EPFL School of Engineering

Continuous Improvement (CIP)

Module 3 – Process

Quality Control

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Week 6, Session 1&2, Mar 28th, 2025

Course Framework

Change Plan
Strategic plan

Continuous Improvement (ME-498)

Module 1	Module 2	Module 3	Module 4	
Introduction	**People**	**Process**	**Technology**	**Final**
Feb 23rd	**March-May**	**March-May**	**March-May**	**May 31st**
CIP Foundations CIP case studies	Managing Change Emotional Intelligence Managing Oneself Connection & Bonding Effective Change Comm. Managing Conflict	Capacity Planning Constraint Management Managing waiting lines Quality Planning Quality Control Quality Improvement Process selection Facility Layout Lean Management	AI for CIP Data Analytics, ML&AI Digital Ecosystems Best case practices	Final presentation & solid understanding of the course

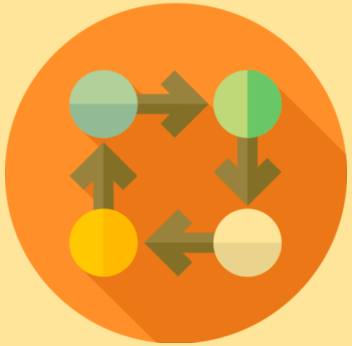
Quality Management – Trilogy

Quality Planning	Quality Control	Quality Improvement
Establishing processes that are capable of meeting standards.	Knowing how corrective action is needed	Finding better ways of doing things
Quality dimensions, determinants, benefits, costs, ethics, tools	Quality control process, Control charts, Interpretation	Process capability, Six Sigma, tools

Quality Control – Questions

Q1. What is Quality Control?, why is it important?

Q2. What are the main questions in inspection?



Q3. What are the main steps of effective control process?

Q4. How control charts are used to monitor a process?

Q5. How do you interpret the control chart?

Q6. What is process capability?

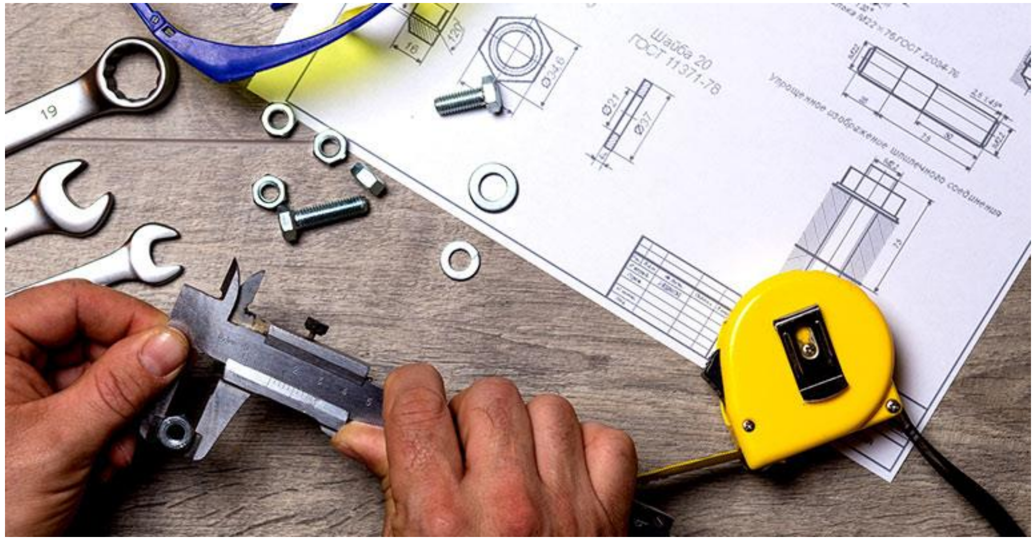
Question 1:

What is Quality Control?
Why it is Important?

Quality Control – Importance & Definition

- **Definition:** A process that **evaluates output** relative to a standard and takes **corrective actions** when its needed.

- **Importance:** due to the **variability** nature in the production/service.



Assignment 6 – Tasks of Quality Control

5 min

Implement the effective quality control steps for your case study; more specifically;

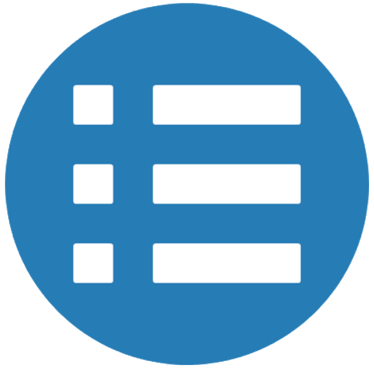
- Define what do you study in the process output (variable or attributes or both?)

Question 2:

What are the main questions in inspection?

Inspection – Main Issues

Why



What?

How?

Where?

How many?

Reminder: Quality costs

Prevention costs

Quality improvement programs, trainings, …

Appraisal costs

Measuring, evaluating, and auditing materials

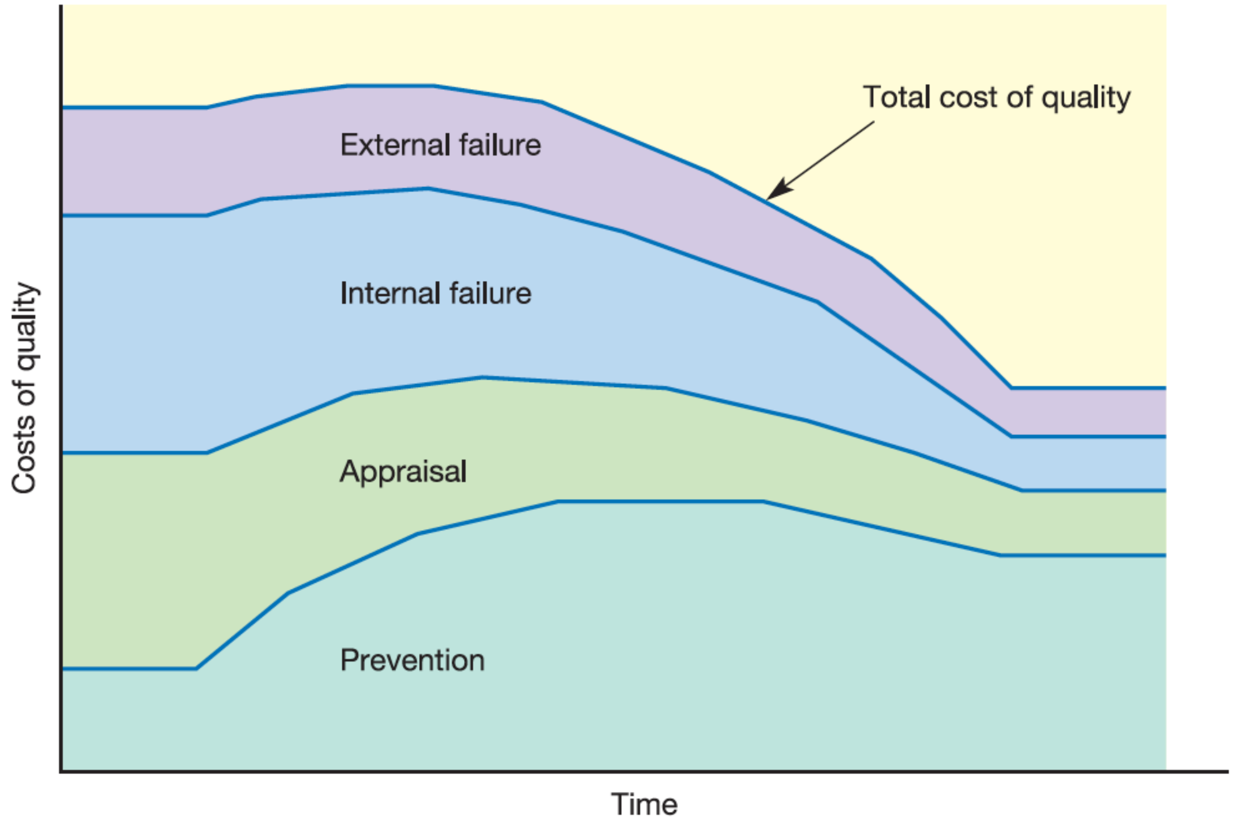
Internal failure costs

Rework costs, problem solving, scrap and downtime

External failure costs

Returned goods, reworking costs, warranty costs, loss of goodwill, liability claims, penalties

Reminder: Quality costs – over time



Source: Nigel Slack, Alistair Brandon-Jones, Robert Johnston, Operations Management, Pearson, 7th edition, 2013.

Inspection – What?

Variables - continuum values

(length, weight, diameter)

Attributes - discrete in nature
(color, taste, smell)

Inspection – How?

On-site

(production line)

Centralized

(Laboratory)

Inspection – Where?

Question: Where should be our inspection points for a grocery store?

Photo source: Adobe Stock

Inspection – Where?

Before production	During production	After production
Inputs	Operations	Outputs
Acceptance Sampling	Process Control	Acceptance Sampling

Process Capability

Inspection – How many?

Single sampling

(a random sample is drawn from every lot; Good/Bad?)

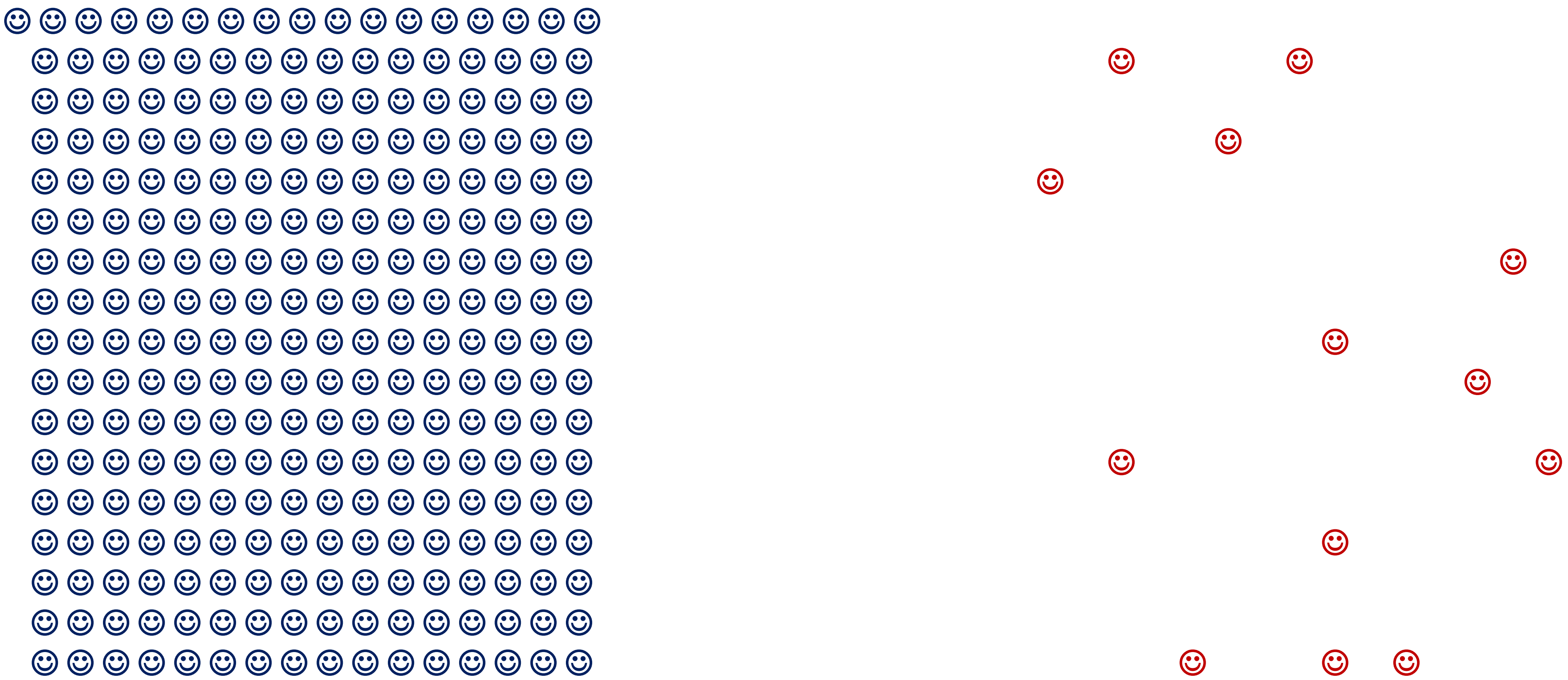
Double sampling

(sampling the lot the second time if the results of the first sample are inconclusive)

Multiple sampling

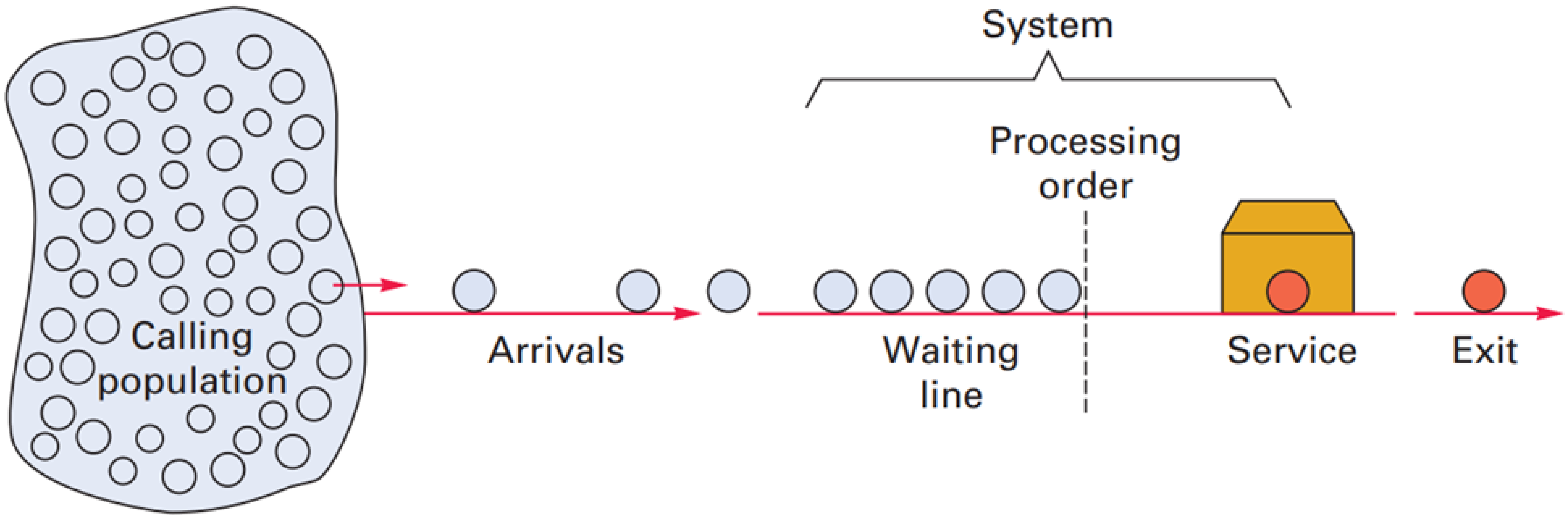
(similar to double sampling except that criteria are set for more than two samples)

Acceptance Sampling



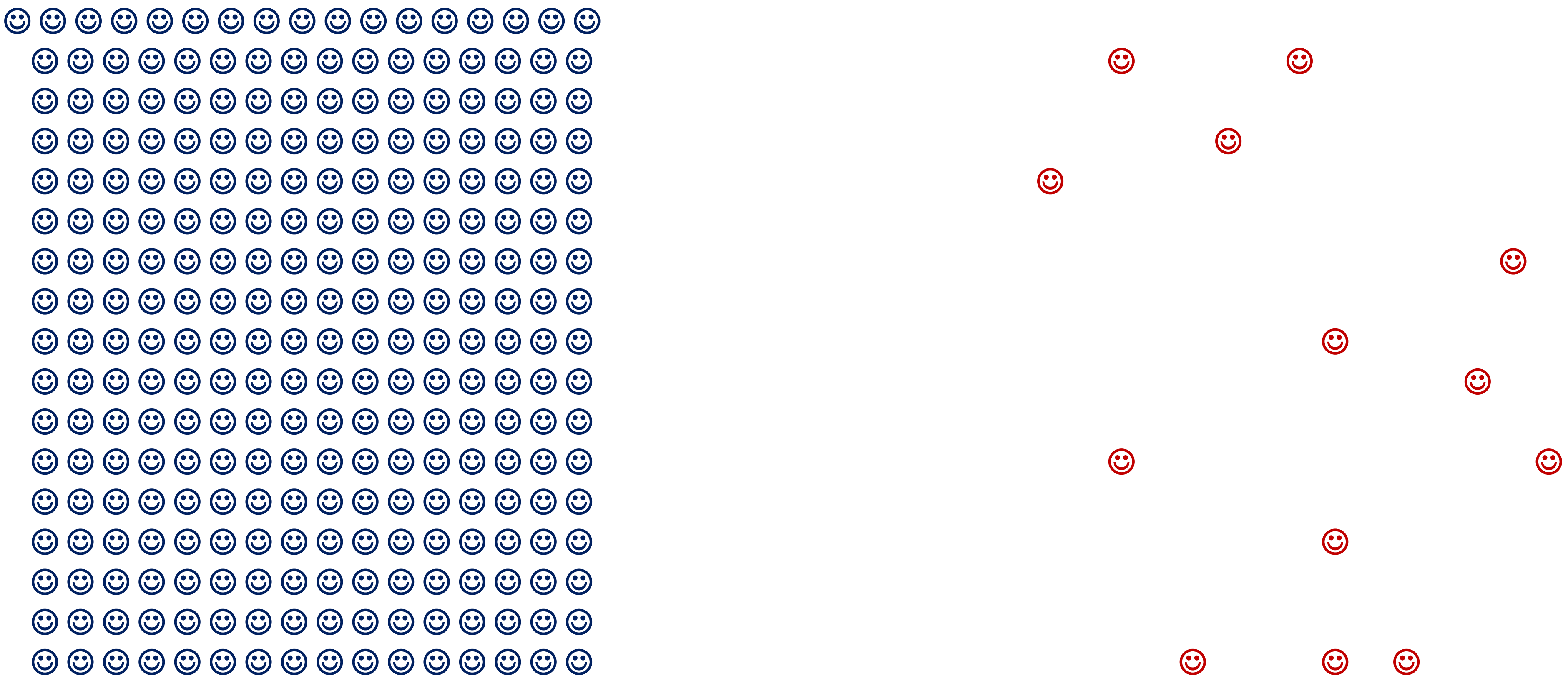
Population Sample

Reminder: A Simple Waiting Line System



Source: Heizer, J., Render, B., & Munson, C. (2015). *Managing Waiting Lines*. In *Operations Management* (12th ed., pp. 782-821). Pearson.

Acceptance Sampling



Population

Sample

Descriptive Statistics

1. The mean

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

$\bar{x}$ = the mean
x_i = observation i, $i = 1, \ldots, n$
n = number of observations

2. The Range

R = Max - Min

3. The Standard Deviation

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

σ = standard deviation of a sample
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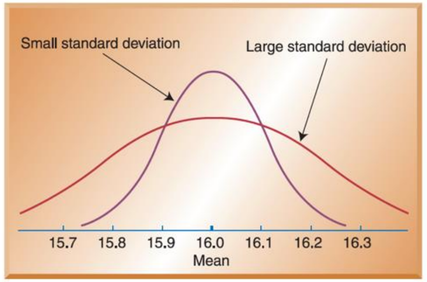
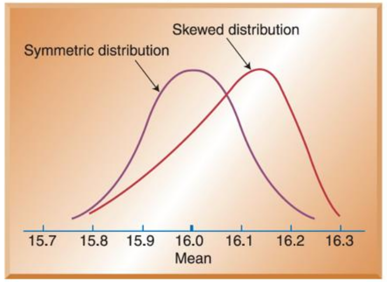
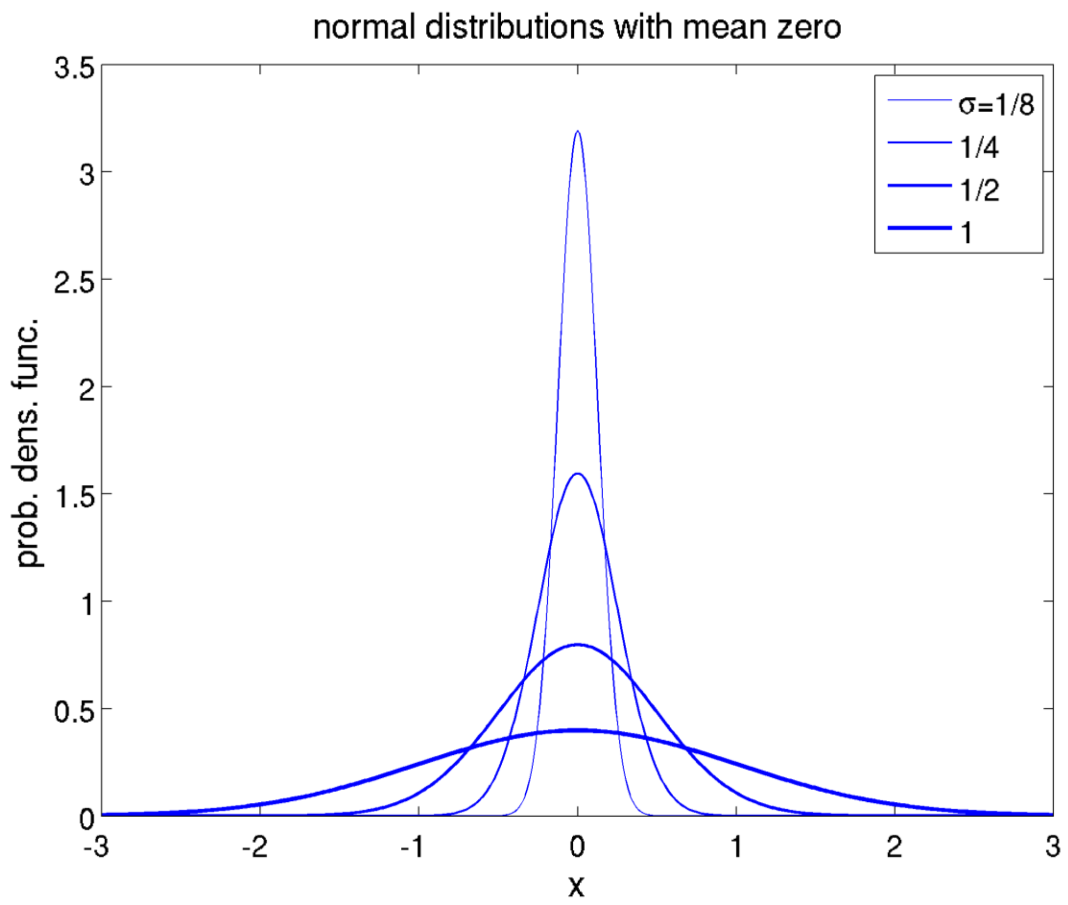
4. Distribution of Data





Acceptance Sampling – Central Limit Theorem



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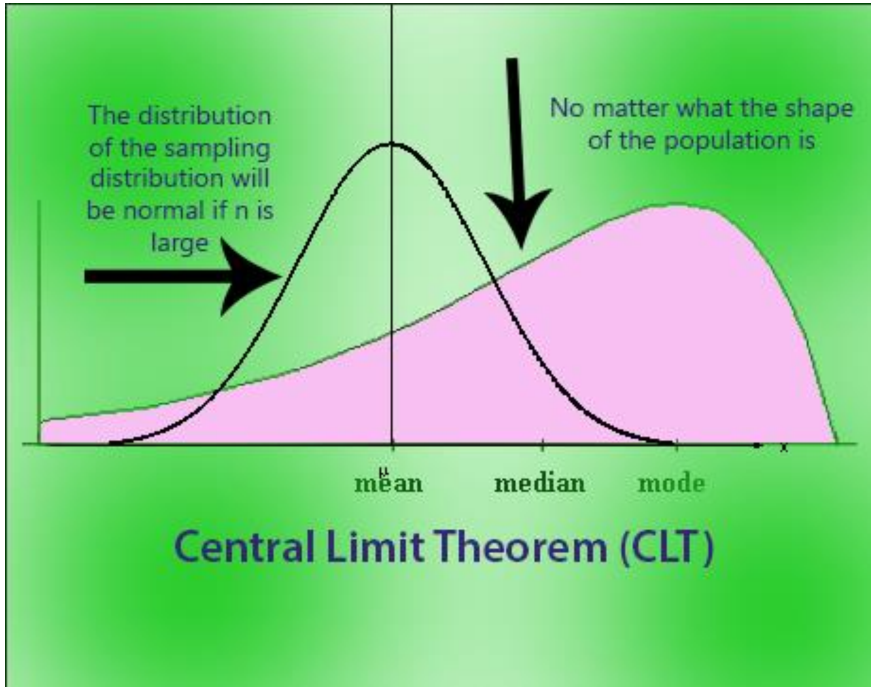
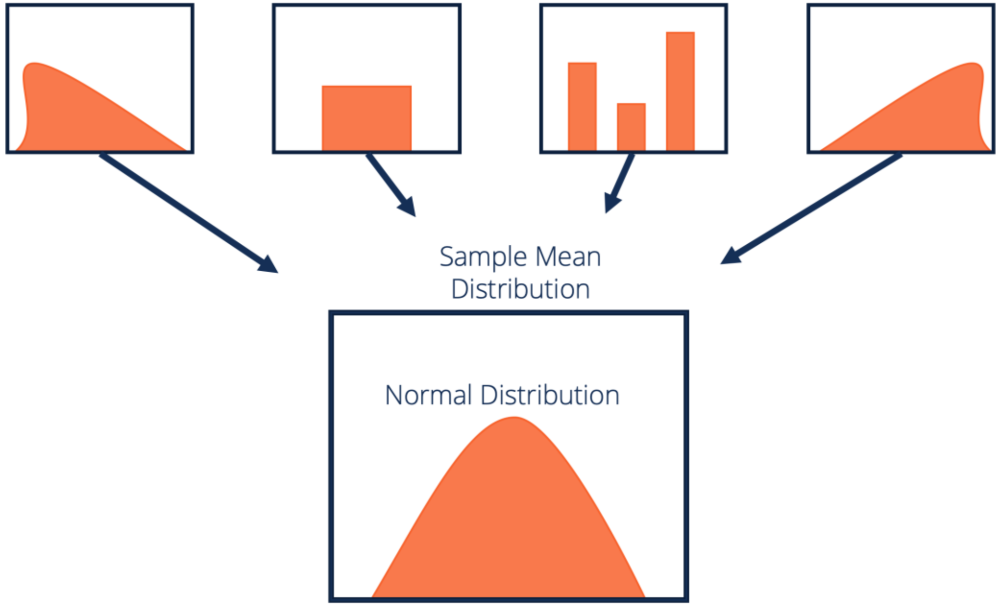
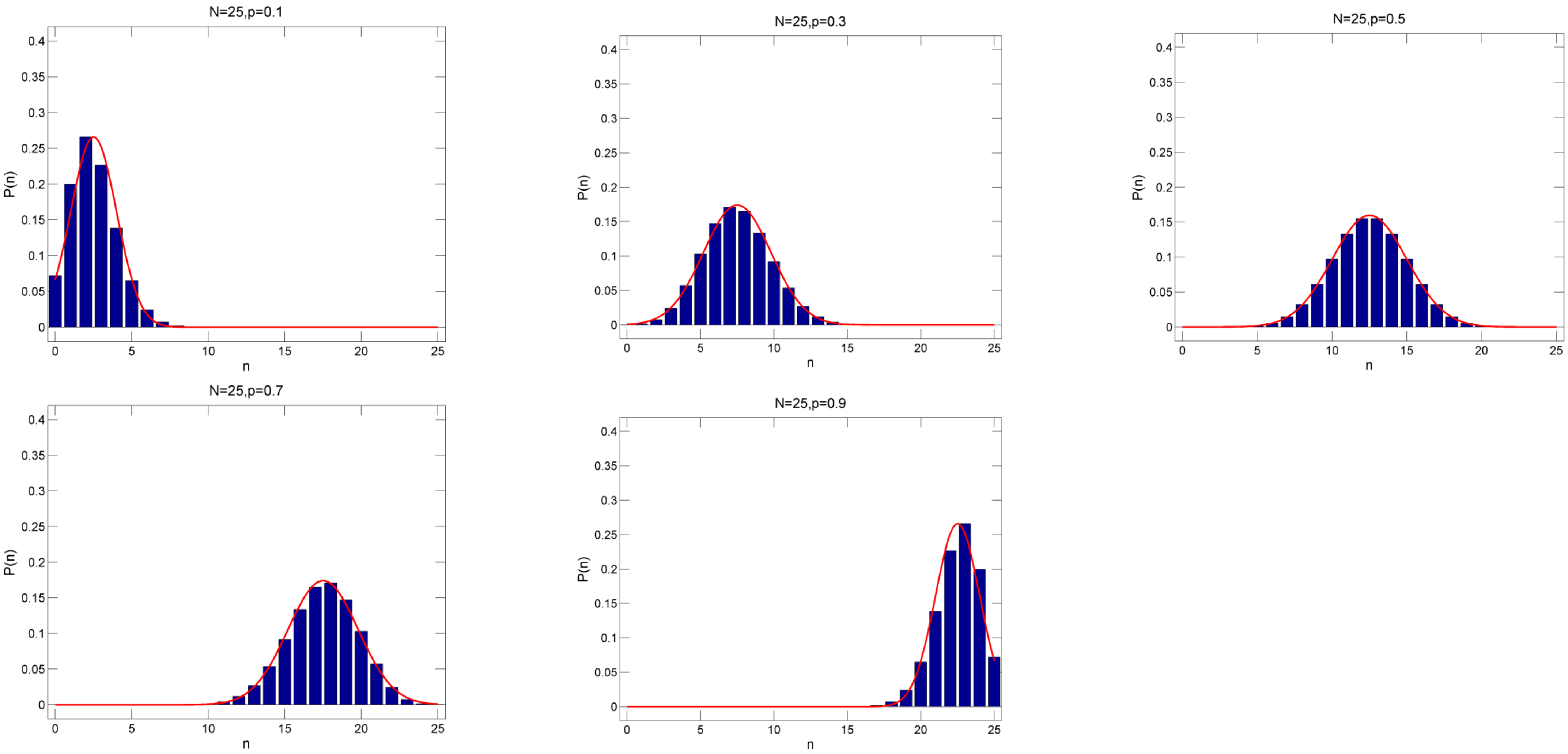




Acceptance Sampling – Binomial approximation by normal dist.



Acceptance Sampling – Type I and II Errors Examples

- **Type 1 Error (False Positive):** You conclude that your new improvement (e.g., a new machine setting or process change) has improved the manufacturing performance when, in reality, it has **not**.

  Example: You change the machine speed, run a test, and see a slight improvement in output. You decide the change is effective, but actually, the improvement was just random variation, not because of your change.

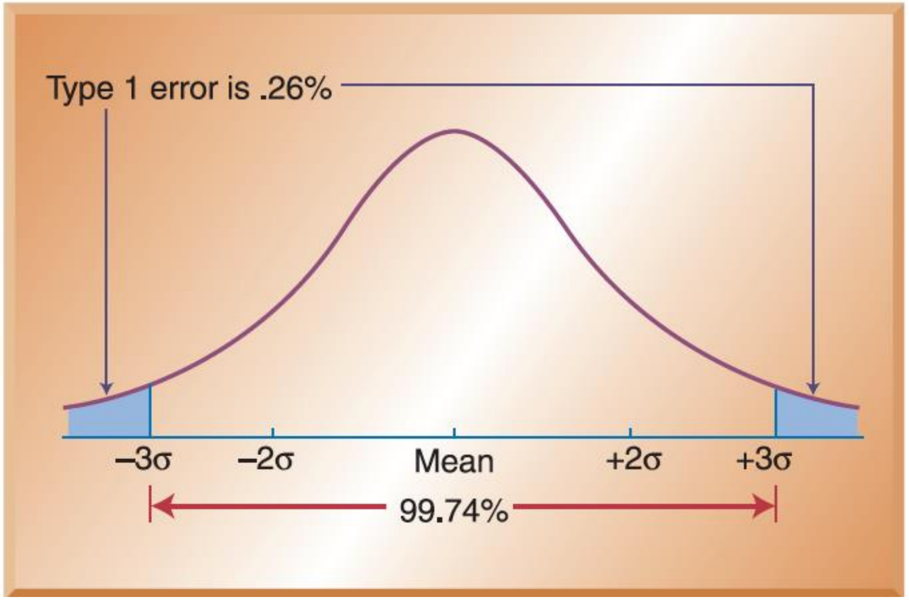
- **Type 2 Error (False Negative):** You conclude that your new improvement **has no effect**, but in reality, it **does improve** the system.

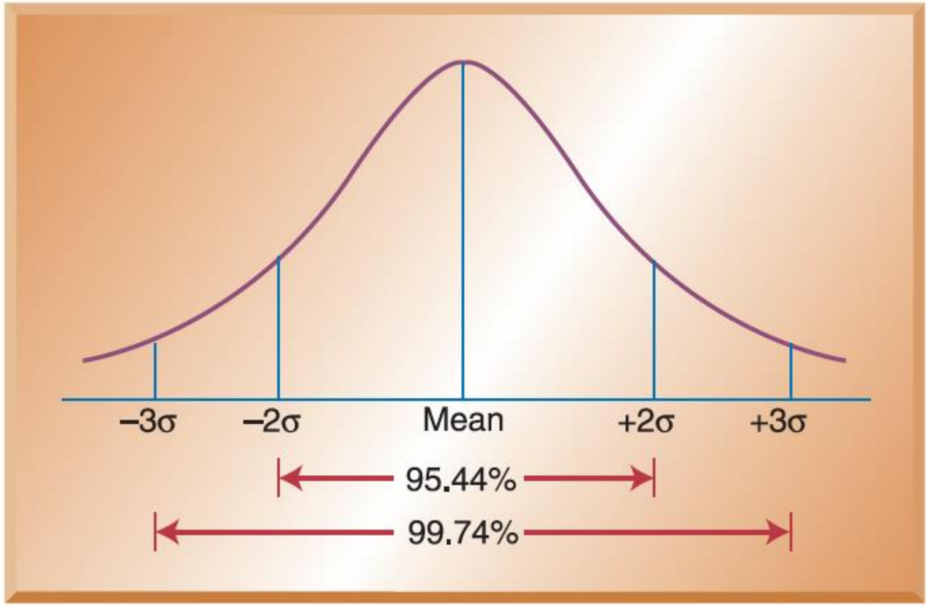
  Example: You test a new quality inspection process, don't see significant results due to limited data, and decide not to implement it. But if you had tested longer, you would have seen a real improvement in defect rates.

Acceptance Sampling – Type I and II Errors Summary

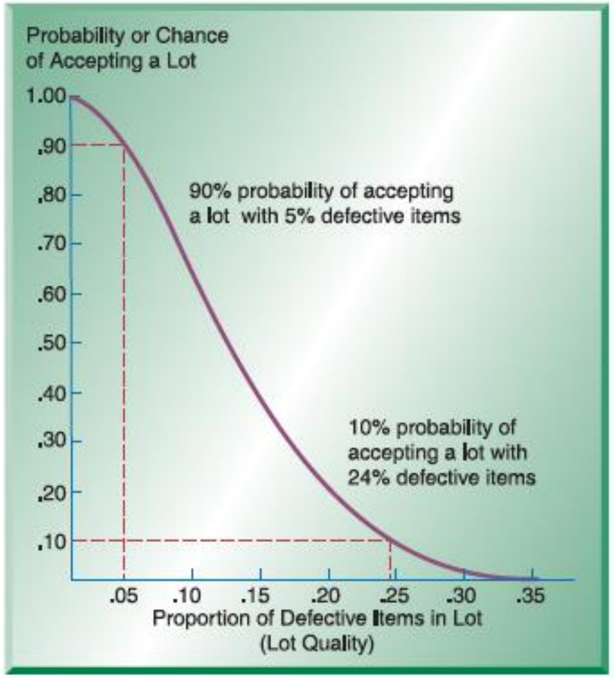
- **Type 1 Error (False Positive):** Acting on “fake” improvement
- **Type 2 Error (False Negative):** Ignoring a “real” improvement
- **Give 2-3 examples**

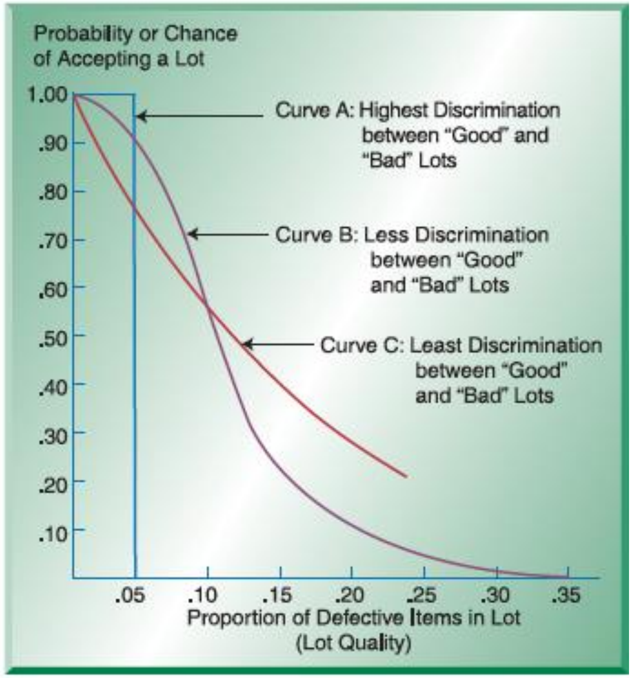
Acceptance Sampling – Type I and II Errors

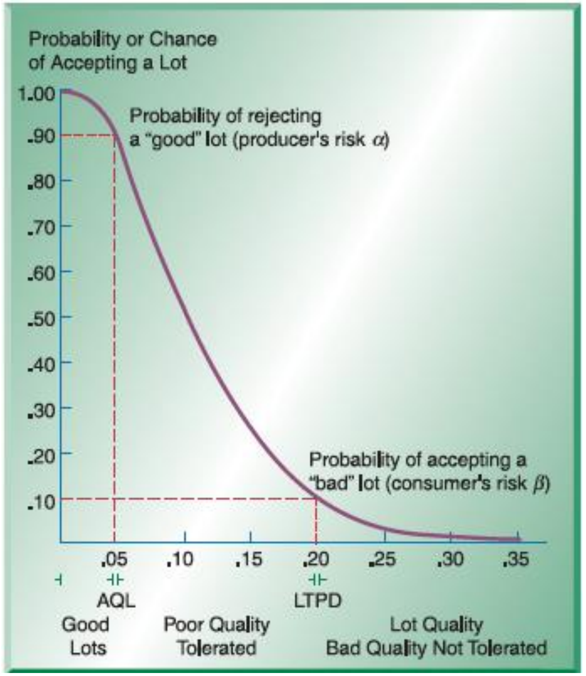




Acceptance Sampling - Operating Characteristic (OC) Curves





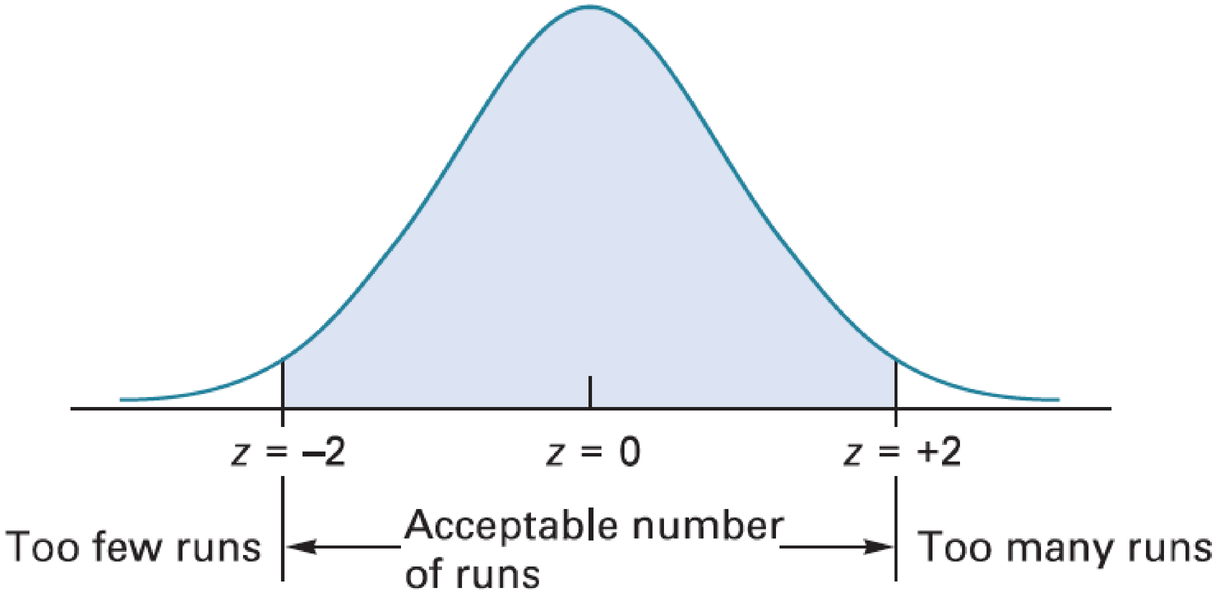


$$AOQ = (P_{ac})p\left(\frac{N-n}{N}\right)$$

P_{ac} = probability of accepting a given lot
p = proportion of defective items in a lot
N = the size of the lot
n = the sample size chosen for inspection

Run Tests – Too Few or Too Many Observations?

- A sampling distribution for runs is used to distinguish chance variation from patterns.



Assignment 6 – Tasks of Quality Control

5 min

Implement the effective quality control steps for your case study; more specifically;

- Define what do you study in the process output (variable or attributes or both?)
- Obtain 4 samples of 6 observations and explain your methodology.
- Compute appropriate sample statistic(s) for each sample. (ex: mean, …)

Question 3:

What are the main steps of effective control process?

Effective Quality Control – Steps

- **Step 1: Define** (what is to be controlled)?
- **Step 2: Measure** (How measurement will be accomplished?)
- **Step 3: Compare** (What level of quality being sough?)
- **Step 4: Evaluate** (What is out of control? How is the variability?)
- **Step 5: Correct** (How corrective actions must be taken?)
- **Step 6: Monitor** (How do you monitor results and ensure corrective actions were effective?)

Define – What is to be controlled?

Variables - continuum values

(length, weight, diameter)

Attributes - discrete in nature
(color, taste, smell)

Measure – How measurement will be accomplished?

Before production	During production	After production
Inputs	Operations	Outputs
Acceptance Sampling	Process Control	Acceptance Sampling

Why

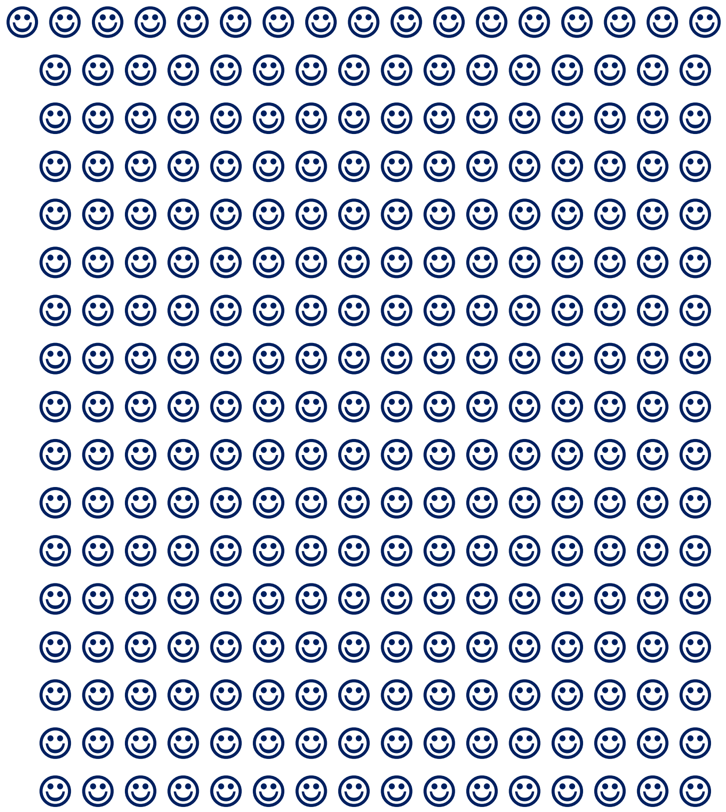
What?

How?

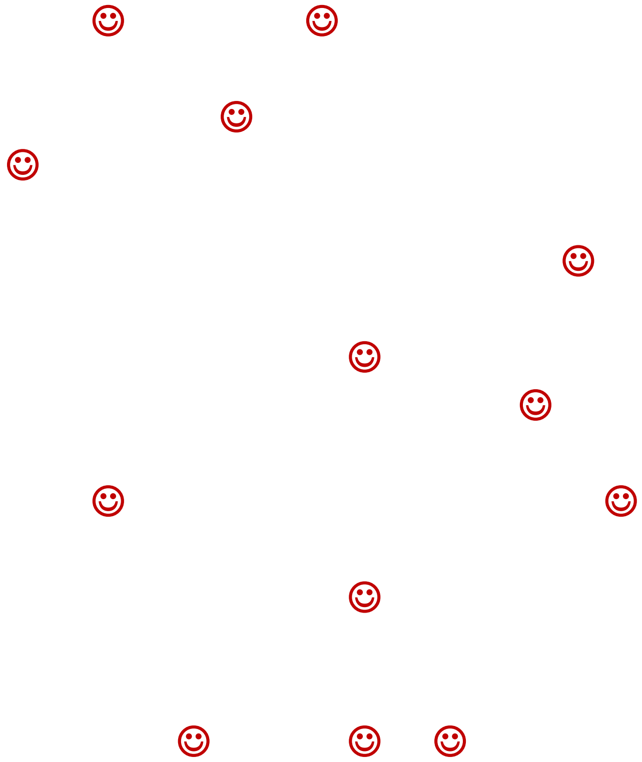
Where?

How many?

Acceptance Sampling



Population



Sample

Sample – Descriptive Statistics

1. The mean

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

$\bar{x}$ = the mean
x_i = observation i, $i = 1, \ldots, n$
n = number of observations

2. The Range

R = Max - Min

3. The Standard Deviation

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

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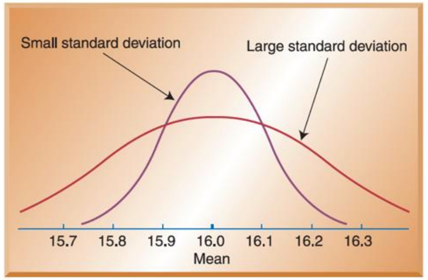
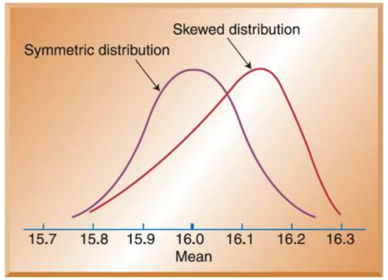
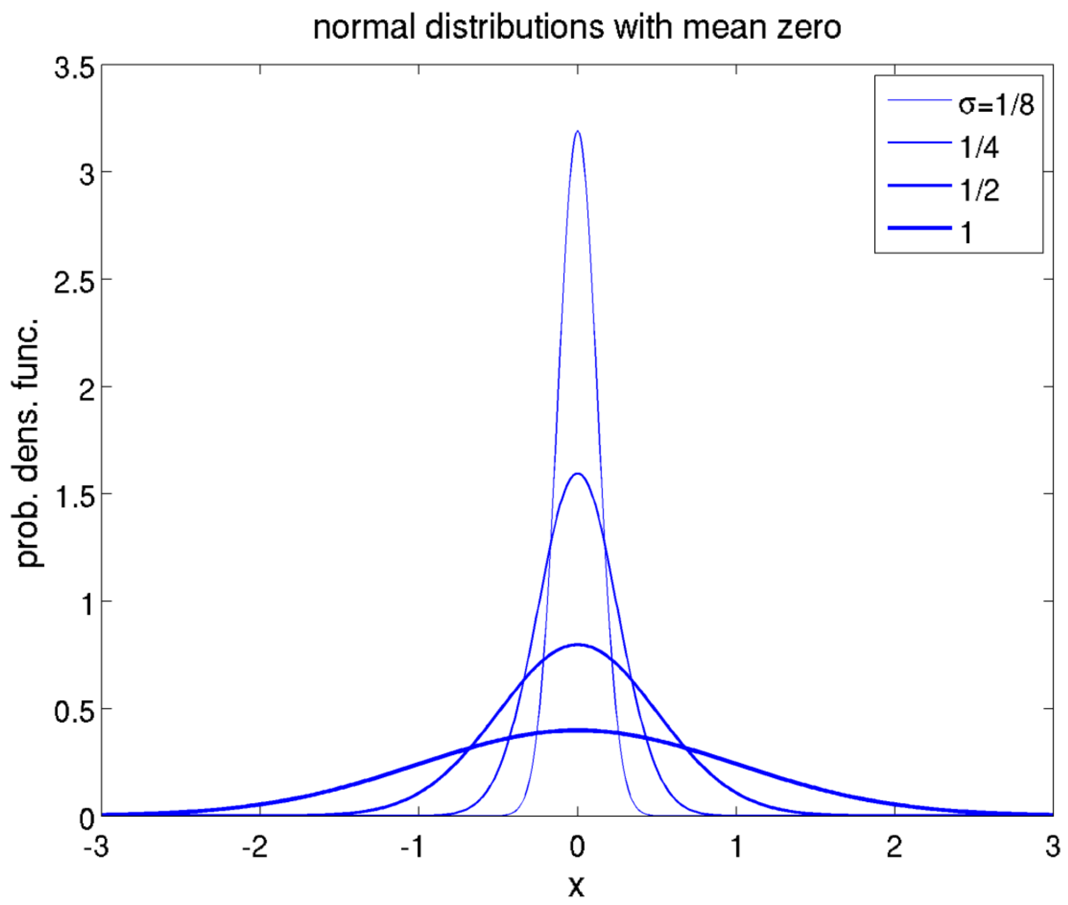
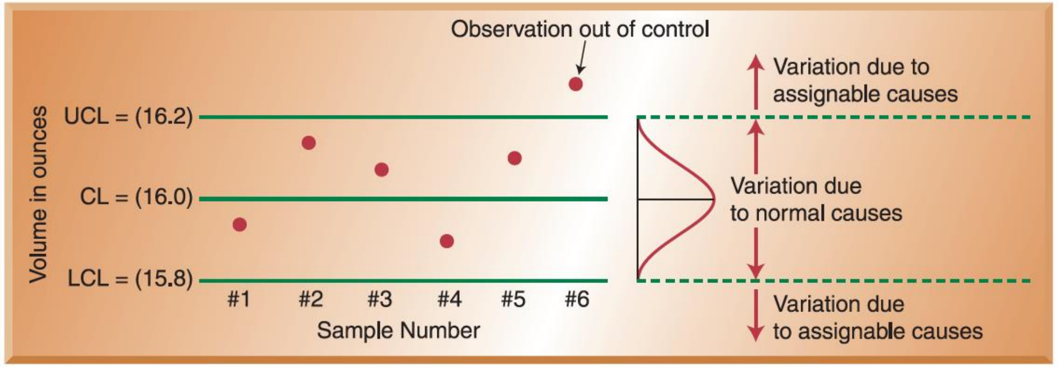




Sample Distribution – Central Limit Theorem



Compare – What level of quality being sought?



Variables

(length, weight, diameter)

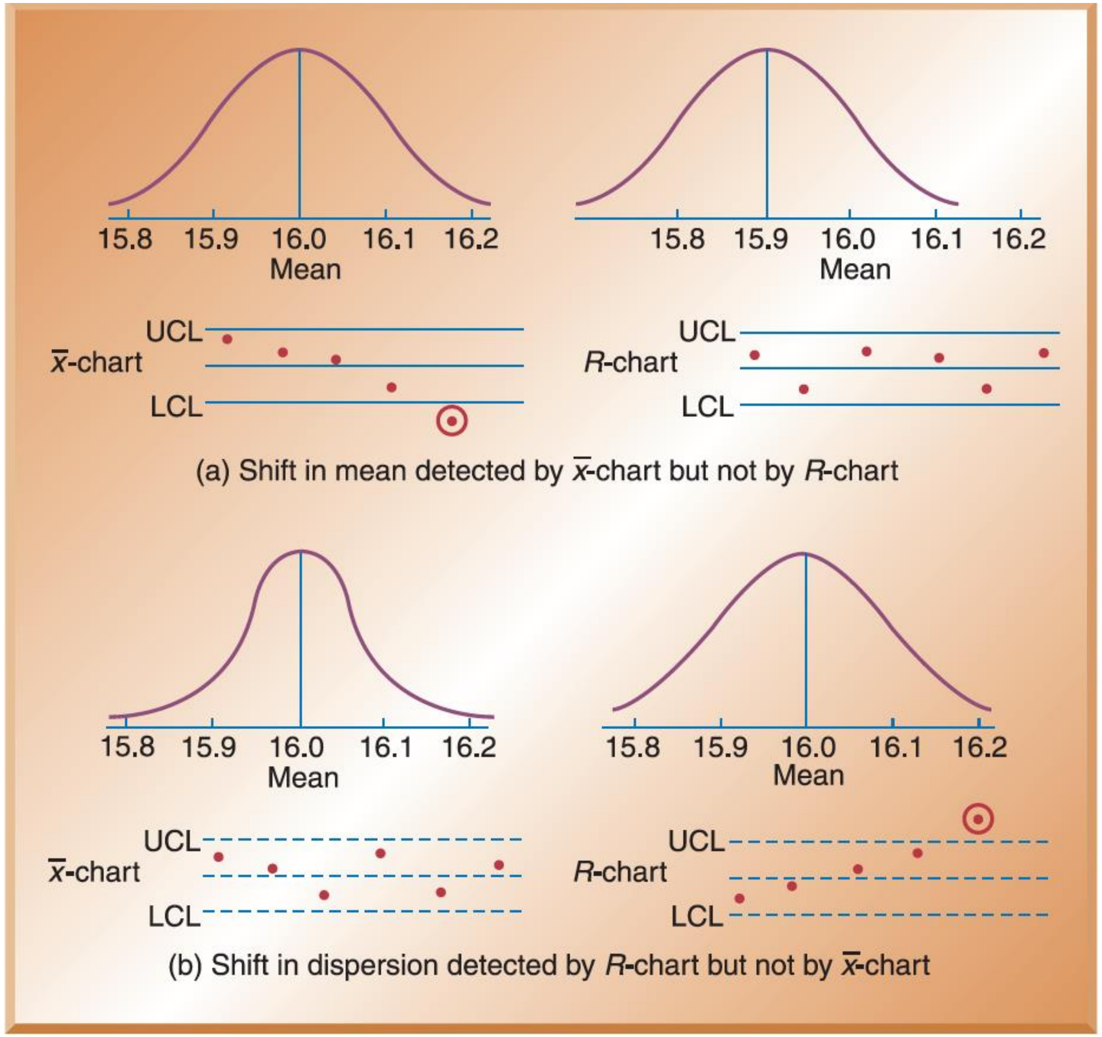
- Mean (x-bar) charts (changes in mean of a process)
- R charts (variability of a process)

Attributes

(color, taste, smell)

- P-chart (proportion of defects in a sample)
- C-chart (number of defects per unit)

Using mean (X-bar) and Range (R) Charts



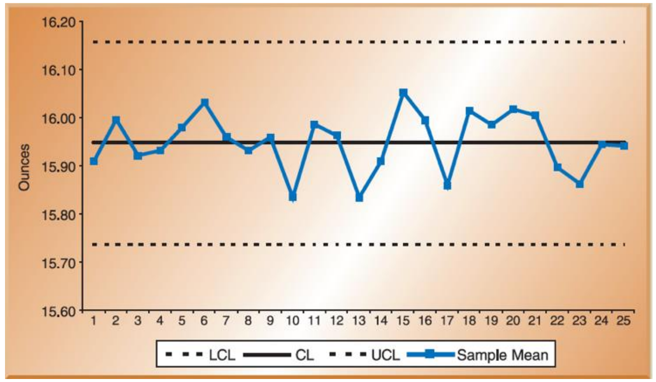
Mean (x-bar) Charts – Control Charts for Variables

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \cdots + \bar{x}_k}{k}$$

$$\text{Upper control limit (UCL)} = \bar{\bar{x}} + z\sigma_{\bar{x}}$$

$$\text{Lower control limit (LCL)} = \bar{\bar{x}} - z\sigma_{\bar{x}}$$

where
- $\bar{\bar{x}}$ = the average of the sample means
- z = standard normal variable (2 for 95.44% confidence, 3 for 99.74% confidence)
- $\sigma_{\bar{x}}$ = standard deviation of the distribution of sample means, computed as $\sigma/\sqrt{n}$
- σ = population (process) standard deviation
- n = sample size (number of observations per sample)



Monitors changes in mean value of a process

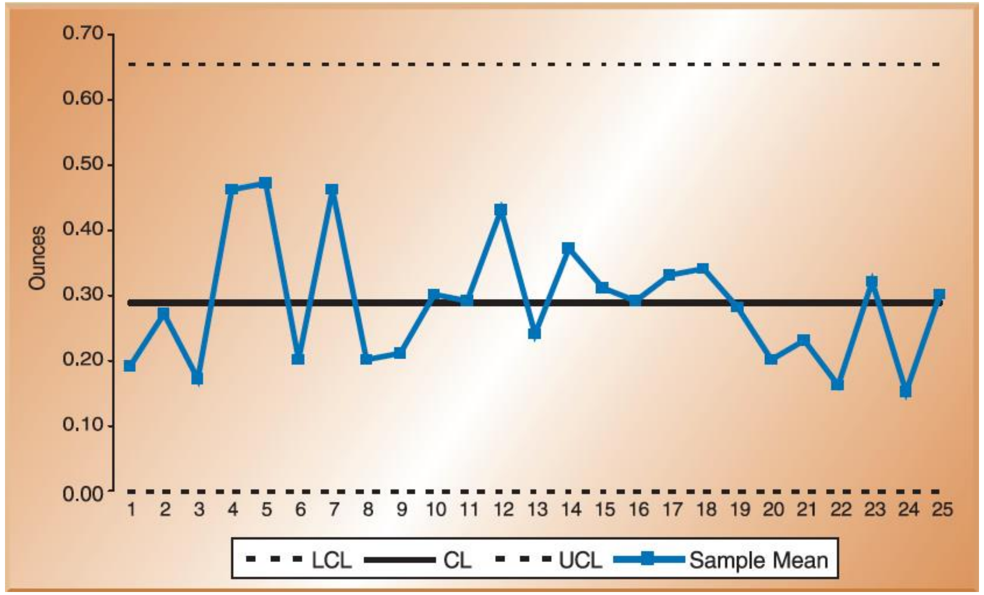
Another way to have an estimate of variability is to use range

$$\text{Upper control limit (UCL)} = \bar{\bar{x}} + A_2\bar{R}$$

$$\text{Lower control limit (LCL)} = \bar{\bar{x}} - A_2\bar{R}$$

where
- $\bar{\bar{x}}$ = average of the sample means
- $\bar{R}$ = average range of the samples
- A_2 = factor obtained from Table

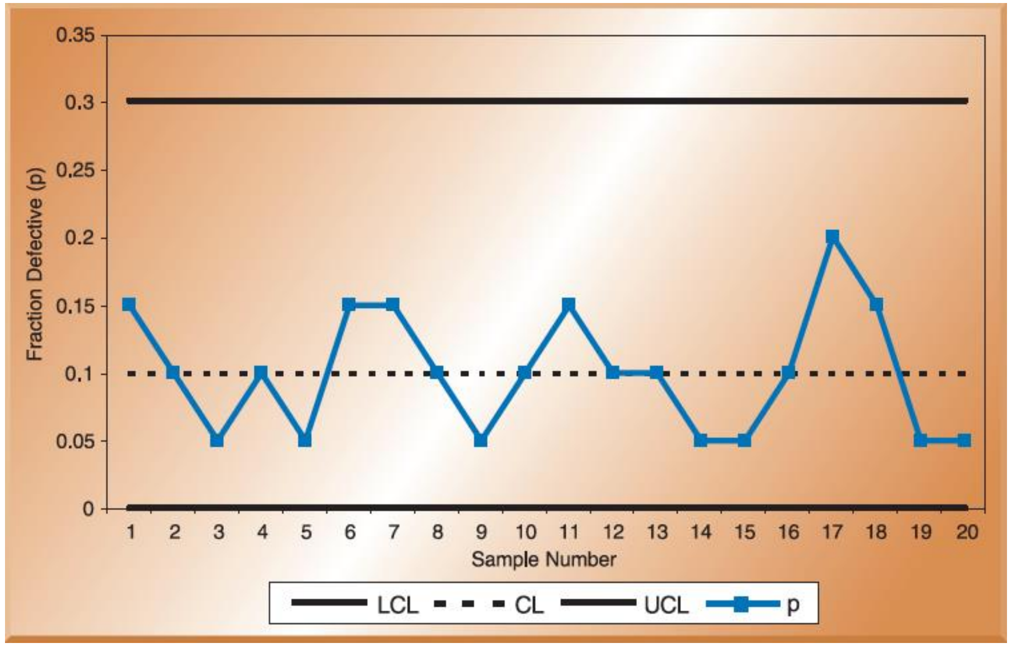
Range (R) Charts – Control Charts for Variables

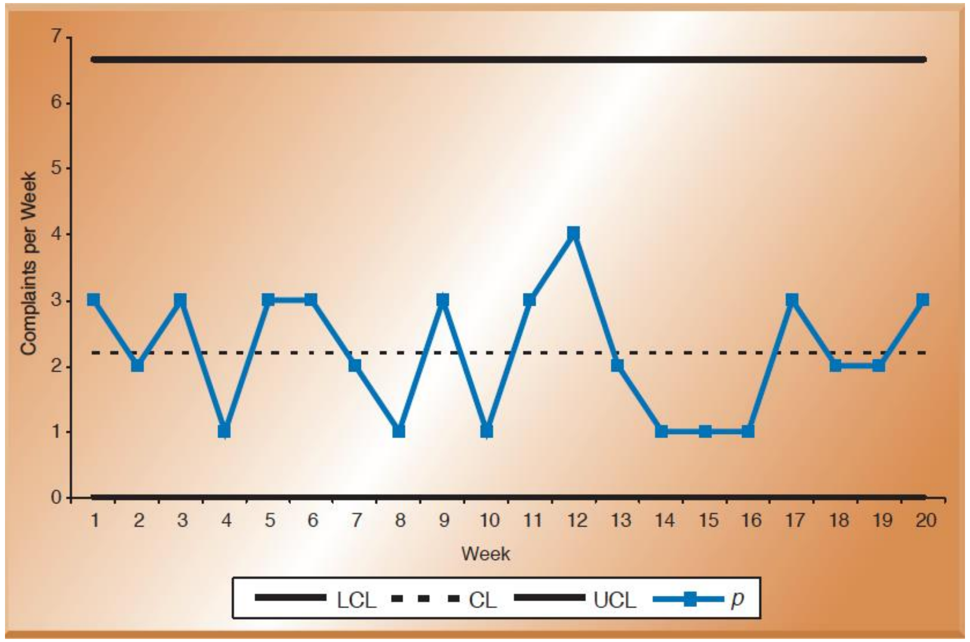


Monitors changes in dispersion/ variability of a process

$$\mathrm{CD} = \overline{R}$$
$$\mathrm{UCL} = D_4\overline{R}$$
$$\mathrm{LCL} = D_3\overline{R}$$

Using P-Charts and C-Charts





Question: When do we use P-charts and C-charts?

P-charts and C-charts are used when **both the total sample size and the number of defects can be computed**.

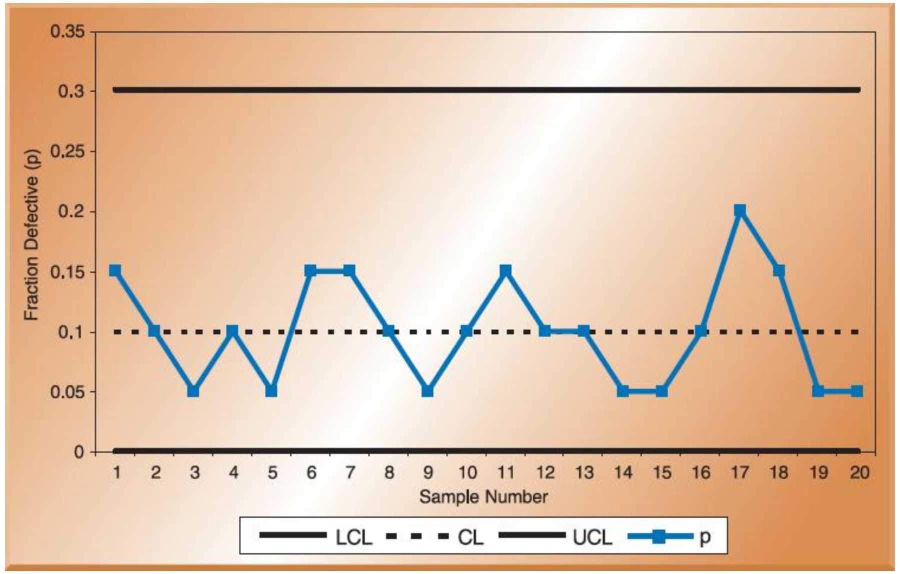
P-Charts – Control Charts for Attributes

$$\text{UCL} = \bar{p} + z\sigma_p$$

$$\text{LCL} = \bar{p} - z\sigma_p$$

where z = standard normal variable
$\bar{p}$ = the sample proportion defective
σ_p = the standard deviation of the average proportion defective

$$\sigma_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$



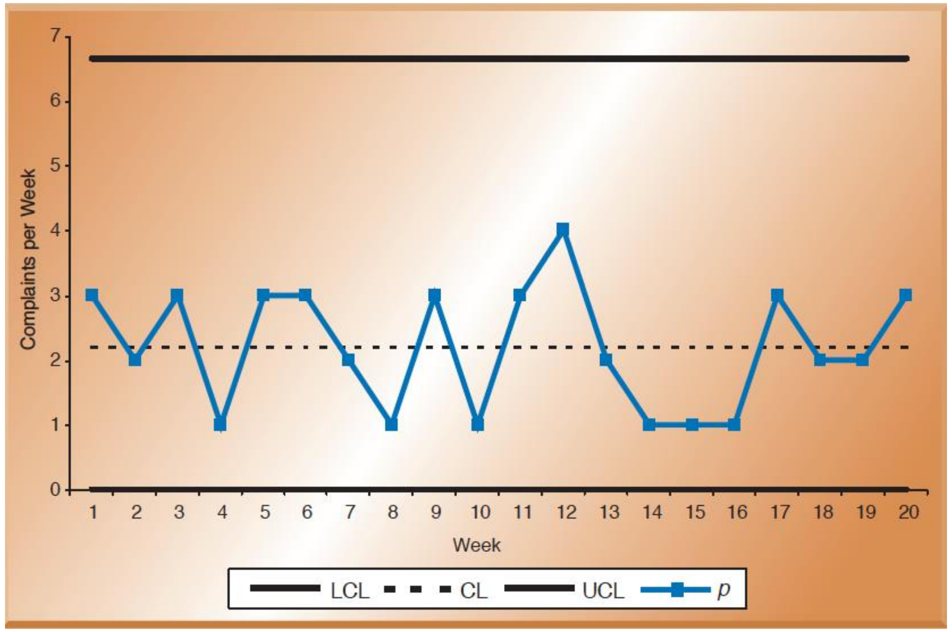
P-charts are used when both the total sample size and the number of defects can be computed.

P-charts monitors the proportion of defects in a sample.

Question: If the lower limit is negative rounded up to zero. Why?

because the computation is an approximation of the binomial distribution.

C-Charts – Control Charts for Attributes



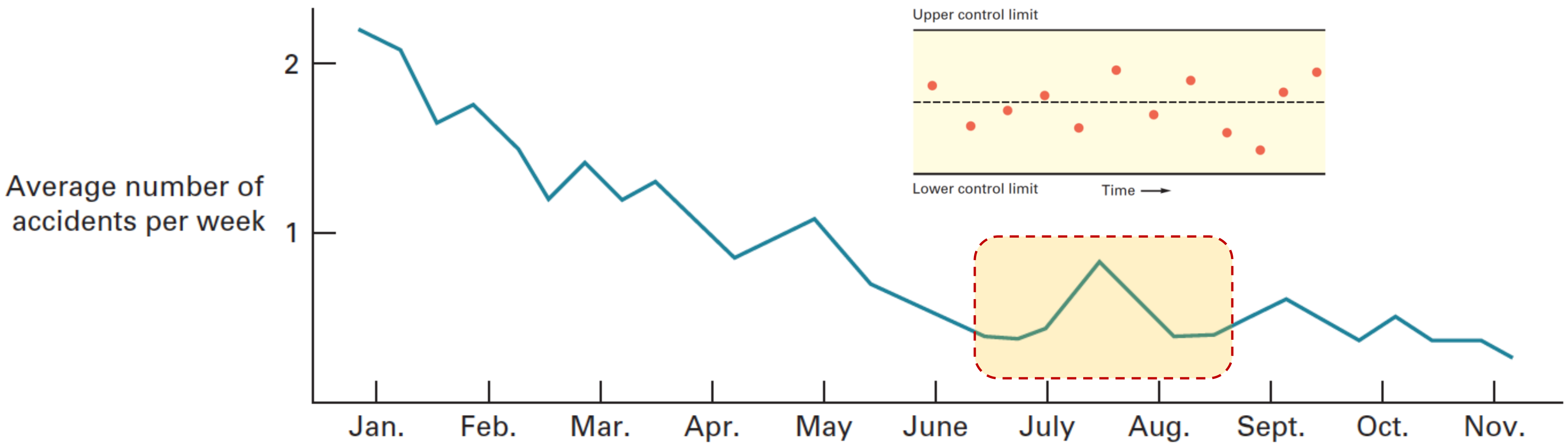
C-charts are used to monitor the number of defects per unit.

$$\mathrm{UCL} = \bar{c} + z\sqrt{\bar{c}}$$

$$\mathrm{LCL} = \bar{c} - z\sqrt{\bar{c}}$$

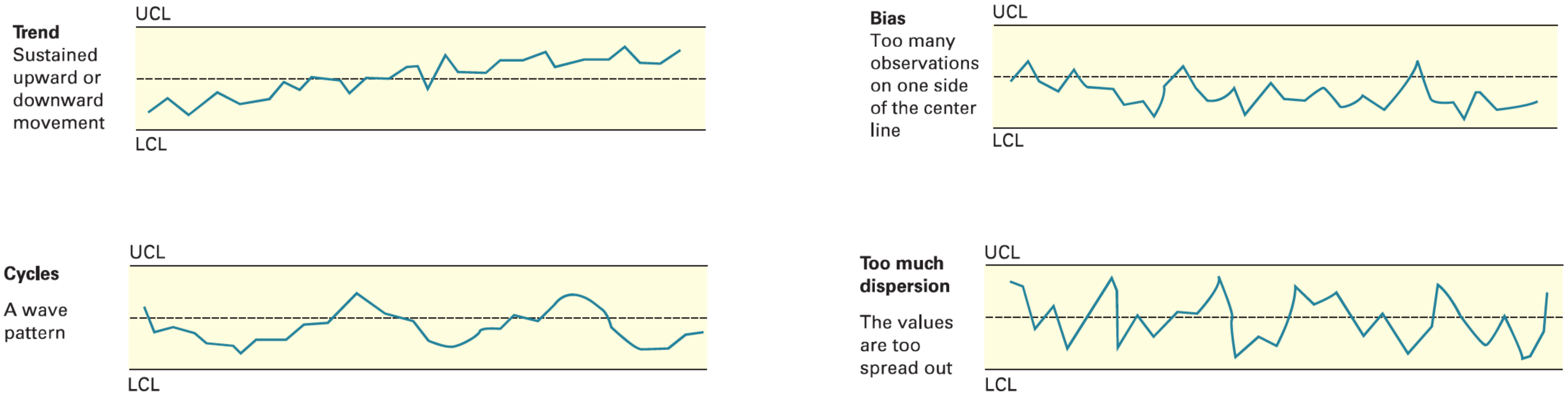
Run Charts

- **Definition:** A tool for tracking results over a period of time.

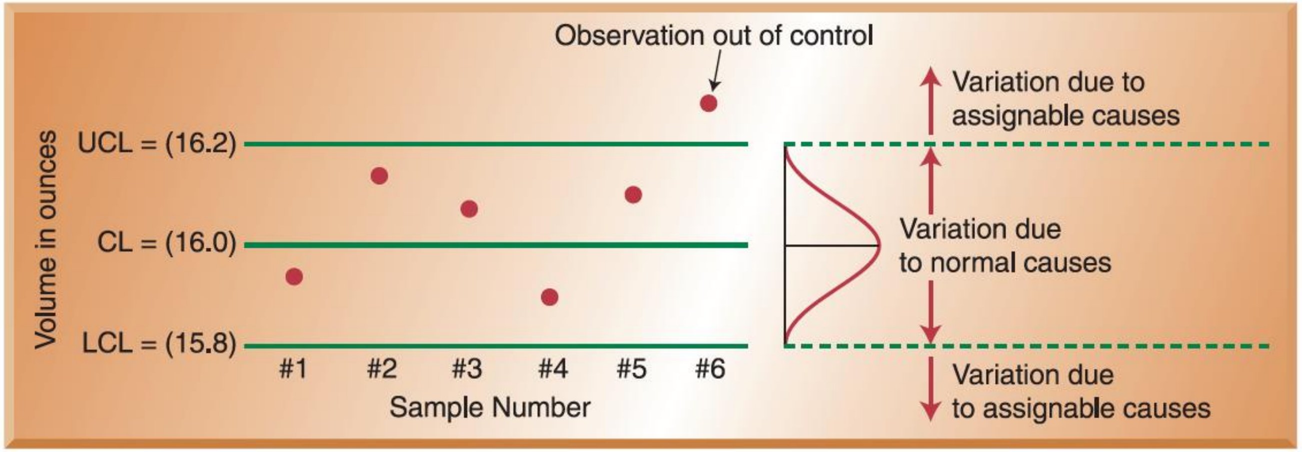


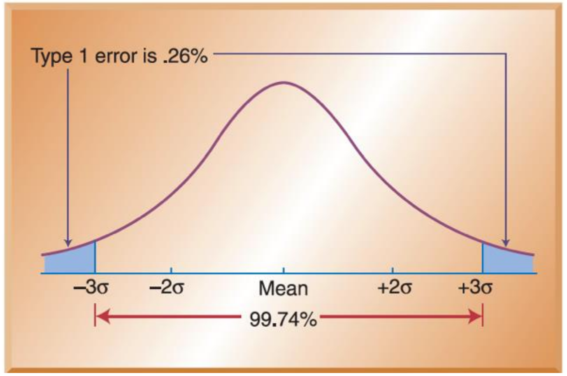
Source: William J. Stevenson, Operations Management, McMcGraw-Hill Education, 12th edition, 2015.

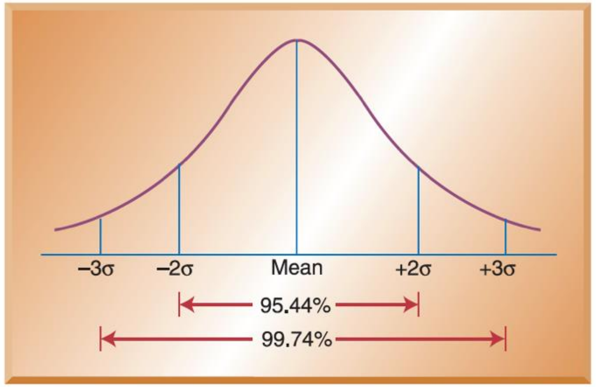
Run Charts – Testing Patterns in a Sequence



Evaluate – What is out of control? How is the variability?

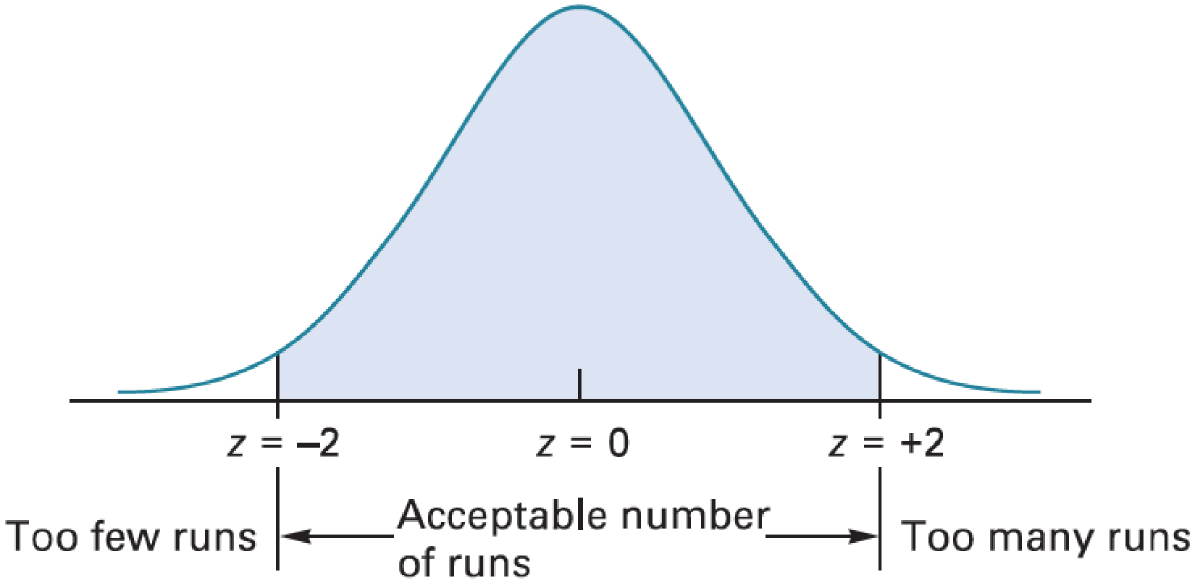






C-charts are used to monitor the number of defects per unit.

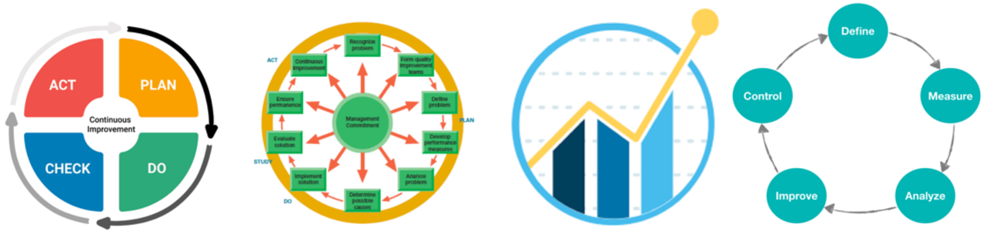
Evaluate – Too Few or Too Many Observations?



A sampling distribution for runs is used to distinguish chance variation from patterns.

Correct – How corrective actions must be taken?

Quality Problem Solving – Systematic Process Improvement



PDCA cycle | Basic steps of problem solving | Process improvement | DMAIC

Sources:
The Second Figure from Donna Summers, Quality, 2nd ed., p. 67. Copyright © 2000 Prentice Hall, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.
William J. Stevenson, Operations Management, Page 388-392, McMcGraw-Hill Education, 12th edition, 2015.

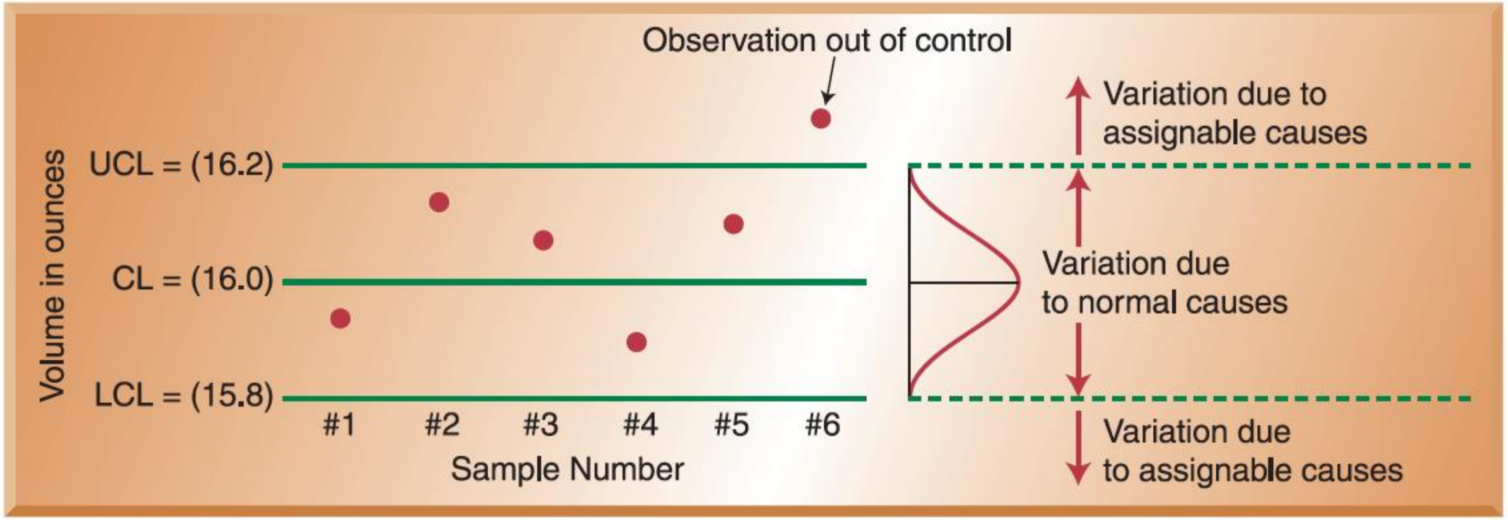
Systematic Idea Generation

Brainstorming | Quality circles | Benchmarking | Design Thinking

Question 4:

How control charts are used to monitor a process?

Developing Control Charts



Types of Control Charts

- **Variables** - continuum values – length, weight, diameter
  - Mean (x-bar) charts (changes in mean value of a process)
  - R charts (changes in dispersion/ variability of a process)

- **Attributes** - discrete in nature – color, taste, smell
  - P-chart (proportion of defects in a sample)
  - C-chart (number of defects per unit)

Mean (x-bar) Charts – Control charts for variables

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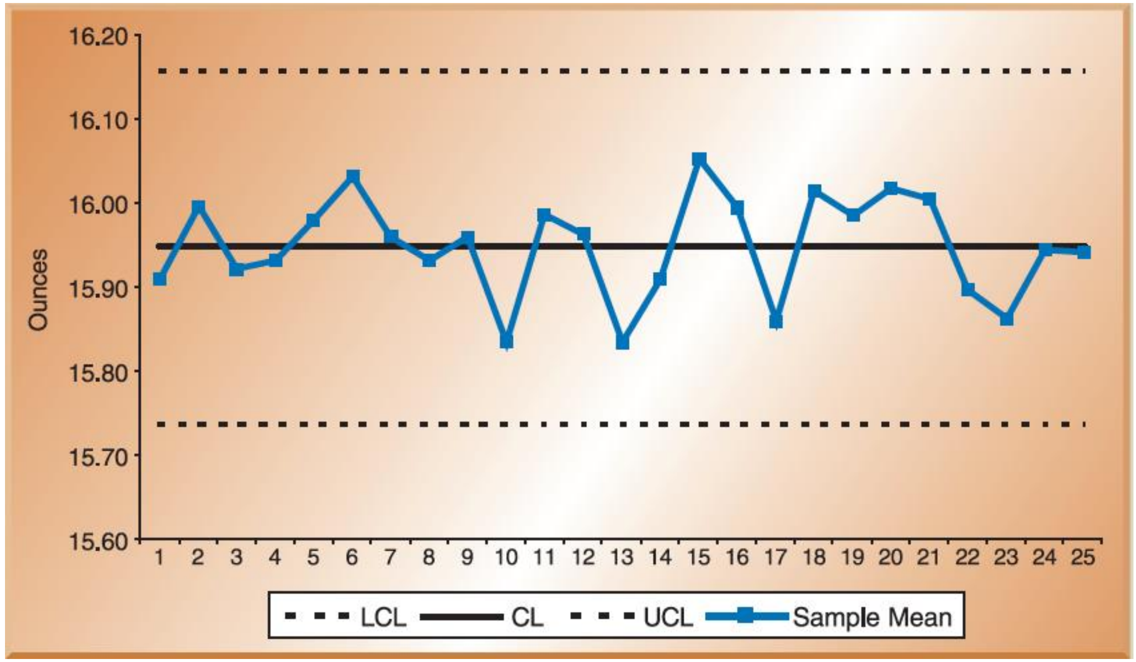
Mean (x-bar) Charts – Control charts for variables

- monitors changes in mean value of a process



Exercise – Quality Control

Please download the problem set from Moodle

Exercise 1 – Control Limits

Exercise – Quality Control

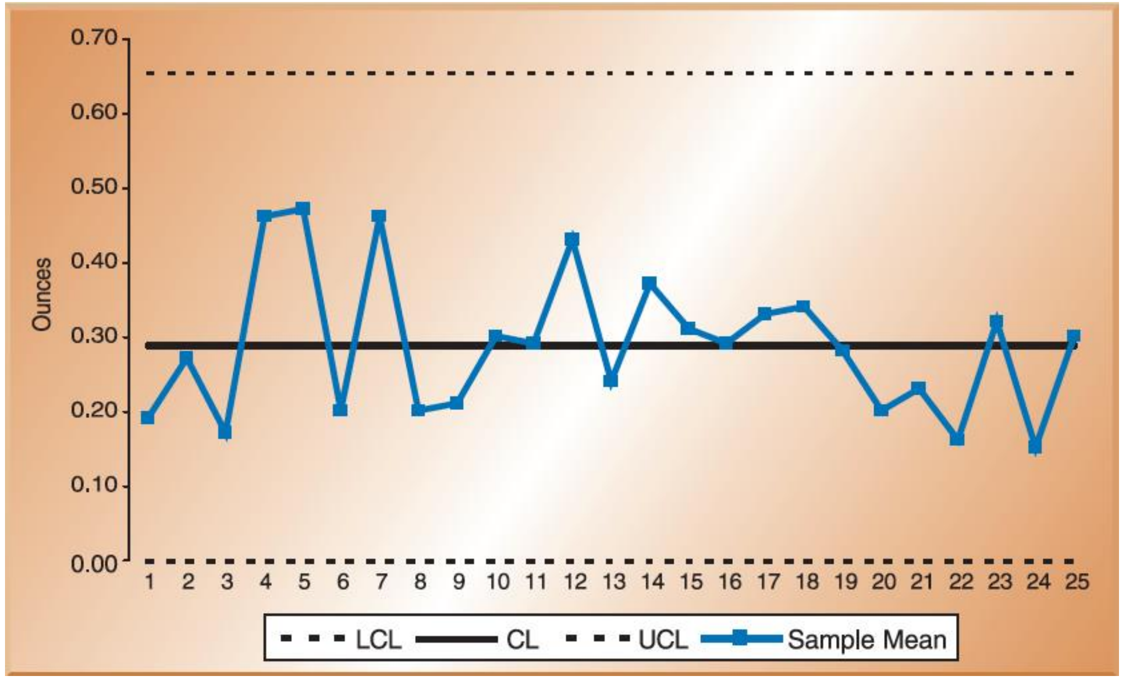
Please download the problem set from Moodle

Exercise 2 – Mean chart

Range (R) Charts – Control charts for variables

- monitors changes in dispersion/ variability of a process

$$CD = \overline{R}$$
$$UCL = D_4\overline{R}$$
$$LCL = D_3\overline{R}$$



Exercise – Quality Control

Please download the problem set from Moodle

Exercise 2 – Range chart

Assignment 6 – Tasks of Quality Control

5 min

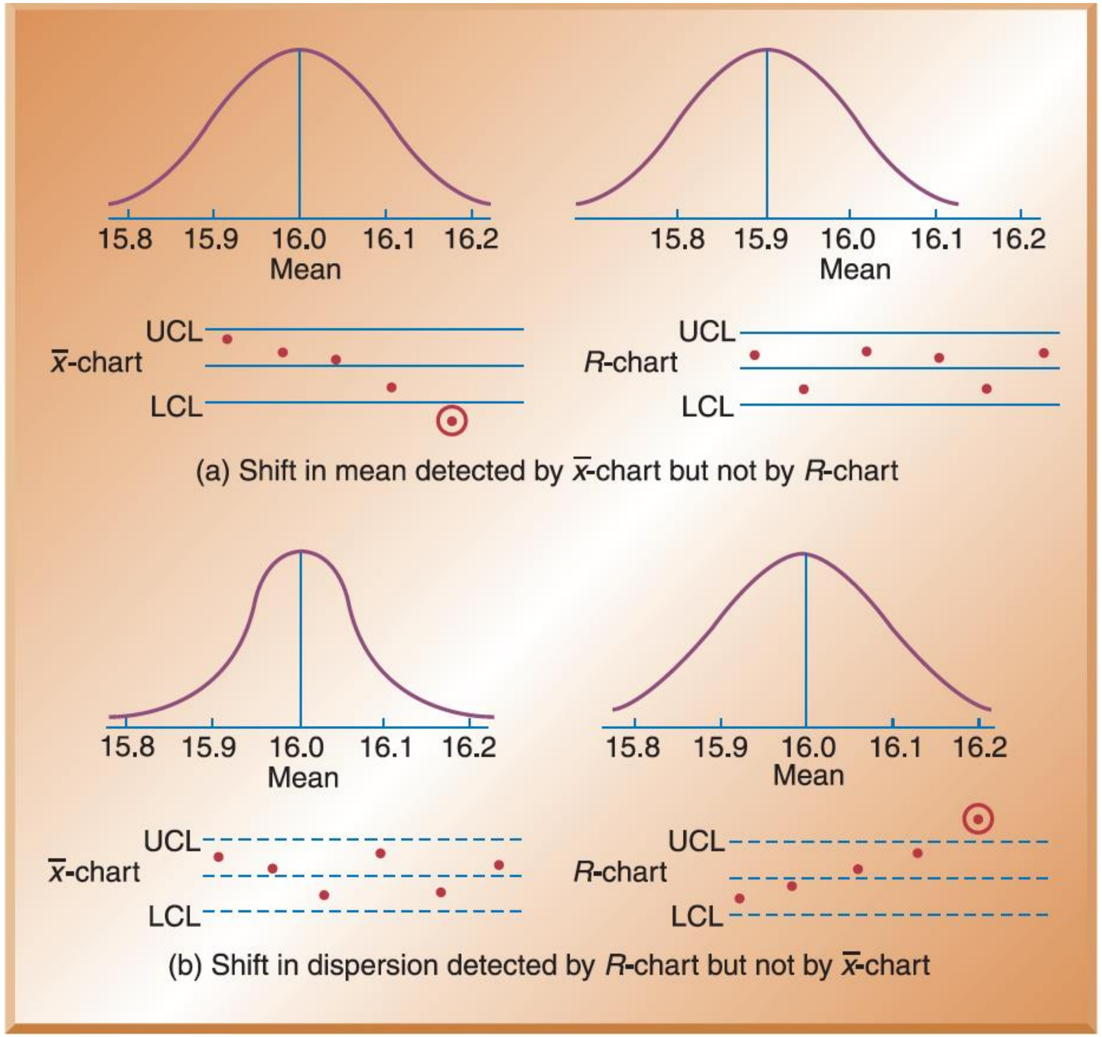
Implement the effective quality control steps for your case study; more specifically;

- Define what do you study in the process output (variable or attributes or both?)
- Obtain 4 samples of 6 observations and explain your methodology.
- Compute appropriate sample statistic(s) for each sample. (ex: mean, …)
- Establish preliminary control limits using the formulas

Question 5:

How do you interpret control charts?

Using mean (X-bar) and Range (R) Charts



Exercise – Quality Control

Please download the problem set from Moodle

Exercise 2 & 3 – Review and interpret

P-Charts – Control Charts for Attributes

- P-charts are used when both the total sample size and the number of defects can be computed.

$$\text{Upper control limit (UCL)} = \bar{\bar{x}} + z\sigma_{\bar{x}}$$

$$\text{Lower control limit (LCL)} = \bar{\bar{x}} - z\sigma_{\bar{x}}$$

where $\bar{\bar{x}}$ = the average of the sample means

z = standard normal variable (2 for 95.44% confidence, 3 for 99.74% confidence)

$\sigma_{\bar{x}}$ = standard deviation of the distribution of sample means, computed as $\sigma/\sqrt{n}$

σ = population (process) standard deviation

n = sample size (number of observations per sample)

Another way to have an estimate of variability is to use range

$$\text{Upper control limit (UCL)} = \bar{\bar{x}} + A_2\bar{R}$$

$$\text{Lower control limit (LCL)} = \bar{\bar{x}} - A_2\bar{R}$$

where $\bar{\bar{x}}$ = average of the sample means

$\bar{R}$ = average range of the samples

A_2 = factor obtained from Table

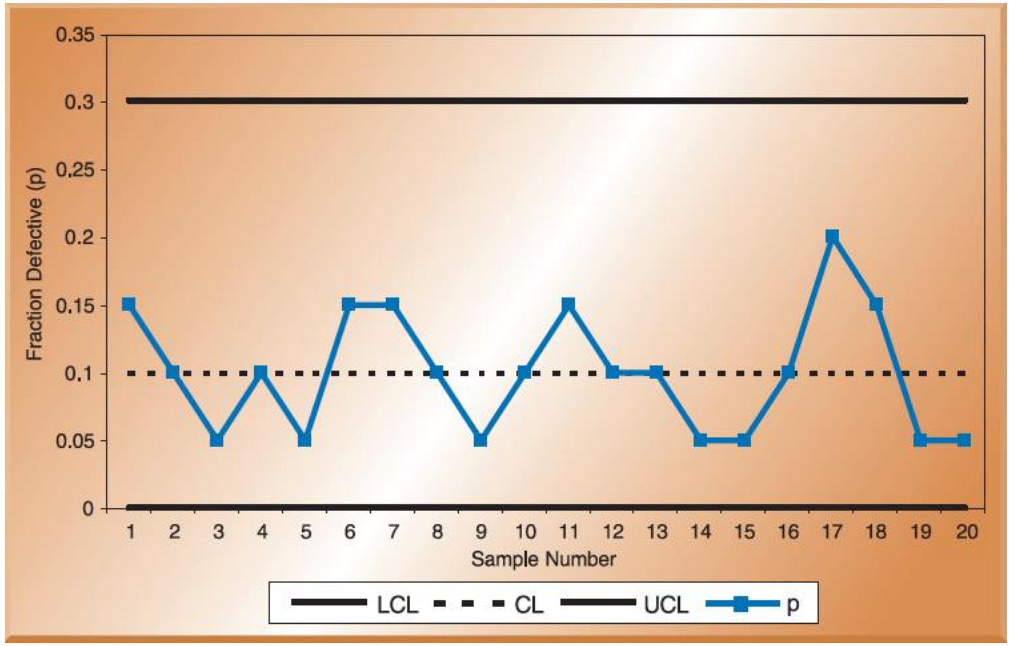
P-Charts – Control Charts for Attributes

- P-charts are used when both the total sample size and the number of defects can be computed.
- P-charts monitors the proportion of defects in a sample.

$$\text{UCL} = \bar{p} + z\sigma_p$$
$$\text{LCL} = \bar{p} - z\sigma_p$$

where z = standard normal variable
$\bar{p}$ = the sample proportion defective
σ_p = the standard deviation of the average proportion defective

$$\sigma_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$



- If the lower limit is negative rounded up to zero. Why? because the computation is an approximation of the binomial distribution.

Exercise – Quality Control

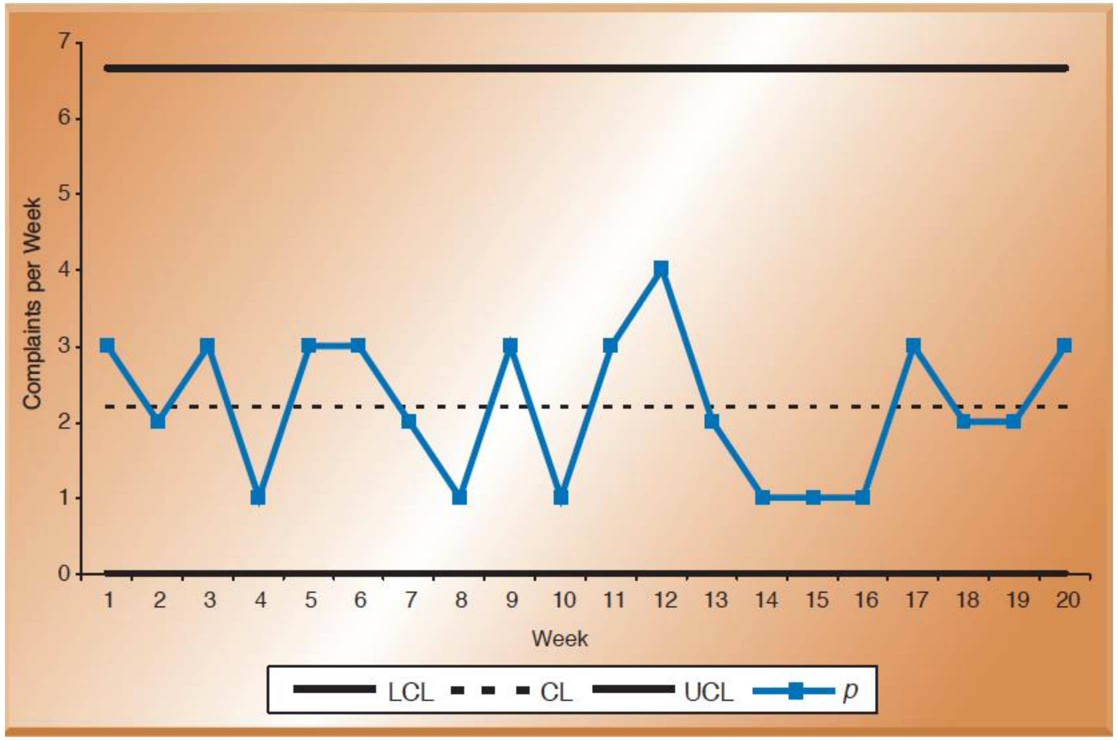
Please download the problem set from Moodle

Exercise 4 – P chart

C-Charts – Control Charts for Attributes

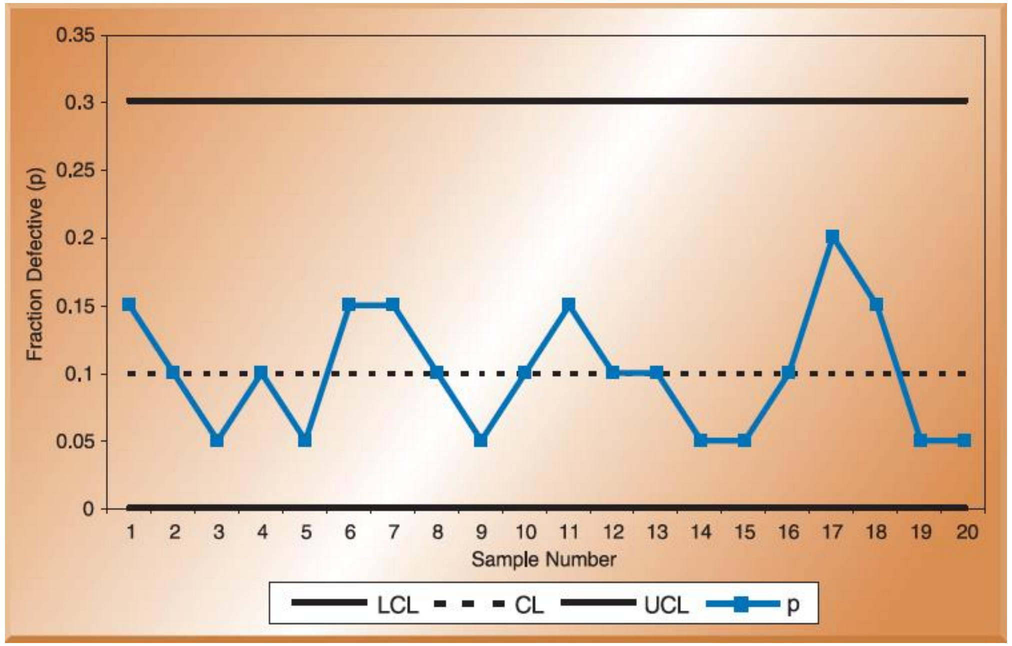
- C-charts are used to monitor the number of defects per unit.

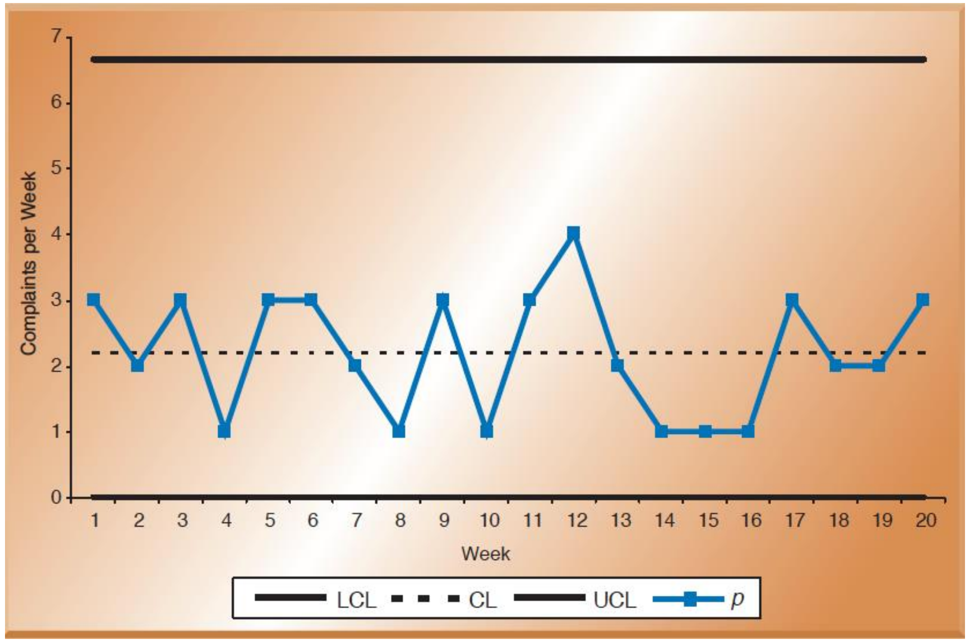
$$\text{UCL} = \bar{c} + z\sqrt{\bar{c}}$$
$$\text{LCL} = \bar{c} - z\sqrt{\bar{c}}$$



Using P-Charts and C-Charts

- P-charts are used when both the total sample size and the number of defects can be computed.





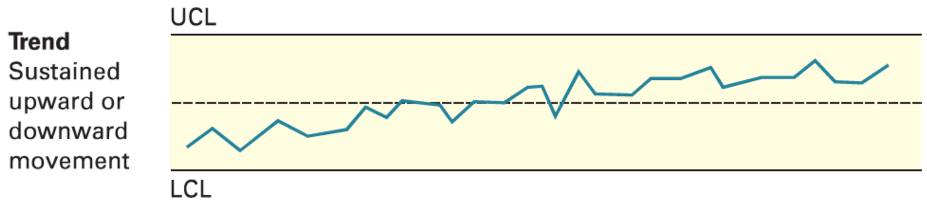
Exercise – Quality Control

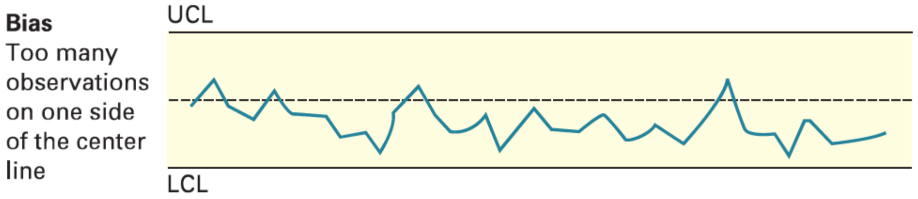
Please download the problem set from Moodle

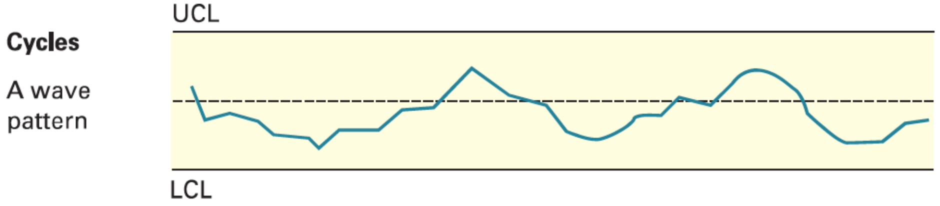
Exercise 5 – C chart

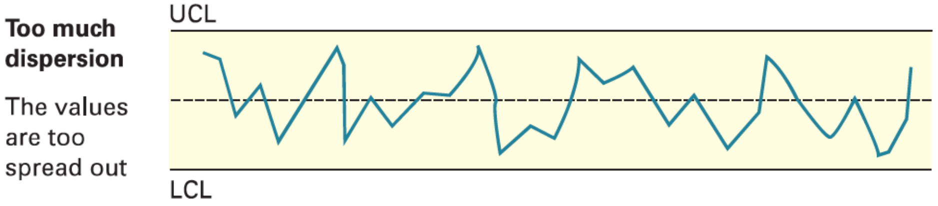
Run Tests

- A test for patterns in a sequences.









Assignment 6 – Tasks of Quality Control

5 min

Implement the effective quality control steps for your case study; more specifically;

- Define what do you study in the process output (variable or attributes or both?)
- Obtain 4 samples of 6 observations and explain your methodology.
- Compute appropriate sample statistic(s) for each sample. (ex: mean, …)
- Establish preliminary control limits using the formulas
- Determine if any point fall outside the control limits.
- Plot the data on the control chart and check for patterns.
- Define if the process is out-of-control and investigate and correct causes of variations.