Statistical Quality Control & Reliability

Introduction

Dept. of Industrial Engineering and Management

Xi ZHANG

Introduction to the class

Introduction to Quality

Flip-over

Introduction to the class

- Instructor: Xi ZHANG, Ph.D.
- Office: Founder Building 512
- Office hours: by appointment via email
- Class Schedule:
  - Thursday: 6:40pm~9:30pm (weekly)
- Contact Information:
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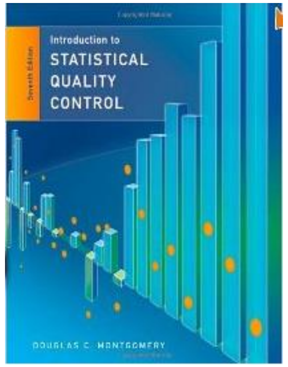
  - Email: xi.zhang@coe.pku.edu.cn
- Your turns!

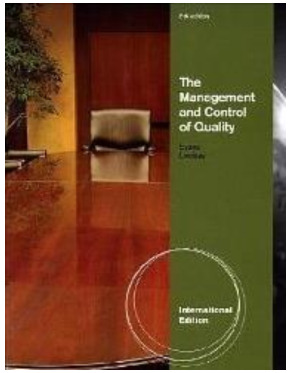
Textbooks

- **Introduction to Statistical Quality Control (Multiple editions), by Douglas Montgomery and George Runger, Wiley, ISBN: 1118146816**

- **Applied Multivariate Statistical Analysis (Multiple editions), by R. A. Johnson and D. W. Wichern, Tsinghua Univ. Press, ISBN: 7302165181**

- **The Management and Control of Quality (Multiple editions), by James Evans, William Lindsay, Thomson Learning, ISBN: 0538452609**





More

- Papers scattered in various journals in many fields
  - Manufacturing
  - Service
  - Healthcare delivery
  - ...

Control Charts Based on Attribute Data: Bibliography and Review

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This paper represents an attempt to offer a comprehensive bibliography of references on control charting using attribute data. A brief overview and perspective is given of some of the work in this area. Suggestions are made for future research topics.

Prerequisites

- Suggested courses

  - Introduction to Probability and Statistics
  - Elementary Statistical Quality Control
  - Multivariate Analysis

- Basic knowledge on statistics/probability, calculus and linear algebra
  - Sample mean, variance, covariance/correlation
  - Normal distribution, t-distribution, F-distribution, Chi^2-distribution
  - Hypothesis testing, confidence interval
  - Basic matrix calculation, eigenvalues and eigenvectors of a matrix

Goals

- To deeply understand the conceptions of statistical process control
- To know how to use advanced control strategies
- To learn the innovative techs in statistical methods (control charts) in quality/process control
- To practice your scholarly reading and presentation skills
- To be familiar with the basic elements of reliability

Plans

- **Introduce advanced statistical tools and concepts that are useful for product/process quality improvements**
- **Develop capability for problem solving and data analysis of quality improvement applications**
- **Demonstrate the procedures of implementation of the quality engineering tools in various application**
- **Focus on generic and advanced data analysis tools that applicable to a wide range of applications including both manufacturing and service such as health care.**

Grading

- **No homework!**
- **No quiz!**
- **One exam!**
- **Three reports!**

1st report (25%)
2nd report (25%)
3rd report (30%)
Exam (20%)
=
Your final score!

- **Team work**
  - ✓ Up to 2 of you form a team, the members in the same team will gain the same score in each report
  - ✓ The first two reports only require oral presentation by displaying your ppt
  - ✓ The 3rd report requires your written report + presentation
- **Criteria**
  - ✓ Understanding 70+
  - ✓ Digging out more information 80+
  - ✓ Developing existing methods with innovations 90+

Importance of Quality

"The first job we have is to turn out quality merchandise that consumers will buy and keep on buying. If we produce it efficiently and economically, we will earn a profit, in which you will share."

- William Procter

Quality, productivity, and cost remain imperatives for modern organizations

- A visit to BK for a Whopper Meal

  - You paid $5.99+tax
  - You gained
    - burger
    - Drink
    - Sundae
    - Fries
    - What else?
  - Suppose every item is 99% good

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

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

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

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

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

Importance of Quality

- Building and maintaining quality into an organization’s goods and services, and more importantly, into the infrastructure of the organization itself is not an easy task
  - Consumer awareness and quality / performance sensitive.
  - Product liability laws
  - Competition is doing it
  - Productivity loss due to defective parts/products
  - Costs of labor, energy, and materials
  - Quality, Productivity and Cost are complementary

Defining ‘QUALITY’

Perfection

Fast delivery

Providing a good, usable product

Consistency

Eliminating waste

Doing it right the first time

Delighting or pleasing customers

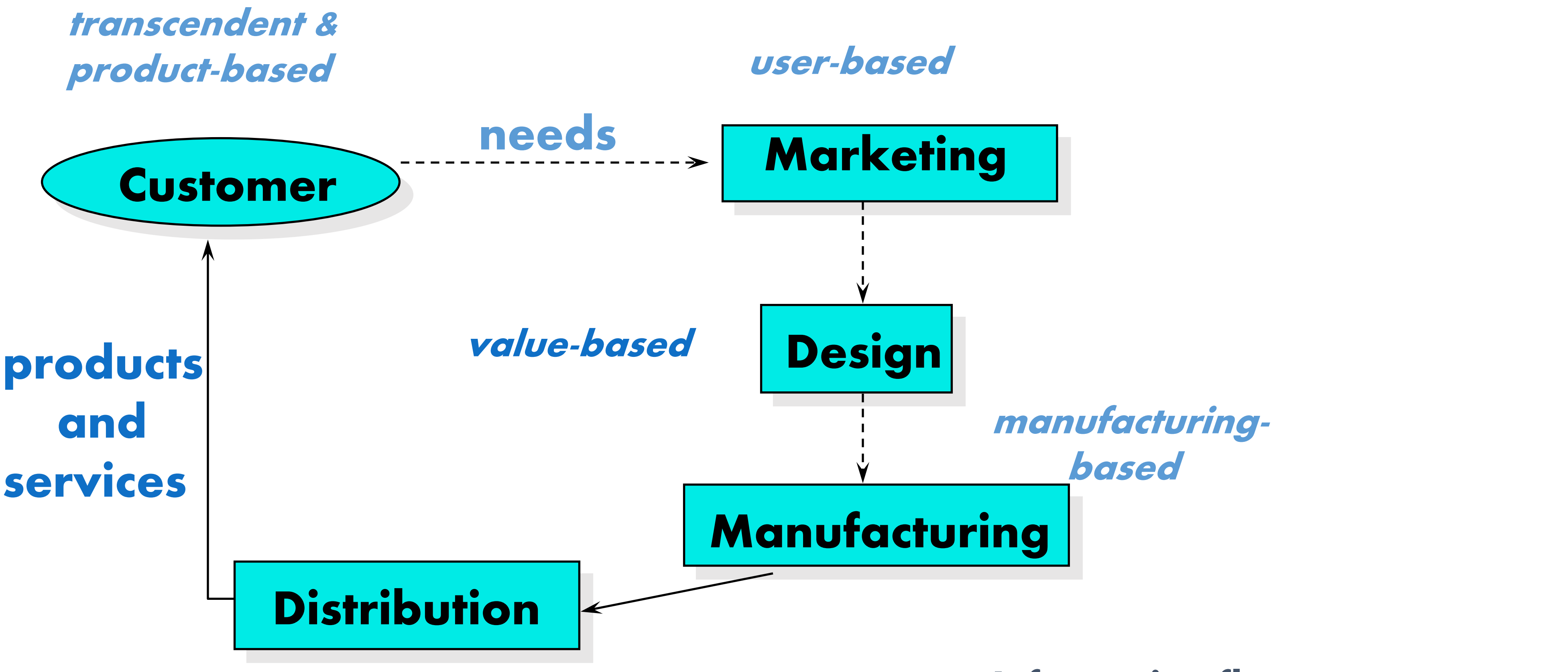
Total customer service and satisfaction

Compliance with policies and procedures

Formal Definitions of Quality

- **Transcendent definition**: excellence
- **Product-based definition**: quantities of product attributes
- **User-based definition**: fitness for intended use
- **Value-based definition**: quality vs. price
- **Manufacturing-based definition**: conformance to specifications

Quality perspectives



Customer-Driven Quality

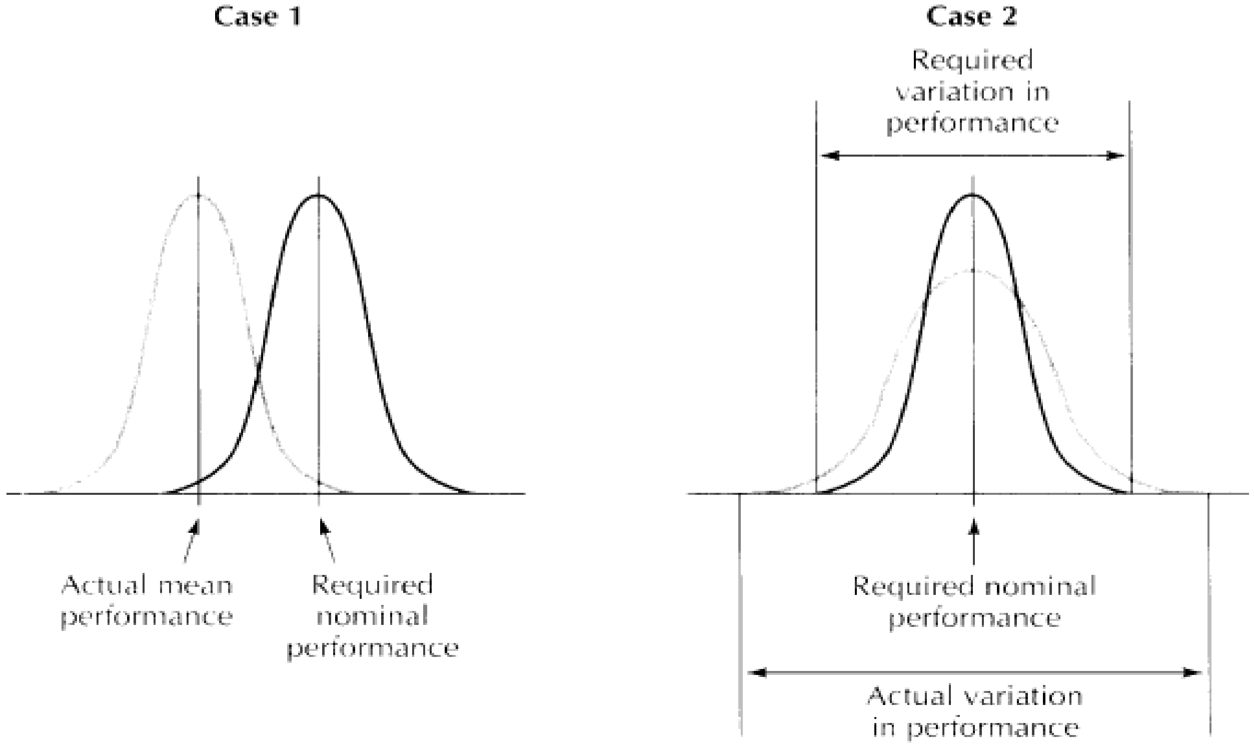
- "Meeting or exceeding customer expectations"
- Customers can be…
  - Consumers
  - External customers
  - Internal customers
- To meet or exceed customer expectations, organizations must fully understand all product and service attributes that contribute to customer value and lead to satisfaction and loyalty

Variables vs. attributes

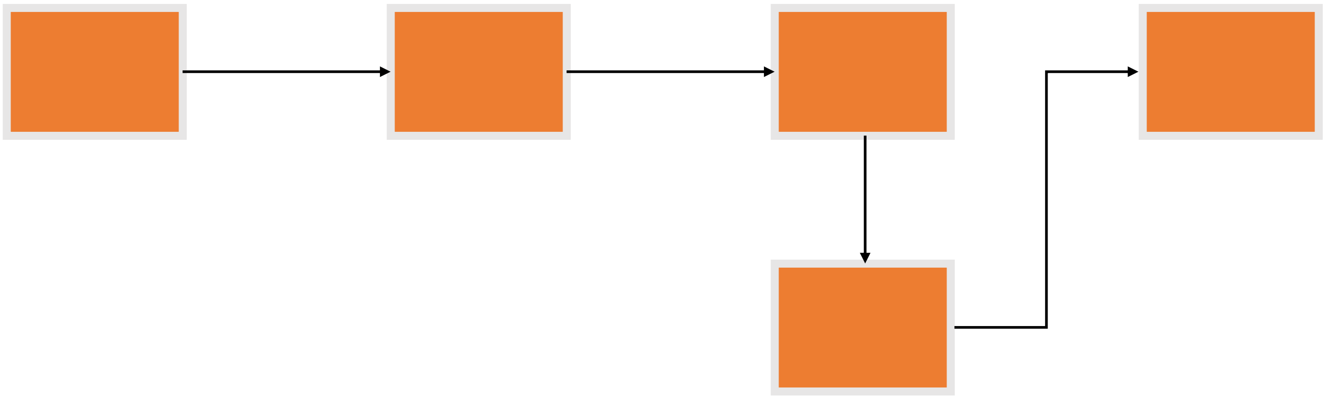
- Variables
  - ✓ Continuous
  - ✓ Examples:
    - Length
    - Temperature
    - Weight
    - Density

- Attributes
  - ✓ Discrete
  - ✓ Examples:
    - # of graduate students in a class
    - # of defects in a LCD display

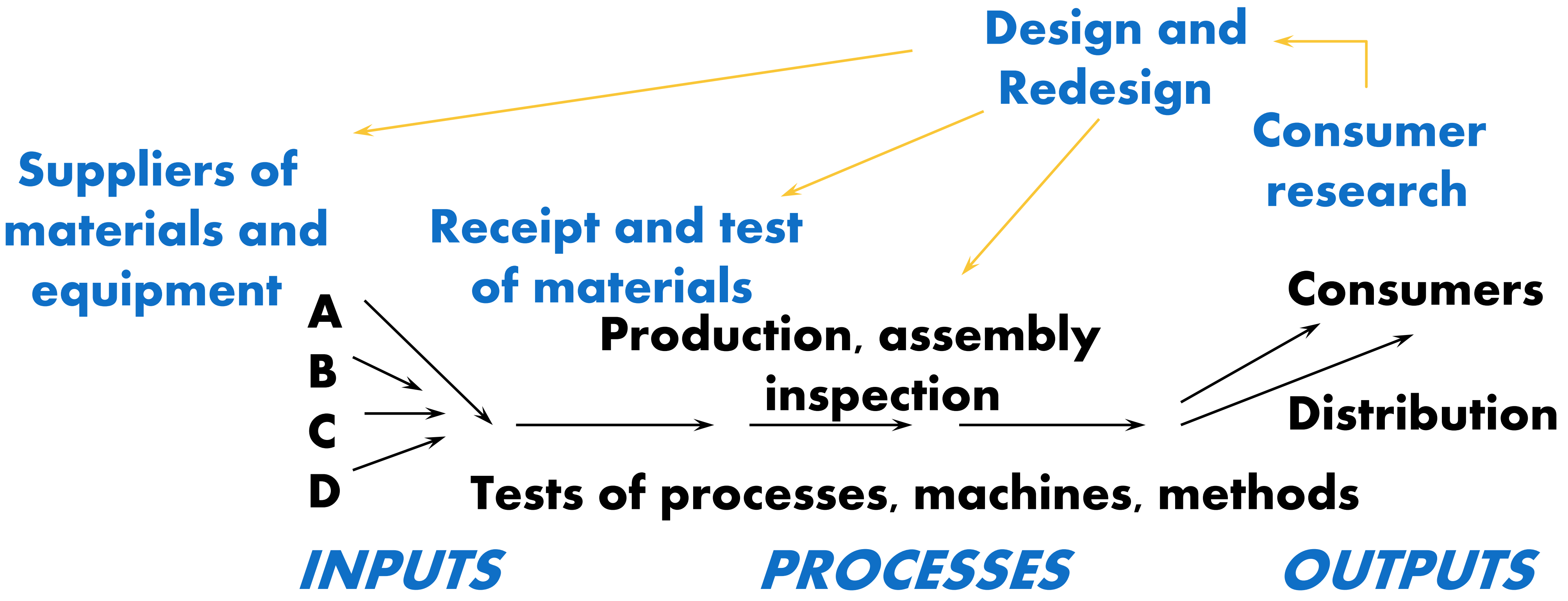
- **Quality means fitness for use**
- **More precisely, quality is inversely proportional to variability from target**
- **In another word, quality is closeness to target**
- **Quality improvement is the reduction of variability in processes and products**



- **Process Focus and Continuous Improvement**
  - **A process is how work creates value for customers**
  - **Processes transform inputs (facilities, materials, capital, equipment, people, and energy) into outputs (goods and services)**
  - **Most processes are cross-functional**

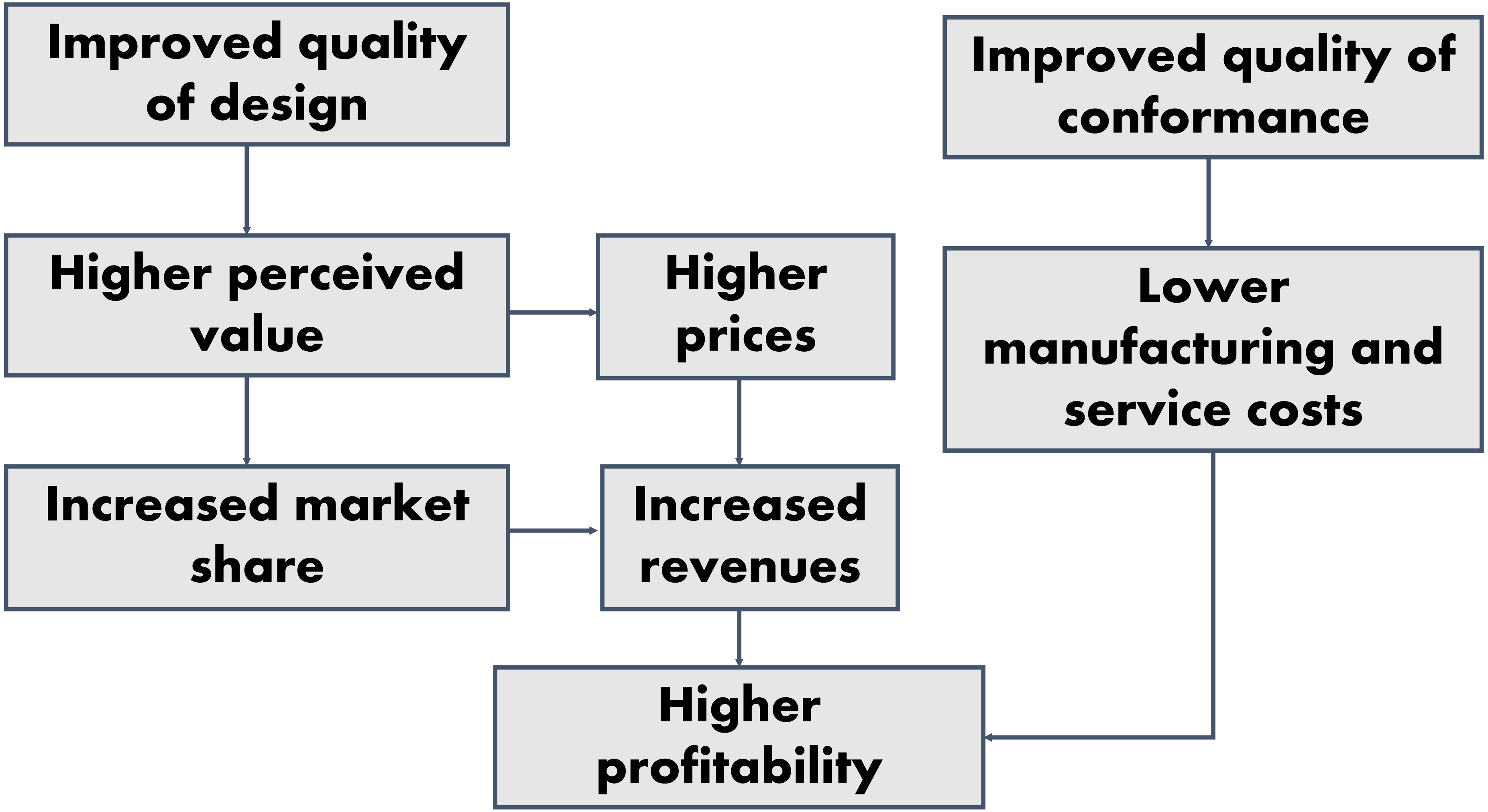


A production system



Source: Out of the Crisis, by Edwards Deming

Quality and Profitability



Quality assurance vs. quality control

Planned and systematic activity directed toward providing customers with goods and services of appropriate quality

A process by which entities review the quality of all factors involved in production

Development of quality control

Middle Ages
: Skilled
craftsmanship
during

Early 20th Century:
statistical
methods at Bell
System

Quality control
during World War
II

Post-war Japan:
evolution of
quality
management as
promoted

1960S:
Statistical process
control

1980S:
US quality crisis

1980S:
TQM
Six Sigma

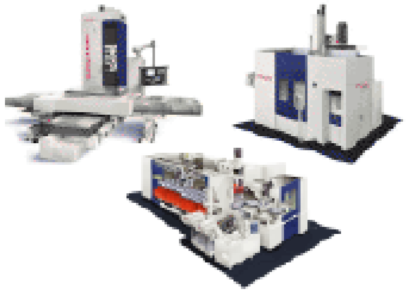
1990S:
Lean
Excellence

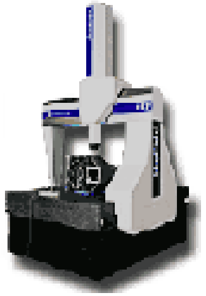
Quality is "a race without a finish line."

Opportunities

- IT revolution
  - Computers
  - Networks
  - Software
  - Sensors
  - actuators
- A big-data era
  - Data everywhere

Manufacturing processes

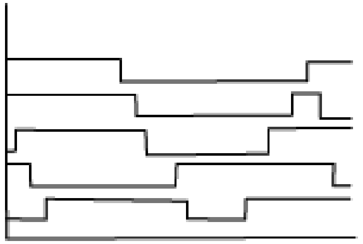


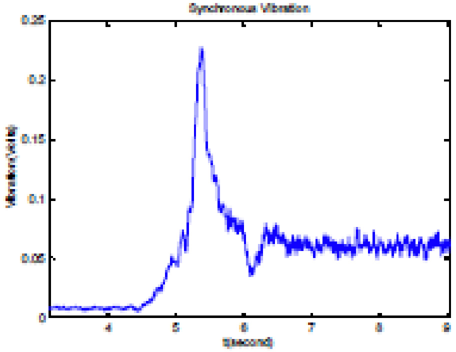


Operational Logic Information

In-Process Sensing Information

Product Quality Information





	x	y	z	Size D	n_1	n_2	n_3
Joint Face	-84.028	288.118	-418.784	-	1.000	-0.007	-0.008
Cover Face	-888.818	244.047	-380.428	-	-1.000	0.007	0.008
Hole D	-80.508	200.886	-878.442	18.087	-1.000	0.008	0.001
x1	-85.281	881.784	-808.181	-	-	-	-
x2	-85.888	880.813	-888.208	-	-	-	-
x3	-88.508	178.728	-484.801	-	-	-	-
y1	-80.481	886.887	-808.802	-	-	-	-
y2	-81.148	884.878	-888.887	-	-	-	-
z1	-80.787	887.083	-440.888	-	-	-	-
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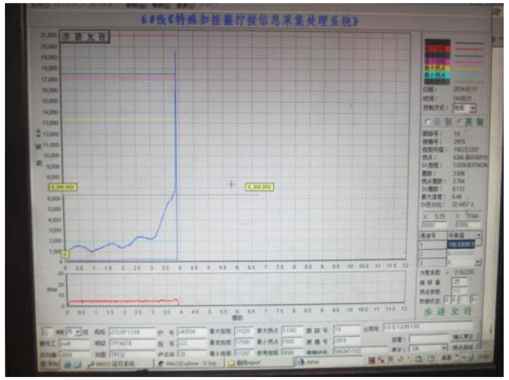


- **The profusion of sensing data provide great opportunities for effective process control and improvement!**
  - **Can the popular quality control technique take advantages of the huge amount of data?**
  - **What are the limitations?**

Control charts

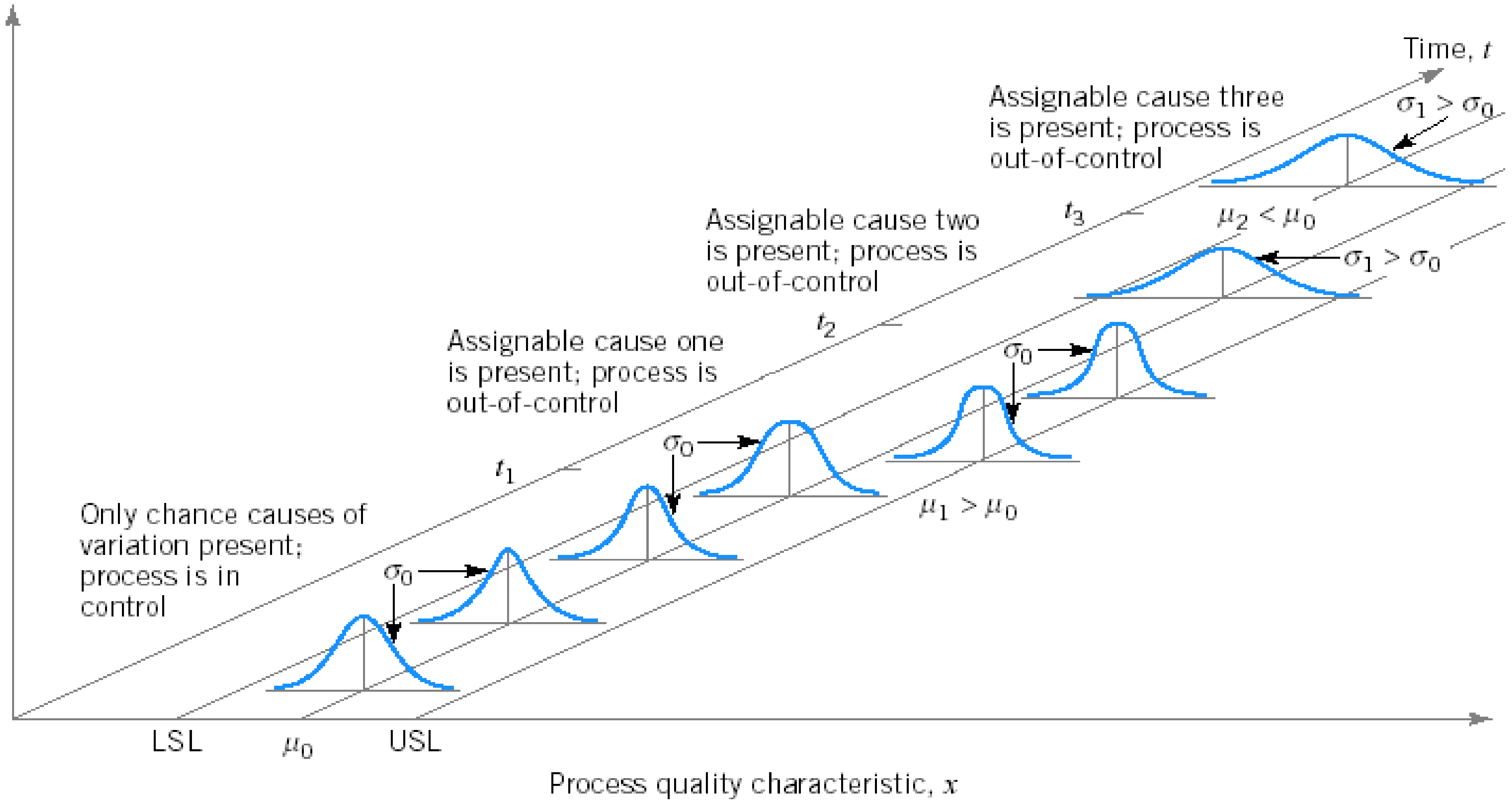
- Why?
  - ✓ Distinguish two process variations:
    - Chance causes and assignable causes
  - ✓ Decide the status of a process
    - in control
    - out of control
  - ✓ Continuously improve quality

Chance Cause vs. Assignable Cause

- systematic problems/inherent problems
  - natural variation
  - background noise
  - Environmental noise
  - …

- problems arise in somewhat unpredictable fashion failure which often indicate a need for a timely repair or suggest
  - operator error
  - material defects
  - …

- **A process is operating with only chance causes of variation present is said to be in statistical control.**
- **A process that is operating in the presence of assignable causes is said to be out of control.**



Chance and assignable causes of variation.

Quick review of random variable distribution

- **Continuous**
  - Uniform
  - Normal
  - Exponential
  - Gamma
  - Weibull
  - …

- **Discrete**
  - Binomial
  - Hypergeometric
  - Poisson
  - Geometric
  - Negative binomial
  - …

Purpose of Using Control Charts

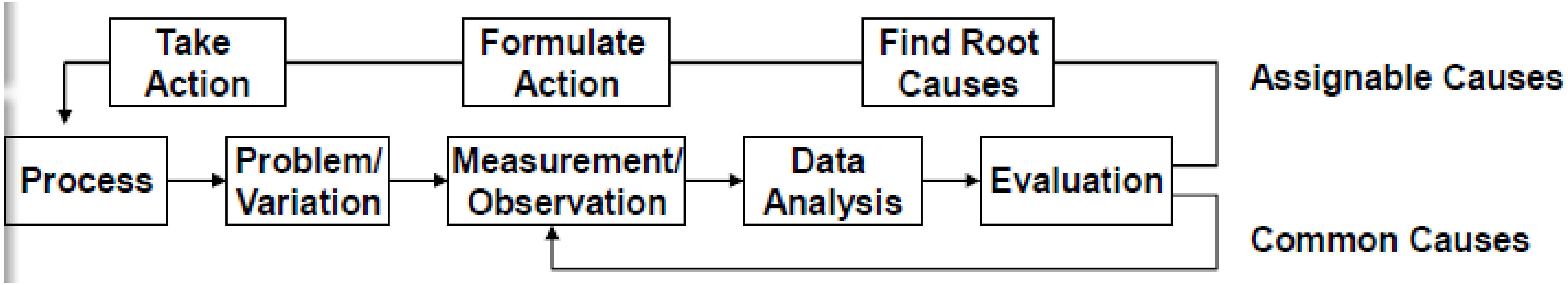
- Most processes *do not* operate in a state of statistical control
- Routine and attentive use of control charts will identify assignable causes. If these causes can be eliminated from the process, variability will be reduced and the process will be improved
- The control chart will only *detect* the occurrence of assignable causes. Management, operator, and engineering action will usually be necessary to *identify and eliminate* the assignable cause

Objectives of Statistical Process Control

- **To quickly detect the occurrence of assignable causes or process shifts so that investigations of the process and corrective actions may be undertaken before many nonconforming units are manufactured**
- **Process Variation Reduction**

Procedure of implementing SPC

- Monitoring the process and detecting process changes
- Diagnosing the assignable causes
- Providing corrective actions plans
- Dealing with resistance to changes/actions
- Instituting controls to hold the gains



What Can a Control Chart Show?

- Is the process in control?
- Is the pattern of variation stable or unstable?
- Is there a shift in the average?
- Does the output from the process meet specifications?

Basis of the Control Chart

- **Control Chart**: is a graphical display of a quality characteristic that has been measured
  - A control chart contains
    - A center line
    - An upper control limit
    - A lower control limit
  - A point that plots within the control limits indicates the process is in control
    - No action is necessary
  - A point that plots outside the control limits is evidence that the process is out of control
    - Investigation and corrective action are required to find and eliminate assignable cause(s)
  - There is a close connection between control charts and hypothesis testing

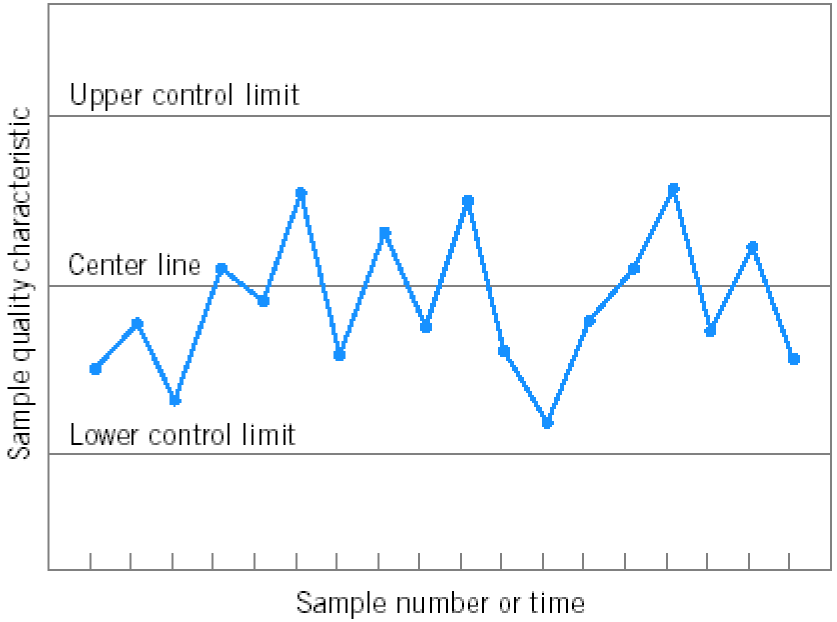


Figure 4-2 A typical control chart.

CL vs. SL

- Control Limits are used to determine if the process is in a state of statistical control

- Specification Limits are used to determine if the product will function in the expected way

An example

- Important quality characteristic in hard bake is resist flow width
- Process is monitored by average flow width
  - Sample of 5 wafers
  - Process mean is 1.5 microns
  - Process standard deviation is 0.15 microns
- Note that all plotted points fall inside the control limits
  - Process is considered to be in statistical control

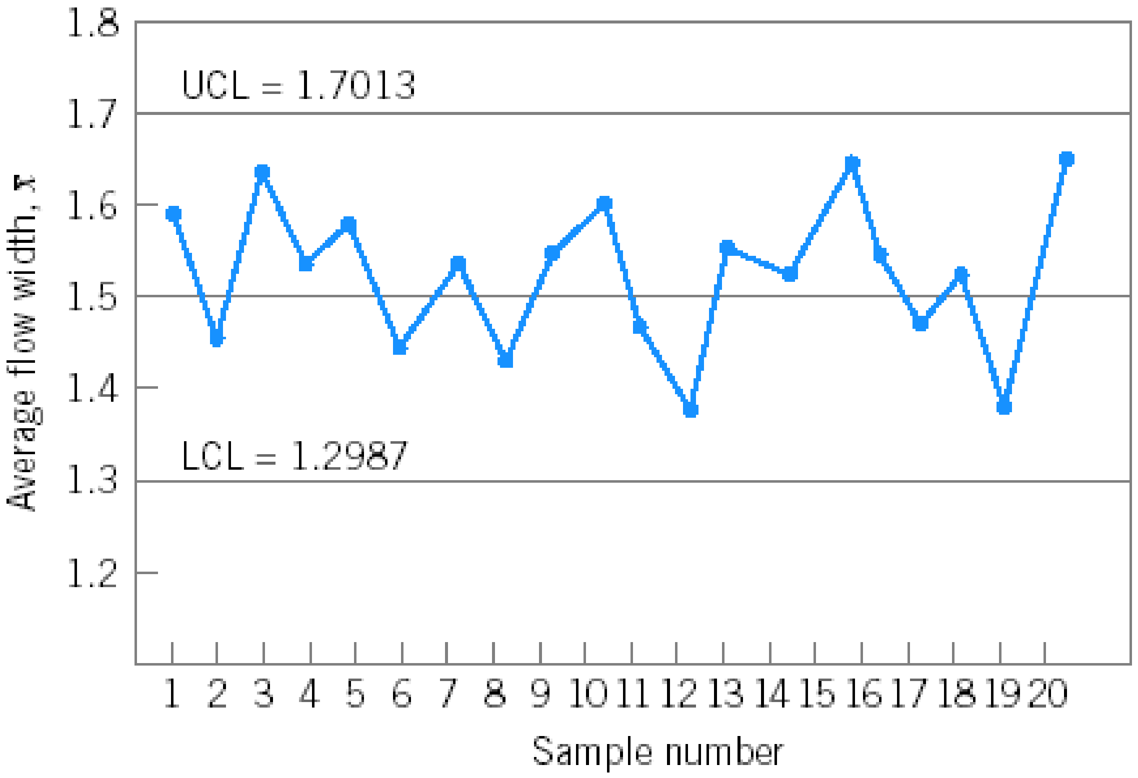


Figure 4-3 $\bar{x}$ control chart for flow width.

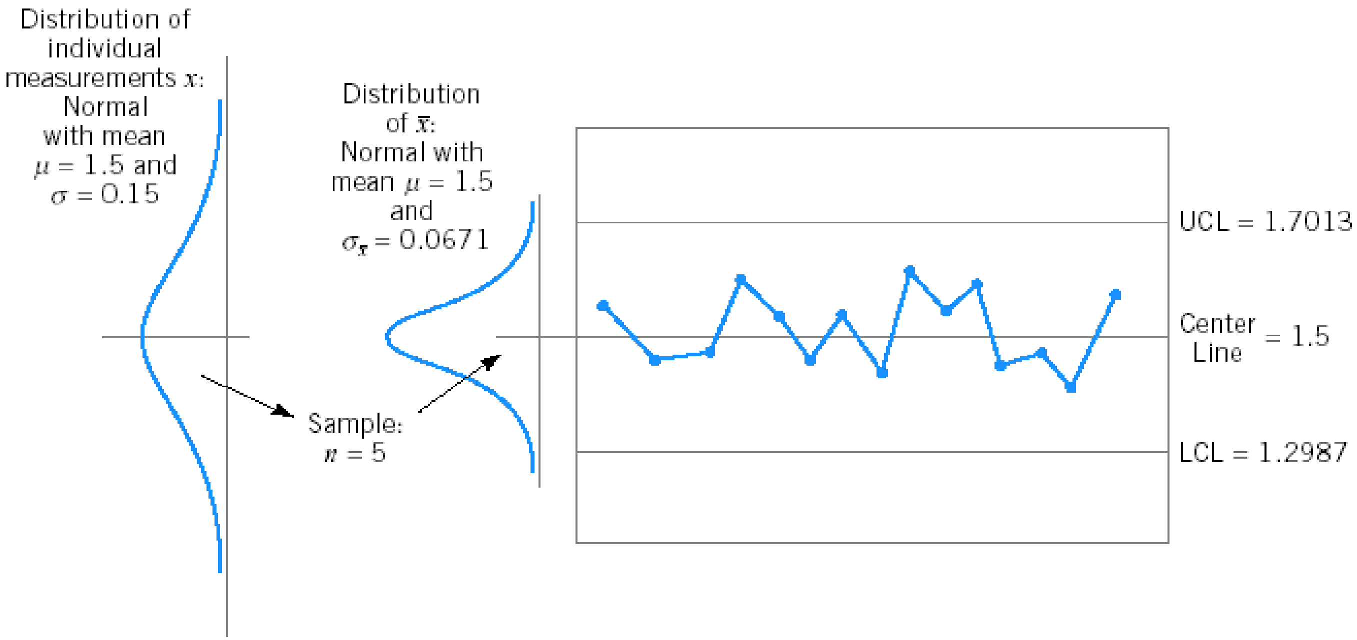
Traditional control charts

- Shewhart Chart
  - Variable data
    - X_bar and R chart
    - X_bar and S Chart
  - Attribute data
    - p and np Chart
    - c and u chart

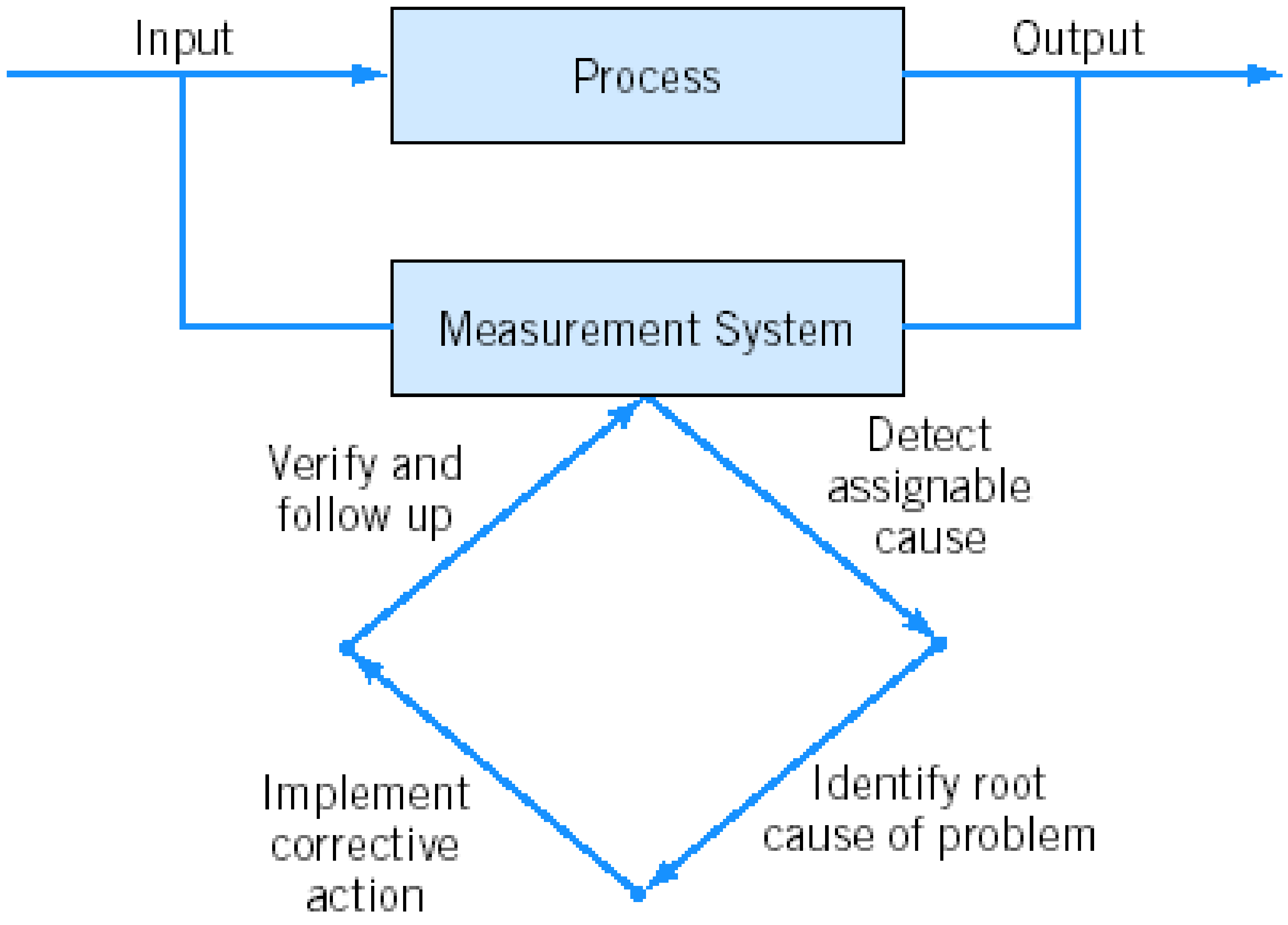
Shewhart Control Chart Model

- **A general model for a control chart by Dr. Walter S. Shewhart**

$$\begin{aligned} \text{UCL} &= \mu_w + L\sigma_w \\ \text{Center line} &= \mu_w \\ \text{LCL} &= \mu_w - L\sigma_w \end{aligned} \tag{4-1}$$



An Effective System for SPC Implementation



More Basic Principles

- Charts may be used to estimate process parameters, which are used to determine capability
- Two general types of control charts
  - Variables Continuous scale of measurement
    - Quality characteristic described by central tendency and a measure of variability
  - Attributes
    - Conforming/nonconforming
    - Counts
- Control chart design encompasses selection of sample size, control limits, and sampling frequency

Types of Process Variability

- **Stationary and uncorrelated – data vary around a fixed mean in a stable or predictable manner**
- **Stationary and autocorrelated – successive observations are dependent with tendency to move in long runs on either side of mean**
- **Nonstationary – process drifts without any sense of a stable or fixed mean**

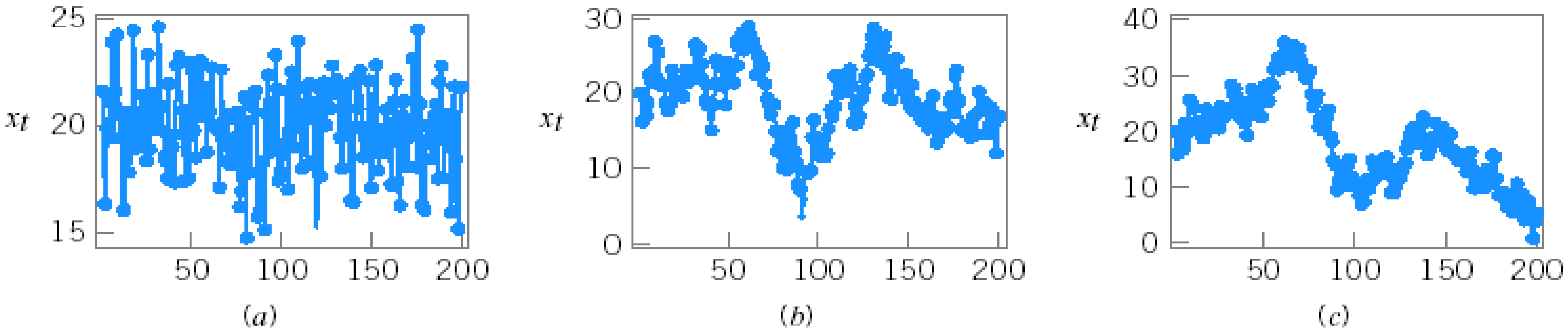


Figure 4-7 Data from three different processes. (*a*) Stationary and uncorrelated (white noise). (*b*) Stationary and autocorrelated. (*c*) Nonstationary.

Control Charts vs. Hypothesis Test

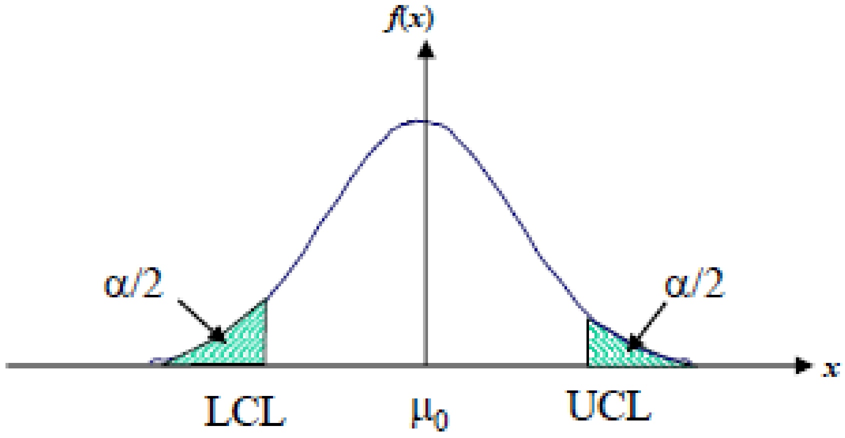
- **Hypothesis Testing**
  - **Hypothesis testing has a rejection region**
  - **H_0 is rejected if the data fall in the rejection region**

$$H_0:\ \mu = \mu_0$$

$$H_1:\ \mu \neq \mu_0$$

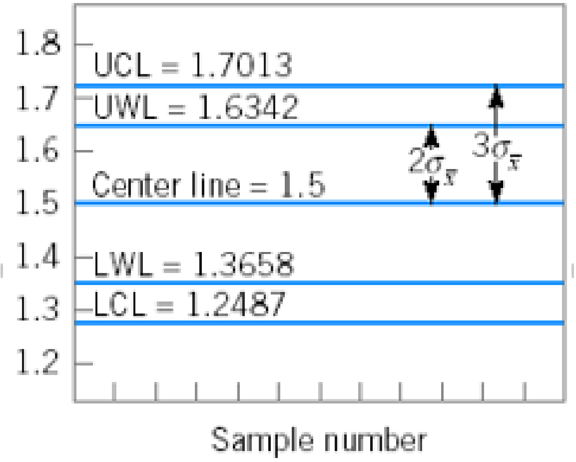
Reject H_0 $\boxed{\text{if } \left| \dfrac{\bar{x} - \mu_0}{\sigma/\sqrt{n}} \right| > Z(\alpha/2)}$

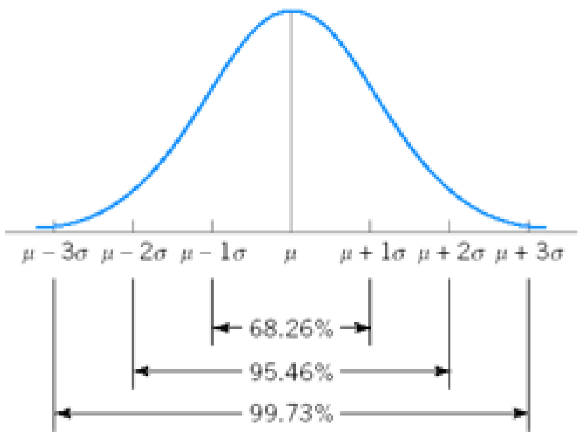
- **Control Charts**
  - **Control chart has UCL & LCL**
  - **The process is out of control if the data beyond the control limits**



Choice of Control Limits

- 3-Sigma Control Limits
  - Probability of type I error is 0.0027
- Probability Limits
  - Type I error probability is chosen directly
  - For example, 0.001 gives 3.09-sigma control limits
- Warning Limits
  - Typically selected as 2-sigma limits





Average run length (平均链长)

- Average run length (ARL)
  - The ARL is the average number of points that must be plotted before a point indicates an out-of-control condition
- If the process observations are uncorrelated

$$ARL = 1/p$$

where p is the probability that any point exceeds the control limits

It is a flip-over time!

Next Class

Traditional control charts