be classified as critical. It will then be imperative to monitor the critical parameters to maintain or improve the process.

Cause-and-Effect Diagrams

Cause-and-effect diagrams were developed by Kaoru Ishikawa in 1943 and thus are often called **Ishikawa diagrams**. They are also known as **fishbone diagrams** because of their appearance (in the plotted form). Basically, **cause-and-effect diagrams** are used to identify and systematically list various causes that can be attributed to a problem (or an effect) (Ishikawa 1976). These diagrams thus help determine which of several causes has the greatest effect. A cause-and-effect diagram can aid in identifying the reasons why a process goes out of control. Alternatively, if a process is stable, these diagrams can help management decide which causes to investigate for process improvement. There are three main applications of cause-and-effect diagrams: cause enumeration, dispersion analysis, and process analysis.

Cause enumeration is usually developed through a brainstorming session in which all possible types of causes (however remote they may be) are listed to show their influence on the problems (or effect) in question. In **dispersion analysis**, each major cause is analyzed thoroughly by investigating the subcauses and their impact on the quality characteristic (or effect) in question. This process is repeated for each major cause in a prioritized order. The cause-and-effect diagram helps us analyze the reasons for any variability or dispersion. When cause-and-effect diagrams are constructed for **process analysis**, the emphasis is on listing the causes in the sequence in which the operations are actually conducted. This process is similar to creating a flow diagram, except that a cause-and-effect diagram lists in detail the causes that influence the quality characteristic of interest at each step of a process.

Example 3-2 One of the quality characteristics of interest in automobile tires is the bore size, which should be within certain specifications. In a cause-and-effect diagram, the final bore size is the effect. Some of the main causes that influence the bore size are the incoming material, mixing process, tubing operation, splicing, press operation, operator, and measuring equipment. For each main cause, subcauses are identified and listed. For the raw material category, the incoming quality is affected by such subcauses as vendor selection process (e.g., is the vendor certified?), the content of scrap tire in the raw material, the density, and the ash content.

Using Minitab, for each **Branch** or main cause, create a column and enter the subcauses in the worksheet. Then, execute the following: **Stat > Quality Tools > Cause-and-Effect**. Under **Causes**, enter the name or column number of the main causes. The **Label** for each branch may be entered to match the column names. In **Effect**, input the brief problem description. Click **OK**. Figure 3-14 shows the completed cause-and-effect diagram.

At times, the main cause is hidden and we may still find that efficiency is low and there are a lot of dissatisfied customer.

Do not be content with this condition. Aim for even higher goals and keep taking up preventive measures. That is what QC Problem-Solving is all about.

7 QC Tools. The Samurai warrior had seven tools, such as a sword, helmet, bow guard and arrow and so on ; he would never venture any where without these tools, which he needed for protection and success. In a similar vein, the seven quality control tool are essential for to-day's workers, engineers, professionals, and managers.

1. Pareto Diagram. The Pareto principle was named after the Italian economist who had developed certain mathematical relationships of vital few and trivial many as applied to distribution of wealth. In studying the problems, it can be generally observed that 80% of the problems result from only 20% of the potential causes.

The primary purpose and use of pareto diagrams is to focus improvement efforts on the most important causes by identifying the vital few and trivial many causes.

The Pareto Chart Indicates the following :

1. What are the problems,
2. Which problem needs to be tackled on priority.
3. What percentage (%) of the total does each problem present.

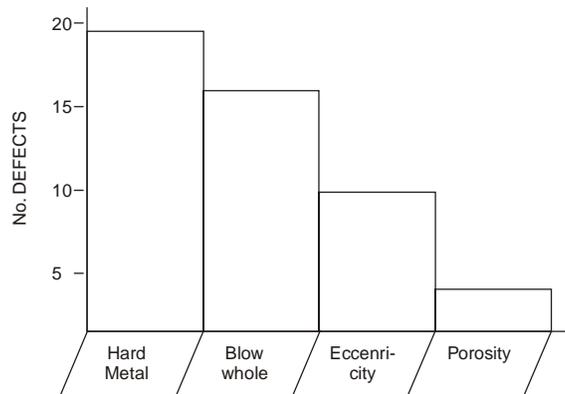
Areas of Application

- Sales — Customer complaints analysis, warranty costs, Market Share
- Production — Analysis of Non-conformance, machine and men Utilization
- Maintenance — Machine down time, break down, spares requirement.
- Safety — Injury types and causes
- Finance — Costs, etc.

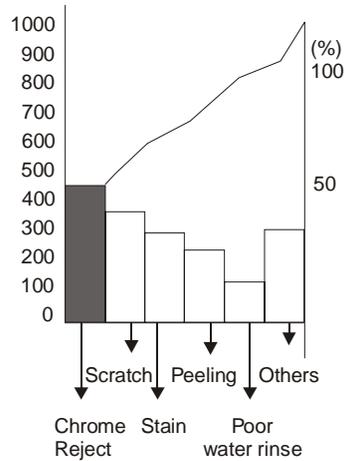
How to construct Pareto Diagram

1. Select the problem area (say customer complaints).
2. Decide the method and the period for data collection.
3. Arrange the data of the items in the descending order.
4. Draw axis on graph with the scale of unit indicated.
5. Draw the bar graph in the descending order.

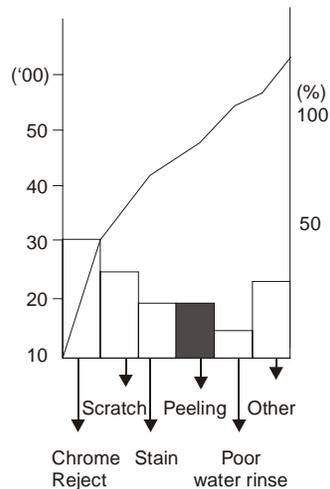
Defects in Casting revealed After machining



Pareto Diagram (A)



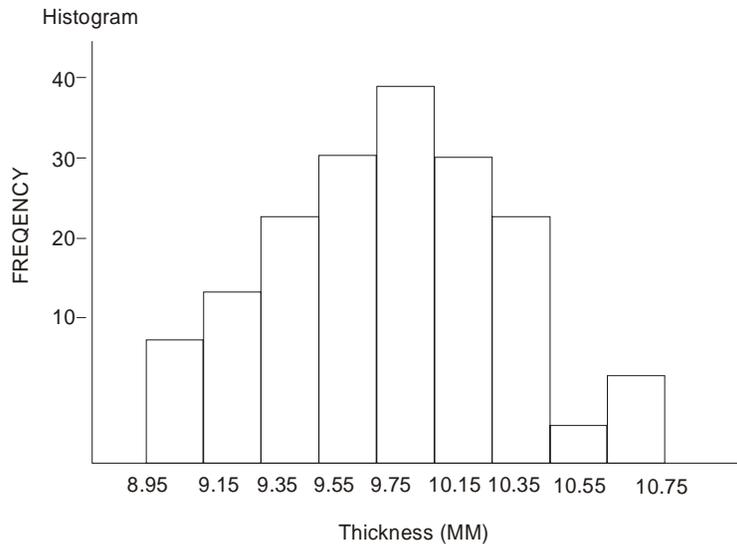
Pareto Diagram (B)



2. Histogram. A histogram is a bar graph which shows the frequency distribution of the data of a group about the central value. The histogram is an important diagnostic tool because it gives a “Birds’s-eye-view” of the variation in a data set.

A histogram can be used for

1. Comparisons of process distribution before and after the improvement action (production, vendor performance, administration, purchase, inspection, etc.)
2. Comparison of different groups (production, vendor to vendor difference etc.)
3. Relationship with specification limits.



3. Cause and Effect Diagram. A cause and effect diagram (also known as Ishikawa diagram or fishbone diagram) is a pictorial representation of all possible causes which are supposed to influence an “effect” which is under consideration.

For every effect there are likely to be several causes. They can be classified under men, methods, materials, machines, policies, procedures, plant etc. These categories are only suggestions. You may use any category that emerges or helps people think creatively.

Steps in Constructing a Causes and Effect Diagram

Address to the member the problem or the “Effect” in question and ask the members what the possible causes could be adopt structured brain storming method (in brain storming encourage ideas, never criticise, allow to develop on other ideas, write all ideas on a flip chart or black board).

Start constructing the diagram. Write the effect or the problem on the right hand side in a rectangular box.

Cluster the causes of the effect under large heading and write against bones.

Interpretation of C and E Diagram

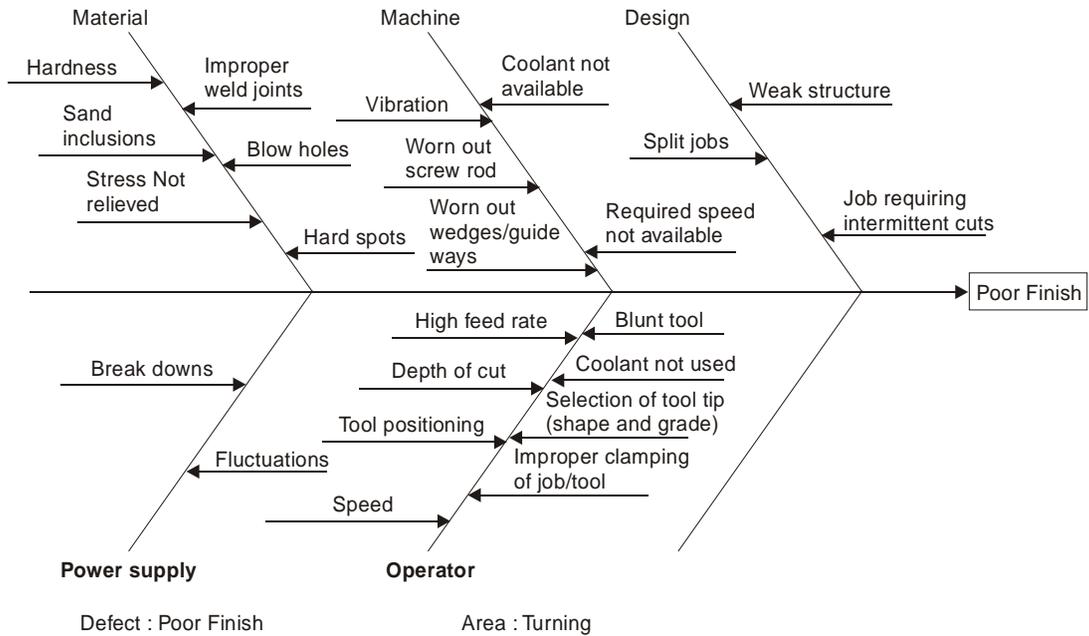
In order to find most basic cause of the problem

Look for causes that appear repeatedly.

Reach a team consensus

Gather data to determine the relative frequencies of the different causes.

Cause and Effect Diagram



4. Check Sheet

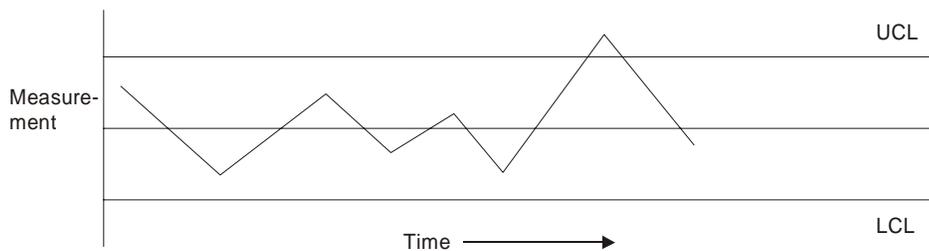
A check sheet is a data gathering format prepared in such a way that the data collection is simplified.

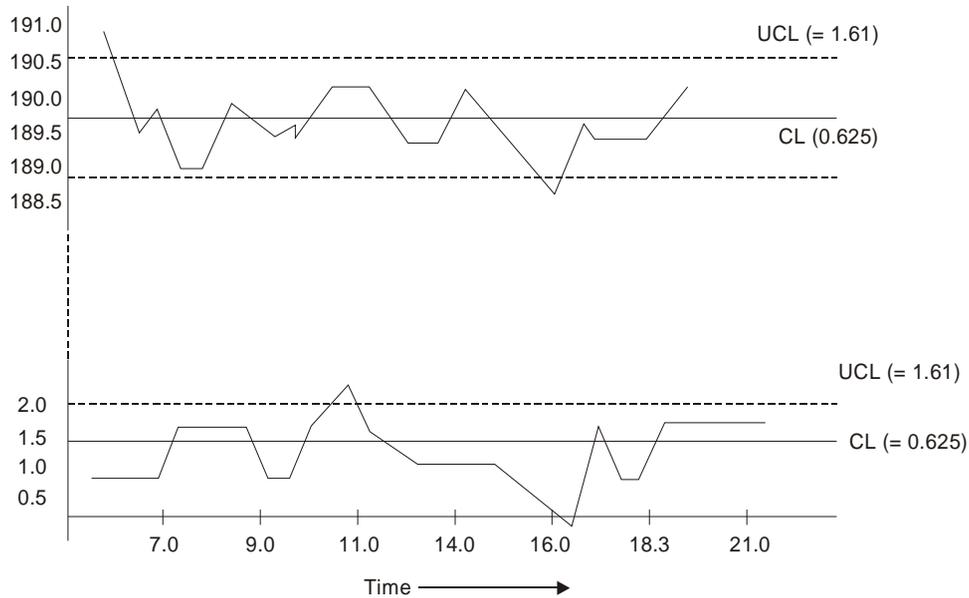
The check sheet preparation considers the representatives of the information to be recorded and simplifies the data that is to be actually recorded everytime to a mere check work. Check sheets are simply an easy to understand form used to answer the question “how often certain events are happening” ? It starts the process of translating into facts.

5. Control Chart

A control chart is a chart to examine whether a process is in stable condition or to ensure that process is maintained in stable condition.

The control limits are indicated by two line viz. Upper control limit and lower control limit. If the points are within the control limit lines, then the process is in stable condition. The fluctuation of the points within the control limit line results from common causes built into the process. However points outside the limits come from a special cause.





6. Stratification

Stratification is the technique of obtaining data in different groups based on segregated causes.

In general the poor quality is resulted due to the influence of multiple causes. To identify the principle cause of poor quality it is necessary to collect the data in different groups according to the different causes.

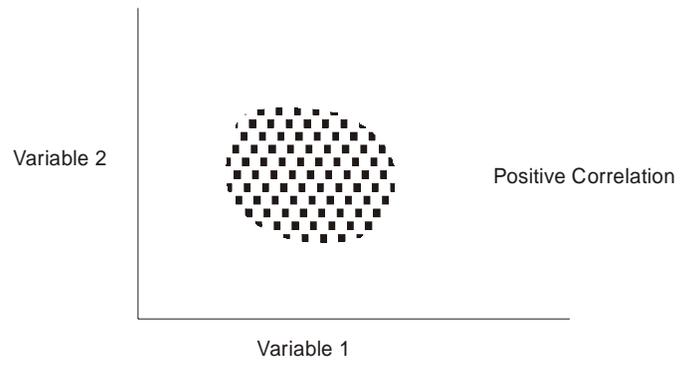
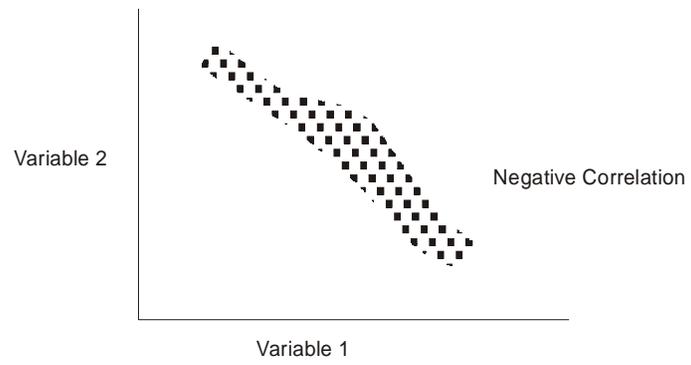
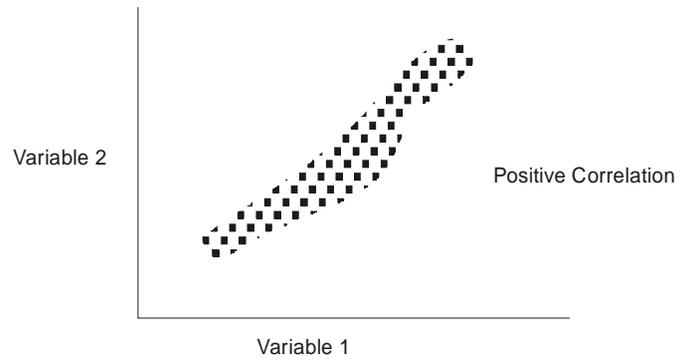
Areas of Application

- Raw Material — Supplier wise stratification
Batch wise stratification
- Production — Machine wise stratification
operator wise stratification shift wise
- Finance — Stratification of income and expenditure as per different categories.
- Safety etc., — Accident type wise stratification.

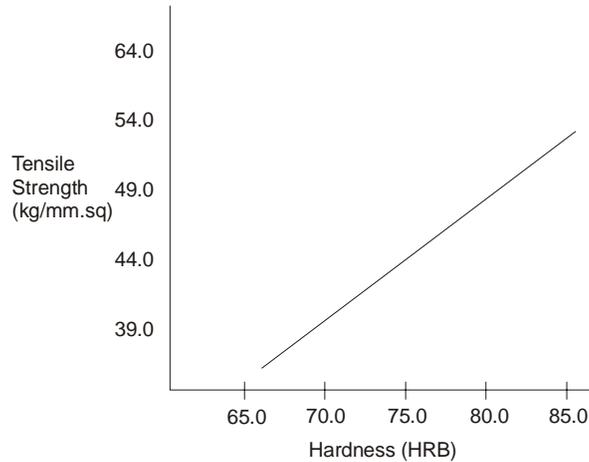
7. Scatter Diagram

Scatter diagram is a simple statistical tool to understand in a better way the relationship between two variables.

It makes clear whether a relationship exists between two variables and the strength of that relationship.



Scatter Diagram



Causes of Variation in Quality

The variation in the quality of the product in any manufacturing process is broadly classified into two classes : Chance causes and Assignable causes.

Chance Causes

The chance causes are those causes which are inherent in manufacturing process by virtue of operational and constructional features of the equipments involved in a manufacturing process. This is because of :

- (1) Machine vibration
- (2) Voltage fluctuation
- (3) Temperature fluctuation
- (4) Tool Chatter
- (5) Composition variation of material etc.

The chance causes are very difficult to trace out, even though it is possible to trace out, it is not economical to eliminate. The chance causes results in only a minute amount of variation in process.

Variation in the chance causes is due to internal factors only. The general pattern of variation under the chance causes will follow a stable statistical distribution (Normal distribution).

Assignable Causes

These are the causes which creates an extraordinary variation in the product quality. Assignable causes variable can always be traced to a specific source. Assignable causes occur due to

- (1) Lack of skill in operation
- (2) Wrong maintenance practices
- (3) New vendors

- (4) Errors in setting jigs and fixtures
- (5) Raw materials defect etc.

Variation due to these causes can be controlled before the defective items are produced. Any one assignable cause can result in a amount of variation in process. If the assignable causes are present, then system will not follow a stable statistical distribution.

CONTROL CHARTS

Definition. A control chart is defined as a statistical tool used to detect the presence of assignable causes in any manufacturing systems and it will be influenced by the pure system of chance causes only.

Control charts are of two types : Variable control charts and Attribute control charts.

Variable Control Charts

A variable control chart is one by which it is possible to measure the quality characteristics of a product. The variable control charts are

- (i) \bar{X} — chart
- (ii) R — chart
- (iii) σ — chart

Attribute Control Chart

An attribute control chart is one in which it is not possible to measure the quality characteristics of a product *i.e.*, it is based on visual inspection only like good or bad, success or failure, accepted or rejected. The attribute control charts are !

- (i) p — chart
- (ii) np — chart
- (iii) c — chart
- (iv) u — chart

Objectives of Control Charts

1. Control charts are used as one source of information to help whether an item or items should be released to the customer.
2. Control charts are used to decide when a normal pattern of variation occurs, the process should be left alone when an unstable pattern of variable occurs which indicates the presence of assignable causes it requires an action to eliminate it.
3. Control charts can be used to establish the product specification.
4. To provide a method of instructing to the operating and supervisory personnel (employees) in the technic of quality control.

Symbols or Notations

\bar{X} : Mean of the sample

\bar{X}^σ : Standard deviation of the sample

\bar{X}^1 : Mean of the population or universe

σ^1 : Standard deviation of the population.

5

DATA ANALYSES AND SAMPLING

- 5-1 Introduction and chapter objectives
- 5-2 Empirical distribution plots
- 5-3 Randomness of a sequence
- 5-4 Validating distributional assumptions
- 5-5 Transformations to achieve normality
- 5-6 Analysis of count data
- 5-7 Concepts in sampling
- Summary

5-1 INTRODUCTION AND CHAPTER OBJECTIVES

In this chapter we continue to expand on the various descriptive and inferential statistical procedures described in Chapter 4. Our objective is to analyze empirical data graphically since they provide comprehensive information and are a viable tool for analysis of product and process data. The information they provide on existing product or process characteristics helps us determine whether these characteristics are close to the desired norm. A second objective is to test for distributional assumptions. Recall that in Chapter 4, for testing hypothesis on various parameters such as the population mean or variance, the assumption of normality was made. We present a method for testing the validity of such an assumption. Further, we discuss some transformations to achieve normality for variables that are non-normal. A third objective involves analyzing qualitative data. Such information is typically frequency-type data obtained from product surveys. Finally, we include a discussion of various sampling techniques. The issue of determination of sample size is of paramount importance in quality. Based on the degree of acceptable risks, expressions are presented for the required sample size.

5-2 EMPIRICAL DISTRIBUTION PLOTS

Histograms

Distribution plots are applicable to quantitative data. In such instances, the quality characteristic values are obtained on a measurable scale. Seldom do we get an idea of process

TABLE 5-1 Inside Diameter (in mm) of Metal Sleeves

Sample	Observations X (Five per Sample)				
1	50.05	50.03	50.02	50.00	49.94
2	49.96	49.99	50.03	50.01	49.98
3	50.01	50.01	50.01	50.00	49.92
4	49.95	49.97	50.02	50.10	50.02
5	50.00	50.01	50.00	50.00	50.09
6	50.02	50.05	49.97	50.02	50.09
7	50.01	49.99	49.96	49.99	50.00
8	50.02	50.00	50.04	50.02	50.00
9	50.06	49.93	49.99	49.99	49.95
10	49.96	49.93	50.08	49.92	50.03
11	50.01	49.96	49.98	50.00	50.02
12	50.04	49.94	50.00	50.03	49.92
13	49.97	49.90	49.98	50.01	49.95
14	50.00	50.01	49.95	49.97	49.94
15	49.97	49.98	50.03	50.08	49.96
16	49.98	50.00	49.97	49.96	49.97
17	50.03	50.04	50.03	50.01	50.01
18	49.98	49.98	49.99	50.05	50.00
19	50.07	50.00	50.02	49.99	49.93
20	49.99	50.06	49.95	49.99	50.02

characteristics just by looking at the individual data values gathered from the process. Such data are often voluminous. Frequency distributions and histograms summarize such information and present it in a format that allows us to draw conclusions regarding the process condition.

A **frequency distribution** is a rearrangement of raw data in ascending or descending order of magnitude, such that the quality characteristic is subdivided into classes and the number of occurrences in each class is presented.

Table 5-1 shows the inside diameter (in millimeters) of metal sleeves produced in a machine shop for 100 randomly selected parts. Twenty samples, each of size 5, were taken. Simply looking at the data in Table 5-1 provides little insight about the process. Even though we know that there is variability in the sleeve diameters, we can hardly identify a pattern in the data (what is the degree of variability?) or comment about the central tendency of the process (about which value are most of the observations concentrated?).

A **histogram** is a graphical display of data such that the characteristic is subdivided into classes, or cells. In a **frequency histogram**, the vertical axis usually represents the number of observations in each class. An alternative representation of the vertical axis could be the percentage.

Example 5-1 For the data in Table 5-1, let us use Minitab to construct a histogram. Choose **Graph > Histogram > Simple**. Click **OK**. Under **Graph variables**, input the column number or name of the variable, in this case Diameter. Click **OK**.

Minitab produces the frequency histogram shown in Figure 5-1. The histogram provides us with a sense of the distribution of the 100 values, where classes of equal width have been created. The midpoints of the classes are 49.00, 49.92, . . . , and so on. A majority of the values

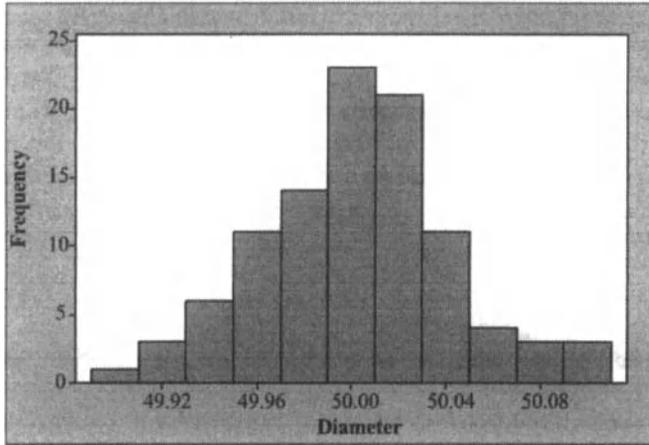


FIGURE 5-1 Frequency histogram of sleeve diameters using Minitab.

are clustered between 49.96 and 50.04. The shape of the distribution resembles a bell-shaped distribution. We will, however, demonstrate a test for normality later in the chapter.

Stem-and-Leaf Plots

Stem-and-leaf plots are another graphical approach to plotting observations and interpreting process characteristics. With frequency histograms, the identities of the individual observations are lost in the process of plotting. In the stem-and-leaf plot, however, individual numerical values are retained. Let's construct a stem-and-leaf plot using the metal sleeves data from Table 5-1.

Example 5-2 Using Minitab, click on **Graph > Stem-and-leaf**. Under **Graph variables**, enter the column number or name of the variable, in this case Diameter. Click **OK**. The output from Minitab is shown in Figure 5-2.

Each data value is split into two parts, the stem and the leaf. For example, the data value 49.90 is displayed with the stem part as 499 and the leaf part as 0. Notice that the decimal

```

Stem-and-leaf of Diameter  N  = 100
Leaf Unit = 0.010

 1   499  0
 7   499  222333
15   499  44455555
28   499  6666667777777
44   499  888888899999999
(25) 500  00000000000001111111111
31   500  22222222223333333
14   500  444455
 8   500  667
 5   500  8899
 1   501  0

```

FIGURE 5-2 Stem-and-leaf plot for the inside diameter of metal sleeves.

possible process changes to undertake. On the other hand, if the sequence is deemed to be random, it may imply the presence of common causes, which lead to variability in the characteristic observed. In this case, systemic changes are necessary to create process improvement.

Run Chart

A **run chart** is a plot of the quality characteristic as a function of the order (or usually time) in which the observations are collected. They provide an idea of the clustering of the data or whether the data are from a mixture of, say, two populations. These inferences are based on the number of runs about the median.

A run (about the median) is defined as one or more consecutive data points on the same side (of the median). When counting runs, points that fall exactly on the reference line (median) are ignored. If the pattern is **random**, the actual number of runs should be close to the number of runs expected, based on the assumption of randomness of the pattern. So, when the number of runs observed is much greater than the number of runs expected, it implies the possibility of the data being from a mixture pattern (say, two populations), causing frequent fluctuations about the median. Similarly, when the number of runs observed is much less than the number of runs expected, it may indicate the possibility of clustering of the data (a nonrandom behavior). We test these situations through the procedure of hypothesis testing and use the ***p*-value** approach, described in Chapter 4.

Another pair of situations involves testing for the presence of a trend or oscillation, both examples of nonrandomness. These tests are conducted by using the number of runs up or down. A trend is an unusually long series of consecutive increases or decreases in the data. In counting the run length, we ignore points that repeat the preceding value. A pattern of oscillation is indicated if the number of runs up or down observed is much greater than the number of runs expected. Similarly, a trend in the data is inferred when the number of runs up or down observed is much less than the number of runs expected. A long run length about the median may also indicate a shift in the data.

Example 5-4 The hemoglobin A1C value is a measure of blood glucose level over a period of about three months. Table 5-3 shows hemoglobin A1C values for a diabetic patient taken every three months. Construct a run chart and comment on whether the process shows

TABLE 5-3 Hemoglobin A1C Values for a Diabetic Patient

Observation	A1C	Observation	A1C	Observation	A1C
1	8.3	11	7.9	21	6.7
2	6.5	12	8.4	22	6.6
3	7.2	13	8.2	23	7.6
4	7.0	14	8.6	24	7.4
5	8.1	15	8.8	25	7.8
6	6.8	16	7.8	26	8.0
7	7.1	17	7.4	27	7.7
8	6.6	18	7.2	28	7.6
9	7.3	19	7.1	29	7.8
10	7.5	20	6.8	30	7.5

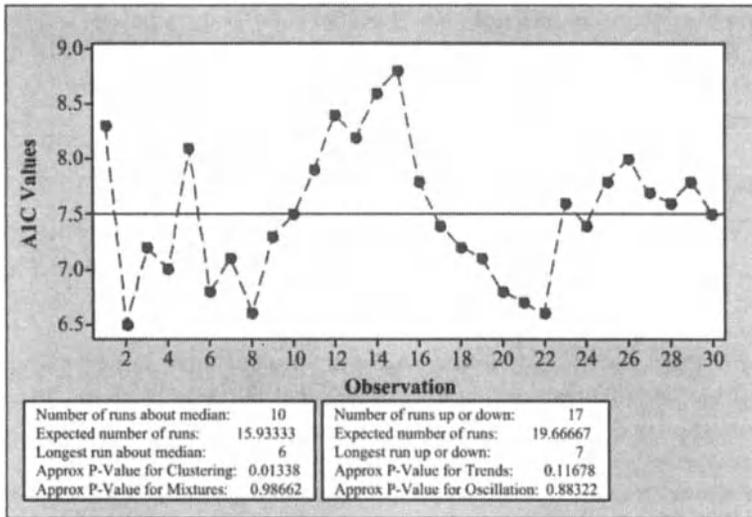


FIGURE 5-5 Run chart of hemoglobin A1C values.

common or special causes of variation. Has there been a significant trend? Test at the 5% level of significance.

Solution Using Minitab, first create a worksheet with the variable, A1C Values, consisting of 30 observations. Click on **Stat > Quality Tools > Run Chart**. Since the A1C Values are entered as a single column in the worksheet, select **Single column**, and enter the column number or name. Under **Subgroup size**, enter the value 1. Click **OK**.

Figure 5-5 shows the run chart of hemoglobin A1C values. Note that the number of runs about the median is 10, while the number of runs expected, if the data are from a distribution of random sequence, is 15.933. Also, the number of runs up or down observed is 17, while the number of runs expected, under the null hypothesis of a random sequence, is 19.667. Let us now test for the presence of clustering or mixtures. Note that the p -value for clustering is $0.01338 < \alpha = 0.05$. Hence, we reject the null hypothesis of a random sequence and conclude that there is significant clustering. The number of runs about the median observed is significantly less than that expected, under the assumption of a random sequence. We find that the p -value for testing the presence of a mixture is 0.98662 (the complement of 0.01338), indicating, obviously, that we cannot conclude the presence of a mixture pattern. Hence, a special cause of variation exists due to clustering of the observations. As a follow-up measure, one could investigate if there were certain traits or patient habits that led to clustering.

In testing for the presence of significant trend or oscillation, we consider the Minitab output in Figure 5-5. The p -value for testing trends is $0.11678 > \alpha = 0.05$, and similarly, the p -value for testing oscillations is 0.88322 (the complement of 0.11678). Hence, no significant trend or oscillations can be concluded. From the plot, observe that the longest run down has a length of 7, which might seem to indicate that there had been a significant declining trend. However, in actually testing a hypothesis on the presence of a trend, it was not found to be significant.

5-4 VALIDATING DISTRIBUTIONAL ASSUMPTIONS

In many statistical techniques, the population from which the sample data is drawn is assumed to have a certain specified distribution so that certain inferences can be made about

Check Sheet

Definition: A simple data collection form consisting of multiple categories with definitions. Data are entered on the form with a simple tally mark each time one of the categories occurs.

Purpose: To facilitate the collection and analysis of data.

A check sheet is a simple means of data collection. The most straightforward check sheet is simply to make a list of items that you expect will appear in a process and to mark a check beside each item when it does appear. This type of data collection can be used for almost anything, from checking off the occurrence of particular types of defects to the counting of expected items (e.g., the number of times the telephone rings before being answered).

How to Construct:

1. Clearly define the objective of the data collection.
2. Determine other information about the source of the data that should be recorded, such as shift, date, or machine.
3. Determine and define all categories of data to be collected.
4. Determine the time period for data collection and who will collect the data.
5. Determine how instructions will be given to those involved in data collection.
6. Design a check sheet by listing categories to be counted.
7. Pilot the check sheet to determine ease of use and reliability of results.
8. Modify the check sheet based on results of the pilot.

Tips:

- Use Ishikawa diagrams or Brainstorming to determine categories to be used on the check sheet.
- Construct an operational definition of each category to ensure data collected is consistent.
- Make check sheet as clear and easy to use as possible.
- Spend adequate time explaining the objective of the data collection to those involved in recording the data to ensure the data will be reliable.◆
- Data collected in this format facilitates easy Pareto analysis.

Beginner's Guide: The 7 Basic Quality Tools

Tool #6 - The Xbar and R Control Chart

The Control Chart Defined

Thus far in our training, we have learned that Histograms and Check sheets consolidate the data collected, to show the overall picture, while the Pareto diagram is used to indicate problem areas. However, for production purposes, we want to know more about the nature of changes that take place over a specified period of time, or as they occur in "real time".

Control charts are generally used in a production or manufacturing environment and are used to control, monitor and IMPROVE a process. Common causes are always present and generally attributed to machines, material and time vs. temperature. This normally takes a minor adjustment to the process to make the correction and return the process to a normal output. HOWEVER, when making a change to the process, it should always be a MINOR change. If a plot is observed that shows a slight deviation trend upward or downward, the "tweaking" adjustment should be a slight change, and then another observation should be made. Too often people will over-correct by making too big of an adjustment which then causes the process to dramatically shift in the other direction. For that reason, all changes to the process should be SLIGHT and GRADUAL!

A control chart is a graph or chart with limit lines, called control lines. There are basically three kinds of control lines:

- the upper control limit (UCL),
- the central line (actual nominal size of product),
- the lower control limit (LCL).

The purpose of drawing a control chart is to detect any changes in the process that would be evident by any abnormal points listed on the graph from the data collected. If these points are plotted in "real time", the operator will immediately see that the point is exceeding one of the control limits, or is heading in that direction, and can make an immediate adjustment. The operator should also record on the chart the cause of the drift, and what was done to correct the problem bringing the process back into a "state of control".

The method in which data is collected to be charted is as follows: A sampling plan is devised to measure parts and then to chart that measurement at a specified interval. The time interval and method of collection will vary. For our example, we will say that we collect data five times a day at specified time intervals. In making the control chart, the daily data is averaged out in order to obtain an average value for that day. Each of these values then becomes a point on the control chart that then represents the characteristics of that given day. To explain further, the five measurements made in one day constitute one sub group, or one plot point. In some manufacturing firms, measurements are taken every 15 minutes, and the four plots (a subgroup) are totaled and then an average value is calculated. This value then equals one plot for the hour, and that plot is placed on the chart; thus, one plot point on the chart every hour of the working day.

It is when these plot points should fall outside the UCL or LCL, that some form of change must occur on the assembly or manufacturing line. Further, the cause needs to be investigated and have proper action taken to prevent it from happening again.....called preventative action, and continuous improvement in the Quality world. The use of control charts is called "process control." In reality, however, a trend will develop that indicates the process is leading away from the center line, and corrective action is usually taken prior to a point exceeding one of the control limits.

There are two main types of Control Charts. Certain data are based upon measurements, such as the measurement of unit parts. These are known as "indiscrete values" or "continuous data". Other types of data are based on counting, such as the number of defective articles or the number of defects. These are known as "discrete values" or "enumerated data".

The Xbar & R Control Chart

An Xbar & R Control Chart is one that shows both the mean value (X), and the range (R). The Xbar portion of the chart mainly shows any changes in the mean value of the process, while the R portion shows any changes in the dispersion of the process. This chart is

particularly useful in that it shows changes in mean value and dispersion of the process at the same time, making it a very effective method for checking abnormalities within the process; and if charted while in progress, also points out a problem in the production flow in real time mode.

Steps In Making the Xbar and R Chart

- **STEP #1 - Collect the data. It is best to have at least 100 samples.**
- **STEP #2 - Divide the data into sub groups, it is recommended the subgroups be of 4 or 5 data points each. The number of samples is represented by the letter " n " and the number of subgroups is represented by the letter " k ". The data should be divided into subgroups in keeping with the following conditions:**
 1. The data obtained should be from the same grouping of products produced.
 2. A sub group should not include data from a different lot or different process.
- **STEP #3 - Record the data on a data sheet. Design the sheet so that it is easy to compute the values of X bar and R for each sub group (see the page in the class example).**
- **STEP #4 - Find the mean value (Xbar). Use the following formula for each subgroup:**

$$\bar{X} = \frac{X1 + X2 + X3 + X4 + X5}{N} = \frac{65.0}{5} = 13.0$$

- **STEP #5 - Find the range, R. Use the following formula for each subgroup.**

$$R = X (\text{largest value}) - X (\text{smallest value}) \text{ Example } 14.0 - 12.1 = 1.9$$

CLASS EXERCISE:

It is now time for you to practice some of your learning. I have completed many of the Xbar and R values for you, however, you really should perform a few calculations to gain the experience. Using the attached Exercise Sheet, calculate the remaining Xbar and R values.

[Click Here for the Excel Spreadsheet Version](#)

[Click Here for the Printable PDF Version](#)

- **STEP #6 - Find the overall mean, or X double bar $\bar{\bar{X}}$.**
Total the mean values of Xbar, for each subgroup and divide by the number of subgroups (k).

$$\bar{\bar{X}} = \frac{13.0 + 12.94 + 12.90 \dots + 12.72}{25} = \frac{323.50}{25} = 12.94$$

- **STEP #7 - Compute the average value of the range (R). Total R for all the groups and divide by the number of subgroups (k).**

$$\bar{R} = \frac{R1 + R2 + R3 \dots Rk}{k}$$

$$\bar{R} = \frac{1.9 + 1.3 + 1.1 \dots + 1.1}{25} = \frac{33.8}{25} = 1.35$$

CLASS EXERCISE PART 2:

On the same Work Sheet that you just computed the X double bar figures, now compute the R bar explained above.

- **STEP #8 - Compute the Control Limit Lines.** Use the following formulas for Xbar and R Control Charts. The coefficients for calculating the control lines are A2, D4, and D3 are located on the bottom of the Work Sheet you are presently using, and presented here:

<i>n</i>	<i>A2</i>	<i>D4</i>	<i>D3</i>
2	1.88	3.267	---
3	1.023	2.575	---
4	0.729	2.282	---
5	0.577	2.115	---
6	0.483	2.004	---
7	0.419	1.924	0.076
8	0.373	1.864	0.136
9	0.337	1.816	0.184
10	0.308	1.777	0.223

Xbar Control Chart:

Central Line (CL) = X double bar figure you calculated.

Upper Control Limit (UCL) = X double bar + A2 * R bar.

Lower Control Limit (LCL) = X double bar - A2 * R bar.

R Control Chart:

Central Line (CL) = R bar figure you calculated.

Upper Control Limit (UCL) = D4 * R bar.

Lower Control Limit (LCL) = D3 * R bar.

For our Class Exercise, the details are as follows:

X Control Chart CL = X double bar = 12.94

- UCL = 12.94 + .577 * 1.35 = 13.719 Note that we are using 5 subgroups, so on the chart n = 5, and under the A2 column, 5 = 0.577. 1.35 is the figure you calculated for R bar.
- LCL = 12.94 - .577 * 1.35 = 12.161

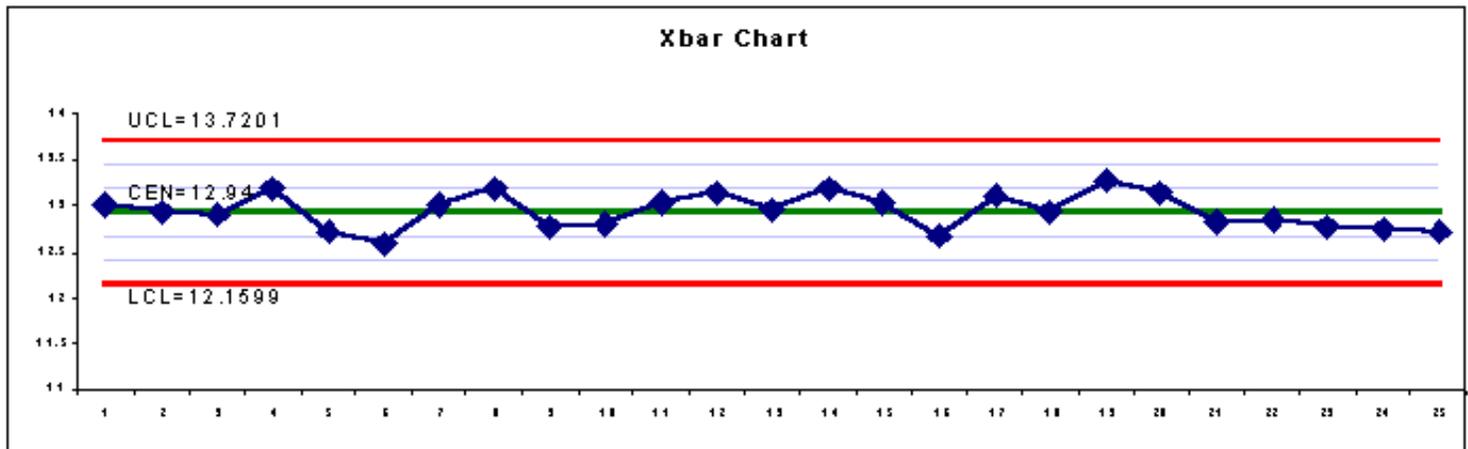
R Control Chart CL = R bar = 1.35

- UCL = 2.115 * 1.35 = 2.86 Note that we are using 5 subgroups, so on the chart n = 5, and under the D4 column, 5 = 2.115.
- LCL = Since our subgroups equal 5, if you look under the D3 column, there is no calculation coefficient to apply, thus there is no LCL.

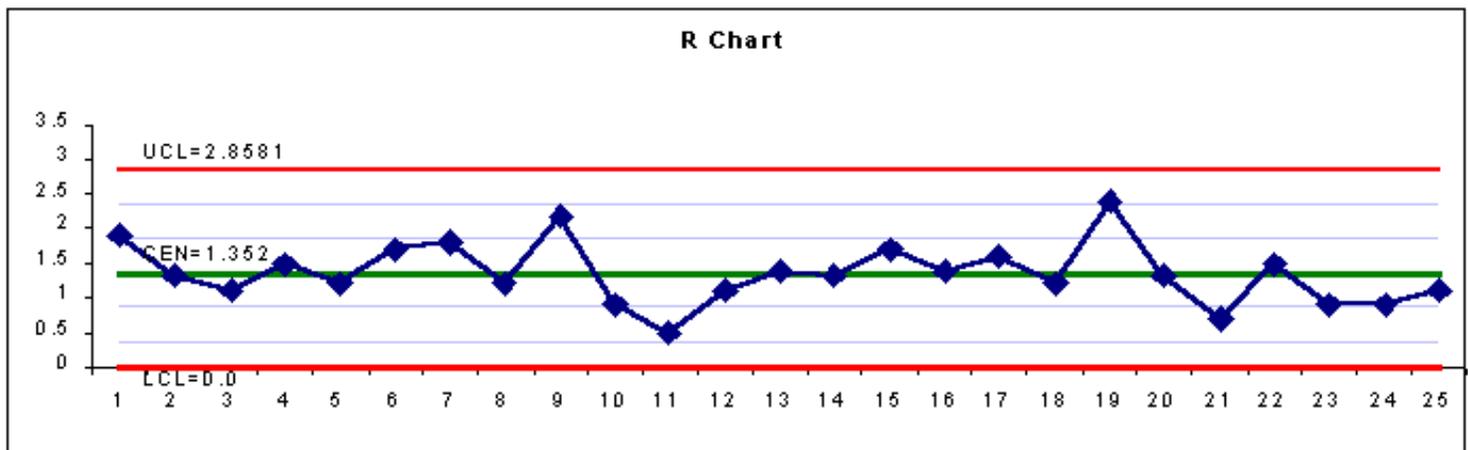
- **STEP #9 - Construct the Control Chart.** Using graph paper or Control Chart paper, set the index so that the upper and lower

control limits will be separated by 20 to 30 mm (units). Draw in the Control lines CL, UCL and LCL, and label them with their appropriate numerical values. It is recommended that you use a blue or black line for the CL, and a red line for the UCL and LCL. The central line is a solid line. The Upper and Lower control limits are usually drawn as broken lines.

- STEP #10 - Plot the Xbar and R values as computed for each subgroup. For the Xbar values, use a dot (.), and for the R values, use an (x). Circle any points that lie outside the control limit lines so that you can distinguish them from the others. The plotted points should be about 2 to 5 mm apart. Below is what our Xbar chart looks like when plotted.



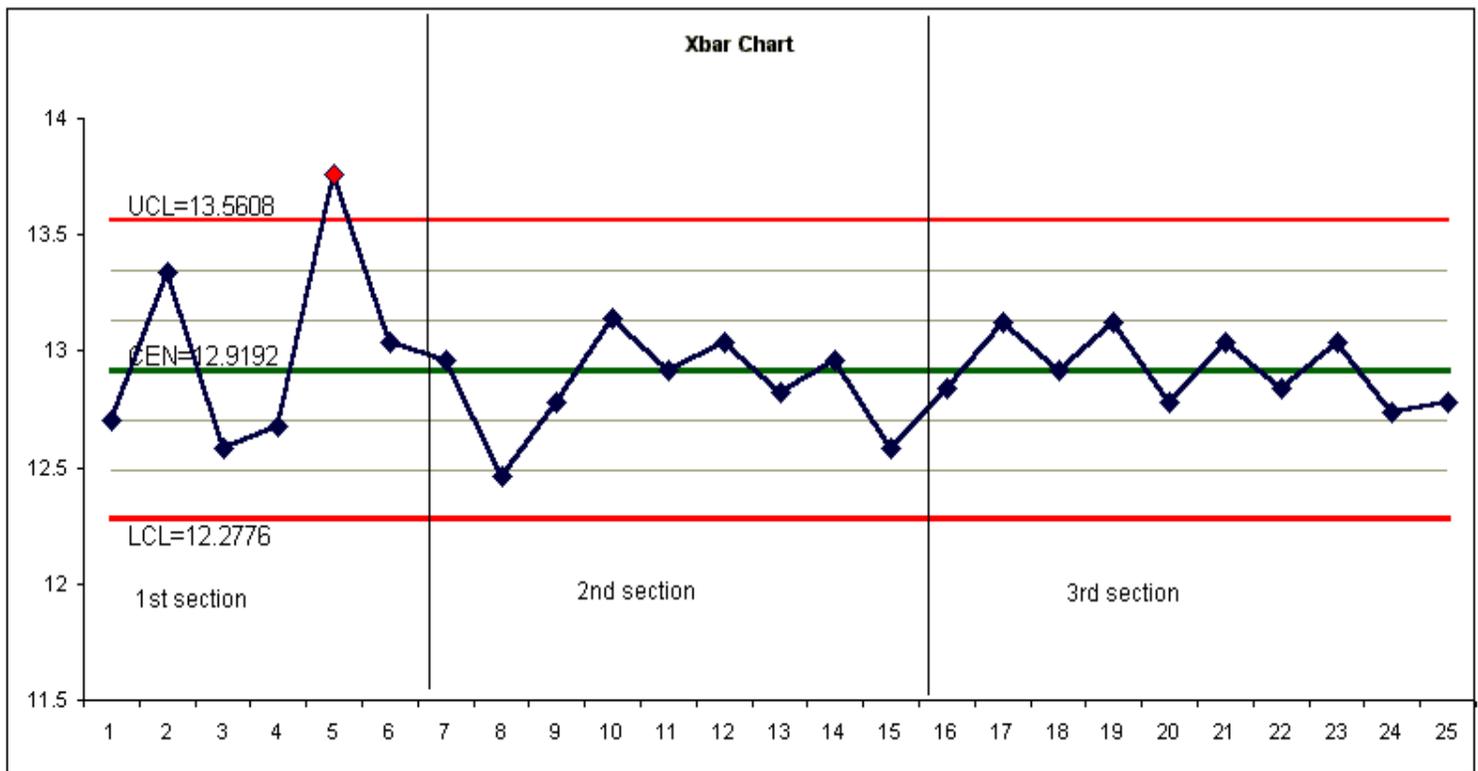
Below is what our Rbar chart looks like when plotted.



- STEP #11 - Write in the necessary information. On the top center of the control charts write the Xbar and R chart, and the R Chart so that you (and others) will know which chart is which. On the upper left hand corner of the Xbar control chart, write the n value to indicate the subgroup size; in this case n = 5.

ANALYSIS OF THE CONTROL CHART

Now that we know how to make a control chart, it is even more important to understand how to interpret them and realize when there is a problem. All processes have some kind of variation, and this process variation can be partitioned into two main components. First, there is natural process variation, frequently called "common cause" or system variation. These are common variations caused by machines, material and the natural flow of the process. Secondly is special cause variation, generally caused by some problem or extraordinary occurrence in the system. It is our job to work at trying to eliminate or minimize both of these types of variation. Below is an example of a few different process variations, and how to recognize a potential problem.



In the above chart, there are three divided sections. The first section is termed "out of statistical control" for several reasons. Notice the inconsistent plot points, and that one point is outside of the control limits. This means that a source of special cause variation is present, it needs to be analyzed and resolved. Having a point outside the control limits is usually the most easily detectable condition. There is almost always an associated cause that can be easily traced to some malfunction in the process.

In the second section, even though the process is now in control, it is not really a smooth flowing process. All the points lie within the control limits, and thus exhibits only common cause variations.

In the third section, you will notice that the trending is more predictable and smoother flowing. It is in this section that there is evidence of process improvement and the variation has been reduced.

Therefore, to summarize, eliminating special cause variation keeps the process in control; process improvement reduces the process variation, and moves the control limits in toward the centerline of the process. At the beginning of this process run, it was in need of adjustment as the product output was sporadic. An adjustment was made, and while the plotted points were now within the boundaries, it is still not centered around the process specification. Finally, the process was tweaked a little more and in the third section, the process seems to center around the CL.

There are a few more terms listed below that you need to become familiar with when analyzing a Xbar Chart and the process :

RUN - When several plotted points line up consecutively on one side of a Central Line (CL), whether it is located above or below the CL, it is called a "run". If there are 7 points in a row on one side of the CL, there is an abnormality in the process and it requires an adjustment.

TREND - If there is a continued rise or fall in a series of points (like an upward or downward slant), it is considered a "trend" and usually indicates a process is drifting out of control. This usually requires a machine adjustment.

PERIODICITY - If the plotted points show the same pattern of change over equal intervals, it is called "periodicity". It looks much like a uniform roller coaster of the same size ups and downs around the centerline. This process should be watched closely as something is causing a defined uniform drift to both sides of the centerline.

HUGGING - When the points on the control chart seem to stick close to the center line or to a control limit line, it is called "hugging of the control line". This usually indicates that a different type of data, or data from different factors (or lines) have been mixed into the sub groupings. To determine if you are experiencing "hugging" of the control line, perform the following exercise. Draw a line equal distance between the centerline and the upper control limit. Then draw another line equal distance between the center line and the lower control limit. If the points remain inside of these new lines, there is an abnormality, and the process needs closer analysis.

FINAL CLASS EXERCISE

Now it is time for the final test to see if you can make a Control Chart. Below is link for a completely filled out data sheet, and a blank variable control chart form. Your challenge is to calculate the subgroups Xbar and Rbar numbers; calculate the CL, UCL and LCL for the data and the Range Chart, and place those limit lines and numbers on the chart. Last, of course, plot the points and indicate if there are any abnormalities observed in the process. Below your forms to work on, you will also find the completed results so you can check your work. Good Luck!

The Blank Variable Control Chart is available in two formats:

For Microsoft Word Format [CLICK THIS LINK](#)

For Adobe Acrobat Format (.pdf) [CLICK THIS LINK](#)

Your Completed Data Sheet for this Exercise is available in two formats:

For Microsoft Excel Format [CHOOSE THIS LINK](#)

For Adobe Acrobat Format (.pdf) [CHOOSE THIS LINK](#)

FINAL PRODUCT COMPARISON: Your Final Xbar and R Chart should look [THIS CHART](#).

[Menu](#) | [Check Sheet](#) | [Pareto Diagram](#) | [Histogram](#) | [Cause-and-Effect](#)
[Scatter Graph](#) | [Control Charts](#) | [Np Control Charts](#)

9. Poka-Yoke to prevent or detect errors.
10. Team dynamics. Which includes problem solving, communication skills and conflict resolution.

Kaizen realies heaving on a culture that encourage suggestions by operators who continually try to incrementally improve their job or process. This change results in a small improvement in weld quality and a substantial improvement in oprator satisfaction. The PDSA cycle described earlier may be used to help implement Kaizen concepts.

Reengineering

According to Hammer and Champy reengineering is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical measures of performances. Many practitioners believe that TQM is associated with only incremental in provements. The Japanese have not only relied on Kaizen but have developed policy management (host in kanri) and policy deployment (hostin tenkai) in large part to product the kind of large-scale break through that Hammer and Champy promote. Clearly there is nothing new in the reengineering concept. It has always been part of the TQM umbrella.

SIX SIGMA (6 σ) QUALITY

An Overview

'Sigma' is used to designate the distribution or spread about the mean (average) of any process. Sigma (σ) is another word for standard deviation. For a business or manufacturing process, the sigma value is a metric that indicates how well that process is performing. The higher the sigma value, (2 σ , 3 σ , 4 σ etc.) the better the process. Sigma measures the capability of the process to perform defect-free-work. A defect is anything that results in customer dissatisfaction. With 6 σ , the common measurment index is 'defects-per-unit', where unit can be virtually anything—a component, a piece of a material, a line of code, an administrative form, a time frame, a distance, etc. **The sigma value indicates how often defects are likely to occur. The higher the sigma value, the less likely a process will produce defects. As sigma value increases, costs go down, cycle time goes down, and customer satisfaction goes up. A 6 σ process simply means that between the target specification and the tolerance limit six standard deviations can be fitted-in,** (Fig. 4.7 explains clearly the difference between the 3 σ and the 6 σ process). Further, a 6 σ process capability means 3.4 ppm defects or 99.99966% good.

Our process is the reality. When we draw the histogram of our process output we come to know how we are ; we can, then, calculate the sigma (σ) value of our process. When we place the tolerance limits, as decided by the competition, on our curve (normally distributed) we come to know where we are. We may be at 2 σ or 3 σ , etc. We now start our journey towards 6 σ . **In other words we have to shrink the variability of our process to such an extent, that the value of sigma of the process reduces to a new low, which can be fitted ± 6 times within the same tolerance limits.** This is Quality Improvement. Such an improved process hardly produces any defect.

What is 6σ ?

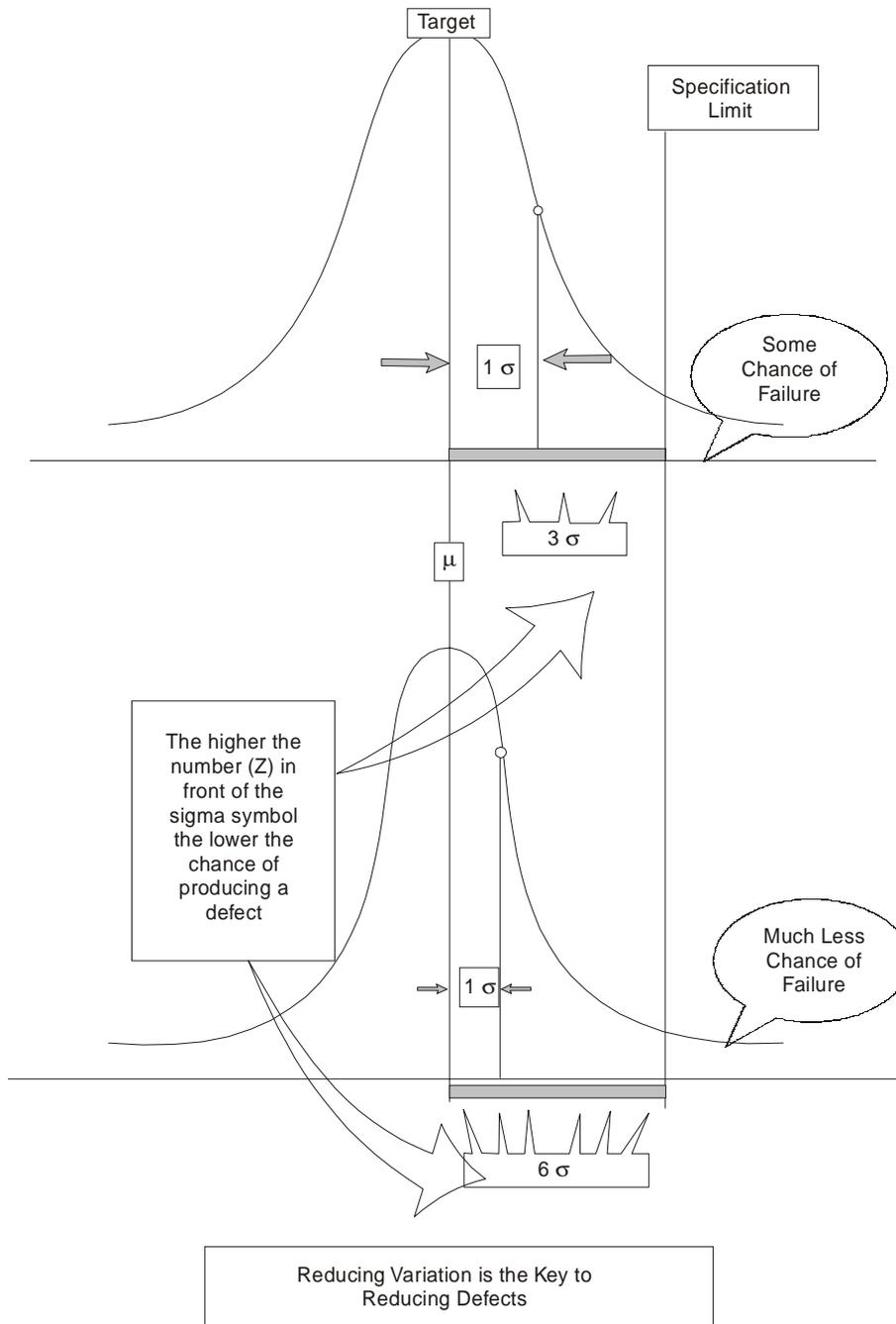


Fig. 4.7. Difference between 3σ and 6σ process.

The Practical Meaning of

<i>99% Good (3.8σ)</i>	<i>99.99966% Good (6σ)</i>
<ul style="list-style-type: none"> • 20,000 lost articles of mail/hour • Unsafe drinking water 15 min./day • 5,000 incorrect surgical procedures/week • 2 short or long landings at airports/day • 200,000 wrong drug prescriptions/year • No electricity for almost 7 hours/month 	<ul style="list-style-type: none"> • Seven articles lost/hour • Unsafe drinking water 1 min./7 months • 1.7 incorrect surgical procedures/week • One short or long landing/5 years • 68 wrong prescription/year • One hour without electricity/34 years

**Six σ As a Goal
(Distribution shifted ± 1.5σ)**

<i>Sigma level</i>	<i>Defects in PPM</i>	<i>Yield in %</i>
2σ	308,538	69,1462
3σ	66,807	93,3193
4σ	6,210	99,3790
5σ	233	99,9767
6σ	34	99,99966

6σ According to Dr. Mikel J. Harry, CEO of Six Sigma Academy, Phoenix, USA

- ☆ **First, it is a statistical measurement.** It tells us how good our products, services and processes really are. It allows us to draw comparisons with other similar or dissimilar products, services and processes. We can see where we need to go and what we must do to get there. In other words, 6σ helps us establish our course and gauge our pace in the race for total customer satisfaction.
- ☆ When we say a process is 6σ, we are saying it is best in class. Such a level of capability will only yield 3.4 instances of nonconformance out of every million opportunities for nonconformance. On the other hand, when we say that some other process is 4σ, we are saying it is average. This translates to 6,210 non-conformities per million opportunities for nonconformance. In this sense, the sigma scale or measure provides us with a “goodness micrometer” for gauging the adequacy of our products, services and processes.
- ☆ **Second, it is a business strategy.** It can greatly help us gain a competitive edge. The reason for this is very simple — as you improve the sigma rating of a process, the product quality improves and costs go down. Naturally, the customer becomes more satisfied as a result.
- ☆ **Third, It is a philosophy.** It is an outlook, a way that we perceive and work within the business world around us. Essentially, the philosophy is one of working smarter, not harder. This translates to making fewer and fewer mistakes in everything we do — from the way we manufacture products to the way we fill out a purchase order. As we discover and neutralize harmful sources of variation, our sigma rating

goes up. Again, this means that our process capability improves and the defects (mistakes) go away.

6 σ According to Mr. Jack Welch, The CEO of The General Electric Co., USA :

- ☆ 6 σ is a disciplined Quality Improvement methodology that focuses on moving every process that touches the customers — every product and service — towards near perfect Quality. It is a measure of the Company's Quality.
- ☆ 'MOTOROLA' pioneered it and 'ALLIED SIGNAL' successfully embraced it. GE took the experiences of these two companies and started implementing it.
- ☆ 6 σ is a top-down system.
- ☆ If you have to successfully implement 6 σ , the Company should be
 - Open to change
 - Hungry to learn and
 - Anxious to move quickly on a good idea
- ☆ We became convinced that 6 σ qualities could play a central role in GE's future, but we also know that it would take years of consistent communication, relentless emphasis and impassioned leadership to move GE on this bold new course.
- ☆ Today, '6 σ ' has spread like wildfire across the company and it is transforming everything we do. It has saved around 1200 million dollars to the company during 1998.
- ☆ '6 σ ' is quickly becoming a part of the genetic code of our future leadership. '6 σ ' training is now an ironclad pre-requisite for promotion to any professional or managerial position in the company — and a requirement for any award of stock options. Senior Executive compensation is now heavily weighted toward 6 σ commitment and success-success now increasingly defined as "eatable" financial returns, for our customers and for us.
- ☆ We believed that there was an ocean of creativity, passion and energy in GE people that had no bottom and no shores. We also believed that there was an "Infinite capacity to improve everything". We believed these then, but there was no methodology or discipline attached to that belief. There is Now. It is '6 σ ' quality, along with a culture of learning, sharing and unending excitement.

6 σ Breakthrough Methodology of Quality Improvement

The methodology is not very unique. It is a slight variant of the methodologies given by many quality gurus. There is nothing breakthrough in the methodology as such. But the solutions/results, we obtain by following this systematic methodology are really breakthrough. The improvement is not just in percentages but in manifold (say 100 times, 1000 times etc.)

The methodology consists of five steps namely Define (D), Measure (M), Analyse (A), Improve (I) and Control (C). Brief explanations for the same are as follows.

Define. The problem which requires breakthrough solution, has to be defined clearly in measurable terms. The problem selected should be vital to the customer and should have relevance to the company's business. In other words it should ensure great customer satisfaction as well as rupee savings to the company. If the company has developed its Business Strategies, the problem should fall under any one of them. Generally any customer

expects defect free products/services and timely deliveries. Majority of the problems will fall under these two categories. Defining the problem in manufacturing area is easier when compared to service areas.

Measure. The second most important step is measurement. We have to measure in terms of numbers to know where we are, and to decide where we go. To quote Dr. Mikel J. Harry — “If you can’t express your process in the form of numbers you don’t really know much about it. And if you don’t know much about it, you can’t control it. And, if you can’t control it, you are at the mercy of chance. And, if you are at the mercy of chance, why bother with it ? Hence we must learn the language of numbers”.

Data is as good as the system that measures it. Hence, before collecting the data a measurement system analysis has to be done and if it is not to the satisfactory level, corrective action has to be taken before measuring the data. Data is of two kinds — Discrete and Continuous. Continuous data is more amenable for Statistical analysis and hence as far as possible attempts should be made to convert the discrete data into continuous data. After collecting the data (discrete) on defects and counting the opportunities to make the defects, we can calculate the defects per opportunity (dpo), which is nothing but the probability of making the defects. From the statistical tables we can find out the corresponding ‘Standard normal deviate’, *i.e.*, the Z value or the sigma value. If it is a continuous data we can find out the sigma value by calculating the mean and the standard deviation of the process and knowing the specification limits. With this we can statistically define the problem.

After defining the problem a cause and effect diagram has to be constructed through brainstorming and segregate the causes into experimental and non-experimental causes. Solutions have to be found and implemented through Standard Operating Procedures (SOP) for the non-experimental causes at this stage itself, which brings down the variability of the process to a great extent. The experimental factors can be carried forward to the next phase-analysis.

Analyse. Statistical analysis has to be carried out at this stage to identify the vital experimental causes. Tests have to be conducted to find out whether the causes (factors) really make statistically significant difference in the effects (responses) when the levels of these factors are changed. The tools used are T-test, F-test, ANOVA, Chi-Square, correlation and Regression. A graphical analysis called multi-vari analysis is also done to segregate the variation of the response into with-in piece, between pieces and over time variations. After identifying the vital few experimental factors they have to be carried forward to the next phase-Improve.

Improve. In this phase we will be optimizing the response. In other words we will be hitting the target value by experimenting with the level settings of the vital few factors. This is called Design of Experiment. There are various stages like Screening design/fractional factorial design, full factorial, full factorial with replication, Central composite design, Method of Steepest ascent, Evolutionary process (EVOP), Taguchi’s method etc. Finally we will be tolerancing the factors at the required levels. In order to conduct the DOE, thorough planning is necessary, because the DOE is time consuming and sometimes costly.

Control. The last phase is to hold the gains that have been obtained from the improve phase. Unless we have good control we are likely to go back to the original state. ‘Statistical Process Control’ (SPC) has to be employed to control the gains. There are various kinds of control charts like I and MR, \bar{X} and R, \bar{X} and S and EWMA for continuous data and p , np , c and u charts for discrete data, to choose from. Also POKA-YOKE (mistake-proof) devices

can be set up to obviate the inadvertent errors. The idea of POKA-YOKE is to respect the intelligence of workers by taking over repetitive tasks that depend on vigilance or memory.

CONCLUSION

This article has only tried to explain the meaning of 'six sigma', without going into the depth of statistics. In effect the 'six sigma' Quality improvement methodology is a strategic bridge between the Quality Philosophy and the statistical tools available, which heavily depends on the Management drive and rigorous practice for its sustenance. To be fairly conversant with this methodology, one has to undergo a minimum of 10 days classroom training and then execute at least one real improvement project. Once the methodology is familiar. I am sure, one will not stop improving. 'Six sigma' is not just a fad ; it has yielded rich dividends in companies like MOTOROLA, GENERAL ELECTRIC, ALLIED SIGNAL, etc. It is now catching up in India and I can mention at least two major companies, viz., M/S BHARAT ELECTRONICS LTD and M/S WIPRO, which are rigorously practicing.

5s

5s is the name of a workplace organization method that uses a list of five words: seiri, seiton, seiso, seiketsu, and shitsuke. Translated into English, they all start with the letter "S". This list of 5s describes how to organize a work space for efficiency and effectiveness by identifying and storing the items used, maintaining the area and items, and sustaining the new order. The decision-making process usually comes from a dialogue about standardization, which builds understanding among employees of how they should do the work.

There are five primary 5S phases: They are known as Sort, Stabilizing, Shine, Standardize and Sustain.

1. Sorting

Eliminate all unnecessary tools, parts. Go through all tools, materials, and so forth in the plant and work area. Keep only essential items and eliminate what is not required, prioritizing things per requirements and keeping them in easily-accessible places. Everything else is stored or discarded.

2. Straightening or Stabilizing

Arrange the work, workers, equipment, parts, and instructions in such a way that the work flows free of waste through the value added tasks with a division of labour necessary to meet demand.

3. Systematic Cleaning

Clean the workspace and all equipment, and keep it clean, tidy and organized. At the end of each shift, clean the work area and be sure everything is restored to its place. This step ensures that the workstation is ready for the next user and that order is sustained.

4. Standardize

Ensure uniform procedures and setups throughout the operation to promote interchangeability.

5. Sustain

Ensure disciplined adherence to rules and procedures to prevent backsliding.

Kaizen

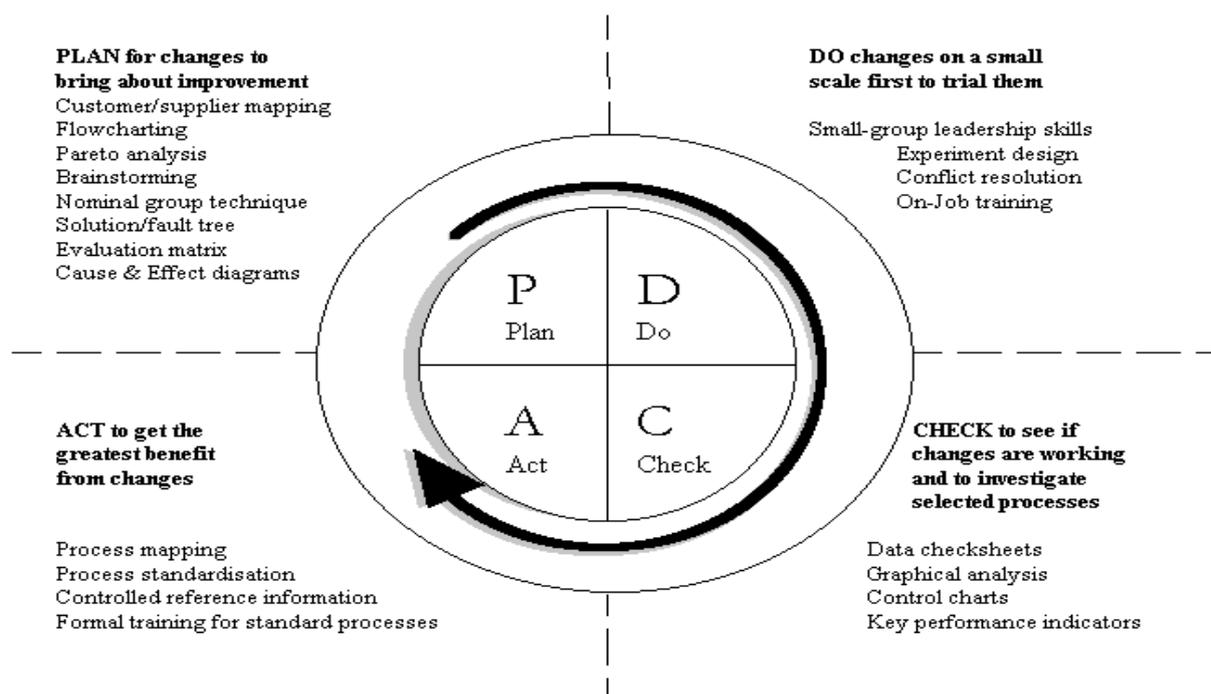
Kaizen is a Japanese word which means good change for "improvement" or "change for the best", refers to philosophy or practices that focus upon continuous improvement of processes in manufacturing, engineering, and business management. It has been applied in healthcare, government, banking, and other industries. Kaizen refers to activities that continually improve all functions, and involves all employees. It also applies to processes, such as purchasing and logistics that cross organizational boundaries into the supply chain. By improving standardized activities and processes, kaizen aims to eliminate waste. Kaizen was first implemented in several Japanese businesses after the Second World War. It has since spread throughout the world. And is now being implemented in environments outside of business and productivity.

The Toyota Productive System is known for kaizen, where all line personnel are expected to stop their moving production line in case of any abnormality and, along with their supervisor, suggest an improvement to resolve the abnormality which may initiate a kaizen.

The cycle of kaizen activity can be defined as:

- *Standardize an operation and activities.*
- *Measure the operation (find cycle time and amount of in-process inventory)*
- *Gauge measurements against requirements*
- *Innovate to meet requirements and increase productivity*
- *Standardize the new, improved operations*
- *Continue cycle ad infinitum*

This is also known as PDCA cycle.



Draw picture of PDCA cycle.

