

# Introduction to Quality Engineering

## 1.1 QUALITY

### 1.1.1 DEFINITION OF QUALITY

How is **quality** defined? It is interesting to observe how its definition varies according to the particular emphasis of quality activities. Juran (1964) defines quality as fitness for use. Crosby (1979) describes quality in terms of conformance to requirements. Deming (1986) says that quality is concerned with the present and future needs of the customer. For Feigenbaum (1983) quality is to do with the combined product characteristics of engineering and manufacture that determine the degree to which the product will meet the expectations of the customer. Taguchi (1986) defines quality as the loss a product causes society once it has been shipped, apart from any losses caused by its intrinsic functions. According to ISO 8402 (International Organization for Standardization, 1986), quality is the totality of features and characteristics of a product or service that have a bearing on its ability to satisfy stated or implied needs.

Recently, the most widely used definition is that of ISO 9001 (2000). It says that a quality is a characteristic that a product or service must have. For example, products must be reliable, useable, and repairable. These are some of the characteristics that a good quality product must have. Similarly, service should be

courteous, efficient, and effective. These are some of the characteristics that a good quality service must have. In short, a quality is a desirable characteristic. However, not all qualities are equal. Some are more important than others. The most important qualities are the ones that customers want. These are the qualities that products and services must have. So providing quality products and services is all about meeting customer requirements. It is all about meeting the needs and expectations of customers. So a quality product or service is one that meets the needs and expectations of customers.

### 1.1.2 ACTIVITIES OF QUALITY

In the manufacturing industry, activities concerned with quality can be divided into six stages:

1. **Product planning:** planning for the function, price, life cycle, etc. of the product concerned.
2. **Product design:** designing the product to have the functions decided in product planning.
3. **Process design:** designing the manufacturing process to have the functions decided in the product design.
4. **Production:** the process of actually making the product so that it is of the designed quality.
5. **Sales:** activities to sell the manufactured product.
6. **After-sales service:** customer service activities such as maintenance and product services.

It is important to note that company-wide activities are necessary to improve quality and productivity at each of the six stages mentioned above. A company needs to build an overall quality system in which all activities interact to produce products of designed quality with minimum costs.

Note that there are three different characteristics of quality in an overall quality system in the manufacturing industry:

1. **Quality of design:** quality of product planning, product design and process design.

2. **Quality of conformance:** quality of production.
3. **Quality of service:** quality of sales and after-sales services.

Nowadays, these three aspects of quality are equally important in the manufacturing company. If any one of them is not up to the mark, then the overall quality system is unbalanced, and the company will face serious problems.

Although these definitions are somewhat different, some common ideas run through them. Quality involves developing specifications to meet customer needs (quality of design), manufacturing products which satisfy those specifications (quality of conformance), and then providing after-sales services. However, Taguchi's definition of product quality is unusual. The loss he refers to may be caused by variability of function, or by harmful side-effects. Hence, if a product costs society no loss, the product is of the best quality, and the poorer the product's quality is, the greater the cost of the product to the society.

An example of loss caused by variability of function would be an automobile tire that does not last long. The driver would suffer a loss if he replaced the flat tire in the middle of a highway at night because the tire has an unexpectedly short life. An example of loss caused by a harmful side-effect would be a cold medicine which causes drowsiness in the person who takes it. Then the person would suffer a loss if this drowsiness caused him to be unable to work.

In the next section we will explore further Taguchi's concept of quality engineering from the standpoint of how quality can be designed, manufactured and measured.

## **1.2 TAGUCHI'S APPROACH TO QUALITY ENGINEERING**

A product's cost can be divided into two main parts: before sale and after sale to the customer. The costs incurred before sale are the manufacturing costs, and the costs incurred after sale are those due to quality loss. A defective product which is scrapped or reworked prior to shipment is viewed by Taguchi as a manu-

facturing cost to the company, but not a quality loss. **Quality engineering** is an interdisciplinary science which is concerned with not only producing satisfactory products for customers but also reducing the total loss (manufacturing cost plus quality loss). Hence, quality engineering involved engineering design, process operations, after-sales services, economics and statistics.

Taguchi's impact on the concept of quality control in the manufacturing industry has been far-reaching. His quality engineering system has been used successfully by many companies in Japan, the USA and elsewhere. Recently it is reported that several companies in Korea have used his methods with great success. Several case studies of his methods can be found in Chapters 6–9. He emphasizes the importance of designing quality control into the manufacturing processes. Also, he stresses that quality variation is the main enemy of quality engineering and that every effort should be made to reduce the variation in quality characteristics. Taguchi extensively uses experimental design primarily as a tool to design products more robust (which means less sensitive) to noise factors.

**Robust design** is an engineering methodology for optimizing the product and process conditions which are minimally sensitive to the various causes of variation, and which produce high-quality products with low development and manufacturing costs. Taguchi's parameter design is an important tool for robust design. His tolerance design can be also classified as a robust design. In a narrow sense robust design is identical to parameter design, but in a wider sense parameter design is a subset of robust design. Two major tools used in robust design are:

- signal-to-noise ratio, which measures quality with emphasis on variation;
- orthogonal arrays, which accommodate many design factors (parameters) simultaneously.

In the rest of this section, the major concepts of Taguchi's quality engineering are introduced.

### 1.2.1 IMPORTANCE OF DESIGN STAGE

Deming observed that 85% of poor quality is attributed to the manufacturing process for which managers are responsible, and only 15% to the workers. Similarly, Taguchi asserts that product and process design have a much greater impact on product quality than manufacturing and inspection. Quality should be designed into the product and not inspected into it.

### 1.2.2 TREATMENT OF QUALITY VARIATION

Taguchi emphasizes, as we have already mentioned, that quality variation is the main enemy of quality engineering. Quality is best achieved by minimizing the deviation from a target. He introduces the **loss function**

$$L(y) = k(y - m)^2,$$

which is to be minimized, where  $y$  is the quality characteristic,  $m$  is the target value and  $k$  is an appropriate constant. He also uses signal-to-noise (SN) ratios which are based in principle on the loss function.

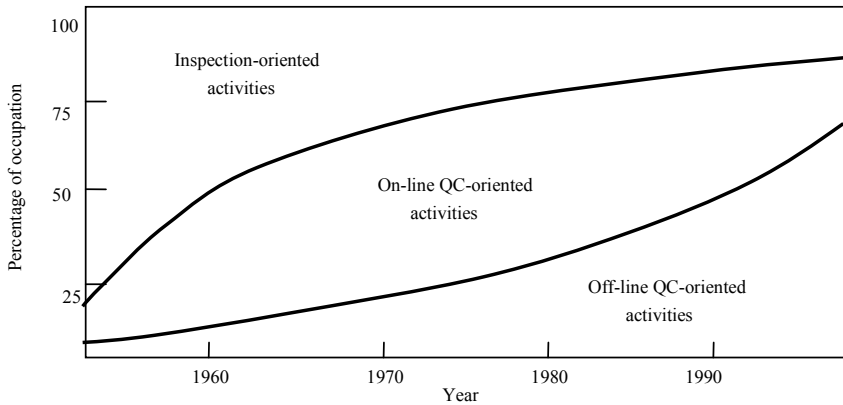
### 1.2.3 OFF-LINE AND ON-LINE QUALITY CONTROL (QC)

As mentioned earlier, the typical quality system of a manufacturing company consists of three aspects: quality of design; quality of conformance; and quality of service. Taguchi divides the quality system into two parts as follows:

- **Off-line QC:** Activities for quality of design through market research and product/process development, which are QC efforts away from production lines.
- **On-line QC:** Activities for quality of conformance and quality of service through manufacturing care, inspection and customer service. These are QC efforts mainly on production lines.

Since the design stage carries greater emphasis in Taguchi's quality engineering, it is said that the off-line QC has the greater

impact on quality. Taguchi's viewpoint on the importance of off-line QC is true in the Korean industry, as shown in Figure 1.1. It is believed that such phenomena hold in most other countries.



**Figure 1.1** The change in importance of QC activities.

## 1.2.4 THREE STEPS IN PRODUCT DESIGN

During the product design and process design phases, there are three steps in each design phase. They are system design, parameter design and tolerance design. The three steps for product design are described below.

1. **System design** (primary design, functional design or concept design). This step involves the development of a prototype design which meets customer requirements, and the determination of materials, parts, components, assembly system, manufacturing technology, etc. The key emphasis here is on using the best available technology at the lowest cost to meet customer requirements obtained through quality function deployment (QFD). System design can play an important role in reducing sensitivity to noise factors as well as in reducing manufacturing costs.
2. **Parameter design** (secondary design). A parameter is the design variable or control factor which affects a product's

functional characteristics. In this step, we determine the levels (values) of design variables (control factors) that minimize the effect of noise factors on the product's quality, minimize the manufacturing cost, and get the mean quality of the product on target. In order to find the optimum levels, fractional factorial designs using tables of orthogonal arrays are often used because there are too many experimental combinations to be tested.

3. **Tolerance design** (tertiary design). During parameter design, we assume that low-grade components and materials which allow some tolerances for noise factors will be used, while minimizing the sensitivity to noise and the quality variation. Tolerance design applies if the reduction in quality variation achieved by parameter design is insufficient. In tolerance design, a trade-off is made between reduction in the quality variation and increase in manufacturing cost. That is, we selectively specify higher-grade parts, materials or components to reduce tolerances in the order of their cost-effectiveness. Since many choices are possible, experimental designs using tables of orthogonal arrays can also be effectively used in tolerance design.

### 1.2.5 THREE STEPS IN PROCESS DESIGN

The results of the three steps in product design by the design department are passed to the production department in the form of specifications. The production department then designs a manufacturing process that will produce adequate products. **Process design** also consists of three steps.

1. System design. This step selects the manufacturing process from knowledge of related manufacturing technology and cost such as automatic control, production cost and productivity.
2. Parameter design. This step decides the optimum operating conditions for each of the component processes and the optimum materials to purchase. The major goal of parameter design is to reduce quality variation (to improve process

capability) by minimizing the influence of noise. Experimental design is often used in this step.

3. **Tolerance design.** In this design, the tolerances of the process conditions and sources of variability are investigated. If the tolerances obtained by the parameter design are not sufficient, economic measures to suppress quality variation will be sought by directly removing its sources of variability. Experimental design is also a powerful tool in this step.

### 1.2.6 USE OF NOISE

The undesirable and uncontrollable sources that can cause deviation from target values in product's functional characteristics are called **noise**, and are divided into three types.

1. **External noise:** operating environment variables such as temperature and humidity, and conditions of use that disturb the functions of a product.
2. **Internal noise:** changes that occur when a product deteriorates during storage, by friction or by wearing out of parts during use.
3. **Unit-to-unit noise:** differences between individual products because of manufacturing-process imperfections such as variations in machine setting.

The overall quality system should be designed to produce a product that is robust with respect to all noise factors. In order to achieve robustness, QC efforts must begin in the product and process design (off-line QC) and must be continued through production operation (on-line QC).

Table 1.1 summarizes the ways to combat variability in functional quality. In this table, the product design stage is called "R&D" and the process design stage is called "production engineering".

**Table 1.1** Quality control activities for dealing with noise factors.

Department countermeasure		Type of noise			
		External	Internal	Unit-to-unit	
Off-line quality control	R&D	1. System design	⊙	⊙	⊙
		2. Parameter design	⊙	⊙	⊙
		3. Tolerance design	○	⊙	⊙
	Production engineering	1. Process diagnosis	×	×	⊙
		2. Parameter design	×	×	⊙
		3. Tolerance design	×	×	⊙
On-line quality control	Production	1. Process diagnosis and adjustment	×	×	⊙
		2. Prediction and correction	×	×	⊙
		3. Measurement and action	×	×	⊙
	Customer relations	After-sales service	×	×	×

Source: Taguchi (1986).

⊙ Possible

○ Possible, but should be a last resort

×

In Table 1.1, Taguchi identifies three forms of on-line QC:

1. Process diagnosis and adjustment: the process is monitored at regular intervals, and necessary adjustment is made if needed.
2. Prediction and correction: past data is used to predict trends in the process. If the process is off target, it is corrected by engineering activities such as feedback control and feed-forward control.
3. Measurement and action: manufactured units are inspected and measured, and action taken (reworking or scrapping of defective units) as appropriate.

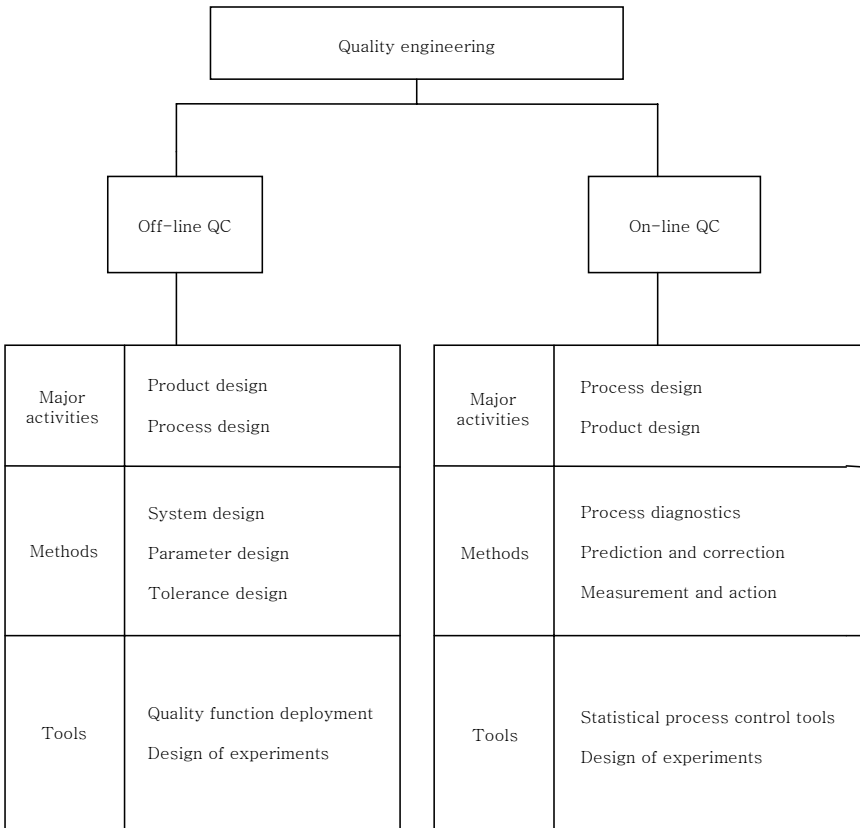
Table 1.1 shows that external and internal noise can be reduced most effectively at the R&D step. However, unit-to-unit noise can be handled in the overall off-line and on-line QC stages.

### 1.2.7 KEY POINTS IN QUALITY IMPROVEMENT PLANNING

Quality improvement efforts should be continuously carried out based on the followed key points:

1. The variation of product quality characteristics from their target values should be reduced. Taguchi views quality improvement as an ongoing effort to reduce variation from the target value. The primary aim of quality improvement is to achieve a population distribution as close to the target as possible. To accomplish this, the SN ratio is adopted.
2. The product and the process should be designed so that they are minimally sensitive to noise factors. Taguchi uses experimental designs as a tool to make products robust to noise factors, and to reduce the effects of variation on product and process quality characteristics. He especially uses constructed tables known as “tables of orthogonal arrays” in which he allocates the noise factors to the “outer array”, and the design factors to the “inner array” in the parameter design. Classical applications of experimental design focused primarily on optimizing average product performance characteristics rather than considering effects on variation.
3. In designing the product and the process, the optimal levels of design factors should be determined to minimize the cost under the condition that the given quality tolerance from the targets are met for each quality characteristic concerned. To achieve this objective, tolerance design is often used.

Earlier, we defined quality engineering as an interdisciplinary science which is concerned with producing satisfactory products for customers while reducing the total cost. If we use the major concepts of Taguchi’s quality engineering, we may define **quality engineering** as “an effective system of engineering management to minimize the total loss of products to society through off-line and on-line quality control activities”. Figure 1.2 shows the major activities, methods and tools of quality engineering.



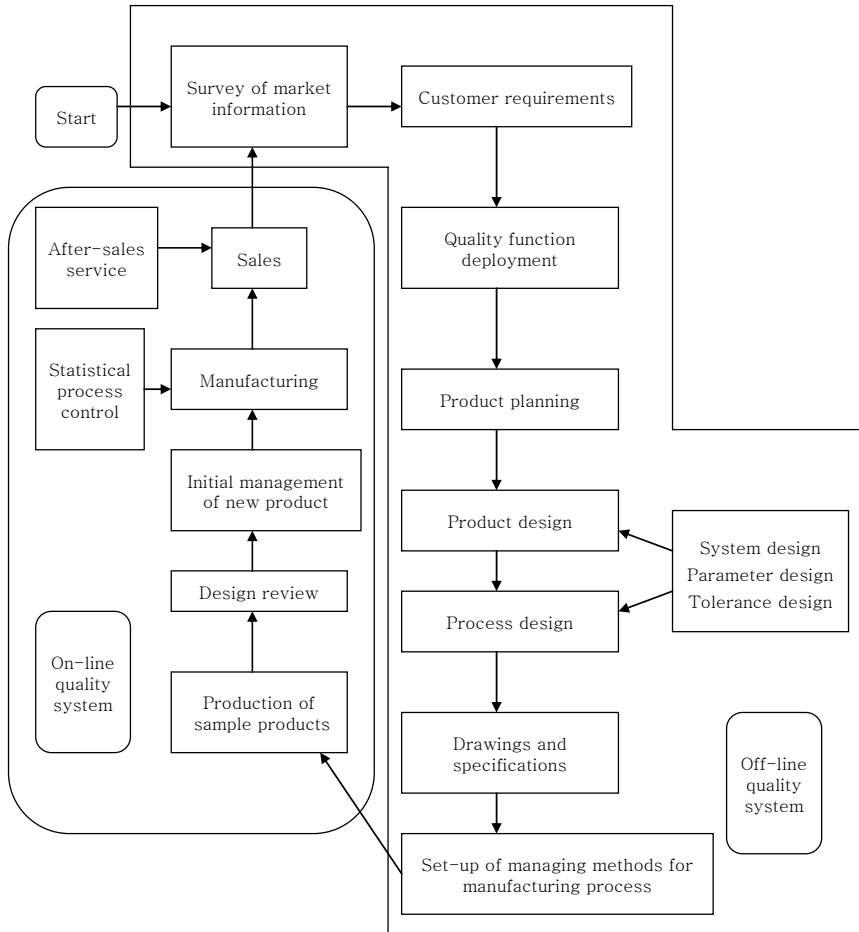
**Figure 1.2** Overview of quality engineering.

### 1.3 STAGES OF NEW PRODUCT DEVELOPMENT

The stages of new product development are dependent on the type of product being developed. However, a general flow diagram for new product development is given in Figure 1.3.

The stages of new product development may be divided into two parts from the viewpoint of a quality system cycle: off-line and on-line quality systems. The off-line quality system starts with the survey of market information and ends with the set-up of managing methods for the manufacturing process. The on-line

quality system begins with the production of sample products and ends with after-sales service activities. Note that three steps in design (system, parameter and tolerance) play a critical role in the off-line quality system. On the other hand, statistical process control (SPC) tools help keep manufacturing under control.



**Figure 1.3** Stages of new product development and the quality system cycle.

## 1.4 QUALITY MANAGEMENT AND SIX SIGMA

We will explain the evolution of QC, quality engineering and quality management in the context of Korean industries. However, much of what we will say holds true in most other national contexts.

QC activity began in Korea in 1961 when the Industrial Standardization Law was announced. Based on this law, Korean Industrial Standards were laid down, and inspection activities dominated QC. When it was realized in the 1970s and early 1980s that inspection alone was not enough for QC, QC activities were stressed in manufacturing processes (on-line QC as shown in Figure 1.1) through quality circles, suggestion schemes, applications of statistic methods, etc.

From the late 1980s, as customer satisfaction (CS) became the critical focus in company management, R&D became based on customer opinion, product planning and product/process design (off-line QC) began to play a major role in quality management. **Quality management** (QM) is the overall management function that implements the quality policy (QP), quality control (QC), quality improvement (QI) and quality assurance (QA) for customer satisfaction under the leadership of senior management and with the full participation of all members of the organization. Here the abbreviations QP, QC, QI and QA have the following meaning:

- QP (quality policy): the overall quality direction and operational philosophy of senior management as regards quality.
- QC (quality control): the operational techniques and activities that are used to fulfill requirements for quality. This is the narrow concept of QC. When we speak of “company-wide QC” or “QC activities in a particular country”, this is a broader concept of QC. Care should be taken to avoid confusion.
- QI (quality improvement): the activities to increase the effectiveness of quality in the stages of R&D and manufacturing.
- QA (quality assurance): the planned and systematic actions to provide adequate confidence that a product or service will meet customer satisfaction for quality.

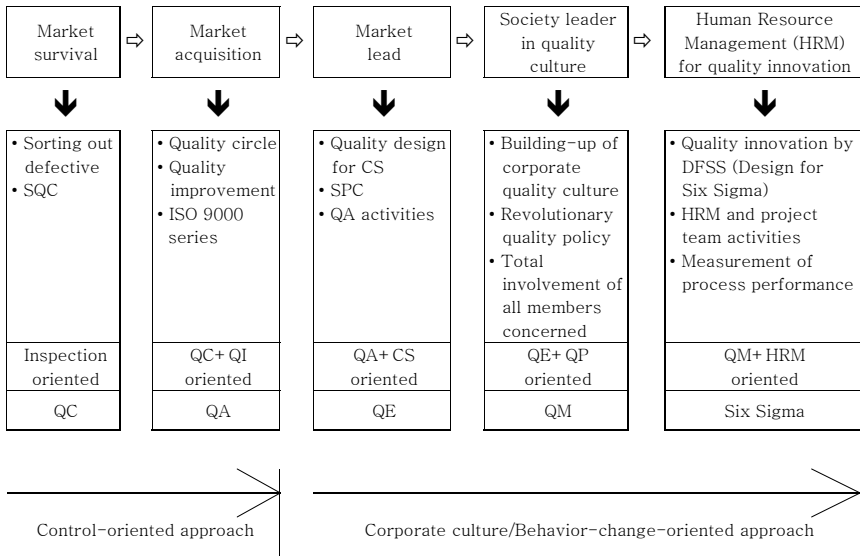


Figure 1.4 The development process of QM.

Since quality engineering (QE) is focused on product/process design and production for customer requirement, we may write QE and QM in the following equations:

$$QE = QC + QI + QA ,$$

$$QM = QP + QC + QI + QA$$

$$= QP + QE .$$

Figure 1.4 shows the development process of QM. Total quality control (TQC) is very similar to QM. However, the emphasis is different. In QM, senior management involvement and customer satisfaction carry more weight, but in TQC, QC and QI by line workers and middle managers are more important. Total quality management (TQM) is actually the same as QM. However, when we add T to QM, we mean to emphasize company-wide efforts for QM activities.

Six Sigma as a management strategy was launched by Motorola in 1987. Six Sigma has evolved significantly and continues to

expand to improve the performance of processes. It seems that recently Six Sigma begins to replace QM or TQM for management innovation. The authors believe that **Six Sigma** is a new strategic paradigm of management innovation for company survival in this 21st century, which implies three things: statistical measurement, management strategy and human resource management. It tells how good our products, services and processes are through statistical measurement of process performance. It is a new management strategy to create quality innovation and total customer satisfaction. For this purpose DFSS (Design for Six Sigma) plays an important role for product and service development. DFSS will be explained in detail in Chapter 13. It is also a wise human resource management, in which full scale training scheme by belt system and project team activities are effectively utilized. Park (2003) and Antony et al. (2006) give more details on Six Sigma and DFSS.