Quality Control

Chapter 1

Quality Improvement in the Modern Business Environment

1-1. The Meaning of Quality and Quality Improvement

1-1.1 Dimensions of Quality

1-1.2 Quality Engineering Technology

We may define **quality** in many ways. Most people have a conceptual understanding of quality as relating to one or more desirable characteristics that a product or service should possess. Although this conceptual understanding is certainly a useful starting point, we will give a more precise and useful definition.

1-1.1 Dimensions of Quality

The quality of a product can be described and evaluated in several ways. Garvin (1987) provides an excellent discussion of **8** components or dimensions of quality.

- Performance
- Reliability
- Durability
- Serviceability
- Aesthetics
- Features
- Perceived Quality
- Conformance to standards


3. Durability
4.Serviceability
2. Reliability
5.Aesthetics
8 Dimensions of Quality
1.Performance
6.Features
8.Conformance to Standards
7.Perceived Quality

Performance

- Will the product perform its intended job?

Potential customers usually evaluate a product to determine if it will perform certain specific functions and determine how well it performs them.

Example

– Evaluate software spreadsheet packages. One outperform another with respect to the execution speed

Reliability

- How often does the product fail?

Complex products, such as many appliances, automobiles, or airplanes, will usually require some repair over their service life.

Example

– You should expect that a machine will require occasional repair, but if the machine requires frequent repair, we say that it is unreliable.

Durability

- How long does the product last?
  - This is the effective service life of the product. The product should perform satisfactorily over a long period of life

Example

- *Major appliance industries are examples of businesses where this dimension of quality is very important to most customers.*

Serviceability

- How easy is it to repair the product?

There are many industries in which the customer's view of quality is directly influenced by how quickly and economically a repair or routine maintenance activity can be accomplished.

Example

- If a company sends the wrong spare part, how hard is it to get this error corrected?
- How long did it take a credit card company to correct an error in your bill?

Aesthetics

- What does the product look like?

This is the visual appeal of the product, often taking into account factors such as style, color, shape, packaging alternatives, tactile characteristics, and other sensory features.

Example

  – Soft-drink beverage manufacturers have relied on the visual appeal of their packaging to differentiate their product from other competitors.

Features

- What will the product do beyond the basics?

Usually, customers associate high quality with products that have added features; that is, those that have features beyond the basic performance of the competition.

Example

  – Spreadsheet software package that has built in statistical analysis features

Perceived quality

- What is the reputation of the company selling this product?

Customers rely on the past reputation of the company concerning quality of its products. This reputation is directly influenced by failures of the product that are highly visible to the public or that require product recalls, and by how the customer is treated when a quality-related problem with the product is reported.

Example

– *Prefer to buy products from a particular company : goods always arrive on time with no damage, good quality of their products, etc…*

Conformance to standards

- Is the product made exactly as the designer intended?

We usually think of a high-quality product as one that exactly meets the requirements placed on it.

Example

  - How well does the hood fit on a new car? Is it perfectly flush with the fender height, and is the gap exactly the same on all sides?

Manufactured parts that do not exactly meet the designer's requirements can cause significant quality problems when they are used as the components of a more complex assembly.

1-1.1 Dimensions of Quality

- **Definitions of Quality**

The **traditional** definition of quality is based on the viewpoint that products and services must meet the requirements of those who use them.

Quality means fitness for use

- quality of design
- quality of conformance

Quality is inversely proportional to variability.

Quality of design

- All goods and services are produced in various grades or levels of quality. These variations in grades or levels of quality are intentional, and, consequently, the appropriate technical term is quality of design.

Example

All automobiles have as their basic objective providing safe transportation for the consumer. However, automobiles differ with respect to size, appointments, appearance, and performance. These design differences include :

- Materials used in construction
- Specifications of the components
- Reliability of drive train components
- Reliability of accessories

Quality of conformance

- How well does the product conform to the specifications required by the design?
- Quality of conformance is influenced by
  - Choice of manufacturing processes
  - Training of the workers
  - Supervision of the workers
  - Motivation of the workers
  - Quality-assurance procedures that were used

Quality is inversely proportional to variability

Note that this definition implies that if variability in the important characteristics of a product decreases, the quality of the product increases (harmful variability)

In Statistics, Variability is a measure of how spread out the data are from the mean.

Variability means the tendency to shift or change of being "variable. We need to reduce the **variation** around the target. That means, it is very basic that process limits are within the spec limits and process average is very close to the target.

"Quality" concept should be AFTER the above condition. If that's so, strive should be reduce the variation of the process while maintaining the process average close to the target.

Quality is inversely proportional to variability

Example

A comparative study of a transmission

- Toyota versus Ford
  - That transmission noise (or lack of it) is wasted energy caused by components that don't fit precisely
  - Imprecise components lead to wear and tear

1-1.1 Dimensions of Quality – Transmission Example

takes up about 75% (for US product) and 25 % (for Japanese product) of the width of the specifications,

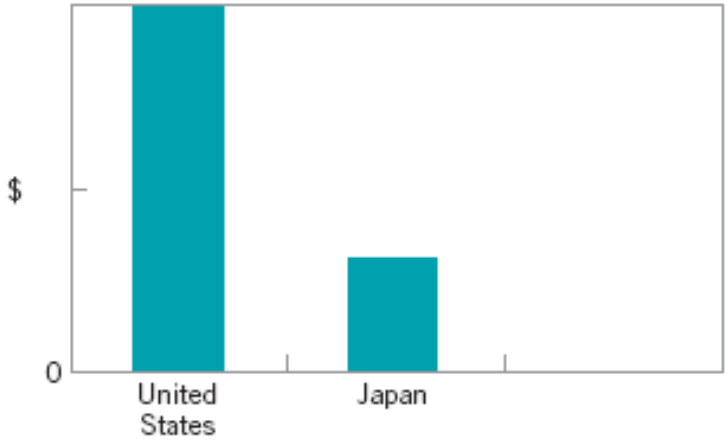


FIGURE 1.1 Warranty costs for transmissions.

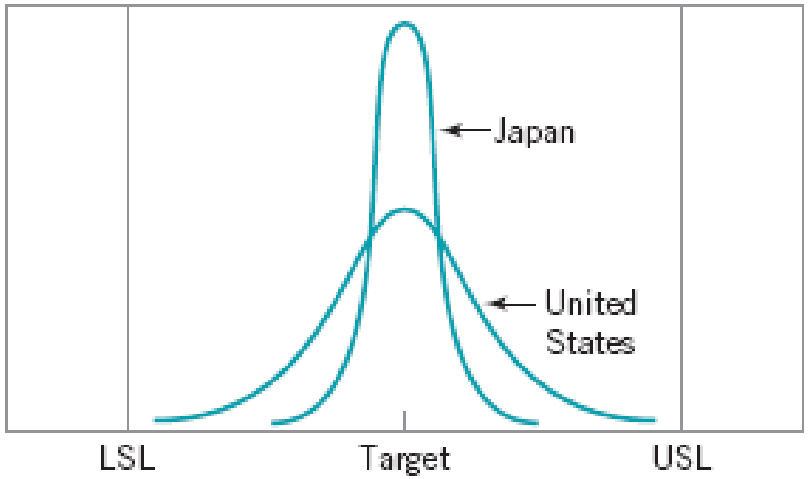


FIGURE 1.2 Distributions of critical dimensions for transmissions.

Your customer does not see the mean of your process, he only sees the variability around that target that you have not removed

Why did the Japanese do this? How did they do this?

The answer to the "why" question is obvious from examination of Fig. 1.1. Reduced variability has directly translated into lower costs.
Furthermore, the Japanese-built transmissions shifted gears more smoothly, ran more quietly, and were generally perceived by the customer as superior to those built in the US. Fewer repairs and warranty claims means less **rework** and the reduction of wasted time, effort, and money. Thus, quality truly is inversely proportional to variability.

How did the Japanese do this? The answer lies in the systematic and effective use of the methods described in this course. It also leads to the following definition of **quality improvement.**

1-1.1 Dimensions of Quality

- **Quality Improvement**

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

Excessive variability in process performance often results in **waste.** For example, consider the wasted money, time, and effort that is associated with the repairs represented in Fig. 1.1.

Alternatively, ***quality improvement*** is also seen as "waste reduction."

1-1.1 Dimensions of Quality

This definition is particularly effective in **service industries,** where there may not be as many things that can be directly measured (like the transmission critical dimensions in Fig. 1.2). In service industries, a quality problem may be an error or a mistake, the correction of which requires effort and expense. By improving the service process, this wasted effort and expense can be avoided.

1-1.2 Quality Engineering Terminology

Every product possesses a number of elements that jointly describe what the user or consumer thinks of as quality. These parameters are often called **Quality Characteristics.** Sometimes these are called **critical-to-quality (CTQ)** characteristics. Quality characteristics may be of several types:

- **Physical -** length, weight, voltage, viscosity
- **Sensory -** taste, appearance, color
- **Time Orientation -** reliability, durability, serviceability

Quality characteristics can relate directly or indirectly to the dimensions of quality discussed in the previous section.

1-1.2 Quality Engineering Terminology

Quality engineering is the set of operational, managerial, and engineering activities that a company uses to ensure that the quality characteristics of a product are at the nominal or required levels.

Most organizations find it difficult (and expensive) to provide the customer with products that have quality characteristics that are always identical from unit to unit, or are at levels that match customer expectations.

Major reason: **VARIABILITY**

There is a certain amount of variability in every product; consequently, no two products are ever identical.

- No two products are ever identical
  - Slight differences in materials
  - Slight differences in machine settings
  - Slight differences in operators
  - Slight differences in ambient temperature during production

Example
The thickness of the blades on a jet turbine engine impeller. If the variation is large, then the customer may perceive the unit to be undesirable and unacceptable.

1-1.2 Quality Engineering Terminology

Since variability can only be described in statistical terms, **statistical methods** play a central role in quality improvement efforts.

Two types of data:

Attributes Data - discrete data, often in the form of counts

Variables Data - continuous measurements such as length, weight

Both types will be discussed in the course

1-1.2 Quality Engineering Terminology

Specifications

For a manufactured product, the specifications are the desired measurements for the quality characteristics of the components and subassemblies that make up the product, as well as the desired values for the quality characteristics in the final product.

Example: the diameter of a shaft used in an automobile transmission cannot be too large or it will not fit into the mating bearing, nor can it be too small, resulting in a loose fit, causing vibration, wear, and early failure of the assembly.

1-1.2 Quality Engineering Terminology

In the service industries, specifications are typically in terms of the maximum amount of time to process an order or to provide a particular service.

Specifications

Nominal or target value

A value of a measurement that corresponds to the desired value for that quality characteristic

1-1.2 Quality Engineering Terminology

Specifications

These target values are usually bounded by a range of values that, most typically, we believe will be sufficiently close to the target so as to not impact the function or performance of the product if the quality characteristic is in that range:

- Upper Specification Limit (USL)
- Lower Specification Limit (LSL)
  - Largest and smallest allowable values

1-1.2 Quality Engineering Terminology

Specifications

- Upper Specification Limit (USL)
- Lower Specification Limit (LSL)

  – One-sided
    - The compression strength of a Coke bottle must be greater than a given psi value

  – Two-sided
    - The weight of potato chips in the bag can be between 7.8 and 8.3 ounces

1-1.2 Quality Engineering Terminology

- When a component or product does not meet specifications, it is considered to be ***nonconforming***.

- A nonconforming product is considered ***defective*** if it has one or more ***nonconformities*** that may seriously affect the safe or effective use of the product.

1.3 Statistical Methods for Quality Control and Improvement

Three major areas:

1-Statistical Process Control (SPC)

2-Design of experiments

3-Acceptance sampling

General model of a process or system

In the case of a manufacturing process, the controllable input factors $x1, x2, \ldots, xp$ are process variable such as temperatures, pressures, feed rates, and other process variables. The inputs $z1, z2, \ldots, zq$ are uncontrollable (or difficult to control) inputs, such as environmental factors or properties of raw materials provided by an external supplier. The production process transforms the input raw materials, component parts, and subassemblies into a finished product that has several quality characteristics. The output variable y is a quality characteristic, that is, a measure of process and product quality.

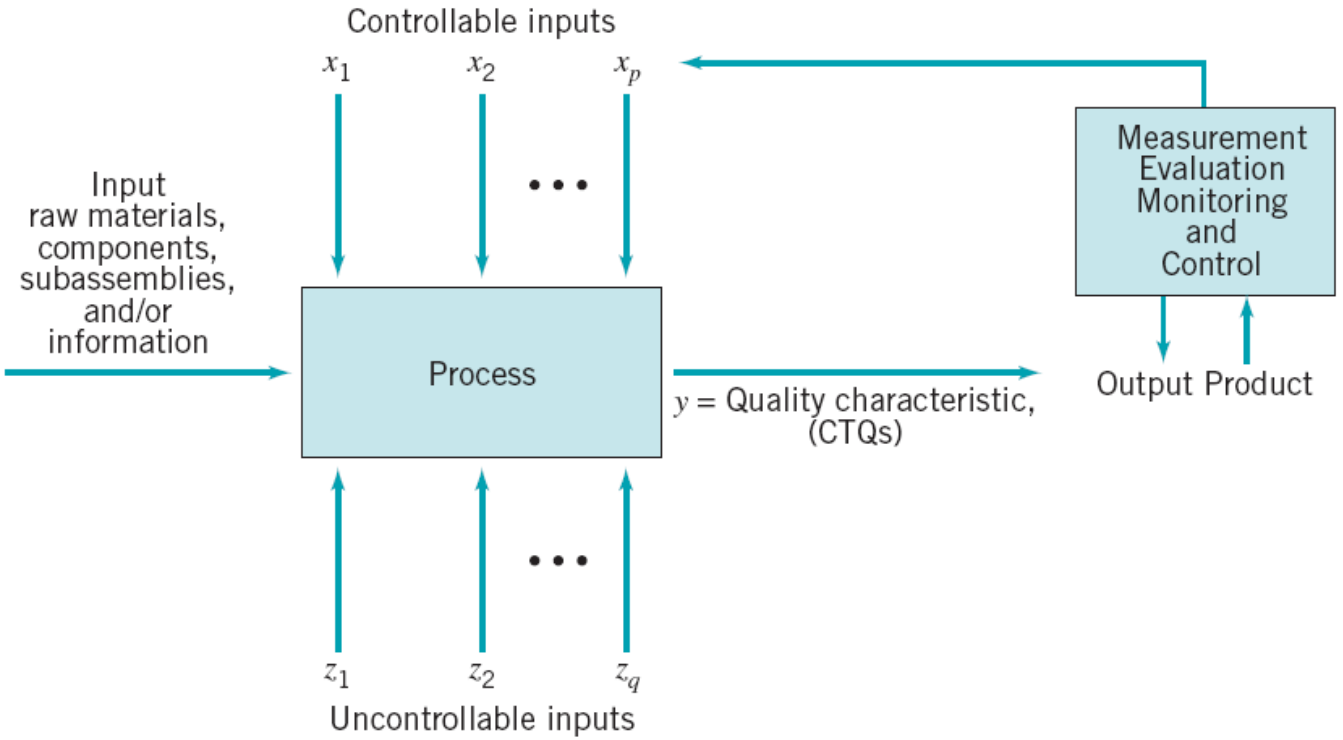


FIGURE 1.3 Production process inputs and outputs.

Example : Process in a financial institution that processes automobile loan applications.

The inputs: the loan applications, which contain information about the customer and his/her credit history, the type of car to be purchased, its price, and the loan amount.

The controllable factors are the type of training that the loan officer receives, the specific rules and policies that the bank imposed on these loans, and the number of people working as loan officers at each time period.

The uncontrollable factors include prevailing interest rates, the amount of capital available for these types of loans in each time period, and the number of loan applications that require processing each period.

The output quality characteristics include whether or not the loan is funded, the number of funded loans that are actually accepted by the applicant, and the cycle time; that is, the length of time that the customer waits until a decision on his/her loan application is made.

In service systems, cycle time is often a very important CTQ.

Statistical process control (SPC)

A method of quality **control** which uses statistical methods. SPC is applied in order to monitor and **control** a **process**. Monitoring and controlling the **process** ensures that it operates at its full potential.

- Control charts, plus other problem-solving tools
- Useful in monitoring processes, reducing variability through elimination of assignable causes

Control Chart

A **control chart** is one of the primary techniques of **statistical process control** (**SPC).** It is a graph used to study how a process changes over time. Data are plotted in time order.

A control chart always has a central line (CL) for the average, an upper line for the upper **control** limit and a lower line for the lower **control** limit. The center line represents where this process characteristic should fall if there are no unusual sources of variability present. The control limits are determined from some simple statistical considerations (historical data) that will be discussed

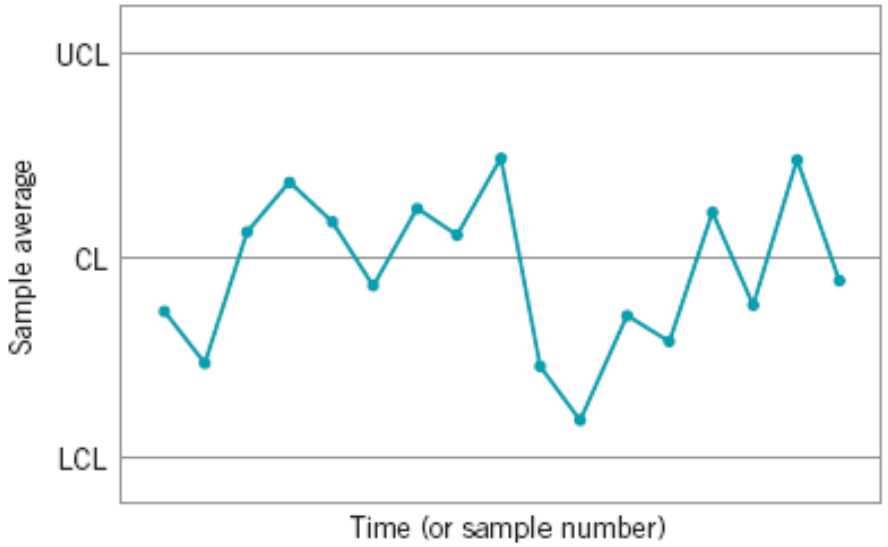


FIGURE 1.4 A typical control chart.

Shewhart charts (after Walter A. Shewhart) or **process-behavior charts**

The control chart is a very useful **process monitoring technique;** when unusual sources of variability are present, sample averages will plot outside the control limits. This is a signal that some investigation of the process should be made and corrective action to remove these unusual sources of variability taken. Systematic use of a control chart is an excellent way to reduce variability.

Designed experiments

Design of Experiments (DOE or DOX) is an approach to systematically varying the controllable input factors in the process then determining the effect these factors have on the output responses.

- Discovering the key factors that influence process performance
- Process optimization

Designed experiments are a major **off-line** quality-control tool, because they are often used during development activities and the early stages of manufacturing, rather than as a routine **on-line** or **in-process** procedure

- The objectives of an experiment may include Determining:
  1. which variables are most influential on the response y
  2. where to set the influential x's so that y is almost always near the desired nominal
  3. where to set the influential x's so that variability in y is small
  4. where to set the influential x's so that the effects of the uncontrollable variables $z_1, z_2, \ldots, z_q$ are minimized

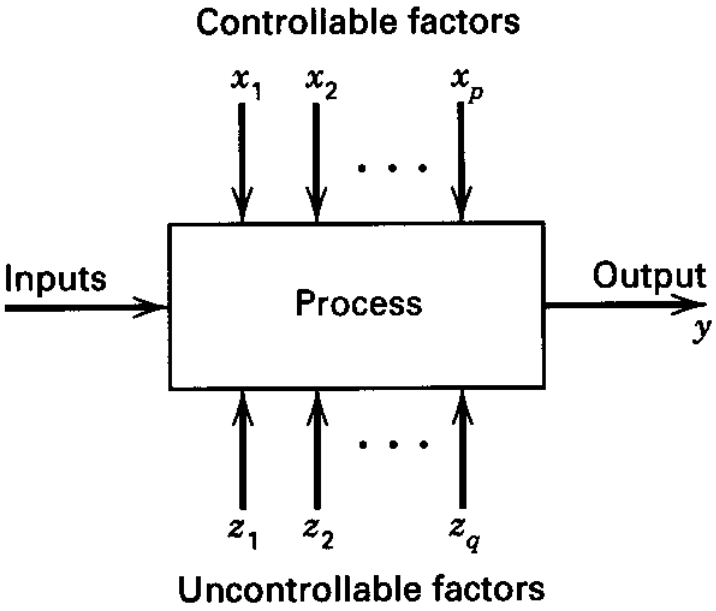


Figure 1-1 General model of a process or system.

Benefits of DOE

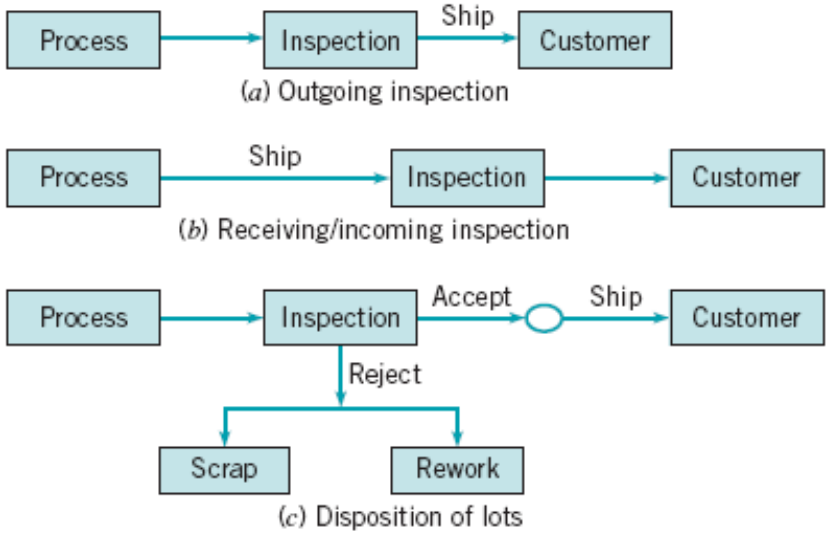
(Design of experiments)

- Reduce **time** to design/develop new products & processes
- Improve **performance** of existing processes
- Improve **reliability** and performance of products
- Achieve product & process **robustness**
- **Evaluation** of materials, design alternatives, **setting** component & system tolerances, etc.

Acceptance Sampling

Acceptance sampling is the inspection and classification of a sample of the product selected at random from a larger batch or lot and the ultimate decision about disposition of the lot. usually occurs at two points: incoming raw materials or components, or final production.

Several different variations of acceptance sampling are shown in Fig. 1.6. In Fig. 1.6*a*, the inspection operation is performed immediately following production, before the product is shipped to the customer. This is usually called **outgoing inspection.** Figure 1.6*b* illustrates **incoming inspection;** that is, a situation in which lots of batches of product are sampled as they are received from the supplier. Various lot-dispositioning decisions are illustrated in Fig. 1.6*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 latter case is often called **rectifying inspection.**



■ FIGURE 1.6 Variations of acceptance sampling.

Inspection does not improve the quality, nor guarantee quality. Inspection is too late. The quality, good or bad, is already in the product.

As Harold F. Dodge said,

You cannot inspect Quality into a product

When the organization realizes this, process improvement efforts begin

The objective

- Systematic reduction of variability
  - First, by using acceptance sampling
  - Then, by using SPC
  - Finally, by using DOE

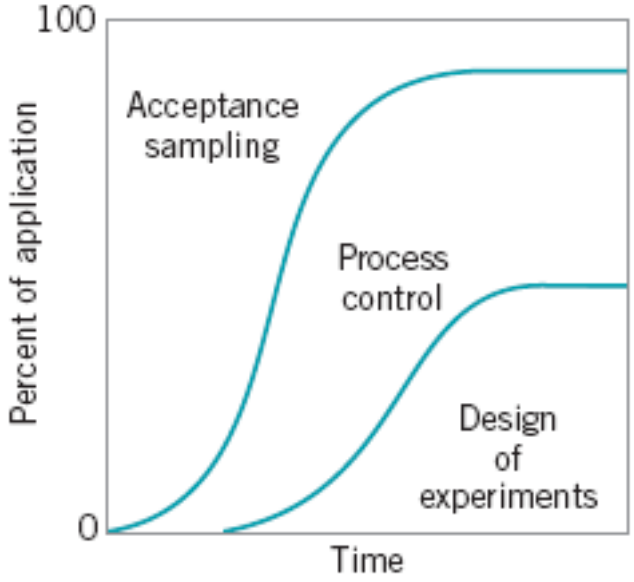


FIGURE 1.7 Phase diagram of the use of quality-engineering methods.

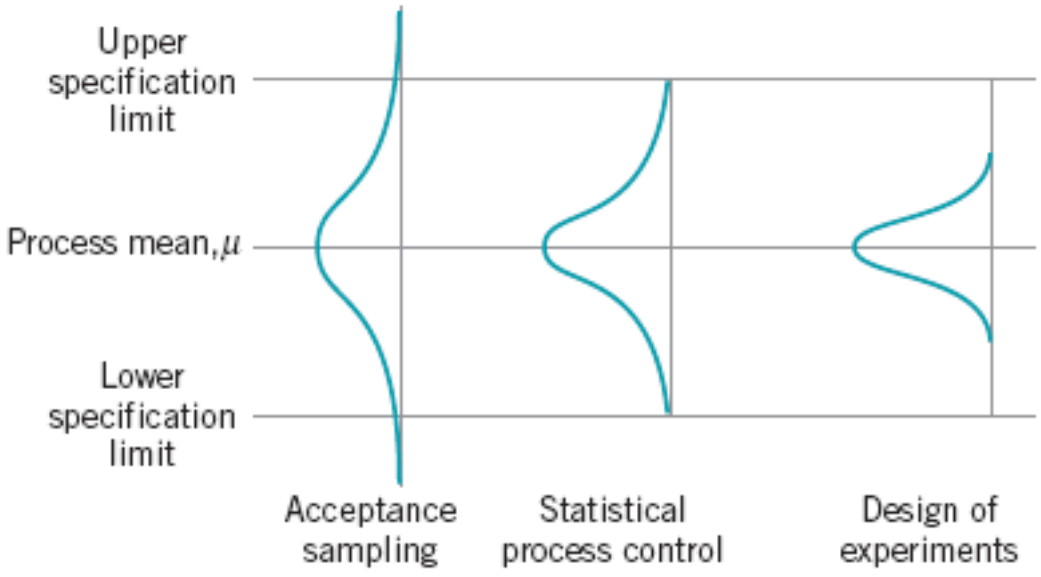


FIGURE 1.8 Application of quality-engineering techniques and the systematic reduction of process variability.

1.4 Management Aspects of Quality Improvement

The management system of an organization must be organized to properly direct the overall quality improvement philosophy and ensure its deployment in all aspects of the business.

Effective management of quality requires the execution of three activities:

1. Quality Planning
2. Quality Assurance
3. Quality Control and Improvement

Quality planning is a strategic activity, and it is just as vital to an organization's long-term business success as the product development plan, the financial plan, the marketing plan, and plans for the utilization of human resources. Without a strategic quality plan, an enormous amount of time, money, and effort will be wasted by the organization dealing with faulty designs, manufacturing defects, field failures, and customer complaints. Quality planning involves identifying customers, both external and those that operate internal to the business, and identifying their needs (this is sometimes called listening to the **voice of the customer**). Then products or services that meet or exceed customer expectations must be developed. The eight dimensions of quality discussed in Section 1-1.1 are an important part of this effort. The organization must then determine how these products and services will be realized. Planning for quality improvement on a specific, systematic basis is also a vital part of this process.

Quality assurance is the set of activities that ensures the quality levels of products and services are properly maintained and that supplier and customer quality issues are properly resolved. Documentation of the quality system is an important component. Quality system documentation involves four components: policy, procedures, work instructions and specifications, and records. Policy generally deals with what is to be done and why, while procedures focus on the methods and personnel that will implement policy. Work instructions and specifications are usually product-, department-, tool-, or machine-oriented. Records are a way of documenting the policies, procedures, and work instructions that have been followed. Records are also used to track specific units or batches of product, so that it can be determined exactly how they were produced. Records are often vital in providing data for dealing with customer complaints, corrective actions, and, if necessary, product recalls. Development, maintenance, and control of documentation are important quality assurance functions. One example of document control is ensuring that specifications and work instructions developed for operating personnel reflect the latest design and engineering changes.

Quality control and improvement involve the set of activities used to ensure that the products and services meet requirements and are improved on a continuous basis. Since variability is often a major source of poor quality, statistical techniques, including SPC and designed experiments, are the major tools of quality control and improvement. Quality improvement is often done on a project-by-project basis and involves teams led by personnel with specialized knowledge of statistical methods and experience in applying them. Projects should be selected so that they have significant business impact and are linked with the overall business goals for quality identified during the planning process. The techniques in this book are integral to successful quality control and improvement.

Why "Quality Improvement" is Important: A Simple Example

- A visit to a fast-food store: Hamburger (bun, meat, special sauce, cheese, pickle, onion, lettuce, tomato), fries, and drink.

- This product has 10 components - is 99% good okay?

$P\{\text{Single meal good}\} = (0.99)^{10} = 0.9044$

Family of four, once a month: $P\{\text{All meals good}\} = (0.9044)^{4} = 0.6690$

$P\{\text{All visits during the year good}\} = (0.6690)^{12} = 0.0080$

$P\{\text{single meal good}\} = (0.999)^{10} = 0.9900, P\{\text{Monthly visit good}\} = (0.99)^{4} = 0.9607$

$P\{\text{All visits in the year good}\} = (0.9607)^{12} = 0.6186$

1.4. Quality Philosophy and Management Strategy

W. Edwards Deming

- Taught engineering, physics in the 1920s, finished PhD in 1928
- Met Walter Shewhart at Western Electric
- Long career in government statistics, USDA, Bureau of the Census
- During WWII, he worked with US defense contractors, deploying statistical methods
- Sent to Japan after WWII to work on the census

Deming's 14 Points

1. Create constancy of purpose toward improvement
2. Adopt a new philosophy, recognize that we are in a time of change, a new economic age
3. Cease reliance on mass inspection to improve quality
4. End the practice of awarding business on the basis of price alone
5. Improve constantly and forever the system of production and service
6. Institute training
7. Improve leadership, recognize that the aim of supervision is help people and equipment to do a better job
8. Drive out fear
9. Break down barriers between departments

14 Points cont'd

10. Eliminate slogans and targets for the workforce such as zero defects
11. Eliminate work standards
12. Remove barriers that rob workers of the right to pride in the quality of their work
13. Institute a vigorous program of education and self-improvement
14. Put everyone to work to accomplish the transformation

Note that the 14 points are about change

1. Create a constancy of purpose

- Focus on the improvement of products and services
- Constantly improve product design and performance
- Invest in R&D
- Innovate

2. Adopt a new philosophy

- Eliminate defective products
  - It costs as much to produce a defective unit as a good one
- Dealing with scrap and rework is very expensive

3. Don’t rely on inspection

- Inspection only sorts out defectives
  - Already have paid to produce them
- Inspection is too late in the process
- It’s also ineffective
- Prevent defectives through process improvement

4. Don’t award business on price alone

- Consider supplier quality as well
  - Give preference to those suppliers that demonstrate process control and process capability

5. Focus on continuous improvement

- Involve the workforce
- Use statistical techniques

6. Invest in training

- Everyone should be trained in the technical aspects of their job, QC, and process improvement
- Workers should be encouraged to put this training to use

7. Practice modern supervision methods

- Help the employees improve the system in which they work

8. Drive out fear

Drive out fear. Many employees are afraid to ask questions or to take a position, even when they do not understand what their job is or what is right or wrong. They will continue to do things the wrong way, or not do them at all. The economic losses from fear are appalling. To assure better quality and productivity, it is necessary that people feel secure. "The only stupid question is the one that is not asked."

9. Break down the barriers

- Break down the barriers between the functional areas of the business
- Only through teamwork can quality and process improvement take place

10. Eliminate targets and slogans

- Useless without a plan for the achievement of the target or goal
- Instead, improve the system and provide information on that

11. Eliminate quotas

- Numerical quotas and work standards often conflict with quality control

Eliminate numerical quotas or work standards. Quotas take into account only numbers, not quality or methods. They are usually a guarantee of inefficiency and high cost. A person, in order to hold a job, will try to meet a quota at any cost, including doing damage to his company.

12. Encourage employees to do their job

- Remove the barriers
- Listen to the workers
- The person doing the job knows more about it than anyone else

13. Have ongoing education and training

- Teach them simple yet powerful statistical techniques
- Use the basic SPC tools, particularly the control chart

14. Involve top management

- Management should be advocates for these points

Take action to accomplish the transformation. It will require a special top management team with a plan of action to carry out the quality mission. Workers cannot do it on their own, nor can managers. A critical mass of people in the company must understand the 14 points.

1-4 Quality Philosophy and Management Strategies

- **Quality Standards and Registration**
  - **ISO 9000**
- **Six Sigma**

Quality Systems and Standards

The International Standards Organization (founded in 1946 in Geneva, Switzerland), known as ISO, has developed a series of standards for quality systems. The first standards were issued in 1987. The current version of the standard is known as the ISO 9000 series. It is a generic standard, broadly applicable to any type of organization, and it is often used to demonstrate a supplier's ability to control its processes. The three standards of ISO 9000 are:

ISO 9000:2000 Quality Management System—Fundamentals and Vocabulary

ISO 9001:2000 Quality Management System—Requirements

ISO 9004:2000 Quality Management System—Guidelines for Performance Improvement

The ISO 9001:2000 standard has eight clauses: (1) Scope, (2) Normative References, (3) Definitions, (4) Quality Management Systems, (5) Management Responsibility, (6) Resource Management, (7) Product (or Service) Realization, and (8) Measurement, Analysis, and Improvement. Clauses 4 through 8 are the most important, and their key components and requirements are shown in Table 1-2. To become certified under the ISO standard, a company must select a **registrar** and prepare for a **certification audit** by this registrar. There is no single independent authority that licenses, regulates, monitors, or qualifies registrars. As we will discuss later, this is a serious problem with the ISO system. Preparing for the certification audit involves many activities, including (usually) an initial or phase I audit that checks the present quality management system against the standard. This is usually followed by establishing teams to ensure that all components of the key clause are developed and implemented, training of personnel, developing applicable documentation, and developing and installing all new components of the quality system that may be required. Then the certification audit takes place. If the company is certified, then periodic **surveillance audits** by the registrar continue, usually on an annual (or perhaps six-month) schedule.

- The ISO certification process focuses heavily on quality assurance, without sufficient weight given to quality planning and quality control and improvement

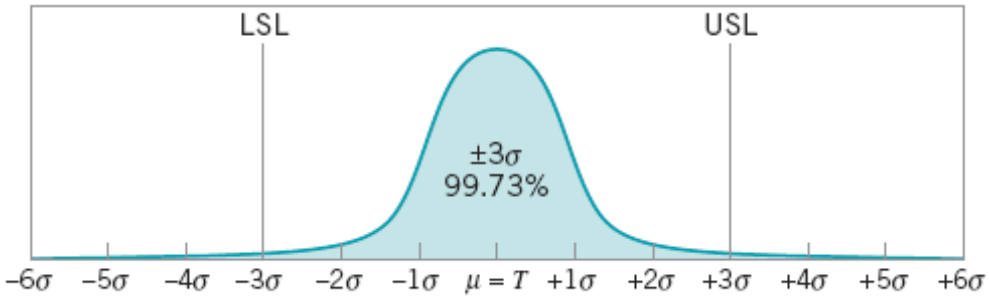
ISO 9000

- Quality system oriented
- Say what you do, do what you say
  - Much effort devoted to paperwork and bookkeeping
  - Not much to reducing variability and improving processes
- US$40 billion annual business worldwide
  - Registrars, auditors, consultants
- Plus, 1000s of hours of internal costs
- Effective?
  - Does it reduce variability?

There is also evidence that ISO certification or certification under one of the other industry-specific standards does little to prevent poor quality products from being designed, manufactured, and delivered to the customer. For example, in 1999–2000, there were numerous incidents of rollover accidents involving Ford Explorer vehicles equipped with Bridgestone/Firestone tires and there were nearly 300 deaths in the United States alone attributed to these accidents, which led to a recall by Bridgestone/Firestone of approximately 6.5 million tires. Apparently, many of the tires involved in these incidents were manufactured at the Bridgestone/Firestone plant in Decatur, Illinois. In an article on this story in *Time* magazine (September 18, 2000), there was a photograph (p. 38) of the sign at the entrance of the Decatur plant which stated that the plant was "QS 9000 Certified" and "ISO 14001 Certified" (ISO 14001 is an environmental standard). Although the assignable causes underlying these incidents have not been fully discovered, there are clear indicators that despite quality systems certification, Bridgestone/Firestone experienced significant quality problems.

Six Sigma

- Motorola developed the **Six-Sigma program** in the late 1980s as a response to the demand for their products. The focus of six-sigma is reducing variability in key product quality characteristics to the level at which failure or defects are extremely unlikely.

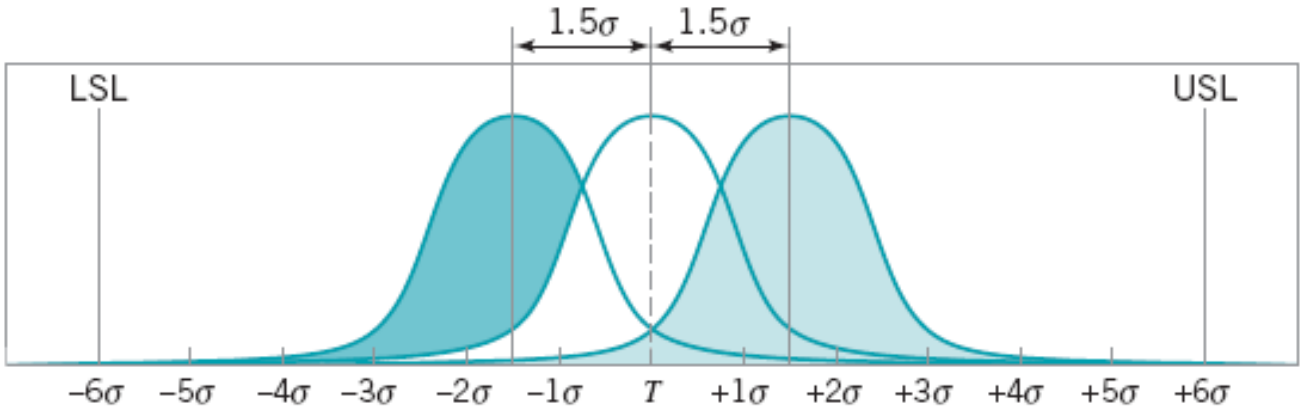


Spec. Limit	Percent Inside Specs	ppm Defective
±1 Sigma	68.27	317300
±2 Sigma	95.45	45500
±3 Sigma	99.73	2700
±4 Sigma	99.9937	63
±5 Sigma	99.999943	0.57
±6 Sigma	99.9999998	0.002

(*a*) Normal distribution centered at the target (*T*)

Figure 1.12*a* shows a normal probability distribution as a model for a quality characteristic with the specification limits at three standard deviations on either side of the mean.

Consider that ± 3s provides 0.00135 in each tail, or 0.00270 in the two tales so, in 1 million parts, 2700 would be defective



Spec. Limit	Percent inside specs	ppm Defective
±1 Sigma	30.23	697700
±2 Sigma	69.13	608700
±3 Sigma	93.32	66810
±4 Sigma	99.3790	6210
±5 Sigma	99.97670	233
±6 Sigma	99.999660	3.4

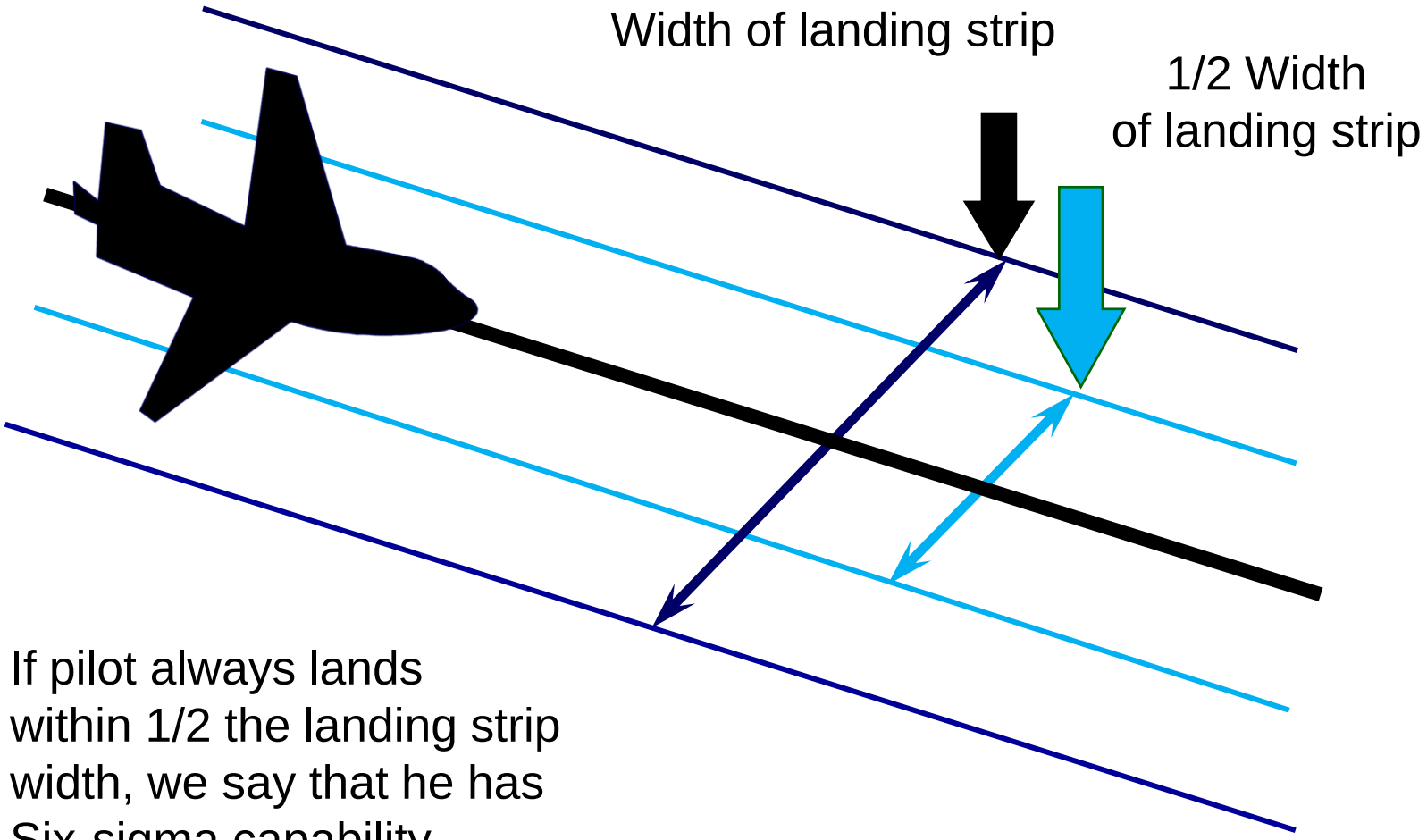
(*b*) Normal distribution with the mean shifted by ±1.5σ from the target

FIGURE 1.12 The Motorola Six-Sigma concept.

Six Sigma

- Consider an assembly of 100 parts that must all function for the assembly to function
  - .9973 x .9973 x …..9973 = $(.9973)^{100}$ = .7631
- Thus, about 23.7% of the products under 3σ will fail
- Not usually an acceptable situation

Pilot's Six-Sigma Performance



If pilot always lands within 1/2 the landing strip width, we say that he has Six-sigma capability.

Six Sigma

- But, $\pm$ 6σ results in 0.999999998 inside specs
  - $(0.999999998)^{100} = .9999998$
  - Or, 2 parts/billion defective
    - i.e., 0.2 ppm
  - Much better than $\pm$ 3σ
- Has moved beyond Motorola
- Has become a method for improving corporate **business performance**
- Companies involved in Six Sigma use teams that work on projects involving quality and costs