# Quality Engineering Class Notes (experimental)

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# Contents

# Chapter 1

# Introduction

Quality Engineering is the study and design of practices aimed improving the "quality" of production. Production is understood in a wide sense, and includes services as well. Quality is understood in many senses. Here are several definitions compiled verbatim from Montgomery [2007] and Wikipedia [2015b]:

1. Montgomery: "Fitness to use".

2. Montgomery: "The reciprocal of variability" (stability?) .

3. American Society for Quality: A combination of quantitative and qualitative perspectives for which each person has his or her own definition; examples of which include, "Meeting the requirements and expectations in service or product that were committed to" and "Pursuit of optimal solutions contributing to confirmed successes, fulfilling accountabilities. In technical usage, quality can have two meanings: (a) The characteristics of a product or service that bear on its ability to satisfy stated or implied needs. (b) A product or service free of deficiencies."

4. Subir Chowdhury: "Quality combines people power and process power".

5. Philip B. Crosby: "Conformance to requirements."

6. W. Edwards Deming: "The efficient production of the quality that the market expects".

7. W. Edwards Deming: "Costs go down and productivity goes up as improvement of quality is accomplished by better management of design, engineering, testing and by improvement of processes."

8. Peter Drucker: "Quality in a product or service is not what the supplier puts in. It is what the customer gets out and is willing to pay for."

9. Victor A. Elias: "Quality is the ability of performance, in each Theme of Performance, to enact a strategy."

10. ISO 9000: "Degree to which a set of inherent characteristics fulfills requirements."

11. Joseph M. Juran: "Fitness for use.".

12. Noriaki Kano and others, present a two-dimensional model of quality: "must-be quality" and "attractive quality." The former is near to "fitness for use" and the latter is what the customer would love, but has not yet thought about. Supporters characterize this model more succinctly as: "Products and services that meet or exceed customers' expectations."

13. Robert Pirsig: "The result of care."

14. Six Sigma: "Number of defects per million opportunities."

15. Genichi Taguchi: "Uniformity around a target value."

16. Genichi Taguchi: "The loss a product imposes on society after it is shipped."

17. Gerald M. Weinberg: "Value to some person".

18. Jonathan D. Rosenblatt: "The efficient fulfilment of a promise".

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**Collecting ideas**

1. Quality is not only about production.

2. Quality is the means, not the end.

3. Quality may deal with the **design** or with **conformance** to a given design.

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Almost all of the above definitions, may apply to different characteristics, we call *dimensions of quality*. Following Wikipedia [2015a] :

Dimensions of Quality

Performance Performance refers to a product's primary operating characteristics. This dimension of quality involves measurable attributes; brands can usually be ranked objectively on individual aspects of performance.

| | |
|---|---|
| Features | Features are additional characteristics that enhance the appeal of the product or service to the user. |
| Reliability | Reliability is the likelihood that a product will not fail within a specific time period. This is a key element for users who need the product to work without fail. |
| Conformance | Conformance is the precision with which the product or service meets the specified standards. |
| Durability | Durability measures the length of a product's life. When the product can be repaired, estimating durability is more complicated. The item will be used until it is no longer economical to operate it. This happens when the repair rate and the associated costs increase significantly. |
| Serviceability | Serviceability is the speed with which the product can be put into service when it breaks down, as well as the competence and the behavior of the service person. |
| Aesthetics | Aesthetics is the subjective dimension indicating the kind of response a user has to a product. It represents the individual's personal preference. |
| Perceived Quality | Perceived Quality is the quality attributed to a good or service based on indirect measures. |

## 1.1 Terminology and Concepts

### 1.1.1 Basic Terminology

| | |
|---|---|
| Quality Characteristics | A.k.a. *Critical to Quality Characteristics* (CTQs). May be physical, sensory, or temporal properties of a process/product. Obviously related to the dimensions of quality. |
| Quality Engineering | "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 and that the variability around these desired levels is minimum." [Montgomery, 2007] |
| Variables | Continuous measurements of some CTQ. |
| Attributes | Discrete measurements of some CTQ. |
| Target Value | The desired level of a particular CTQ. A.k.a. *nominal* value. |

| | |
|---:|:---|
| Specifications | The set of target values of a process. |
| USL & LSL | Largest and smallest allowable values of a CTQ. |
| Non-conformity | A non conforming product is one that fails to meet the specification. |
| Defect | A non-conformity that is serious enough to affect the use of the product. |

### 1.1.2 Statistical Terminology

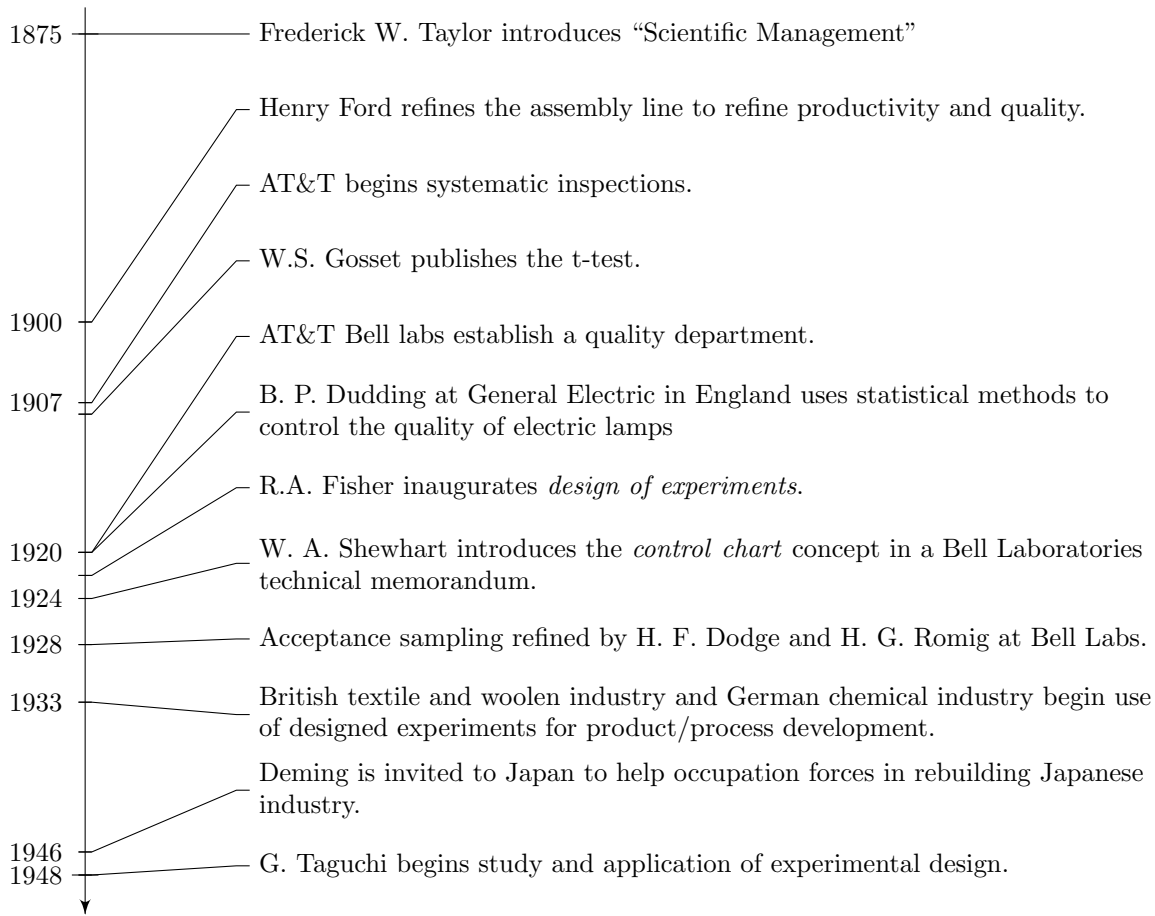| | |
|---:|:---|
| Exploratory Statistics | |
| Causal Inference | |
| Predictive Analytics | |
| SPC | Statistical Process Control |
| DOE | Design of experiments |
| Acceptance Sampling | |
| Control Chart | |
| Controllable Inputs | |
| Uncontrollable Inputs | |
| Factorial Design | |
| Off-line quality control | |
| On-line quality control | A.k.a. *in-process* procedure. |
| Engineering control | A.k.a. *automatic control*, or *feedback control*. |
| Ingoing Inspection | |
| Outgoing Inspection | |

## 1.2   Some History

| Year | Event |
|------|-------|
| 1875 | Frederick W. Taylor introduces "Scientific Management" |
|      | Henry Ford refines the assembly line to refine productivity and quality. |
|      | AT&T begins systematic inspections. |
|      | W.S. Gosset publishes the t-test. |
| 1900 | AT&T Bell labs establish a quality department. |
| 1907 | B. P. Dudding at General Electric in England uses statistical methods to control the quality of electric lamps |
|      | R.A. Fisher inaugurates *design of experiments*. |
| 1920 | W. A. Shewhart introduces the *control chart* concept in a Bell Laboratories technical memorandum. |
| 1924 | |
| 1928 | Acceptance sampling refined by H. F. Dodge and H. G. Romig at Bell Labs. |
| 1933 | British textile and woolen industry and German chemical industry begin use of designed experiments for product/process development. |
|      | Deming is invited to Japan to help occupation forces in rebuilding Japanese industry. |
| 1946 | |
| 1948 | G. Taguchi begins study and application of experimental design. |

Table 1.1: Adapted from [Montgomery, 2007, Table 1.1].

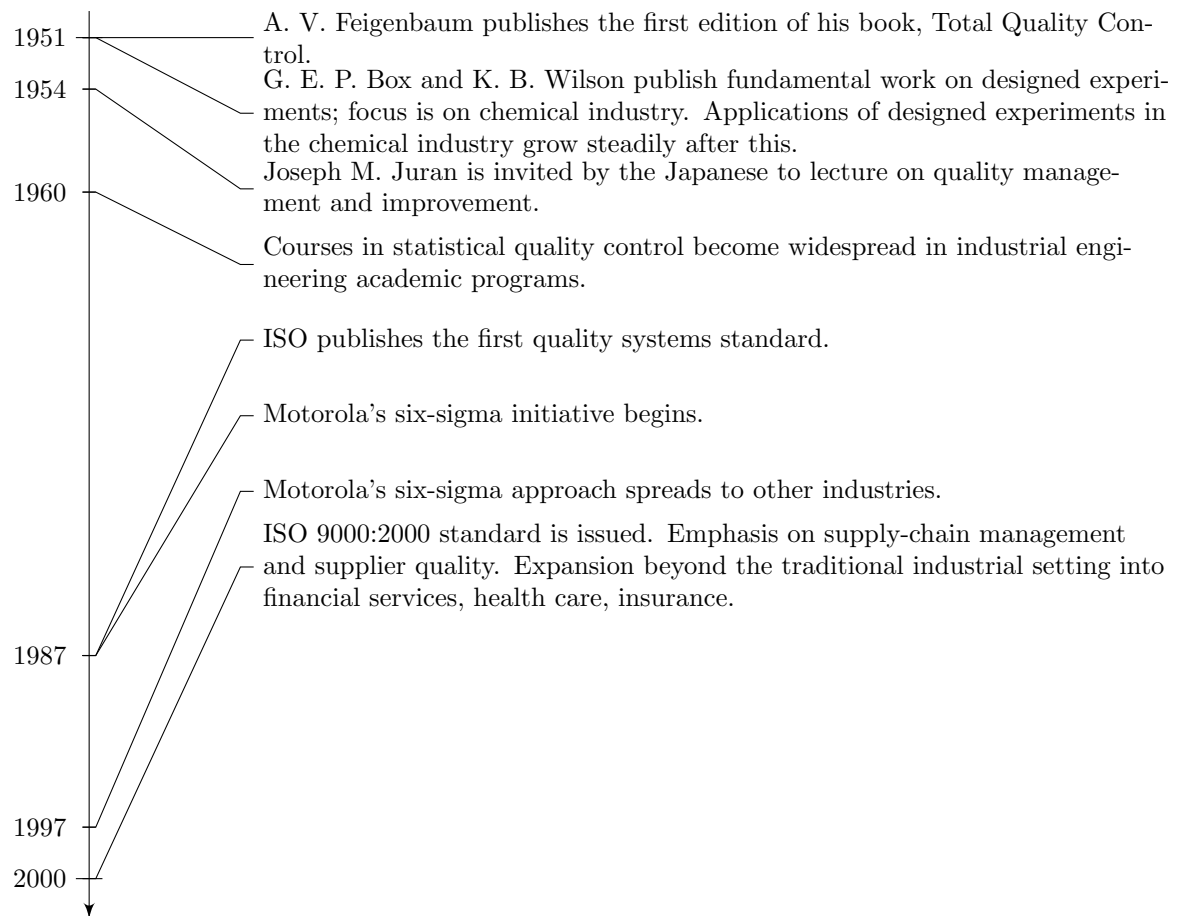| 1951 | A. V. Feigenbaum publishes the first edition of his book, Total Quality Control. |
|---|---|
| 1954 | G. E. P. Box and K. B. Wilson publish fundamental work on designed experiments; focus is on chemical industry. Applications of designed experiments in the chemical industry grow steadily after this. |
| 1960 | Joseph M. Juran is invited by the Japanese to lecture on quality management and improvement. |
| | Courses in statistical quality control become widespread in industrial engineering academic programs. |
| 1987 | ISO publishes the first quality systems standard. |
| | Motorola's six-sigma initiative begins. |
| 1997 | Motorola's six-sigma approach spreads to other industries. |
| 2000 | ISO 9000:2000 standard is issued. Emphasis on supply-chain management and supplier quality. Expansion beyond the traditional industrial setting into financial services, health care, insurance. |

Table 1.2: Adapted from [Montgomery, 2007, Table 1.1].

## 1.3 Management Aspects of Improving Quality

The founding fathers of QC have many do's-and-don'ts for managers. See Montgomery [2007, Sec 1.4] for details. As usual, we collect recurring ideas:

1. The responsibility for quality rests with management.

2. QC is not a one-time project, but an on-going process. It may advance continuously, or incrementally.

3. QC is (or should be) manifested in organizational structure, training, recruitment, incentives, knowledge management, to name a few.

## 1.4   Programs and Initiatives

### 1.4.1   Zero Defects Program (ZD)

Quoting Wikipedia [2015d]:

> . . . a management-led program to eliminate defects in industrial production that enjoyed brief popularity in American industry from 1964 to the early 1970's. Quality expert Philip Crosby later incorporated it into his "Absolutes of Quality Management" and it enjoyed a renaissance in the American automobile industry, as a performance goal more than as a program, in the 1990s. Although applicable to any type of enterprise, it has been primarily adopted within supply chains wherever large volumes of components are being purchased (common items such as nuts and bolts are good examples).

### 1.4.2   Quality is Free Initiative

Quoting Montgomery [2007]:

> . . . in which management worked on identifying the cost of quality (or the cost of *nonquality*, as the Quality is Free devotees so cleverly put it). Indeed, identification of quality costs can be very useful, but the Quality is Free practitioners often had no idea about what to do to actually improve many types of complex industrial processes.

### 1.4.3   Value Engineering Program (VE)

Quoting Wikipedia [2015c]:

Value engineering (VE) is systematic method to improve the "value" of goods or products and services by using an examination of function. Value, as defined, is the ratio of function to cost. Value can therefore be increased by either improving the function or reducing the cost. It is a primary tenet of value engineering that basic functions be preserved and not be reduced as a consequence of pursuing value improvements.

### 1.4.4 Total Quality Management (TQM)

TQM originates in the 1980's with the ideas of Deming and Juran. It is a very wide framework that attempts at capturing the company-wide efforts required for QC. According to Montgomery [2007, p.23]:

TQM has only had moderate success for a variety of reasons, but frequently because there is insufficient effort devoted to widespread utilization of the technical tools of variability reduction. Many organizations saw the mission of TQM as one of training. Consequently, many TQM efforts engaged in widespread training of the workforce in the philosophy of quality improvement and a few basic methods. This training was usually placed in the hands of human resources departments, and much of it was ineffective. The trainers often had no real idea about what methods should be taught, and success was usually measured by the percentage of the workforce that had been "trained," not by whether any measurable impact on business results had been achieved.

...Another reason for the erratic success of TQM is that many managers and executives have regarded it as just another "program" to improve quality. During the 1950's and 1960's, programs such as Zero Defects and Value Engineering abounded, but they had little real impact on quality and productivity improvement.

### 1.4.5 Six-Sigma

Quoting Montgomery [2007]:

Products with many components typically have many opportunities for failure or defects to occur. 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
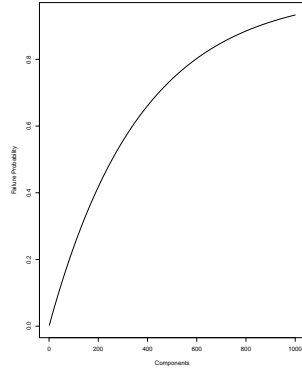
Figure 1.1: sss

in key product quality characteristics to the level at which failure
or defects are extremely unlikely.

Time for some math! Assume a device has $m$ components. The failure
probability of component $j \in 1, \ldots, m$ is $\alpha_j$. What is the probability of the
device failing, when assuming independent failures?

$$P(\text{failure}) = P(\text{at least one failure}) \qquad (1.1)$$
$$= 1 - P(\text{no failure})$$
$$= 1 - \prod_{j=1}^{m}(1 - \alpha_j)$$

The failure rates $\{\alpha_j\}_{j=1^m}$ are implied by the quality performance. Assuming
the classical *3-sigma* quality performance, and for $Z \sim \mathcal{N}(0, \sigma)$:

$$\alpha_j < P(|Z| > 3\sigma) = 0.0027, \quad \forall j = 1, \ldots, m$$

This is known as the *2700 parts per million (ppm) defective* performance.
Plugging the 3-sigma performance in Eq.(1.1) thus returns     PPM

$$P(\text{3-sigma failure}) < 1 - (1 - 0.0027)^m$$

When viewed as a function of components:

## 1.4.6 Quality Systems and Standards

The first quality standard issued by the International Standards Organization
(ISO) in 1987. Current quality standards are known as *ISO9000 series*.     ISO9000
These include:

ISO9000:2000 Quality Management System—Fundamentals and Vocabulary

ISO9001:2000 Quality Management System—Requirements

ISO9004:2000 Quality Management System—Guidelines for Performance Improvement

In Israel, it is the Standards Institute of Israel[1] that may give ISO9000 (like any ISO) certifications upon inspecting the candidate organization. As emphasized by Montgomery [2007, p.24], ISO9000 is mostly a knowledge management oriented set of rules and best practices. It may help to preserve quality, but it does not, nor does it aim to, *improve* quality.

## 1.5  DMAIC

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[1]https://portal.sii.org.il/heb/qualityauth/certificationtypes/qualitylinks/iso9001/

# Chapter 2

# Descriptive Statistics

## 2.1   Summary Statistics

### 2.1.1   Categorical Data

**Univariate**

**Bivariate**

### 2.1.2   Continuous Data

**Univariate**

Location measures

Scale measures

Asymmetry measures

**Bivariate**

Correlation

## 2.2 Visualization

### 2.2.1 Categorical Data

Univariate

Bivariate

### 2.2.2 Continuous Data

Univariate

Bivariate

Multivariate Data

# Chapter 3

# Statistical Inference

# Chapter 4

# System Capability Analysis

# Chapter 5

# Statistical Process Control

## 5.1  Univariate Control Charts

### 5.1.1  Control Charts for Variables

### 5.1.2  Control Charts for Attributes

## 5.2  Multivariate Control Charts

## 5.3  Non-Statistical Target Functions

# Chapter 6

# Design of Experiments

# Chapter 7

# Acceptance Sampling

# Chapter 8

# Reliability

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