LECTURES 6
QUALITY MANAGEMENT

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WHERE ARE WE

- **Lecture 1 - 2 Introduction and Operations Strategy**
- **Lecture 3 – 5 Process**
  - Bottleneck analysis
  - Little’s law
  - Production / Service processes
  - Queueing model
- **Lecture 6 Quality Management**

LEARNING OBJECTIVES FOR TODAY

Definition and cost of quality

Capability of a process

How processes are monitored with control charts

Understand six-sigma quality and methodology

DEFINING QUALITY

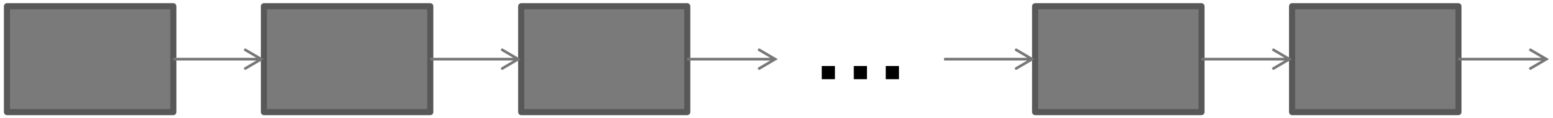
Quality

- **Conformance quality**: The degree to which the product or service design specifications are met
- **Design quality**: Inherent value / specification of a product or service, e.g., performance, features, aesthetics, etc.

Defect: Product that can not meet its design specifications
Source of defects: variability

SMALL VARIATIONS MAY CAUSE BIG DEFECTIVE RATIOS

- **Assembly operations for a automobile**
- **10 steps**
- **Each step has a 1% probability of failure (2%)**
- **What is the probability of a defect?**



A COMPARISON OF U.S. AND JAPANESE PRODUCTS IN 70-80' BY RUSSEL AND TAYLOR 1999

Quality of Automobiles	Things go wrong in the first 8 month per 100 cars	
Chrysler	285	
GM	256	
Ford	214	
Japanese average	132	
Quality of Semiconductors	**U.S.**	**Japanese**
Defective on Delivery	16%	0%
Failure after 1,000 hours	14%	1%
Quality of Room Air Conditioners	**U.S.**	**Japanese**
Fabrication defects	4.4%	<0.1%
Assembly line defects	63.5%	0.9%
Warranty cost (as % of sales)	2.2%	0.6%
Quality of Color TVs	**U.S.**	**Japanese**
Assembly line defects per set	1.4	0.01

COSTS OF QUALITY

Appraisal costs (评估成本)

- Costs of inspection, testing and other tasks to ensure that the products or process is acceptable

Prevention costs (预防成本)

- Quality planning
- Process control
- Quality training
- Quality improvement process implementation

COSTS OF QUALITY

Internal failure cost (prior to purchase of customers)

- Costs for defects incurred within the system: scrap, rework, repair

External failure cost (after purchase of customers)

- Customer complaints
- Warranties
- Product recall
- Returned material
- Potential loss of market share (goodwill)

QUALITY COST REPORT

Prevention costs	$	Internal failure costs	$
Quality training	2,000	Scrap	15,000
Reliability consulting	10,000	Repair	18,000
Pilot product runs	5,000	Rework	12,000
Systems development	8,000	Downtime	6,000
Appraisal costs	**$**	**External failure costs**	**$**
Materials inspection	6,000	Warranty costs	14,000
Supplies inspection	3,000	Out-of-warranty repairs	6,000
Reliability testing	5,000	Customer complaints	3,000
Lab testing	25,000	Product liability	10,000
		Transportation losses	5,0000
Total Quality Costs	**$153,000**		

QUANTITATIVE QUALITY MANAGEMENT

1. **How well is a process designed to meet expectation?**
2. **How do we know a process is not deviating from its normal state?**

WHICH OF THE TWO PROCESSES ARE BETTER ?

Suppose we want to produce something of length 5 mm ±0.01 mm, there are samples from two processes:

a) **5.001 mm, 5.002 mm, 5.001 mm, 5.002 mm, 5.001 mm**

b) **5.01 mm, 4.99 mm, 5.01 mm, 4.09 mm, 5.00 mm**

PROCESS CAPABILITY

- **Question: How well is a process designed to meet expectation?**
- **Specification Limit (Tolerance Limit)**
  - The specification that we want our product to fit in
  - We want to produce something of length 5 mm $\pm$0.01 mm
  - The EU 1677-88 resolution requires cucumber of highest quality with curvature no more than 10 mm
- **Production process:**
  - The production output has variability
  - We use a distribution to describe the production output (process distribution)
  - Theoretically, the process distribution is not known unless we use this process to produce many, many products, i.e., complete sampling

SAMPLING

- **In order to learn about the production output, we can use a partial sampling**
- **Sample statistics are calculated based on the samples**
  - Sample mean
  - Sample standard deviation
  - Sample range
  - …

SAMPLE MEAN

- **A sample mean is the sum of the observations divided by the total number of observations.**

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

x_i = observations of a quality characteristic
n = total number of observations
$\bar{x}$ = sample mean

SAMPLE RANGE

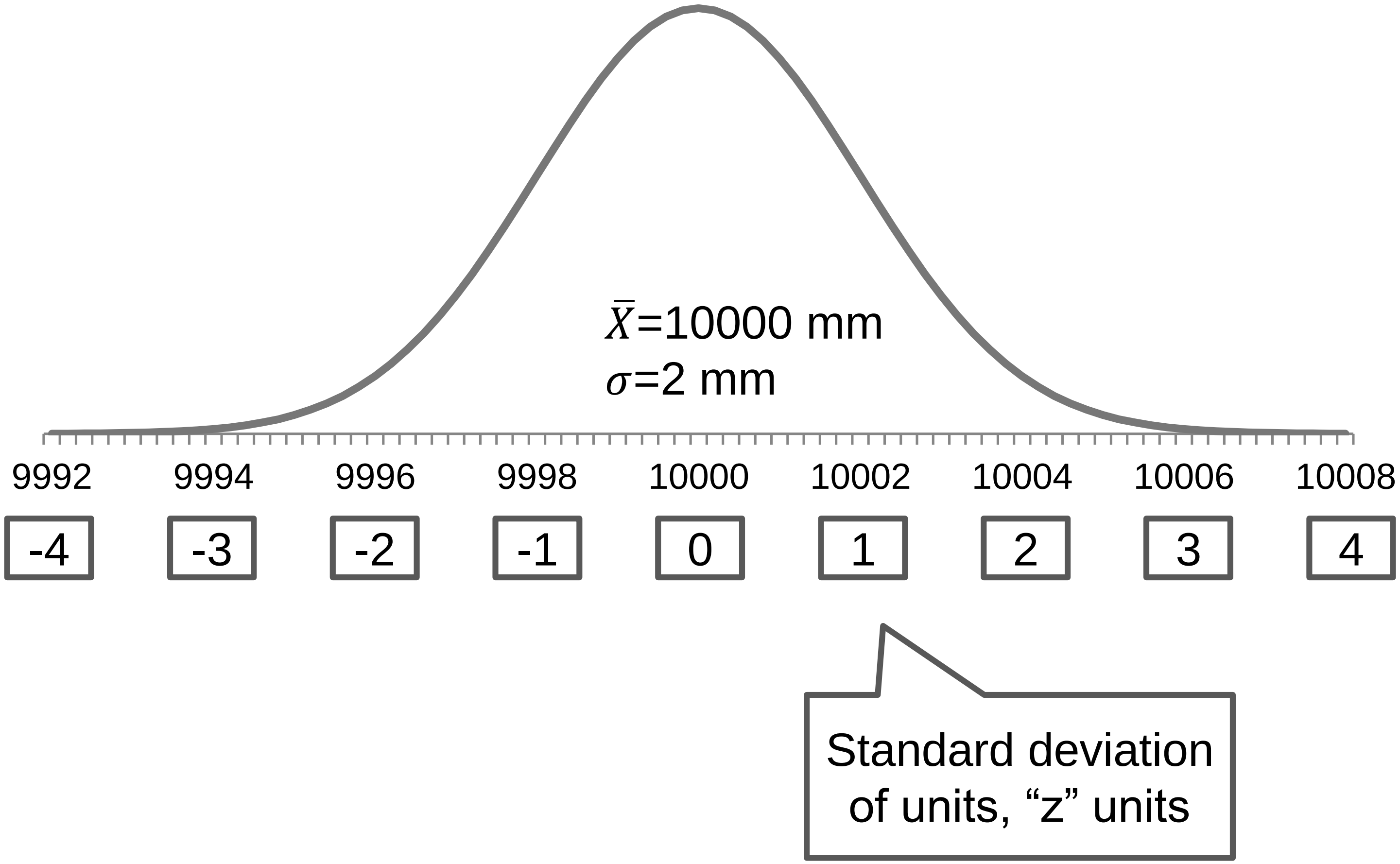
- **The range (R) is the difference between the largest observation in a sample and the smallest**
- **The standard deviation is the defined as follows:**

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

σ = standard deviation of the sample
x_i = observations of a quality characteristic
n = total number of observations
$\bar{x}$ = sample mean

PROCESS OUTPUT IS ASSUMED TO BE A NORMAL DISTRIBUTION

μ = mean of the process output, or $\bar{X}$
σ = standard deviation of the process output



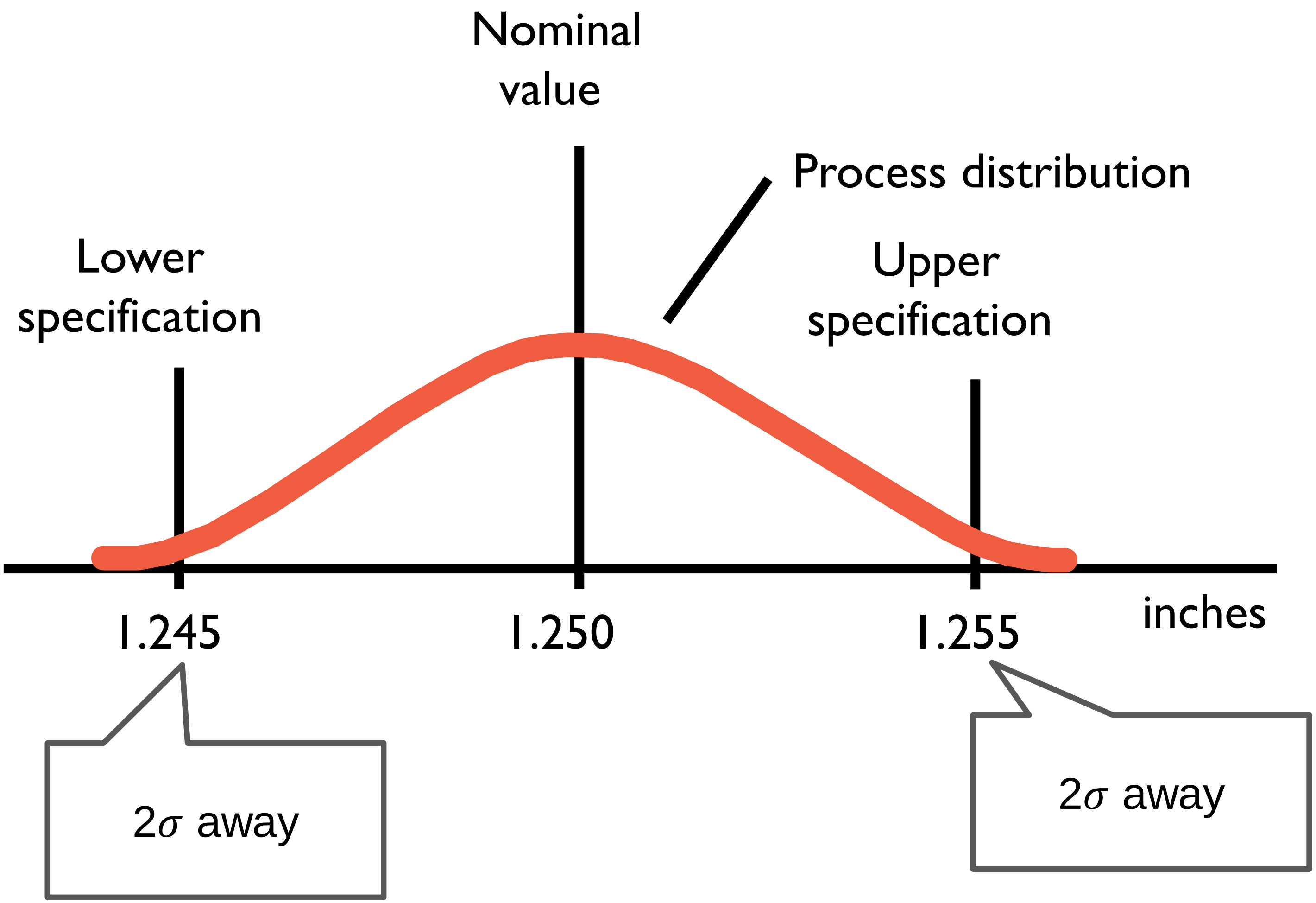
PROCESS OUTPUT IS ASSUMED TO BE A NORMAL DISTRIBUTION

- **Probability of producing product more than σ away from μ is about 31.73%**
- **Probability of more than 2σ away from μ is about 4.55%**
- **Probability of more than 3σ away from μ is about 0.27%**

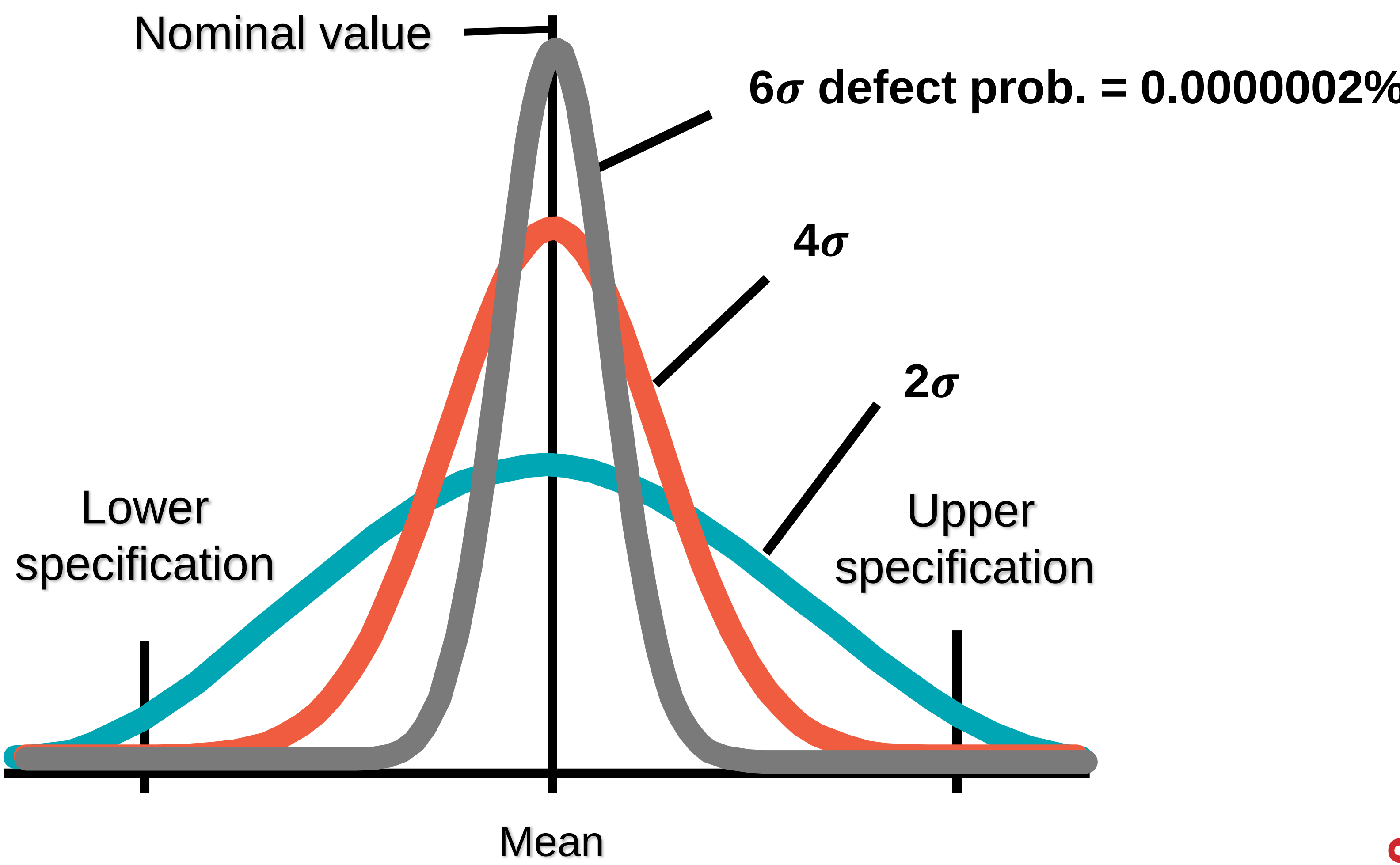
PROBABILITY OF PRODUCING A DEFECTIVE PRODUCT

- **Example: When we produce a bearing, we want its diameter to be 1.250 inches (nominal value) +- 0.005 inch (tolerance)**
- **Suppose a process producing bearings with average diameter 1.250 inches and standard deviation 0.0025 inch.**
- **What is the probability that it will produce a defective bearing?**
- **Answer: 4.55%**

SPECIFICATION LIMITS



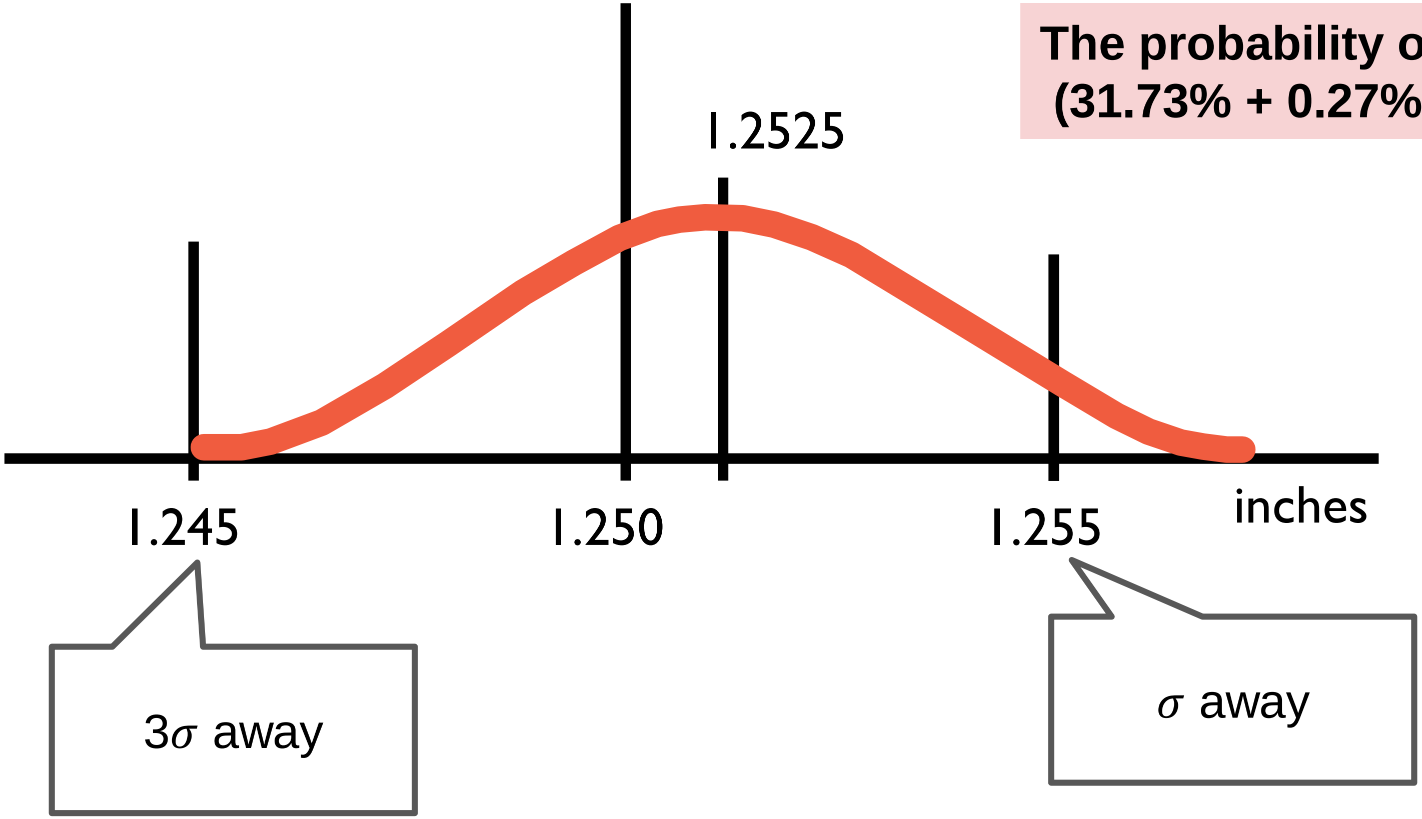
EFFECTS OF REDUCING PROCESS VARIABILITY



WHEN THE PROCESS IS NOT CENTERED

- **Sometimes the process is not centered:**
  - The process mean = 1.2525, stdev = 0.0025

The probability of defect is (31.73% + 0.27%)/2 = 16%



MEASUREMENT OF PROCESS CAPABILITY

- **Capability index (C_{pk}) is an index that measures the potential for a process to generate outputs relative to either upper or lower specifications.**

- $C_{pk} =$ **minimum of** $\frac{\bar{X}-LTL}{3\sigma}$ **and** $\frac{UTL-\bar{X}}{3\sigma}$

- **LTL = lower tolerance limit (or upper specification limit)**
- **UTL = upper tolerance limit (or lower specification limit)**

EXAMPLE

The quality manager is assessing the capability of a process that puts pressurized grease in an aerosol can. The design specification call for an average of 60 pounds per square inch (psi) of pressure in each can with upper tolerance limit of 65 psi and lower limit of 55 psi. A sample is taken from production and it is found that the cans average 61 psi with a standard deviation of 2 psi. What is the capability of the process? What is the probability of producing a defect?

EXAMPLE

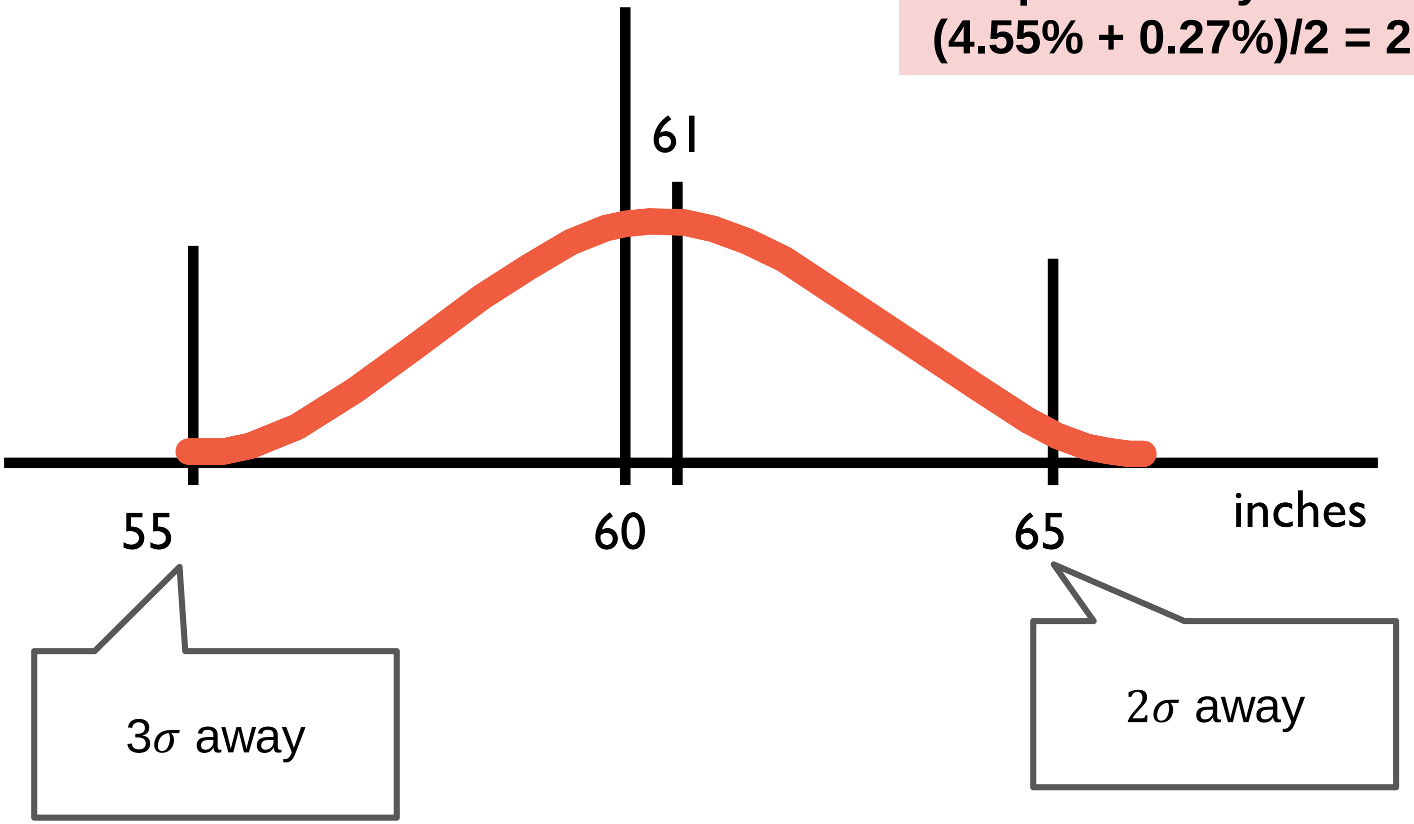
- **UTL = 65, LTL = 55,** $\bar{X} = 61, \sigma = 2$
- **C_{pk}= minimum of** $\frac{\bar{X} - LTL}{3\sigma}$ **and** $\frac{UTL - \bar{X}}{3\sigma}$

  = minimum of $\frac{61-55}{6}$ **and** $\frac{65-61}{6}$

  = minimum of 1 and 0.667 = 0.667

EXAMPLE

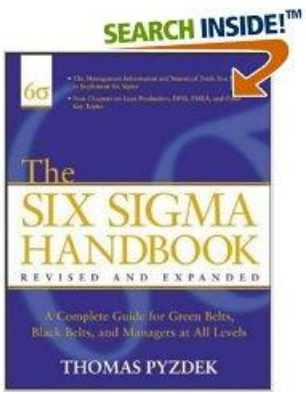
The probability of defect:

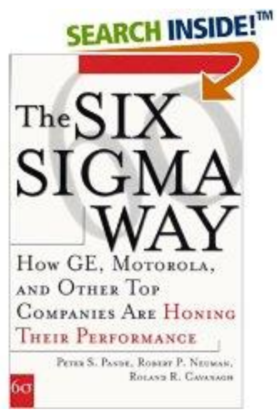


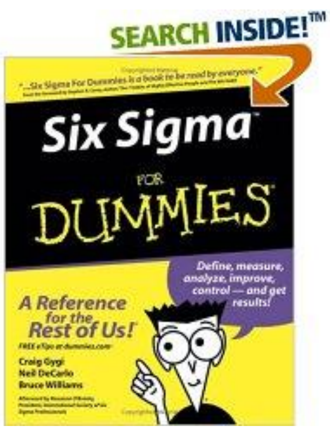
The probability of defect is (4.55% + 0.27%)/2 = 2.41%

“SIX SIGMA”

- Many companies look for a C_{pk} of 1.3 or better, 6-Sigma company wants 2.0!
- 6-Sigma represents 0.002 defects per million opportunities (DPMO)
- Six Sigma now becomes a standard or philosophy in quality management by minimizing defects and variability in processes.







STATISTICAL PROCESS CONTROL (SPC)

- **SPC: the quantitative aspects of quality management**
  - Use statistical techniques to determine whether a process is deviates from its normal state.
  - SPC is a statistical method to understand the variations of process output

VARIATION AROUND US

- **It is generally accepted that as variation is reduced, quality is improved.**
- **However, engineers also know that it is impossible to have zero variability.**
- **The design limits are often referred to as the upper and lower specification limits**
- **A traditional way of interpreting such a specification is that any part that falls within the allowed range is equally good, whereas any part falling outside the range is totally bad.**

VARIATION AROUND US

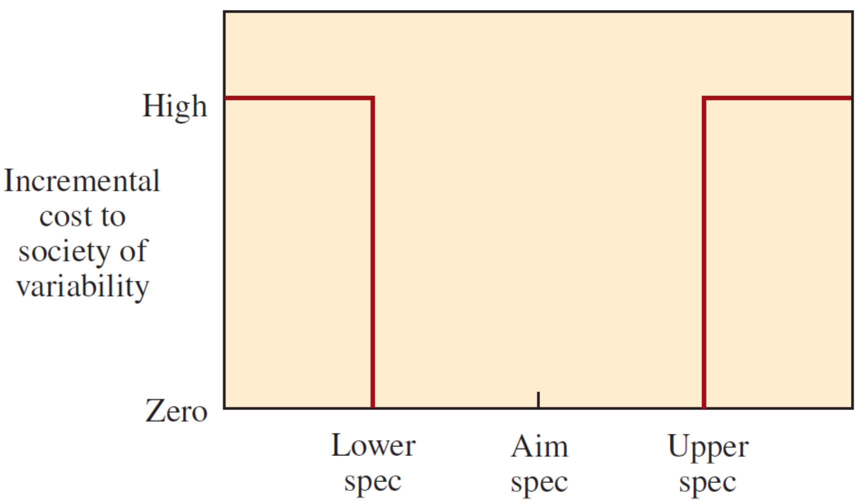
- **Genichi Taguchi, a noted quality expert from Japan, has pointed out that the traditional view is nonsense for two reasons:**

1. From the customer's view, there is often practically no difference between a product just inside specifications and a product just outside. Conversely, there is a far greater difference in the quality of a product that is at the target and the quality of one that is near a limit.

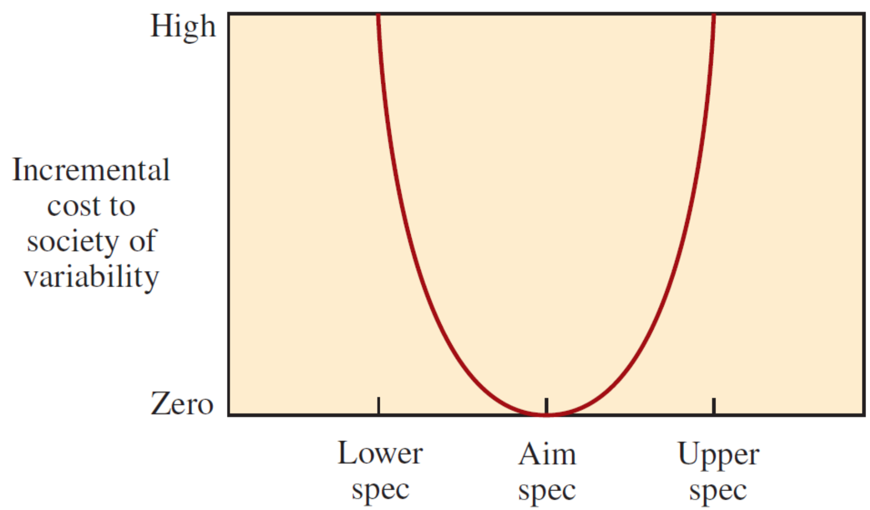
2. As customers get more demanding, there is pressure to reduce variability.

VARIATION AROUND US

A Traditional View of the Cost of Variability



Taguchi's View of the Cost of Variability



CAUSE OF VARIATION

- **Common causes (normal):**
  - Inherent in the process itself. They are purely random, unidentifiable sources of variation that are unavoidable with the current process.
  - A typical assumption is that the distribution is symmetric, with most observations near the center.
- **Assignable causes (abnormal):**
  - Variations that are caused by identifiable factors and may be managed.
  - E.g. variation caused by improper setup of machines or unequal training of workers
  - We want to make sure whenever assignable causes occur, we are able to identify them: **statistical process control**

TWO TYPES OF LIMITS

The upper and lower process control limits relate to how consistent our process is for making a product.

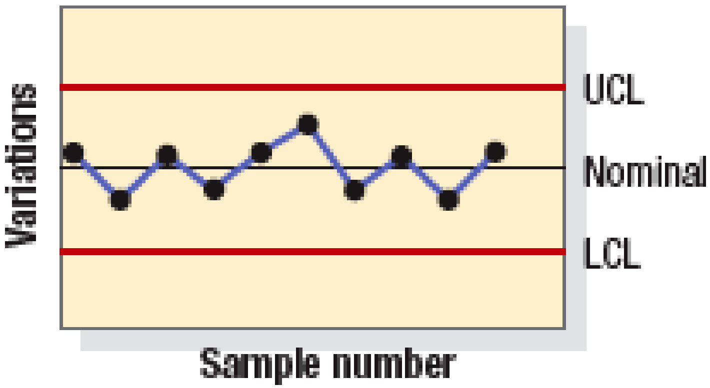
The upper and lower specification limits are related to the design of the part.

If the process limits are slightly greater than the specification limits, then this is not good.

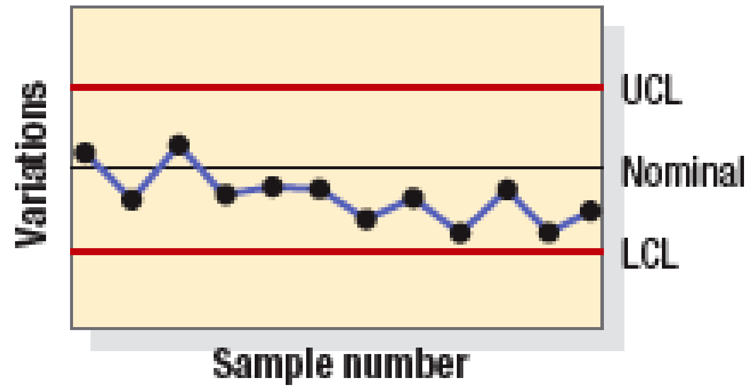
CONTROL CHARTS

- **Control chart: A time-ordered diagram that is used to determine whether observed variations are abnormal.**
- **A sample statistic that falls between the upper control limit (UCL) and lower control limit (LCL) indicates that the process is exhibiting a common causes of variation**
- **A sample statistic that falls outside the control limits indicates the process is exhibiting assignable causes of variation**

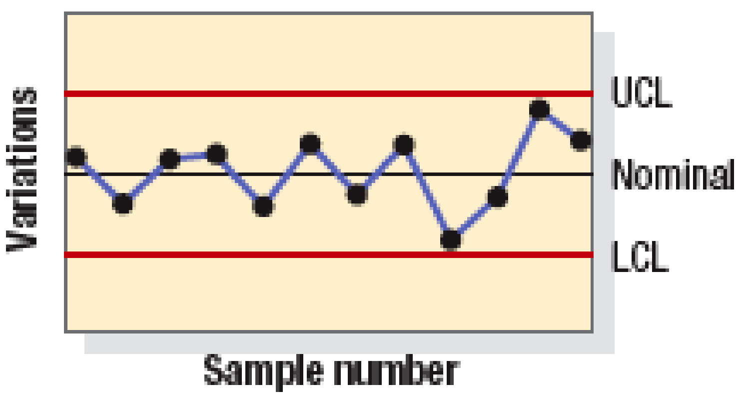
CONTROL CHARTS EXAMPLES



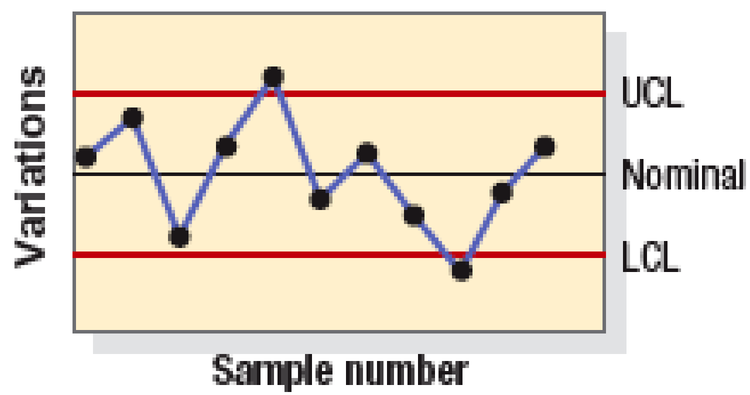
(a) Normal—No action



(b) Run—Take action



(c) Sudden change—Monitor

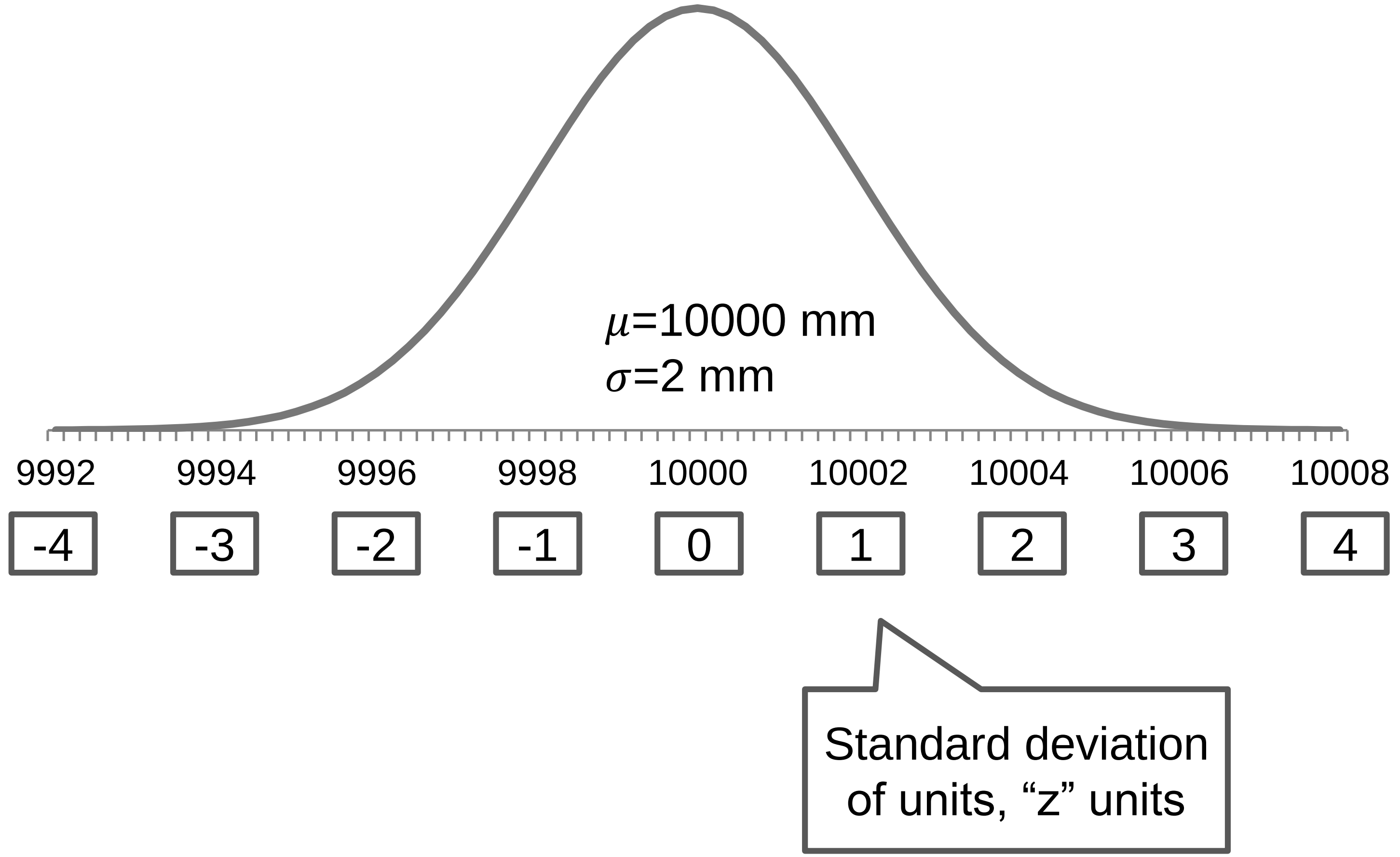


(d) Exceeds control limits—Take action

INDICATORS OF OUT OF CONTROL CONDITIONS

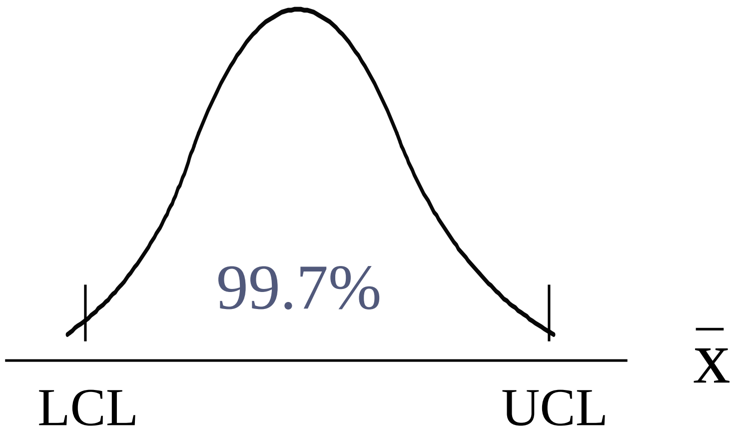
- **A trend in the observations (the process is drifting)**
- **A sudden or step change in the observations**
- **A run of five or more observations on the same side of the mean**
- **Several observations near the control limits (Normally only 1 in 20 observations are more than 2 standard deviations from the mean)**
- **One or more observations outside of the control limits**

CONTROL LIMITS ARE BASED ON THE NORMAL CURVE



CONTROL LIMITS

- **We establish the Upper Control Limits (UCL) and the Lower Control Limits (LCL) with plus or minus 3 standard deviations from some x-bar or mean value. Based on this we can expect 99.7% of our sample observations to fall within these limits, i.e., if the process is in normal state, 99.7% the chance that the calculated measure is within the control limits**



TYPES OF MEASUREMENT

- **Variable Measurement: continuous variable**
  - Characteristics that can measured in a continuous fashion, such as weight, length, volume, or time
- **Attribute Measurement: binary variable**
  - Characteristics that are in binary state such as good or bad

STATISTICAL CONTROL METHODS

- $\bar{X}$**-chart is used to see whether the process is generating output, on average, whether its current performance, with respect to the average of performance measure, is consistent with past performance**
- ***R*-chart (Range Chart) is used to monitor process variability**
- ***p*-chart (Probability Chart) is used to monitor the defective rate of a batch**

EXAMPLE OF X AND R-CHARTS

Sample #	Each unit in sample				
1	10.60	10.40	10.30	9.90	10.20
2	9.98	10.25	10.05	10.23	10.33
3	9.85	9.90	10.20	10.25	10.15
4	10.20	10.10	10.30	9.90	9.95
5	10.30	10.20	10.24	10.50	10.30
6	10.10	10.30	10.20	10.30	9.90
7	9.98	9.90	10.20	10.40	10.10
8	10.10	10.30	10.40	10.24	10.30
9	10.30	10.20	10.60	10.50	10.10
10	10.30	10.40	10.50	10.10	10.20
11	9.90	9.50	10.20	10.30	10.35
12	10.10	10.36	10.50	9.80	9.95
13	10.20	10.50	10.70	10.10	9.90
14	10.20	10.60	10.50	10.30	10.40

EXAMPLE OF X AND R-CHARTS

Sample #	Each unit in sample					$\bar{X}$	*R*
1	10.60	10.40	10.30	9.90	10.20	10.28	.70
2	9.98	10.25	10.05	10.23	10.33	10.17	.35
3	9.85	9.90	10.20	10.25	10.15	10.07	.40
4	10.20	10.10	10.30	9.90	9.95	10.09	.40
5	10.30	10.20	10.24	10.50	10.30	10.31	.30
6	10.10	10.30	10.20	10.30	9.90	10.16	.40
7	9.98	9.90	10.20	10.40	10.10	10.12	.50
8	10.10	10.30	10.40	10.24	10.30	10.27	.30
9	10.30	10.20	10.60	10.50	10.10	10.34	.50
10	10.30	10.40	10.50	10.10	10.20	10.30	.40
11	9.90	9.50	10.20	10.30	10.35	10.05	.85
12	10.10	10.36	10.50	9.80	9.95	10.14	.70
13	10.20	10.50	10.70	10.10	9.90	10.28	.80
14	10.20	10.60	10.50	10.30	10.40	10.40	.40

EXAMPLE OF X AND *R*-CHARTS

- **We calculate the $\overline{X}$ for each sample:**
  - 10.28, 10.17, 10.07, 10.09, 10.31, 10.16, 10.12, 10.27, 10.34 10.30, 10.05, 10.14,10.28, 10.40
- **Also calculate the *R* (Range) for each sample:**
  - .70, .35, .40, .40, .30, .40, .50, .30, .50, .40, .85, .70, .80, .40
- **Calculate the mean of means: $\overline{\overline{X}}$ = 10.21 and mean of the ranges : $\overline{R}$=0.50**

EXAMPLE OF X AND *R*-CHARTS

$\bar{X}$ Chart Control Limits

UCL = $\bar{\bar{X}} + A_2 \bar{R}$
LCL = $\bar{\bar{X}} - A_2 \bar{R}$

R Chart Control Limits

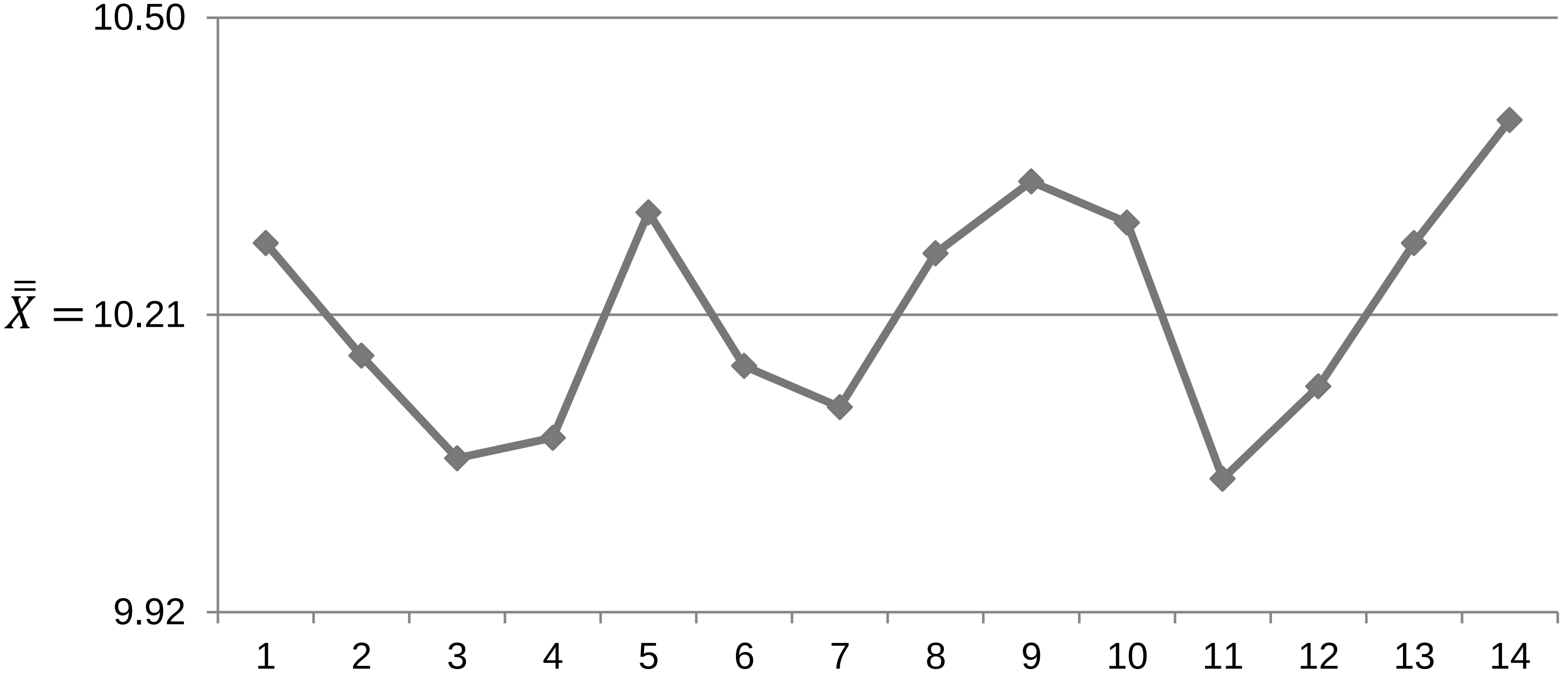
UCL = $D_4 \bar{R}$
LCL = $D_3 \bar{R}$

# in each sample	A_2	D_3	D_4
2	1.88	0	3.27
3	1.02	0	2.57
4	0.73	0	2.28
5	0.58	0	2.11
6	0.48	0	2.00
7	0.42	0.08	1.92
8	0.37	0.14	1.86
9	0.34	0.18	1.82
10	0.31	0.22	1.78
11	0.29	0.26	1.74
12	0.27	0.28	1.72

EXAMPLE OF X AND *R*-CHARTS

UCL = $\bar{\bar{X}} + A_2\,\bar{R}$ **=10.21+0.58 x 0.50=10.50**

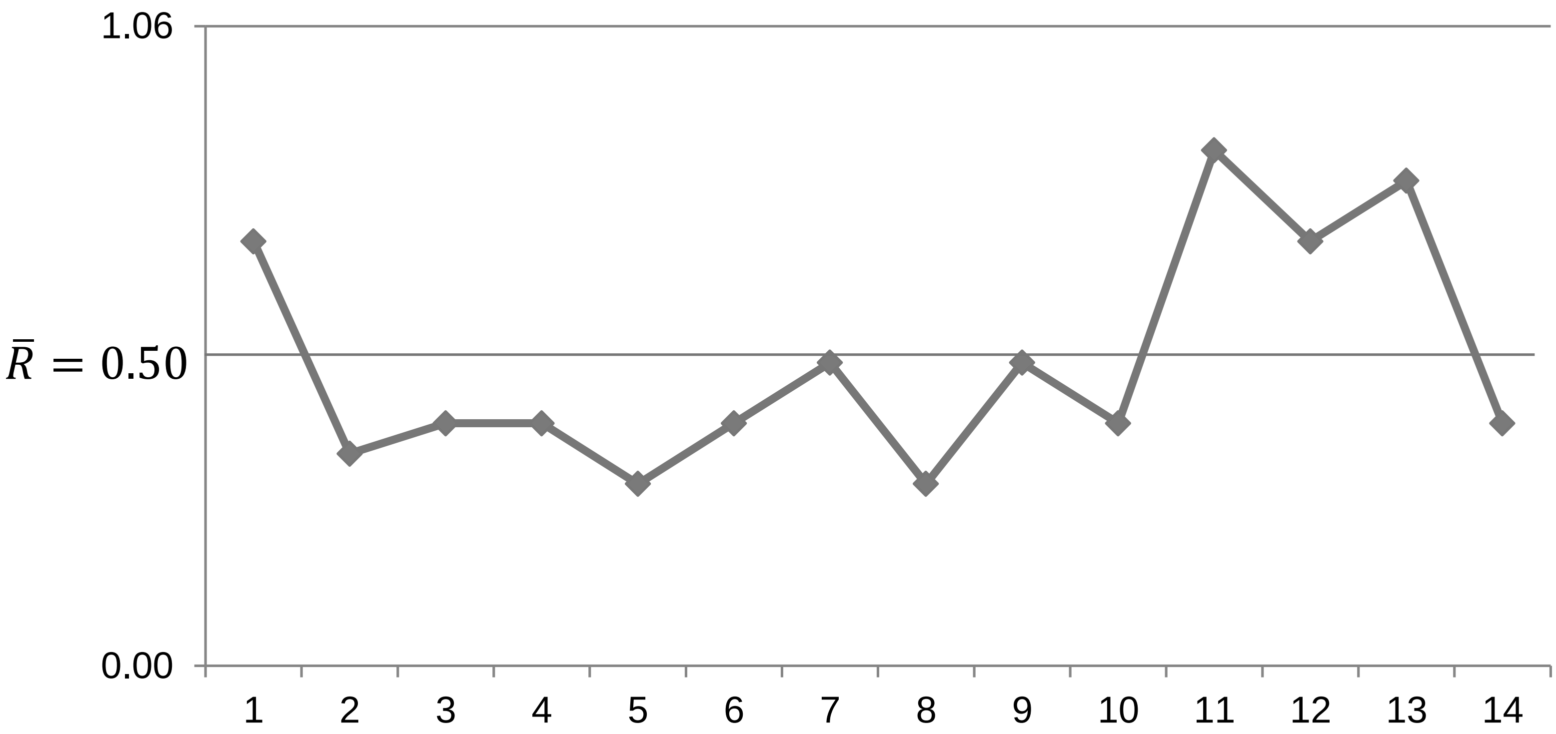
LCL =$\bar{\bar{X}} - A_2\,\bar{R}$ **=10.21-0.58 x 0.50=9.92**



EXAMPLE OF X AND *R*-CHARTS

UCL = $D_4\ \bar{R}$ = 2.11 x 0.50 = 1.06

LCL = $D_3\ \bar{R}$ = 0 x 0.50 = 0



EXAMPLE OF P - CHART

Sample	Number inspected	Number of defects	Defection ratio
1	300	10	0.03333
2	300	8	0.02667
3	300	9	0.03000
4	300	13	0.04333
5	300	7	0.02333
6	300	7	0.02333
7	300	6	0.02000
8	300	11	0.03667
9	300	12	0.04000
10	300	8	0.02667
Total	3000	91	0.03033

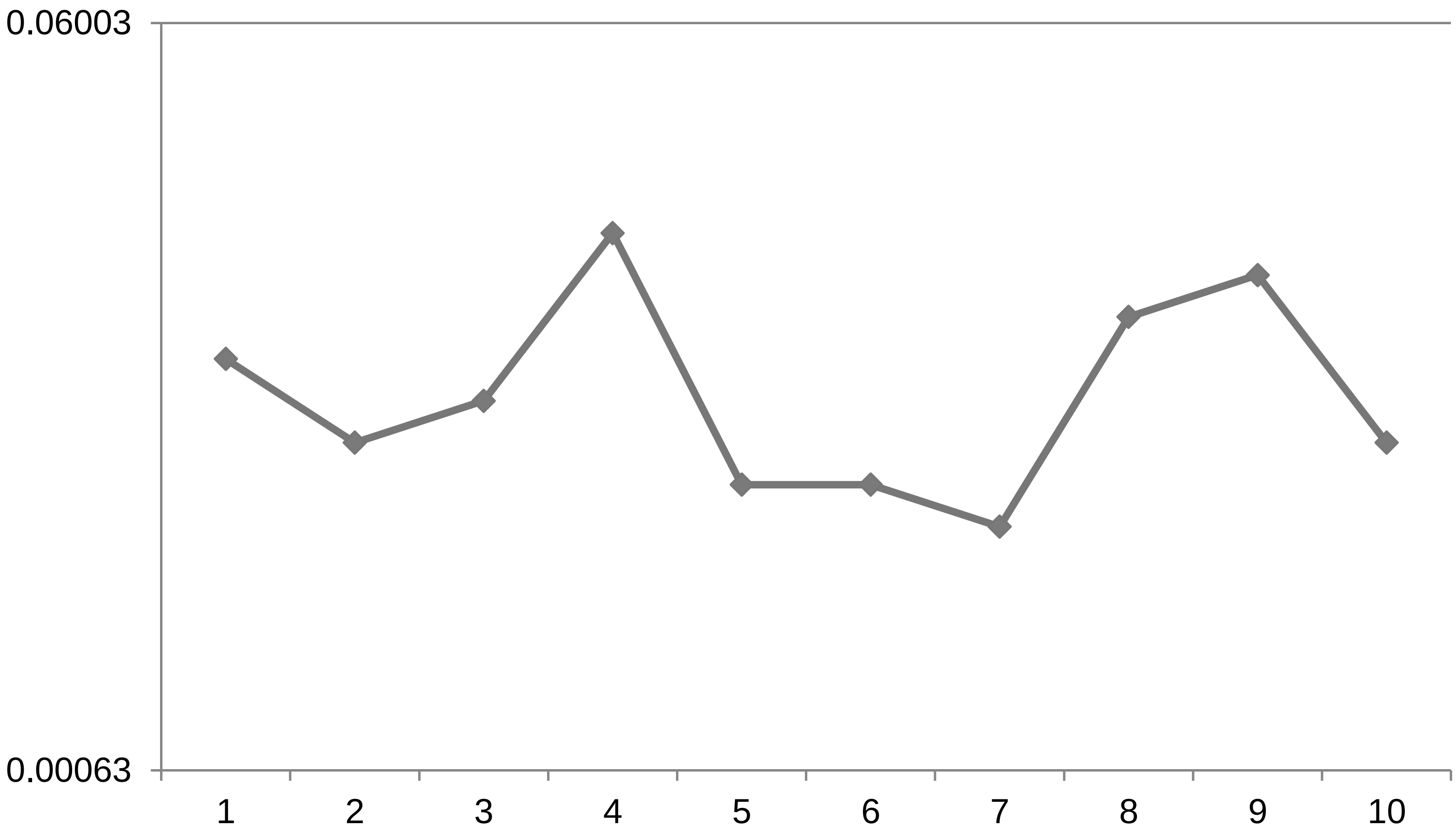
EXAMPLE OF *P* - CHART

- **Calculate**
- $\bar{p} = \frac{Total\ Number\ of\ Defective}{Total\ Number\ of\ Observations} = \frac{91}{3000} = 0.03033$
- $s_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = \sqrt{\frac{0.03033(1-0.03033)}{300}} = 0.00990$

- **The control limits:**
- **UCL =** $\bar{p} + zs_p$**=0.03033+3x0.00990 = 0.06003**
- **LCL =** $\bar{p} - zs_p$**=0.03033-3x0.00990 = 0.00063**

- **Note:**
  - n = sample size
  - z = number of standard deviations

EXAMPLE OF *P* - CHART



TYPE I AND TYPE II ERRORS

- **Control charts are not perfect tools for detecting shifts in process because they are based on samples**
- **Type I error: when there is no shift of process but the sample result falls out of the control limits**
  - Consequence : looking for assignable causes that do not exist
- **Type II error: when there is shift of process but the sample result still fall inside the control limits**
  - Consequence: Undetected process change.

HOW DO WE USE SPC

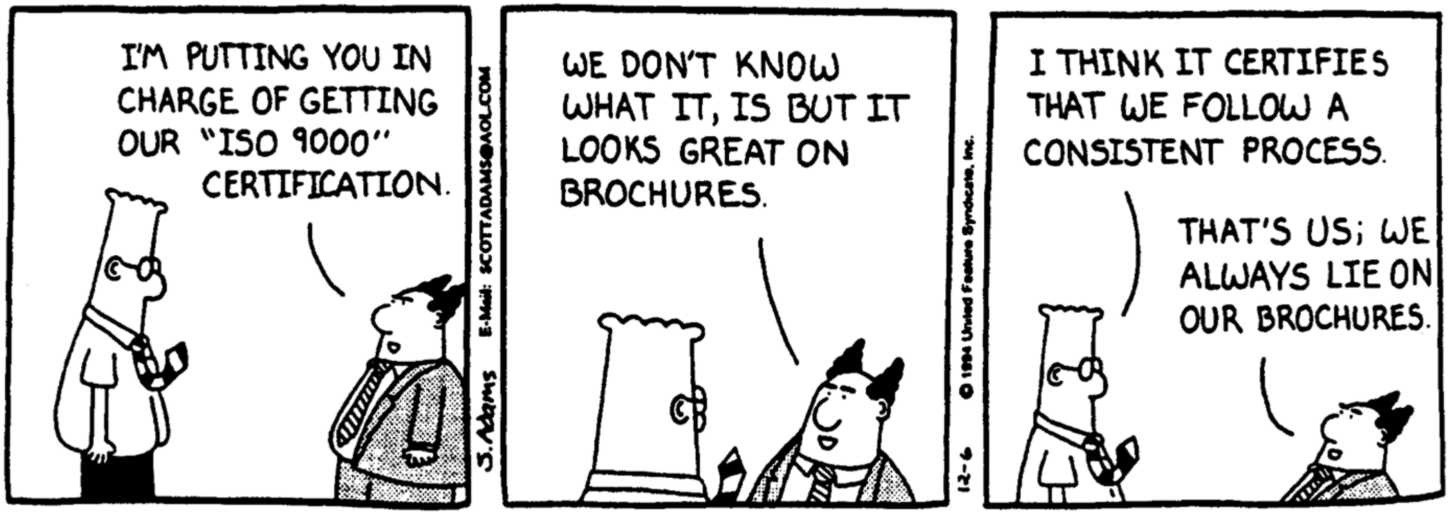
1. Sample the process
2. When erratic observations are indicated, find the assignable cause
3. Eliminate the problems, incorporate improvements
4. Repeat the procedure

Note:

1. A control chart does not tell us if the process is “good” or “bad”!
2. It only tells us whether the process is consistent or not

INTERNATIONAL QUALITY DOCUMENTATION STANDARDS

- ISO: International Organization for Standardization
- ISO 9000: A set of standards governing documentation of a quality program
- Pertain to the process of how a product is produced, rather than the product itself.



INTERNATIONAL QUALITY DOCUMENTATION STANDARDS

- ISO 14000: a family of standards related to environmental management
- Documentation standards that require participating companies to keep track of their raw materials use and their generation, treatment, and disposal of hazardous wastes.
- ISO 9000 + ISO 14000 = ISO 19011

TOTAL QUALITY MANAGEMENT (TQM)

- **A philosophy that "managing the entire organization so that it excels on all dimensions of products and services that are important to the customer"**
- **Two goals**

1. **Careful design of the product or service.**
2. **Ensuring that the organization's systems can consistently produce the design.**
    - Process-centered, Integrated system, Strategic and systematic approach, Fact-based decision making, Communications
    - Customer satisfaction
    - Employee involvement
    - Continuous improvement

CONTINUOUS IMPROVEMENT (KAIZEN)

- **The philosophy of continually seeking ways to improve processes based on a Japanese concept called kaizen**
- **Kaizen(改善)**
  - Train employees in the methods of statistical process control and other tools
  - Make these methods a normal aspect of operations
  - Build work teams and encourage employee involvement
  - Utilize problem-solving tools within the work teams
  - Develop a sense of operator ownership in the process

SOME QUALITY MANAGEMENT GURUS

William Edwards Deming, (1900–1993) Deming is widely credited with improving production in the United States during World War II. Best known for his work in Japan.

Joseph Moses Juran, (1904 - 2008) He wrote several books, and is known worldwide as one of the most important 20th century thinkers in quality management.

Genichi Taguchi, 田口 玄一, (1924 - 2012) From the 1950s onwards, Taguchi developed a methodology for applying statistics to improve the quality of manufactured goods.