PART 1

STATISTICAL QUALITY CONTROL

PART ONE

INTRODUCTION

1

Introduction and Overview

1.1 THE MEANING OF QUALITY

When we use the expression "quality product" in common parlance, we usually intend to think in terms of a good or excellent product. In industry, a *quality* product is one that fulfills customer's expectations. These expectations or standards of performance are based on the intended use and the selling price of the product. For example a customer expects a different standard of performance from a plain steel washer than from a chrome plated steel washer because the intended use and the selling price are different. Quality, then must be judged in terms of *customer satisfaction.* A simple and easily understandable definition of quality is then

Quality means fitness for use.

However, the most modern definition of quality is

Quality is inversely proportional to variability.

We may note that this definition implies that if variability in the important characteristics of a product decreases, the quality of the product increases and hence the expression

Quality improvement is the reduction of variability in processes and products.

1.2 THE FOCUS OF THIS BOOK

PART-1 of this book is about the use of statistical techniques to improve the quality of products used by our society. It deals primarily with various types of Shewhart control charts and with various types of acceptance sampling systems and procedures. Developed in the 1920s, Shewhart control charts got their name from their inventor, Walter A. Shewhart, when he was with Bell Telephone Laboratories. Also with Bell Labs at that time was Harold F. Dodge, who is best remembered for his many developments in the use of tables and procedures for product acceptance based on the mathematics of probability. While the tools were developed in a manufacturing environment they have proved to be equally useful in nonmanufacturing areas.

PART-2 of this book deals with quality management techniques in detail. Quality costs; ISO 9000, Six sigma and TQM in which SQC has major role, have been discussed extensively.

1.3 THE CONTROL-CHART VIEWPOINT

One purpose of this book is to explain the control-chart point of view in some detail. SQC-PART-TWO, entitled "Statistical Process Control," (SPC) is primarily devoted to this exposition. In spite of the apparent simplicity of the control chart, many people involved in trying to manage and improve quality find that its use calls for entirely new point of view. Briefly stated, the main principles are these :

1. Measured quality of manufactured product is always subject to a certain amount of variation as the result of chance.
2. Some "constant system of chance causes" is inherent in any particular scheme of production and inspection.
3. Variation within this stable pattern is inevitable.
4. The reasons for variation outside this stable pattern may be discovered and corrected.

These simple principles provide the foundation of statistical process control.

The *constant system of chance causes* referred to by Shewhart also has been called a *stable system* or defined as *statistical stability.* W. Edwards Deming referred to these constant or stable systems as *common causes of variation* constantly operating within a system. Variation outside this stable system called *assignable causes* variation by Shewhart and *special causes* variation by Deming, may be detected using control charts and its cause(s) eliminated through analysis and corrective action. Often these actions result in substantial improvement in the quality of products and services and reductions in spoilage, rework, and error rates. Moreover, by identifying certain quality variations as inevitable chance variations, the control chart tells when to leave a process alone and thus prevents unnecessarily frequent adjustments that tend to increase variability rather than decrease it.

Through its disclosure of the natural capabilities of a production process, the control-chart technique permits better decisions on engineering tolerances and better comparisons between alternative designs and between alternative production or service methods.

1.3.1 Some Statistical Tools

Many of the techniques developed by mathematical statisticians for the analysis of data may be used in the control of product quality. The expression *statistical quality control* may be used to cover all uses of statistical techniques for this purpose. However, it often relates particularly to five separate but related techniques that constitute the most common working statistical tools in quality control. These tools are :

1. The frequency distribution for measurable quality characteristics primarily used for presentation and analysis of data and also for computation of certain statistical measures.
2. The Shewhart control charts for measurable quality characteristics. In technical language of the subject, these are described as charts for variables, or as charts for $\overline{X}$ and R (sample average and range) and charts for $\overline{X}$ and s (sample average and standard deviation)*.

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* The symbol $\overline{X}$ is read as "X bar" or as "bar X". The bar over any symbol always indicates an average. Thus $\overline{X}$ means an average of the X's. R and s are alternative measures of the dispersion of a set of data. Their calculation and meaning are explained in Chaps. 2 and 3.

3. The Shewhart control chart for fraction rejected, or p chart.
4. The Shewhart control chart for number of nonconformities, or c chart.
5. The portion of sampling theory that deals with quality protection given by any specified sampling acceptance procedure.

SQC-PART-TWO of this book deals with (1), (2), (3), and (4) and also introduces some other statistical techniques for comparing processes. SQC PART-THREE deals with (5) and includes a number of procedures for sampling acceptance, many of which may be used as an aid in sampling for process control purposes. In the use of statistical methods to control product quality, these are the tools for cost reduction and quality improvement that are the most widely applied.

1.3.2 Variables and Attributes Data

Data that are collected for the quality control purposes are obtained by direct observation and are classified as either *variables* or *attributes.*

Variables are those quality characteristics which are measurable such as a weight measured in grams or a dimension in mm.

Attributes are those quality characteristics which are classified as either conforming or nonconforming to specifications.

Many quality characteristics which are variables in nature but are inspected as conforming or nonconforming to specifications and hence reported as attributes. This applies for example, to gauging of dimension of machine parts by go and not-go gauges.

1.3.3 Some Benefits to be Expected from the Use of Frequency Distributions

One of the established characteristics of modern manufacturing is that no two pieces are made exactly alike. The variation may be small but it is a fact that it does exist. This variation generally takes a definite frequency pattern, which cannot be known by examining a few pieces.

The frequency distribution states that the individual pieces tell relatively little when they are studied by themselves. The lot or batch of which these pieces are a part, yields the significant information. Individual pieces are best thought of as units of larger lot. Truly to represent the quality characteristics of these pieces requires the study of a sample of adequate size drawn from the lot to which the pieces belong.

The frequency distribution helps to establish the principle that some amount of variation must always be expected among the manufactured product and further helps to establish the general nature of this variation. Thus it helps answering such questions as :

1. Is the variation in a process such that parts can be produced within specification limits *i.e.* upper specification limit (designated as U or USL_x) and lower specification limit (designated as L or LSL_x) as far as a particular quality characteristic is concerned ?
2. How does the average value of the quality characteristic compare with specification limits?

Depending upon the shape of the distribution pattern decisions can be taken regarding acceptability of lot and regarding adjustment of the process centering and thus reducing the scrap to minimum possible.

1.3.4 Some Benefits to be Expected from the Use of Control Charts for Variables

Trouble is a common state of affairs in manufacturing. Whenever the trouble consists of difficulty in meeting quality specifications that are expressed in terms of variables, the Shewhart control charts for $\overline{X}$ and R are indispensable tools in the hands of the troubleshooter. They provide information on three matters, all of which need to be known as a basis for action. These are :

1. Basic variability of the quality characteristic
2. Consistency of performance
3. Average level of the quality characteristic.

1.3.5 Some Benefits to be Expected from the Use of Control Charts for Fraction Rejected

The ratio of the number of items rejected to the number of items inspected is known as *fraction rejected**.

The Shewhart control charts for fraction rejected (known as p chart) generally makes use of data that either are already available for other purposes or can readily be made available. Simple statistical calculations provide control limits that tell whether assignable causes of variation appear to be present or whether the variations from day to day (or lot to lot, supplier to supplier, or whatever the classification basis may be) are explainable on chance grounds.

The introduction of p chart results in substantial reductions in average fraction rejected. The p chart is also of great value in dealing with outside suppliers.

1.3.6 Some Benefits to be Expected from the Use of Control Charts for Nonconformities

This type of control chart known as c chart applies to two rather specialized situations. One is the case where a count is made of the number of nonconformities of such type as blemishes in a painted or plated surface of a given area, weak spots in the insulation of rubber-covered wire of a given length, or imperfections in a bolt of cloth. The other is the case of inspection of fairly complex assembled units in which there are a great many opportunites for occurrences of nonconformities of various types, and the total number of nonconformities of all types found is recorded for each unit.

As in other types of control charts, the control limits are set in a way to detect the presence or absence of assignable causes of variation, and they therefore tell when to take action on the process and when not to do so. Experience indicates that erratic variation in inspection standards and inspection practices seems particularly likely to exist in this type of inspection and that the control chart for nonconformities generally proves helpful in standardizing inspection methods.

1.4 SCIENTIFIC ACCEPTANCE SAMPLING

Acceptance inspection is an essential part of manufacturing for quality improvement. Inspection can occur at many points in a manufacturing cycle. *Acceptance sampling,* defined as the

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*It is commonly expressed as a decimal fraction, such as 0.025. The decimal fraction may be multiplied by 100 to convert it into percent rejected, such as 2.5%.

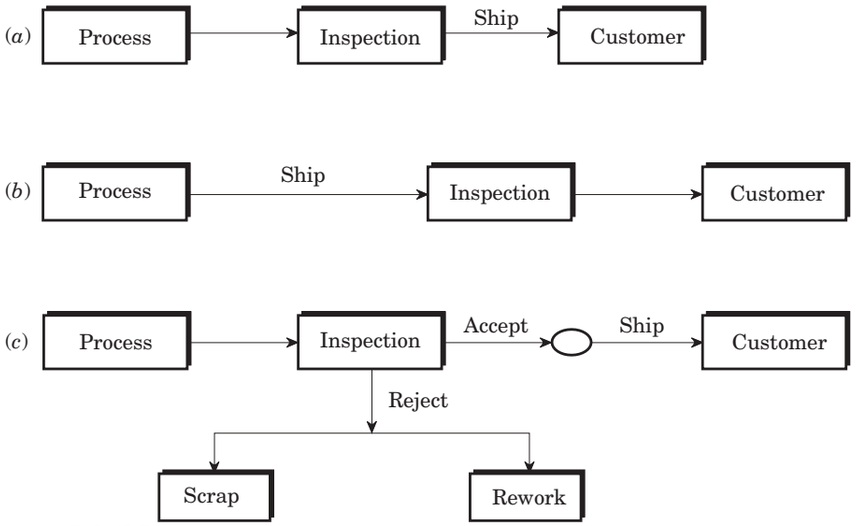

FIGURE 1.1 Variations of acceptance sampling. (a) Outgoing inspection ; (b) Receiving imcoming inspection ; (c) Disposition of lot

inspection and classification of a sample of units selected at random from a larger batch or lot and the ultimate decision about disposition of the lot.

Several different variations of acceptance sampling are shown in Fig 1.1. In Fig 1.1 (a), the inspection operation is performed immediately following production, before the product is shipped to the customer. This is usually called *outgoing inspection.* Figure 1.1 (b) illustrates *incoming inspection* ; that is, a situation where lots or batches of product are sampled as they are received from the supplier. Various lot dispositioning decisions are illustrated in Fig 1.1 (c). Sampled lots may either be accepted or rejected. Items in a rejected lot are typically either scrapped or recycled, or they may be reworked or replaced with good units. This later case is often called *rectifying inspection*.

Much inspection, either for process control or for product acceptance, is by sampling. Often 100% inspection turns out to be impracticable or clearly uneconomical. Moreover, the quality of the product accepted may actually be better with scientific acceptance sampling procedures than would be the case if the same product were subjected to 100% inspection. Sampling inspection has a number of psychological advantage over 100% inspection, where inspectors' fatigue on repetitive operations may be a serious obstacle.

It is common knowledge that on many types of inspection, even several 100% inspections will not eliminate all the nonconforming product from a stream of product, a portion of which does not conform to specifications. The best protection against the acceptance of nonconforming product is, of course, having the product made right in the first place. Good sampling acceptance procedures may often contribute to this objective through more effective pressure for quality improvement than can be exerted with 100% inspection. Some sampling schemes also provide a better basis for diagnosis of quality troubles than is common with 100% inspection.

It should be recognized that although statistical sampling acceptance procedures are generally superior to traditional sampling methods established without reference to the laws of probability, anyone who uses acceptance sampling must face the fact that whenever a portion

of the stream of products submitted for acceptance does not conform to specifications, some nonconforming items are likely to be passed by any sampling acceptance scheme. The statistical approach to acceptance sampling frankly faces this fact. It attempts to evaluate the risk assumed with alternative sampling procedures and to make a decission as to the degree of protection needed in any instance. It is then possible to choose a sampling acceptance scheme that gives a desired degree of protection with due consideration for the various costs involved. SQC PART-THREE of this book deals with various scientific acceptance sampling schemes.

1.5 MEANINGS AND USAGE OF THE WORDS *DEFECTIVE* AND *DEFECT*

The technical meanings of the words *defective* and *defect* as used in the manufacturing industries differ from the common meanings of these words as used in every day speech. This difference between the technical and popular meanings of these words has been a source of misunderstanding in litigation, particularly in product liability suits.

- In technical sense when a manufactured article fails to conform to specification(s) it is known as *defective.* Similarly a *defect* is a failure of the part or article to conform to some one specification. A manufactured item that is defective may contain one defect or several of them.
- In popular sense, when a manufactured article is unsatisfactory with reference to its intended purpose, it is known as *defective.* Similarly a *defect* of a manufactured article is some characteristic of the article that makes it unsatisfactory for its intended purpose.

  Obviously it is impossible for manufacturers to take any action that will change the popular meanings of *defective* and *defect.* The one way the confusion between the technical and popular meanings can be eliminated is to substitute other words or phrases when the technical meanings are intended. An article that does not conform to specifications in some respect can be described as *nonconforming* rather than a *defective.* A failure to conform to a particular specification can be called a *nonconformity* or *nonconformance* rather than a *defect.* In describing the results of acceptance inspection, it is possible to say *percent rejected* or *nonconforming* rather than *percent defective.*

SQC PART-TWO of this book deals with various aspects of process control, with particular emphasis on the contributions that can be made by the different types of control charts. In this portion of the book, it has been possible to eliminate the words *defective* and *defect* in nearly all cases.

SQC PART-THREE of this book describes a number of acceptance sampling systems that use the words *defective* and *defect* in their technical sense. While some of the commercial versions of standards for acceptance sampling have replaced them, the more frequently used military versions have retained them. As long as these words continue to be used in the official documents describing such systems, writers explaining the systems will also need to use the words.

1.6 STATISTICAL QUALITY CONTROL MAY HAVE USEFUL BY-PRODUCTS

The techniques of statistical quality control bring certain desirable results that cannot be achieved as well in any other way. These might be described as the direct benefits of statistical

quality control. In addition, the introduction of these techniques into any business often causes certain desirable changes that might be described as *by-products.*

One such by-product may be the establishment or improvement of inspecting standards, with the preparation of definite instructions for each inspection procedure. Another may be the periodic evaluation of departmental performance in quality terms. Still another may be the evaluation of different suppliers quality performance in terms of average fraction rejected, with choice of future suppliers based on these findings.

Sometimes an important by-product of statistical quality control may be the establishment of effective process inspection where none has previously existed. In some manufacturing concerns there is little or no process inspection ; inspection takes place some days—or even weeks or months—after production with no chance to associate any rejected product with possible causes in the production departments. Statistical quality control, with its emphasis (explained in later chapters) on keeping track of the order of production, tends to call for inspection close to the point of production.

1.7 REASONS FOR USE OF THE ADJECTIVE *STATISTICAL*

The word *statistics* has generally two quite different meanings. In one sense, it refers to any facts that stated in terms of numbers; in this sense, it is a plural noun. Thus one may say "statistics *are* kept in the sales department regarding all branch office sales." In the other sense, it refers to a body of methods by which useful conclusions can be drawn from numerical data. In this sense, it is a singular noun. Thus one may say “Satatistics *is* based in large part on the law of large numbers and the mathematical theory of probability.” It is in this second sense that the adjective *statistical* is accurately used in the expression *statistical quality control.*

The control of quality of manufactured product is a function that existed long before statistical methods were applied to the analysis of quality data and that exists today whether or not statistical techniques are used. Properly used, the expression *quality control* applies to a function much broader than the expression *statistical quality control.* The use of *quality control, or Q.C.,* in the sense of *statistical quality control* inevitably leads to confusion as to the meaning of the expression.

In the long run this confusion is likely to be more serious than any troubles introduced by the use of an extra word. For this reason, throughout this book the expression *quality control* is always used in the broader sense of the control of quality of product by whatever methods may be used and the adjective *statistical* is always employed where the control of product quality by statistical methods is referred to.

1.8 NON-MANUFACTURING APPLICATIONS OF STATISTICAL QUALITY CONTROL TECHNIQUES

Although control charts and statistical types of acceptance sampling procedures were originally developed for use in mass production manufacturing, these techniques are applicable to most other types of activities in all sectors of the economy including service business, government, education, and health care.

Applications to business processes and in areas outside manufacturing are discussed in some places throughout this book. Some of the examples are drawn from the service and public sectors of the economy. For instance, certain acceptance sampling systems are well suited for checking errors in clerical work and verifying the accuracy of inventory counts. Control charts may be applied to many business variables to discover their average values, the range of variation that can be expected as a matter of chance, and the presence or absense of special cause variation. These efforts may lead to uncovering potential improvement projects and, when completed, will help assess the success of the effort.

1.9 THE HUMAN FACTOR IN INTRODUCING STATISTICAL QUALITY CONTROL

Installation of statistical quality control is not only a technical problem, it is also a problem of human relations. As is only too well known to any quality control engineer that one of the most frequent causes of failure is the resistance built up by the shop people against the outside engineer who has come to establish the new method. Resistance to change is after all, a normal human reaction. It may be aggravated by fear of loss of standing or even of losing one's job, by suspicion or simple stubborness. Much time may have to be invested in tactful diplomacy to overcome this resistance.

In dealing with this phase of quality control, the inside inspection supervisor is in a far better position than the outside engineer. The former not only knows his people, machines and product, but has already has an opportunity to gain the confidence of both foremen and operators. This will prove helpful when he begins with his new project; moreover he is not pressed constantly for time in completing his task, but outside person, as a rule, is expected to show results quickly.

1.10 A BRIEF REVIEW OF COMMON TERMINOLOGY ASSOCIATED WITH QUALITY

This book is primarily concerned with the techniques of statistical control of the quality, however, it is useful to review the other terms usually associated with quality.

Quality assurance system is an effective method of attaining and maintaining the desired quality standards. It is based on the fact that quality is the responsibility of all functions. Compliance to ISO 9000 series of standards of equivalent standards helps in achieving quality assurance.

Quality indices are the various mathematical figures to indicate the progress in quality achievement. One of the most useful and easily understood indices is saving in money due to reduction in scrap and rework.

Reliability is defined as the probability that a device will perform its intended function for a specified period of time under stated conditions. The statement "the probability of survival of a piece of equipment is 95% for 1,000 hours of operation" means that on the average 95 of 100 such piece would operate without failure for 1,000 hours.

The incorporation of a time constraint in the reliability definition is not unusual. No product lasts forever, after its useful life period is over; it begins to show signs of wearing out, and a rapidly rising failure rate. Chapter 14 in this book discusses some such failures. The manufac-

turer therefore restricts his prediction of the reliability of the product to a time span that does not reach into the wear out region of the life of the equipment.

Product quality, on the other hand is not mathematically linked to a time period, nor is it stated is terms of a probability of performance. It may best be defined as the degree of conformance of the product to the applicable specifications, standards, and workmanship criteria.

It should be noted that the high quality of an item is not necessarily synonymous with high reliability. For instance, a component used in an assembly, or system, may have been exposed to all the necessary quality control and have met all of its specification requirements and yet run into unforeseen difficulties when working as part of the overall equipment. This difficulty may stem, for example from a lack of recognition of adverse electrical or mechanical interactions between components. This is a reliability problem that should have been solved by system analysis, including a component application review. Such an analysis could well have resulted in a recommendation for substitution of a more suitable component for the application. Clearly, the most stringent quality control measures applied to the unsuitable component would not have altered the situation.

1.11 SOME SITUATIONS NOT REQUIRING STATISTICAL QUALITY CONTROL

Merely installing the statistical quality control techniques may not help in reducing the nonconforming product or improving the quality. The matter must be considered thoroughly in order to decide upon a plan. Such preliminary thinking may indicate that statistical quality control is not applicable to the majority of portions in the plant.

For example, in stamping out non-precision metal blanks on punch presses, it will be sufficient for the operator or foreman to give the product an occasional spot check for burrs and scratch marks. This will be sufficient to detect deficiencies in the blanking die or material and ensure a satisfactory product. Generally speaking, any elaborate statistical quality control is uncalled for on product or operations where all the following conditions exist :

1. Nonconforming work is unlikely.
2. The quality of the product can be checked quickly.
3. The product is a non-precision product.

1.12 QUALITY MANAGEMENT

Although statistical techniques are the critical technical tools for quality control and improvement, to be used most effectively they must be implemented within and be part of a management system that is quality driven. In effect, the management system must direct the quality improvement philosophy and ensure its implementation in all aspects of the business. The managerial framework to accomplish this is usually called **TQM**, although other widely used names include **Company Wide Quality Control (CWQC)** and **Total Quality Assurance (TQA).** Some companies have developed their own nomenclature (for example, Motorola's is called **six-sigma).**

PART-2 of this book gives enough insight of current quality management techniques.

PROBLEMS AND SOLUTIONS

Problem 1.1 *State whether the following statements are True (T) or False (F) :*

1. Statistical process control was originally developed in Japan and brought to the United States after World War II.
2. TQM is now being applied in services industries as well as manufacturing industries.
3. Controlling variability is an essential aspect of maintaining quality.
4. Control charts help us to detect inherent variation.
5. Quality is always measured using samples.
6. Quality is measured through inspection.

Solution. 1. (F) 2. (T) 3. (T) 4. (F) 5. (F) 6. (F)

Problem 1.2 *Choose the correct statement :*

1. Which of the following charts is used to monitor the attribute ?
   (*a*) $\bar{X}$-Chart (*b*) *A*-Chart
   (*c*) *p*-Chart (*d*) None of the above
2. Which of the following people was ***not*** directly involved in quality control.
   (*a*) Deming (*b*) Pareto
   (*c*) Roming (*d*) Ishikawa
3. Which kind of variation can be seen in a control chart ?
   (*a*) Inherent variation (*b*) Special cause variation
   (*c*) Random variation (*d*) All the above
4. Who was primarily responsible for the development of control charts ?
   (*a*) Crossby (*b*) Ishikawa
   (*c*) Dodge (*d*) Shewhart
5. Which of the following is ***not*** an aspect of quality ?
   (*a*) Luxuriousness (*b*) Fitness for use
   (*c*) Consistency (*d*) Conformance to requirements.
6. CQI stands for
   (*a*) Constant quality increments
   (*b*) Continuous quality improvement
   (*c*) Continuous quality increases
   (*d*) Complete quality implementation

Solution. 1. (*c*) 2. (*b*) 3. (*d*) 4. (*d*) 5. (*a*) 6. (*b*)

Problem 1.3 *Choose the correct statement for the following.*

1. Design quality is :
   (*a*) Specification meeting customer requirements
   (*b*) Output meeting specification
   (*c*) Process producing to specification

2. Conformance quality is :
   (*a*) Output meeting specification
   (*b*) specification meeting customer requirements
   (*c*) process producing to specifications
3. Operational quality is :
   (*a*) Output meeting specification
   (*b*) process producing to specification
   (*c*) specification meeting customer requirements
4. Service quality
   (*a*) cannot be measured
   (*b*) is a matter of opinion
   (*c*) is not important
5. SQC aims at
   (*a*) zero defect
   (*b*) minimum defect
   (*c*) optimum defect

Solution. 1 (*a*) 2. (*a*) 3. (*b*) 4. (*b*) 5. (*c*)

Problem 1.4 (*a*) *What are the various approaches to definitions of 'quality' ?*
(*b*) *What is the simplest and appropriate definition of quality ?*

Solution. (*a*) As there is no clear or agreed definition of quality, various definitions of quality can be categorized into *five approaches* as follows :

The Transcendent Approach The transcendent approach views quality as synonymous with innate *excellence*. A 'quality' car is a Rolls Royce. Using this approach, quality is being defined as the absolute the best possible, in terms of the product's or service specification.

The Manufacturing-based Approach The manufacturing-based approach is concerned with making products or providing services that are *free of errors* and that conform precisely to their design specification. A car which is less expensive than a Rolls Royce, or a Swatch Watch, although not necessarily the 'best' available, is defined as a 'quality' product provided it has been built or delivered precisely to its design specification.

The User-based Approach The user-based approach is about making sure that the product. The user-based is *fit for its purpose*. This definition demonstrates concern not only for its adherence to specification but also with appropriateness of that specification for the customer. A watch that is manufactured precisely for its design specification yet falls to pieces after two days is clearly not fit for its purpose.

The Product-based Approach The product-based approach views quality as a precise and *measurable set of characteristics*. A watch, for example, may be designed to run, without the need for servicing for at least five years while keeping time correct to within five seconds.

The Value-based Approach This approach contends that quality should be perceived in relation to price. A customer may will be willing to accept something of a lower specification quality, if the price is low.

(*b*) The simplest and perhaps the appropriate definition of the quality is "consistent conformance to customers' expectations".

Problem 1.5 *Distinguish clearly between quality control and inspection.*

Solution. For any organization associated with manufacturing activities, both inspection and quality are essential. However, there is marked difference between the two. In the inspection activity, the emphasis is placed on the quality of past output. For example, if the production schedule calls for manufacture of 1,000 couplings with a length of 10.000 ± 0.250 cm., the inspector will concern himself only with whether the couplings that have been produced to this specification. Those do not, will be rejected and production will continue until the required number, *i.e* 1,000 couplings have been produced.

As opposed to this, the emphasis in the quality control activity is on the quality of future output. There are various ways of controlling this quality. However, one of the most important methods is based on techniques of a statistical nature. For example in the case of above couplings, as the coupling are produced, periodic samples might be taken of the output and the coupling in each sample inspected. If the quality of the items in a particular sample is satisfactory, production will be allowed to continue. But if it is not, corrective action will be immediately taken. In brief, what is learned from the inspection of a sample of the product is used as a basis for deciding whether any changes should be made in production process.

Problem 1.6 *Describe the various usual meanings given to the word "quality".*

Solution. The word "quality" has come to have a set of different meanings in addition to "fitness for use". Much confusion results when the word "quality" is uttered by person who has one of these meanings in mind, only to have the word intepreted in a variety of ways by different listeners.

Experience indicates that the most usual meanings given to the word "quality" include :

Fitness of use This is the historic meaning. In earlier times, fitness for use referred to the degree to which a specific product or services satisfied the requirements of a specific user. In our times there is still a lot of this face to face meeting over fitness for use. Increasingly, however commerce is transacted through a distribution chain, requiring the concept of specification, and creating two parameters of fitness of use :

(*a*) quality or design, or grade

(*b*) quality or conformance.

With the proliferation of complex, long-life products, two added parameters of fitness for use have arisen :

(*c*) availablity, *i.e.* the extent to which the user can secure containing use of the product

(*d*) customer service *i.e.* the extent to which the manfacturer and the distribution chain make good in the event of product failure.

Grade This is the degree to which a class or category of product possesses satisfaction for people generally. The term "quality of design" sometimes used as synonymous with grade. The term "brand" is often used to describe a producer's designation for a particular grade.

Quality of conformance This is the degree to which a specific product conforms to a design or specification.

Quality characteristic This is any distinguishing feature of a grade or a product, *i.e.* appearance, dimension, performance, length of life, dependability, reliability, durability, maintainability, taste odour etc.

The quality function This is the name for that area of responsibility in industrial units through which we achieve fitness for use.

A department Some industrial units have names containing the word "quality", *e.g.* quality control department and these names may be abbreviated to the single word "quality".

In the literature of statistical quality control the word 'quality' is usually related to some measurement made on the items produced, a good quality item having one which conforms to standards specified for the measurements.

Problem 1.7 *Suggest some general ways to diagonse the quality problems.*

Solution. The quality problem can be diagonsed by using appropriate control tools depending upon the meaning or perception of "quality". At a broad level, quality is best modelled as the gap between customers' expectations concerning the product or service and their perceptions concerning the product or service. Modelling quality this way will allow the development of a diagnostic tool which is based around the perception-expectation gap. If such a gap exists it is likely to be caused by one or more of the gaps between factors which influence expectations and perceptions.

There are four main gaps :

1. the gap between a customer's specification and the operation's specification;
2. the gap between the product or service concept and the way the organization has specified it;
3. the gap between the way quality has been specified and the actual delivered quality;
4. the gap between the actual delivered quality and the way the product or service has been described to the customer.

It is the third gap (between the specification of quality and the actual quality delivered) which of particular concern to operations managers.

Problem 1.8 *Why are statistical methods of quality control so important ?*

Solution. The most effective way that has so far been developed for getting at the facts about quality characteristice is to use statistical methods. Often the statistical methods are referred to as tools for dealing with quality problems. As a matter of fact these are much more than that. As Dr. Walter A. Shewhart puts it, they provide us with a looking at the universe. They pervade all phases of existence. They lead us to a better understanding of universal truth:

Inherent variability is present in all things

It is this that prevents us from ever achieving an "exact" measurement of any thing. We have nothing "exact" to measure with ! As Dr. W. Edwards Deming puts it, the science of exactness becomes the science of dealing most effectively with inexactness. Statistical methods offer us the most effective means of dealing with inexactness.

Problem 1.9 (*a*) *How can statistical process control help quality planning and control ?*

(*b*) *Mention briefly the various statistical control charts in SQC work.*

Solution. (*a*) Statistical process control (SPC) involves using control charts to track the performance of one or more quality characteristics in the operation. The power of control charting lies in its ability to set control limits derived from the statistics of the natural variation of processes. These control limits are often set at $\pm$ 3 standard deviations of the natural variation of the process samples.

Control charts can be used for either attributes or variables. An attribute is a quality characteristic which has two states (for example, right or wrong). A variable is one which can be measured on a continuously variable scale.

Process control charts allow operations managers to distinguish between the 'normal' variation inherent in any process and the variations which could be caused by the process going out of control.

(*b*) Statistical process control charts are useful for measuring the current quality generated by the process and for detecting whether the process has changed to the detriment of quality. Thus *R*-charts are used to monitor process variability, $\overline{X}$-charts and *p*-charts identify abnormal variations in the process average, and *c*-charts are used for controlling the number of defects when a product or service process could result in several defects. The presence of abnormal variation triggers a search for assignable causes.

Problem 1.10 (*a*) *List out some reasons why quality is important in manufacturing.*

(*b*) *List some reasons why quality is important in (i) services (ii) not-for-profit organizations.*

(*c*) *Statistical process control is concerned with :*

(*i*) *controlling process variability*

(*ii*) *ensuring output is within specifications*

Advice the ***incorrect*** *statement in part* (*c*).

Solution. (*a*) Some important reasons for importance of quality in manufacturing are :

1. survival
2. competitive advantage
3. influence on cost
4. influence on image

(*b*) Some reasons for important of quality in services and not-for-profit organizations are :

1. influence on cost
2. influence on image
3. influence on pay masters
4. social responsibility

(*c*) (*i*)

Problem 1.11 (*a*) *What are the three areas in which statistics can be applied to control and improve quality.*

(*b*) *Name three area of SQC.*

(*c*) *Which are generally considered better, preventive or corrective approaches to quality control ? Why ?*

Solution. (*a*) Three identified areas which use statistics for control and quality improvement as follows:

1. Establishment of a target or planned level of performance.
2. Measurement of the actual performance and comparison of these measurements to the target value.
3. Some type of corrective action if the actual measurements are not within some established range near the target value.

(*b*) Three areas of SQC are :

1. SPC are employed to infer whether the processing operations are performing within the usual amount of chance-cause variation.
2. SAS — to accept or reject lots on the basis of the results of samples.
3. Traditional statistical techniques which involve design of experiments and other investigative techniques that might help in improving quality.

(*c*) Generally it is better to concentrate an preventive approaches that keep processes working properly so that defective items will not be made.

Problem 1.12 *"Quality control is fine, but my product is different. It is not easily subject to control. It is too complicated". Such types of remarks came from a person who sought examples of modern statistical quality control.*

Is he justified ? Why or why not ?

Solution. The remarks seem to be unjustified because the difference is almost always superficial. There is no field of human material experience that does not function in a statistical manner. As long as the materials, men, methods, and machines are used, the problems of quality variation exists. As long as these exists, the methods of statistical quality control are needed.

If a detailed analysis of scrap and rework in terms of momey is made and the cost of nonconforming products in terms of customer good-will and reputation is realized, one will certainly come to the conclusion that it is better to spend some portion of this amount to bring about a greater reduction in losses and an improved competitive position.

Problem 1.13 *In what types of production units the statistical techniques of quality control are applicable ?*

Solution. Broadly speaking these techniques are applicable only to manufacturing units organized on a quality or mass production basis. Whenever production is repetitive, either in a continuous flow or lot by lot, these quality control techniques will prove to be of ultimate benefit. As a matter of experience it is found that the method is not economic if an individual lot runs for less than two-hour or three eight-hour shifts through the production process to be "quality controlled". There are exceptions of course. Where small batches repeat constantly, *e.g.* in aircraft production on short orders, quality control is still applicable. The original application of quality control to a machine shop took place in a precision engineering firms where the average batch size was around 500-1,500 piece parts.

The basic control chart methods are also applicable to product inspection, as distinct from process inspection. It is in this sphere, rather than in that of quality control proper, that the use of these methods leads to the greatest economics in inspection effort and, therewith, to corresponding saving in manpower.

Problem 1.14 *Comment of the following statement :*

> *"Control of quality by statistics is the recording of the actual fluctuations in the dimensions of the product of the machines and the statistics so compiled are then available for future guidance. Quality control charts and records can only serve a useful purpose by having as their obejct the reduction of scrap material and wastage of time, but as the chart is recorded after the event, it is difficult to understand how even this would be achieved".*

Solution. The statements cited above is an almost perfect example of what quality control is *not*. The one who has made this statement has clearly failed to grasp the fact that the quality control is essentially news and *not* history. The outstanding and characteristic feature of the quality control chart is its practical value as a signalling device, indicating to all concerned the onset of impending troubles, and providing objective evidence upon which the appropriate preventive measures may be based. Perhaps the best definition of quality control is that *it puts process inspection on a sound basis.*

Problem 1.15 *Write a descriptive account of the Shewhart Quality Monitor.*

Solution. Walter Shewhart developed a quality control model which completely altered the nature of industrial quality performance. The primary component of this model is a monitor which is able to determine whether or not a stable system exists. The Shewhart model monitors a process to determine whether or not the system is regularly meeting expectations ; delivering the specified outcome whithin the expected range of variation ; and achieving the manager's objectives while maintaining a stable process.

In essence, the monitor distinguishes between the many, small random factors that perturb but cannot be removed from a system and the relatively large causal factors which are called *assignable causes of variation*. Something can and must be done about assignable causes since they are both unwanted and identifiable. The Shewhart nonitor, using the methodology of *statistical quality control* can tell us that something seems to be changing ; that the system no longer appears to be following an established (stable) pattern. This is very vital information. Figure. 1.2 locates the Shewhart monitor within the flows of the control system.

Assignable causes of variation are disturbances that can enter the system and remain undetected until large penalties have to be paid for the poor quality of production that has occurred. The Shewhart control monitor is designed to recognize that such assignable disturbances have occurred once spotted, assignable casues ordinarily can be removed. At the same time, other causes of variation exist in almost all systems and nothing can be done about them. They are called *chance causes of variation* which can neither be discarded nor removed. Chance causes arise from so many infinitesimal sources that even if a few were found and something done about them, the overall effect would be negligible. It is vital that the quality control engineer be able to separate the two types of causes of variation and not confuse or lump them together.

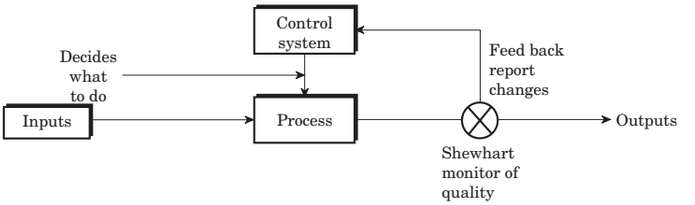

FIGURE 1.2 Shewhart monitor whithin the flows of the control system.

The Shewhart model establishes a procedure for determining whether the variation that is observed is as small as it can be. That is, whether the observed variability is the result only of chance causes factors or whether there is trouble in the system about which something can be done. This control monitor provides differentiation between types of disturbances. It is expected that the output of a determinate machine will produce a stable set of characteristics in the product. But various things can happen. A tool can shift position. The quality of material that is being worked on can change.

Shewhart proposed the notion that by measuring a *sequence* of outputs in terms of a specified characteristic, it would be possible to derive *control limits* that describe the range of process behaviours that *should* be expected *if* the process were stable. As long as the observed values fall within the control limits and do so *without discernible patterns,* no disturbance to the system is believed to have occurred. Thus, as long as the measurements of outputs produced by the system fall between the limits and give evidence of purely random behaviour, the process is called *stable*. When the observed results no longer appear to be random, one test of which is that they fall outside the limits then the system is termed *out* of *control* and technical or managerial action is called for.

A pertinent aspect of statistical control is the fact that *many* production systems, when they are first translated from design to practice and monitored by the Shewart control model are revealed to be out of control. By making judicious changes in the *system's design*, the process can be brought gradually under control. Thereafter, it can be monitored for new disturbances that might enter the system.

Problem 1.16 *Some of the commonly encountered criticisms of quality control are :*

1. *Quality control reduces engineering limits, i.e. the working tolerances.*
2. *Production is slowed down, by stopping jobs that are according to drawing.*
3. *Statistics must be kept involving time and paper.*
4. *Overheads are increased by spending time and money in measuring parts whose dimensions are within the specified limits.*

Are these objections justified ? Why or why not ?

Solution. *Objection 1* is by far the most common and arises quite clearly from a misconception as to the relation between control limits and engineering limits. The fact that the former lie inside the latter in no way means that the production process is being controlled within narrower working limits, for these two sets of limits are not directly comparable. The control limits apply only to the *average value* of the several measurement comprising the patrol inspector's "sample". As long as successive samples average fall inside their control limits—the criterion of a stable

process level—the corresponding *individual* measurements will fall inside certain other limits which define the inherent precision of the production process. It is these latter limits, and not the former, which are directly comparable with the tolerance or engineering limits. They are the so-called *stability limits* for the product and are, in fact, the "limits of accuracy" inherent in production process. The point to bear in mind in interpreting the control charts ($\bar{X}$ and R) is, then, that the *control limits connot be referred directly to the engineering limits,* for these two sets of limits relate to two differect kinds of dimensional values. They can only be compared through "Relative Precision Index" (R.P.I).

Objection 2 attacks the basic operational principle of the control chart as means for taking corrective action *before* nonconforming items are produced. It is likewise founded on the misconception that control limits are merely "narrower working limits", and that a point on the control chart falling inside the engineering limits thus represents a "job that is according to drawing".

Objections 3 and *4* are readily met by pointing out that any system of practical and permanent value requires paper work as well as time and money spent in running it. One does not object on that score to production control or stock control systems—so why object to a quality control system ? Provided such a system pays for itself by reducing scrap and rejected parts, why should it not be introduced into inspection.

Problem 1.17 *(a) How would you answer an operator who said that 'quality is the inspector's reponsibility'?*

(b) How far it can be said that quality is everybody's business ? Do you agree with this concept?

Solution. (*a*) An inspection can only measure work to see whether or not it is right. No amount of inspection will put right that which an operator has incorrectly made.

(*b*) After giving due considerations to the consumer's requirements, the design of the product will go to the production planners, where the following will probably take place.

1. The design will be examined for any obvious inconsistencies.
2. The sequence of operations will be decided, and for each :

(*i*) a detailed method will be prepared,

(*ii*) any special jigs or other equipment will be designed, manufactured and checked,

(*iii*) machines and other process equipment will be specified and made available,

(*iv*) supplies of raw materials will be arranged,

(*v*) supervisor will obtain and train suitable operators.

When all is ready, the job will be loaded onto the workshops for the manufacture of each operation in turn. This will inevitably involve a large number of operators, inspectors, supervisors etc. Indeed practically everyone in a company contributes in some way to the quality produced, so that it is often said that 'quality is every body's business'.

Whilst this concept is perfectly true, it does present difficulties. If quality is everybody's business, there is a real risk that it will become nobody's reponsibility. To offset this, the present day practice is to employ someone to coordinate the quality effort. His title may be quality manager or chief inspector etc. and the department he controls may be called the quality assurance department, quality control department or inspection department.

Problem 1.18 *(a) Who do you consider really sets the quality standard ? Is it the inspector, designer or someone else ?*

(b) A production engineer once remarked, "It is no good trying to set quality standards for everythings, we expect our operators to use their common sense". How would you have answered him ?

(c) a company produced a component made of soft rubber, in which the drawing called for a hole 0.100 ± 0.001 inch in diameter. This was checked with a plug gauge, but there were endless arguments between the operators and inspection. Discuss why this might be, and what should be done about it.

Solution. (*a*) In principle, the consumer sets the quality standard. The designer merely interprets the consumer's requirements into manufacturing drawings and specifications.

(*b*) In order to keep a check, some sort of quality standard is almost always better than no standard at all.

(*c*) Soft rubber probably will not hold tolerances as tight as this, especially to check with a plug gauge, so that the result depends on how much pressure the inspection uses. If tolerance as tight as this are really necessary, then a method of measurement must be found which does not deform the rubber.

Problem 1.19 *Discuss in detail some benefits of statistical quality control.*

Solution. Statistical quality control is one of the tools of quality management. It has manufacturing as well as non-manufacturing benefits.

Throughout the ages the business man has sought to out do his competitors. He has found that one the most successful ways of doing this is to increase the value of the ratio :

Quality / Cost

This is done by offering better quality at the same cost, by offering the same quality at a lower cost or by both raising the quality and lowering the cost.

Although most people realize that there is such a thing as quality variation, few appreciate the nature of such variations or how to evaluate them. It is the purpose of SQC to provide a basis for a better understanding of the variations that exist in quality characteristics and to help directly or indirectly to improve quality or to lower costs, or both. With respect to quality, the SQC techniques help to achieve a better quality level and better uniformity of quality. With respect to costs they help to achieve better utilization of raw materials, more efficient utilizations of equipment, and less scrap and rework. In addition, they help to achieve better inspection, improved producer-consumer relations and better specifications. It is difficult to place these advantages in discrete categories ; hence the above classification is primarily one of convenience. It is better to consider these items individually.

Better quality level At one time or another virtually everyone has computed an average, the common method being to add the separate items and divide by the number of items. The layman is generally inclined to accept this figure as costituting all he needs to know about the quality level. While in some cases this may be so, there are times when it will be very inadequate.

Specifications of measurable quality characteristic generally state one of three things : (*a*) an aimed-at value with plus and minus tolerance, (*b*) a maximum value only, (*c*) a minimum

value only. If a tolerance band is specified, the aimed-at value is usually in the centre of the band *e.g.* 1.055 ± 0.001 in. Sometimes we encounter lop-sided tolerances, *e.g.* $1.052 + 0.001 ; - 0.002$ in. These immediately raise the question whether it is possible to aimed away from the centre of the band and still not exceed either tolerance limit. Unless the band is wider than that resulting from chance fluctuations or the distribution of the quality characteristic markedly lopsided, such specifications are unrealistic.

If the aimed-at is at the centre of the tolerance, we are faced with the question of whether we must hold closely to the aimed-at value. If it is possible to let the quality level fluctuate to some exent, how far can such fluctuations go before the danger of producing nonconforming items arises ? A statistical analysis will provide us with the basis for answering this question.

The mere fact that the average of recently producd items lies at the centre of the tolerance band (or at some other desired point) is not enough in itself. Only if virtually all items fall within the band and *if we can reasonably expect them to do so in the immediate future* is the situation a healthy one. Only if the process is controlled, *i.e.* if such fluctuations as occur are due to chance factors and not to identifiable and economically removable causes, and the level is satifactory, we can be satisfied with the process.

In only one tolerance limit is stated. *e.g.*, 6,500 kg/cm^2 or 0.050% sulphur maximum, the problem becomes one of how closely the quality level may be permitted to approach the limit. To keep the quality level a great distance away is usually costly. To let it approach too close means the production of nonconforming items. Statistical methods provide a means of arriving at the best answer.

Better uniformity of quality As recently as about 200 years ago it was believed that many items could be made exactly alike if sufficient care was taken in the manufacturing process. Not until many years later was it realised that exact duplication of anything is impossible, and that certain amount of fluctuation in any quality characteristic is inherent. As long as this variation is such that no assignable causes can be economically identified the opeation is said to be statistically controlled.

In general, manufacturers would probably like to make statistically controlled products, but it is safe to say that many of them today are undoubtedly issuing relatively uncontrolled products. In a few rare cases, the product may be found to be more uniform than is needed to function satisfactorily. Where such uniformity is costly to obtain (and it usually is), it is economically wasteful.

Better utilization of raw materials Where more than one source of raw materials is available, statistical methods provide the most effective means or determining the relative merits of each source. Where the costs associate with each source are essentially the same, the source(s) that will provide suitable quality levels and suitable uniformity may be identified. Where costs differ appreciably, quality and costs may be balanced to obtain the most economical results.

More efficient use of equipment Several machines may presumbly be alike, yet vary considerably in the quality of the product they turn out. The prompt identification of machines needing repair or adjustment may be an importment step in keeping a mass production system flowing smoothly. A control chart on each machine will promptly identify a machine needing attention.

Records of the inherent presision of each of several machines available to do a certain type of job will permit the most efficient selection of the right machine--a machine capable of meeting the precision required without waste of precision ability. A statistical analysis offers the best evaluation of a machine's capabilities.

Less scrap and rework The proper way to make most products is to make them right the first time. Unless the tolerances are very wide, this will be impossible in a process that is not operating in a statistically controlled manner. As control is gradually achieved through the identification and elimination or control of assignable causes, nonconforming work will decrease. To realize their full potentialities, modern mass prodcution industries must be operated in a statistically controlled manner. It is the only way to avoid a constantly recurring scrap and rework problem.

Better inspection The primary purpose of inspection is to determine the existing state of quality with a view to acceptance or rejection. Inspection procedures may be placed in three general classification more than 100 percent inspection, 100 percent inspection, and sampling inspection.

The fact that some critical quality characteristics are inspected two or more times on each item is an obvious admission that so called 100 percent inspection is not perfect. In general, good 100 percent inspection may be expected to eliminate only 85 to 95 percent of the nonconforming items.

If the test method is destructive or is costly to perform, sampling inspection is used. The sampling plans that most readily suggest themselves to the layman (*e.g.*inspect ten items and allow no defectives, or inspect 10 percent of the product and allow some stated small number of defectives) rarely accomplish their intended purpose. Sampling theory has so many ramifications that the advice of statistician familiar with the nature of sampling variation should always be sought before putting a sampling plan into effect.

In connection with the general subject of inspection, it should be remembered that quality cannot be inspected into a product : it must result from the manufacturing process.

Improved producer-consumer relations When a manufacturer plans to use semi-finished or finished parts supplied by a vendor as part of his raw materials, he generally assumes that the materials supplied will be essentially constant in its quality characteristics. When it is not, the manufacturing schedule may be seriously disrupted. Lack of an adequate apprasial of quality may make claims adjustments difficult.

If the vendor brings his process under statistical quality control, and can produce the evidence to show that his product is satisfactory, he is less likely to get claims and is in a position to refute unjust claims. Similarly, the consumer who can produce statistical evidence establishing lack of control is more likely to get proper attention from the vendor. When both vendor and consumer have an adequate apraisal of product quality, relationships are almost certain to improve. Statistical methods offer the best way of getting such appraisals and it is for this reason that they find an important place in ISO 9000/IS: 14000 standards.

The consuming public also expects uniformity in the products it buys. Only as such uniformity is found, the producer establishs a reputation for dependability.

Better specifications The general subject of specifications involves so many ramifications that we shall only attempt to touch lightly on some of the statistical implications. In writing

specifications, it is now generally recognised that tolerance limits must be placed upon measurable quality characteristics. These tolerance limits must be reconciled with actual needs and ability to produce. There is no use in specifying a closer tolerance than is needed or than can be produced. Statistical methods offer the best way of appraising the potentialities of a process so that in turn specifications may be written more realistically and practically.

Problem 1.20 *How quality has beneficial effect on profit ?*

Solution. There are many benefits of high quality or quality improvement. All these benefits ultimately lead to higher profit thorough different routes as depicted in Fig. 1.3.

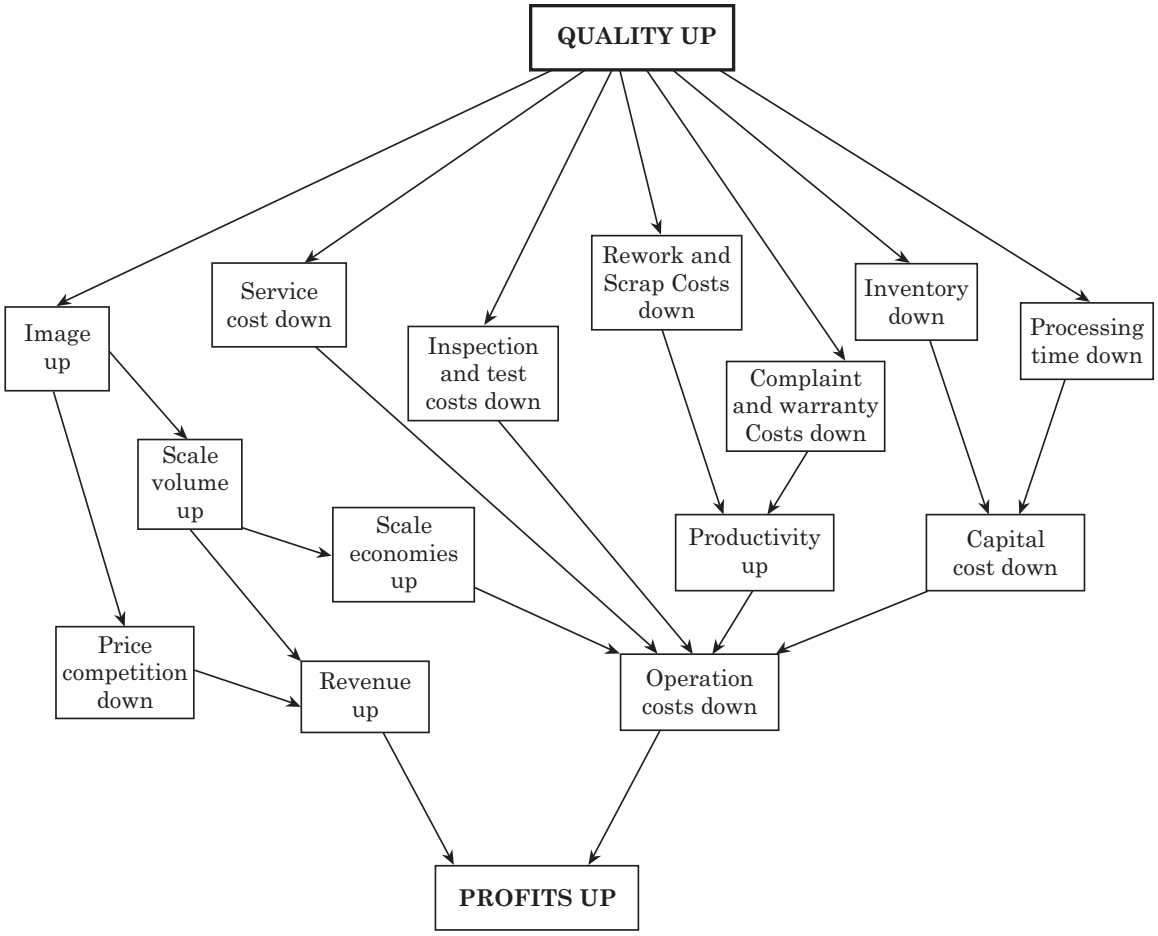

FIGURE 1.3 Benefits of quality on profit.

PROBLEMS

1-1 What do you understand by statistical quality control (SQC) ? Briefly mention its usefulness in large manufacturing industries.

1-2 When is a manufacturing process said to be in a state of statistical control ?

1-3 Describe briefly your understanding of the term "quality".

1-4 If a company maintains a good quality programme will this ensure high reliability of its products ? Why ?

1-5 Explain clearly why SQC is more applicable in a mass production industry.

1-6 "SQC sometimes does not workout in practice quite the way it is supposed to." How does it work? Is what happens good ? Explain.

1-7 "Quality control is attained most efficiently, of course not by the inspection operation itself but by getting at the causes." Comment on the statement. Describe the various devices employed for the maintenance of quality in a uniform flow of manufactured product.

1-8 What are the objectives of statistical quality control ?

1-9 What is the difference between "assignable causes" and "chance causes" ? What is the significance of this difference in statistical quality control ? How will these causes be identified in practice ?

1-10 Describe briefly some by-product applications of statistical quality control.

1-11 Describe some limitations of statistical quality control.

1-12 Define briefly the following: (*a*) Control (*b*) Quality Control (*c*) Statistical Quality control
[**Hint:** (*a*) ***Control*** is the totality of all means whereby we establish and achieve a standard of performance. (*b*) ***Quality control*** is the totality of all means whereby we establish and achieve a quality specification. (*c*) ***Statistical quality control*** is that part of the means for establishing and achieving a quality specification, which requires use of the tools of statistics.]

1-13 Can quality control exist without feedback? How about quantity control ? Explain your answer.

1-14 Discuss some of the statistical tools for quality control.

1-15 "Quality control is primarily the responsibility of the operators themselves" Do you believe this statement to be true? Why or why not ?

1-16 To you personally what is "quality"? What does it mean to (*a*) the man-on-the street, and (*b*) the manufacturer ?

1-17 Discuss the need for SQC. Who is credited with the introduction of
(*a*) Statistical Control Charts
(*b*) Sampling inspection tables.
[**Hint :** (*a*) Shewhart (*b*) Dodge and Romig.]

1-18 Distinguish between usual or chance variation and unusual or assignable variation, in respect of quality control.
(*a*) What two possible causes may variablity in products be attributed to ? (*b*) Discuss the two causes of variability.

1-19 How can free communication between the quality control engineer and the planning engineer help the latter to plan production?

1-20 Show how a statistical presentation of the inspection records may help to reduce costs.

1-21 Explain some benefits of using SQC tools.

1-22 "Quality" cannot be inspected into a product nor can it be advertised in, it must be designed and built in. Discuss.

1-23 It has been argued that the definition of product quality as "fitness for intended purpose" is more likely to lead to commercial success than is a definition such as "conformance to specification". Discuss the implication of these alternative definitions for the quality control function within a manufacturing enterprise.

1-24 'Quality is free!' proclaimed the title of Philip Crosby's book in the 1970s. In what ways can investments in developing quality management in the business pay for themselves and make a difference to the overall bottom level of the company?

1-25 What does quality matter to business?

1-26 (*a*) Explain what is meat by 'quality'.
(*b*) Explain briefly why quality control is so important in modern manufaturing industries.

1-27 Explain briefly why record keeping is essential to a quality control system.

1-28 Briefly describe what is meant by 'quality assurance' and explain how it can be achieved.

1-29 List use main advantages of a "right first time" policy

1-30 "Quality management is sometimes over engineered".

1-31 Explain why statistical process control is an important concept for managing quality.