Build4Scale

U.S. Department of Energy

Sustaining Quality and Warranty

Module 7A Key Quality Needs to Measure and Assess

Motivation

Why is this module important?

- If the product doesn't conform to quality standards (from the customer's point of view), the customer may be unsatisfied, and you may not be able to sell the product.
- The company selling the product is responsible for maintaining 100% control of the product's quality. While the supplier's quality control is critical, the supplier is not responsible for the final product sold.
- There are many sources of variability that impact the product's quality.

Module Outline

- Learning objectives
- Acceptance sampling strategies
  - —Benefits and risks
  - —Sampling plans
  - —Operating characteristics curve
- Statistical process control (SPC)
  - —Understanding types and importance of variations
  - —Variable and attribute control charts
  - —Control chart examples

Learning Objectives

- LO1. Determine quality needs of incoming parts
- LO2. Develop quality monitoring control plan

What This Module Addresses

- How to implement and conduct efficient acceptance-sampling schemes to decide whether to accept/reject product batches
- What sources of variability impact product quality
- How to use control charts to keep the manufacturing process within statistical control

Acceptance Sampling

What it is and how it works

- **Acceptance sampling** verifies that parts coming from a vendor comply with quality requirements

How it works:

- A company receives a shipment from its vendor (the company randomly selects a sample from the lot and inspects it)
- Based on the results of inspection, the company accepts or rejects the lot—also known as **lot sentencing**

Note: Acceptance sampling plans do not provide a methodology for quality control. They are used only to accept or reject the lots. For real quality control, use SPC tools such as control charts.

Acceptance Sampling

When is it needed?

- When dealing with an unproven supplier
- During start-ups and when manufacturing new products
- During destructive testing
- When the cost of 100% inspection is very high, or doing so is not technically feasible
- When products are likely to suffer damage during shipment

Acceptance Sampling

Key benefits

- Motivates suppliers to get it right the first time
- Costs less because it requires less inspection-related work (reduces labor and instrument costs)
- Minimizes handling of parts—meaning less likelihood of damaging a part during the inspection
- Can reduce the amount of inspection error significantly
- Applies to destructive testing

Acceptance Sampling

Disadvantages

- Creates risk of accepting bad lots and rejecting good lots
- Does not provide adequate information about the product or manufacturing process
- Requires significant planning and documentation to conduct acceptance sampling compared to 100% inspection

Note: 100% inspection will be considerably more expensive than this

Types Of Sampling Plans

Single and double

- **Single sampling plan**: Make a lot-sentencing decision based on one sample of *n* units
- **Double sampling plan**: Make a lot-sentencing decision based on two samples
  - —If you decide to reject the lot due to the first sample, you may take a second sample
  - —If the total number of defective items in both samples is less than a predetermined number of defectives, then accept the lot; otherwise, reject it

Types Of Sampling Plans

Multiple and sequential

- **Multiple sampling plan**: This plan is similar to the double-sampling technique, but you take more than two samples before making a lot-sentencing decision

Note: In multiple sampling, the sample sizes, *n*, are usually smaller than they are in single or double sampling

- **Sequential sampling plan**: You select units from the lot one at a time. Based on inspection of each unit, accept a lot, reject it, or select another one.

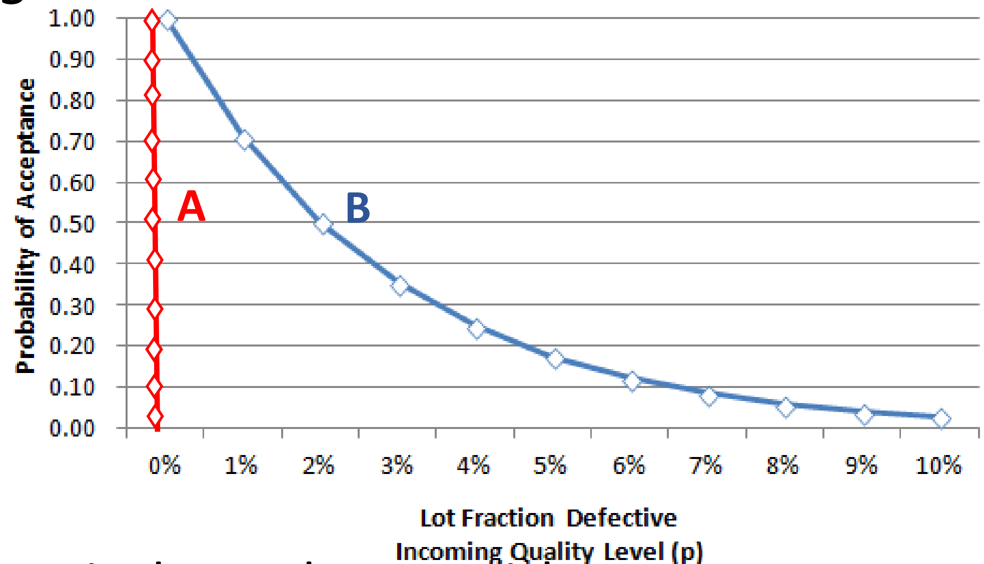
Formation of Lots for Inspection

Key considerations

- It is more economical to inspect a larger lot than a smaller lot
- Lots should be homogeneous
- Lots should be formed so that they conform to the materials-handling systems used in both the supplier's and consumer's facilities

Acceptance Sampling

Operating characteristic curves



- This curve is dependent on risk acceptance to part malfunction
- Line "A" suggests a part that has high risk associated with faultiness—i.e., a part is expensive to replace, and a defect will cause catastrophic failure, like a part in a pacemaker
- Line "B" suggests a part that has low risk associated with faultiness—i.e., a part is easy to replace, and a defect will not cause catastrophic issue, an easy-to-replace filter

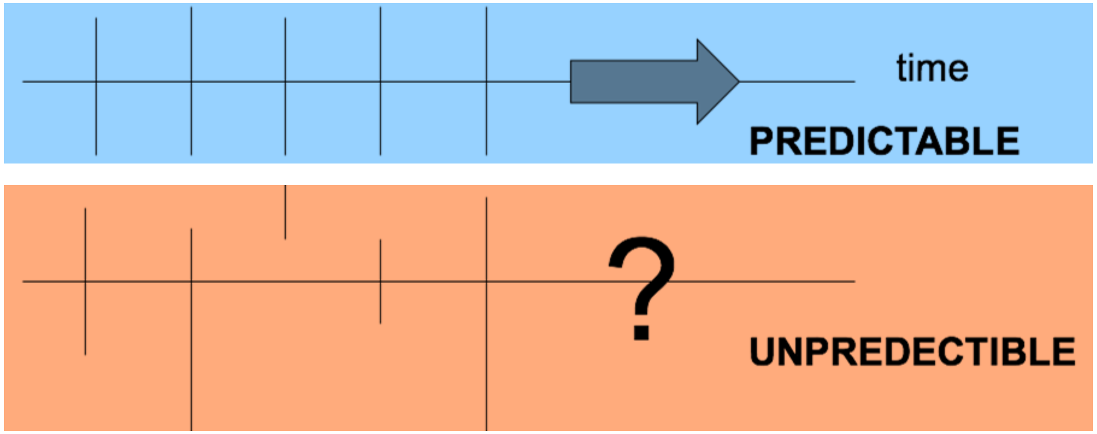
Statistical Process Control

What it is and how to account for it

- Understanding types and importance of variations
- Sources of variations
- Variable and attribute control charts
- Control chart examples

Understanding Variation

Why it's important



- When a process is stable, we consider it **predictable**
- A process affected by special causes is unstable and therefore considered **unpredictable**
- Unpredictable processes need evaluations for acceptability

While a fast food burger should have consistency—not unpredictability—the placement of the pickle may vary, but the burger will still be acceptable.

Sources Of Variation

Total process variation

Total Process Variation = Common Cause Variation + Special Cause Variation

Variation is often due to differences in:

- People
- Machines
- Materials
- Methods
- Measurement
- Environment

Sources Of Variation

Common cause variation

Total Process Variation = **Common Cause Variation** + **Special Cause Variation**

Variation is often due to:

- Naturally occurring and expected events
- The result of normal variation in materials, tools, machines, operators, and the environment

"Common cause" variation in our burger example would be the placement of pickles on different sides of the buns. We expect that level of variation, and it is acceptable.

Sources Of Variation

Special cause variation

Total Process Variation = **Common Cause Variation** + **Special Cause Variation**

Variation is often due to:

- Abnormal or unexpected variation
- An assignable cause
- Variation beyond what is considered inherent to the process

"Special cause" variation would be realizing many burgers had 10 pickles instead of 1. Clearly, something unusual is causing unacceptable variation and it needs addressing!

Statistical Process Control

What it is and how to account for it

- **SPC** monitors a process to identify special causes of variation and the need for corrective action when appropriate
- SPC relies on **control charts**

Control Charts:

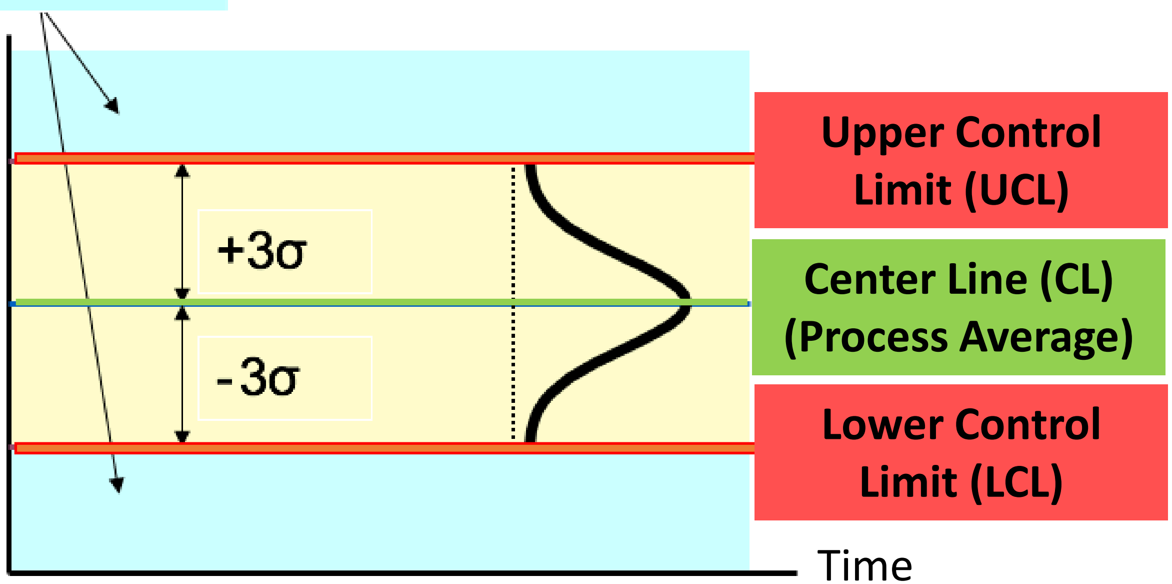
- Establish a state of statistical control
- Monitor a process and signal when it's out of control
- Determine process capability

Control Charts

Basics

Special Cause Variation:
Range of **unexpected** variability

Common Cause Variation: Range of **expected** variability



UCL = Process Average + 3 Standard Deviations
LCL = Process Average – 3 Standard Deviations

Control Charts

Commonly used types

Variables data (used for measured numeric data):

- The standard charts for variables data, **X-bar** and **Range charts** (R-charts) help determine if a process is stable and predictable
- They use actual numeric data from a process
- X-bar and s-charts (an s-chart is more accurate than an R-chart but needs more data)
- Charts for individuals (x-charts)

Definitions in the following slides

Control Charts

Commonly used types (cont.)

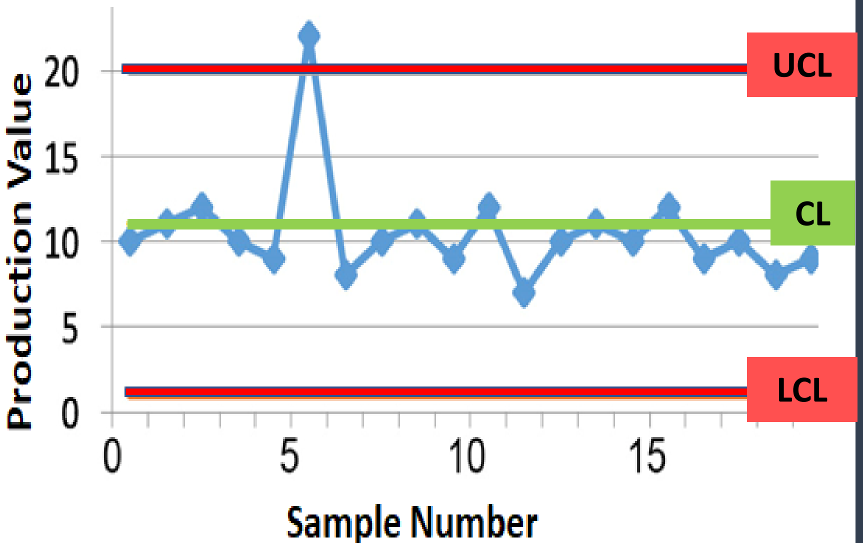
Attribute data (used when variable data is not available):

- Attribute data is qualitative data
- For “proportion defectives” (p-chart)
- For “number of defects per item” (c-chart), **attribute data** is not acceptable for production part submissions unless you can obtain **variable data**. Examples of use include the presence or absence of a required label, or the installation of all required fasteners.

X-Bar and R-Chart

What they are and when to use them (cont.)

- The **R-chart** monitors variables data from regular sample collections. An R-chart shows how the range of the subgroups changes over time.
- Processes that have a subgroup size of two or more use it
- It starts with at least 20 subgroups of observed values
- The chart tells when to correct the process and when to leave it alone
- It distinguishes between normal and abnormal variation



Computing Control Limits

- The value $\mathbf{A_2R}$ is used to estimate $\mathbf{3\sigma}$ (where A_2 is known as the Shewhart Factor) and it depends on the subgroup size $\boldsymbol{n}$
- The upper and lower control limits are as follows:

Upper Control Limit (UCL) $= \bar{\bar{x}} + A_2(\bar{R})$

Lower Control Limit (LCL) $= \bar{\bar{x}} - A_2(\bar{R})$

R-chart Control Limits

- The upper and lower control limits for an R-chart are as follows:

Upper Control Limit (UCL) $= D_4(\overline{R})$

Lower Control Limit (LCL) $= D_3(\overline{R})$

Where $\mathbf{D_4}$ and $\mathbf{D_3}$ are taken from the **Shewhart table** for subgroup size = *n*

X-Bar and R-Charts

Example

Process measurements

Sample Collected on Day Number	Individual Measurements				Subgroup Measurements	
					Mean, X-Bar	Range, R
1	15	17	15	11	14.5	6
2	12	16	9	15	13.0	7
3	17	21	18	20	19.0	4
4	14	18	13	17	15.5	4
					Grand Mean equals $\bar{\bar{X}}$	Mean Range equals $\bar{R}$

X-Bar and R-Charts

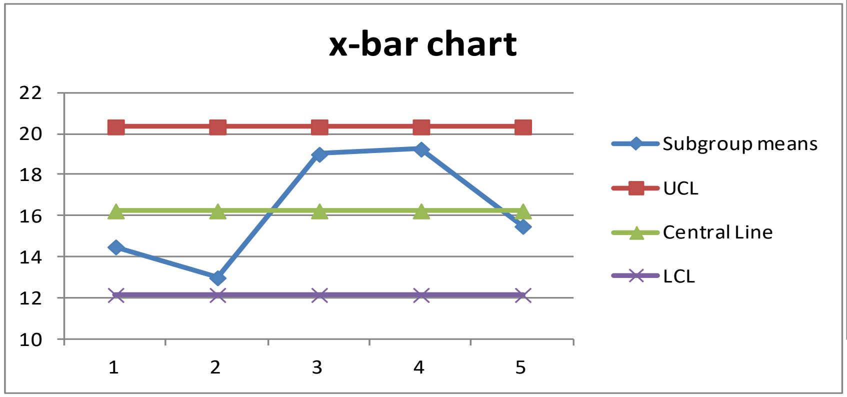
Solution

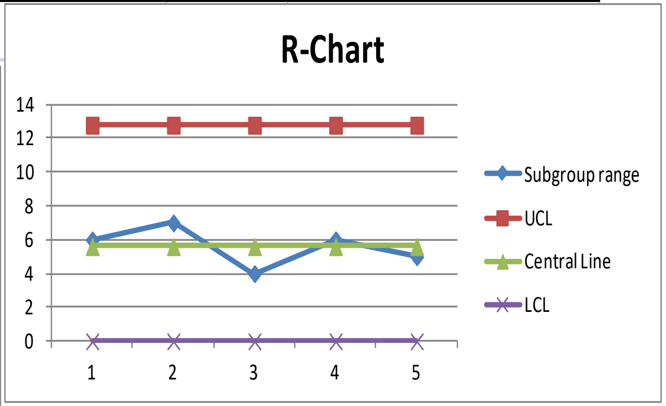
Sample Collected on day	Individual measurements				Subgroup measures: Mean, $\bar{x}$	Subgroup measures: Range, R
1	15	17	15	11	14.5	6
2	12	16	9	15	13	7
3	17	21	18	20	19	4
4	16	19	20	22	19.25	6
5	14	18	13	17	15.5	5
Grand mean					16.25	5.6

Control Limit calculations	x-bar Chart	R-Chart
LCL	12.1676	0
Grand Mean (Center Line)	16.25	5.6
UCL	20.3324	12.7792

For n= 4, from Appendix 2 of your textbook

A2	D3	D4
0.729	0	2.282





Process Stability

- Process variation is random variation (i.e., has a common cause) and not nonrandom variation (i.e., has no special or assignable causes)
- The use of process control charts determines process stability
- Generally, if at least one point plots beyond the control limits or much farther away from the process mean than is expected, the process is out of control
- Additionally, if the data points behave in a systematic or nonrandom manner, then the process may be out of control

Attribute Charts

- Attribute charts can assist in monitoring processes providing goods or services
- These charts can be used whenever counts or percentages of nonconformities can be obtained
- **p chart:** fraction nonconforming
- **np chart:** number nonconforming
- **Percent nonconforming charts**
- **c charts:** counts of nonconformities
- **u charts:** nonconformities per unit

Selecting Attribute Control Charts

C-Charts

When studying the proportion of products rendered unusable by nonconformities, one the following charts should be used:

- Fraction nonconforming (p) chart
- Number nonconforming (np) chart
- Percent nonconforming chart should be used

When tracking the number of nonconformities, one of the following charts should be used:

- Number of nonconformities (c) chart
- Number of nonconformities per unit (u) chart

C-Charts Fraction Nonconforming

Development

The sample fraction nonconforming is given as

$$\hat{p} = \frac{D}{n}$$

where $\hat{p}$ is a random variable with mean and variance

$$\mu = p \qquad \sigma^2 = \frac{p(1-p)}{n}$$

C-Charts Fraction Nonconforming

Standard given

- If a standard value of ***p*** is given, then the control limits for the fraction nonconforming are as follows:

Upper Control Limit (UCL) $= p + 3\sqrt{\frac{p(1-p)}{n}}$

Center Line (CL) $= p$

Lower Control Limit (LCL) $= p - 3\sqrt{\frac{p(1-p)}{n}}$

C-Charts Fraction Nonconforming

No standard given

- If no standard value of **p** is given, then the control limits for the fraction nonconforming are as follows:

Upper Control Limit (UCL) $= \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$

Center Line (CL) $= p$

Lower Control Limit (LCL) $= \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$

where

$$\bar{p} = \frac{\sum_{i=1}^{m} D_i}{mn} = \frac{\sum_{i=1}^{m} \hat{p}_i}{m}$$

C-Charts Fraction Nonconforming

Example 1

- A process that produces bearing housings is investigated. Select 10 samples a lot size of 100.

Sample #	1	2	3	4	5	6	7	8	9	10
# Nonconf.	5	2	3	8	4	1	2	6	3	4

- Is this process operating in statistical control?

C-Charts Fraction Nonconforming

Example 1 (cont.)

n = 100, m = 10

Sample #	1	2	3	4	5	6	7	8	9	10
# Nonconf.	5	2	3	8	4	1	2	6	3	4
Fraction Nonconf. (p_i)	0.05	0.02	0.03	0.08	0.04	0.01	0.02	0.06	0.03	0.04

$$\bar{p} = \frac{\sum_{i=1}^{m} \hat{p}_i}{m} = 0.038$$

C-Charts Fraction Nonconforming

Example 1 (cont.)

Control Limits are:

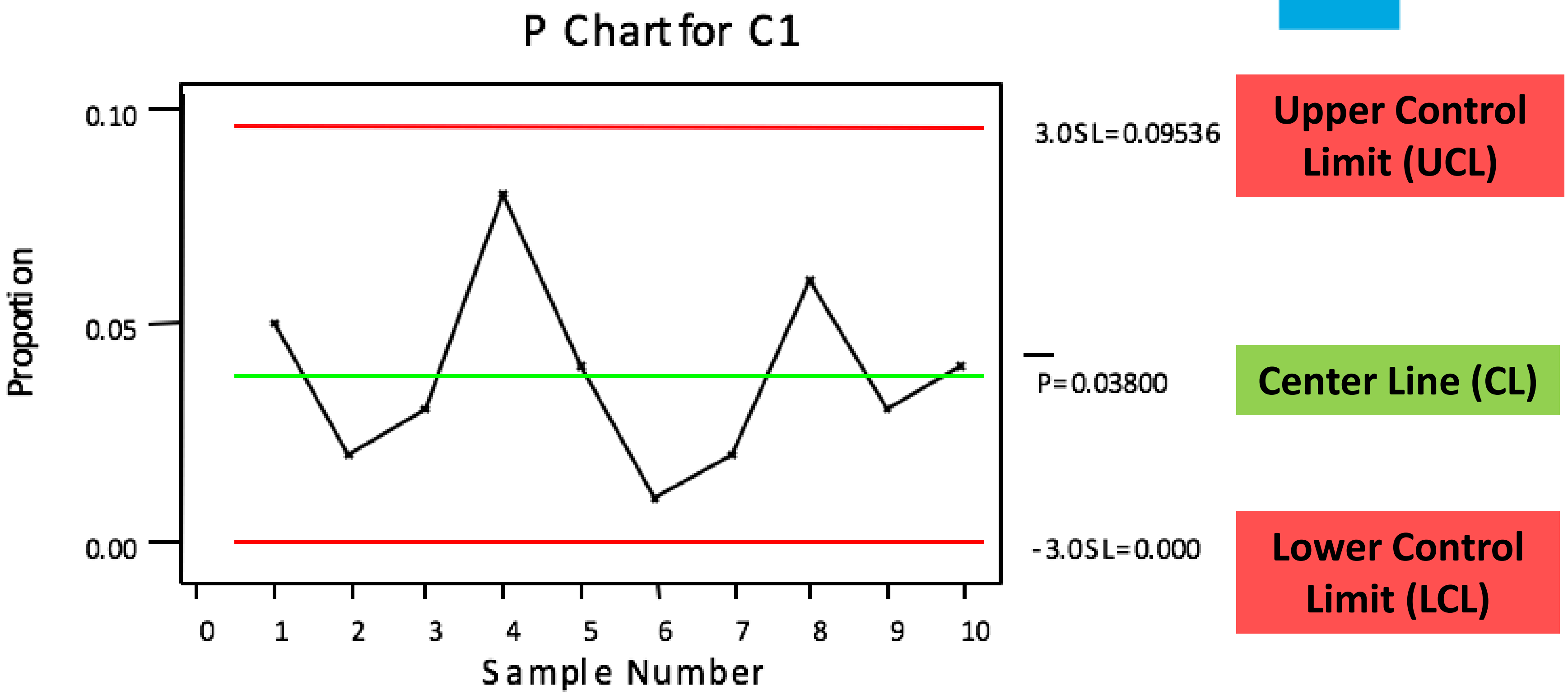
Upper Control Limit (UCL) $= 0.038 + 3\sqrt{\frac{0.038(1-0.038)}{100}} = 0.095$

Center Line (CL) $= 0.038$

Lower Control Limit (LCL) $= 0.038 + 3\sqrt{\frac{0.038(1-0.038)}{100}} = -0.02 \rightarrow 0$

C-Charts Fraction Nonconforming

Example 1 (cont.)



- Variation is acceptable when results stay within the upper and lower control limits

Nonconformities or Defects

- There are many instances where an item will contain nonconformities, but the item itself is not classified as nonconforming.
- It is often important to construct control charts (c-charts) for the total number of nonconformities or the average number of nonconformities for a given "area of opportunity." (The inspection must be the same for each unit.)

Constant Sample Size

Procedures

C-chart

Standard Given:

$$UCL = c + 3\sqrt{c}$$

$$CL = c$$

$$LCL = c - 3\sqrt{c}$$

No Standard Given:

$$UCL = \bar{c} + 3\sqrt{\bar{c}}$$

$$CL = \bar{c}$$

$$LCL = \bar{c} - 3\sqrt{\bar{c}}$$

C-Charts

Example 2 – *Pure & White*

- Pure & White, a manufacturer of copy-machine paper, monitors their production using a c-chart. Pure & White produces paper rolls that are 12 feet long and 6 feet in diameter
  - —A sample is taken from each completed roll, *n*=1, and the lab checks it for nonconformities
- Nonconformities include discolorations, inconsistent paper thickness, flecks of dirt in the paper, moisture content, and ability to take ink. All of these nonconformities have the same weight on the c-chart
- A sample may come from anywhere in the roll so that the area of opportunity for these nonconformities is large, while the overall quality of the paper creates only a very small chance of a specific nonconformity occurring at any one location

C-Charts

Example 2 – Pure & White (cont.)

- Create a c-chart for the Pure & White company by using the data given in the table

Center line	11
UCL_c	20
LCL_c	1

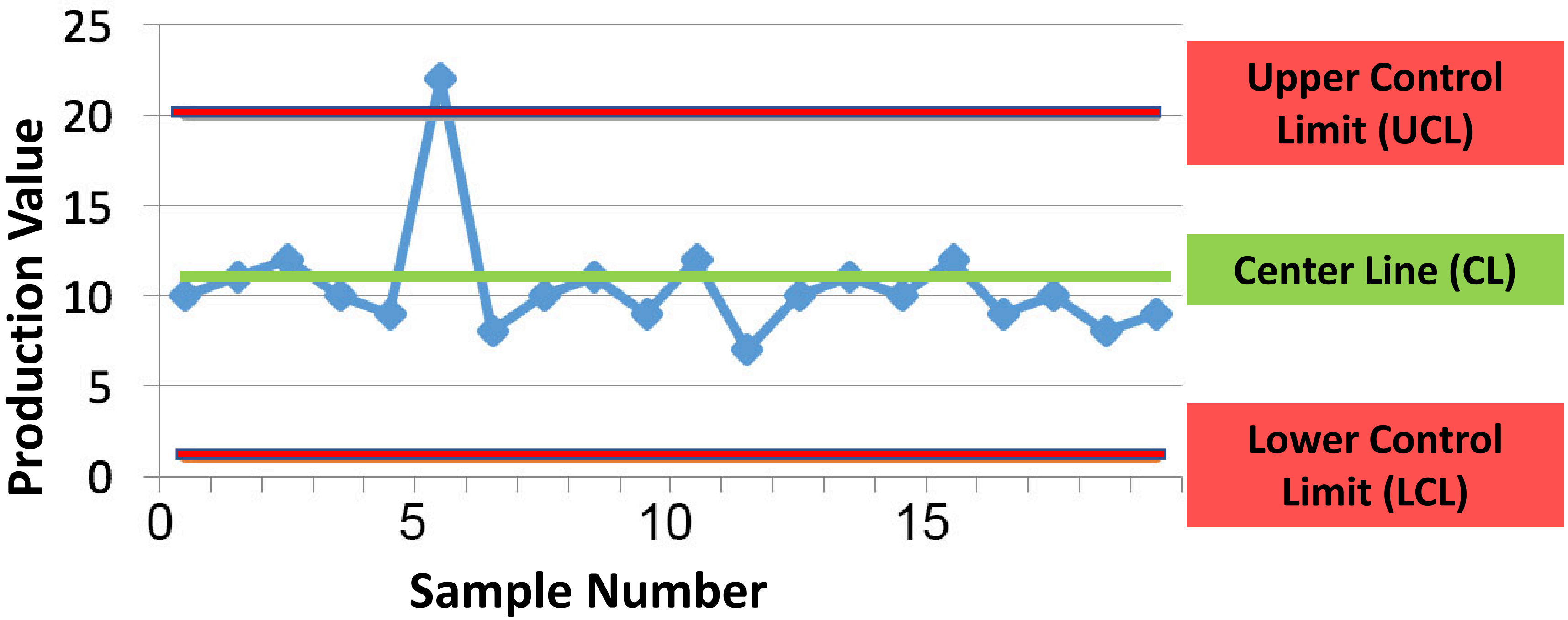
Sample Number	Production Value
8	10
9	11
10	9
11	12
12	7
13	10

C-Charts

Example 2 – Pure & White (cont.)

- Is this process under statistical control? **No.**

Note: The plot points represent the count of nonconformities (c-value) in each sample (per prior slide values)



List Of Terms

In glossary

- **Acceptance sampling** uses statistical sampling to determine whether to accept or reject a production lot of material.
- **Single sampling plan** a single sampling plan for attributes is a statistical method by which the lot is accepted or rejected on the basis of one sample.
- **Double sampling plan** is performed after the first sample is tested. There are then three outcome possibilities: 1) accept lot, 2) reject lot, 3) no decision. If the outcome is (3), and a second sample is taken then the procedure is to combine the results of both samples and make a final deciding on that information.
- **Multiple sampling plans** are the extension of the double sampling plans when more than two samples are needed to reach a conclusion. The advantage of multiple sampling is a smaller sample size.
- **Sequential sampling** is the ultimate extension of the multiple samples where items are selected from a lot one at a time and after inspection of each a decision is made to accept the lot or select a both sample to review.
- **Predictable Variation** also referred to as **Expected Variation** are processes for which process variation is the result of random causes. The more stable processes produce products that adhere to specifications to a greater degree than those produced by unstable processes. The more variation in measured product characteristics, the less the product adheres to specifications,
- **Unpredictable Variation** also referred to as **Unexpected Variation** falls outside the upper and lower acceptable limits established for a product specification, which can lead to product discard or salvage. Therefore, a key manufacturing performance objective is the establishment of stable and predictable processes that limits variation to what can be described as random, minimum variation around target values.
- **Statistical Process Control (SPC)** is a method of quality control which employs statistical methods to monitor and control a process. This helps ensure the process operates efficiently, producing more specification-conforming product with less waste (rework or scrap).
- **Control Charts** also known as Shewhart charts (after Walter A. Shewhart) or process-behavior charts, are a statistical process control tool used to determine if a manufacturing or business process is in a state of control.

List Of Terms

In glossary (cont.)

- **X and R Chart x ¯ {\displaystyle {\bar {x}}} Xx xxxx and x and** is a type of control chart used to monitor variables data when samples are collected at regular intervals from a business or industrial process.
- **Attribute Data** is data that can't fit into a continuous scale but instead is chunked into distinct *buckets,* like small/medium/large, pass/fail, acceptable/not acceptable, and so on.
- **Variable Data** is data, such as length or pressure, in a time-ordered sequence. In contrast, attribute control charts plot count data, such as the number of defects or defective units.
- **X-bar chart** - is a type of Shewhart control chart that is used to monitor the arithmetic means of successive samples of constant size, n. This type of control chart is used for characteristics that can be measured on a continuous scale, such as weight, temperature, thickness etc.
- **R-Chart** or Range Chart plots average **R** value, or **R**-bar tp determine the upper control limit.
- **Shewhart Individuals Control Chart or Table** is used in statistical quality *control*, the individual/moving-range chart is a type of *control* chart used to monitor variables data from a business or industrial process for which it is impractical to use rational subgroups.
- **P-Chart** - is a type of control chart used to monitor the proportion of nonconforming units in a sample, where the sample proportion nonconforming is defined as the ratio of the number of nonconforming units to the sample size, n.
- **NP Chart** - is a type of control chart used to monitor the number of nonconforming units in a sample.
- **Percent Nonconforming Charts** is a statistical quality control chart used to monitor the proportion of nonconforming units in a sample, where the sample proportion nonconforming is defined as the ratio of the number of nonconforming units to the sample size.
- **C Charts** is a type of control chart used to monitor "count"-type data, typically total number of nonconformities per unit. It is also occasionally used to monitor the total number of events occurring in a given unit of time.
- **U Charts** is a type of control chart used to monitor "count"-type data where the sample size is greater than one, typically the average number of nonconformities per unit.