Process Variations and Quality

• Quality is inversely proportional to variability (Variability & Quality are enemies).

• The more variation in product characteristics, in delivery times, in work practices: the more waste, higher costs and poor quality, is delivered to our customers. (Out of the Crisis, 1982)
Causes of Product Variations

Product characteristics variations are mainly caused by the variations in the components of the process (**5 M and E**):

- **Man** Power
- **Machines**
- **Methods**
- **Materials**
- **Measurements**
- **Environment**

![Diagram](image)

Process Variations Causes

1. **Common causes** are ever-present in the process;
   "====== Natural Variations"

2. **Special causes** are intermittent effects that must be investigated immediately.
   "====== Assignable Causes Variations"

- Management and quality professionals (YOU) should help manufacturing people to identify and remove special causes and reduce the occurrence of common causes in the process.
Process Variation

*Process Variability*

Variations due to:

**Natural Causes:**
- Temperature variation
- Material variation
- Customer differences
- Operator performance

**Special Causes:**
- Machine is breaking
- Untrained operative
- Machine movement
- Process has changed

Must be monitored

Early and visible warning required

Control Charts

Of all the quality tools for analyzing data, the control chart is the most useful.

No other tool captures the voice of your process better.

Control charts are used to determine whether your process is operating in statistical control.
Control Charts

The control chart is a means of visualizing the variations that occur in the process data and its components.

It shows whether the process is in a stable state (in statistical control) or out of statistical control.

Use of Variable Control Charts in Manufacturing

The objectives of the variable control charts are:

- For process improvement
- To determine the process capability.
- For decisions regarding product specifications
- For current decisions on the production process
- For current decisions on recently produced items
Control Charts

**BENEFITS OF CONTROL CHARTS**

- Help you recognize and understand variability and how to control it
- Identify “special causes” of variation and changes in performance
- Keep you from fixing a process that is varying randomly within control limits; that is, no “special causes” are present. If you want to improve it, you have to objectively identify and eliminate the root causes of the process variation
- Assist in the diagnosis of process problems
- Determine if process improvement effects are having the desired affects

Control Charts Types

- **Continuous Numerical Data**
  - Variables Charts
    - $\bar{X}$ Chart
    - Chart
    - $s$ Chart
  - Control Charts
- **Categorical or Discrete Numerical Data**
  - Attributes Charts
    - $P$ Chart
    - $C$ Chart
  - Other Charts:
    - ImR, EWMA, CUSUM..
Variable Control Charts Interpretation

control charts help to determine if the process is:
(a) in statistical control; or (b) out of statistical control.

Variable Control Charts Interpretation

Quality Characteristic

- Variable - a single quality characteristic that can be measured on a numerical scale.

- When working with variables, we should monitor both the mean value of the characteristic and the variability associated with the characteristic.

The Quality characteristic must be measurable.
It can expressed in terms of the seven basic units:
1. Length
2. Mass
3. Time
4. Electrical current
5. Temperature
6. Substance
7. Luminosity
Part 1 – Variable Control Charts

Example of a method of reporting inspection results

Control Chart Techniques

Procedure for establishing a pair of control charts for the average $\bar{X}$ and the range $R$:

1. Select the quality characteristic
2. Choose the rational subgroup
3. Collect the data
4. Determine the trial center line and control limits
5. Establish the revised central line and control limits
6. Achieve the objective
Control Charts for $\bar{X}$ and $R$

Notation for variables control charts

• $n$ - size of the sample (sometimes called a subgroup) chosen at a point in time
• $m$ - number of samples selected
• $\bar{x}_i$ = average of the observations in the $i$th sample (where $i = 1, 2, ..., m$)
• $\bar{X}$ = grand average or “average of the averages” (this value is used as the center line of the control chart)

Notation and values

• $R_i$ = range of the values in the $i$th sample
  $$R_i = x_{\text{max}} - x_{\text{min}}$$
• $\bar{R}$ = average range for all $m$ samples
• $\mu$ is the true process mean
• $\sigma$ is the true process standard deviation
Control Charts for $\bar{X}$ and $R$

Statistical Basis of the Charts

• Assume the quality characteristic of interest is normally distributed with mean $\mu$, and standard deviation, $\sigma$.

• If $x_1, x_2, \ldots, x_n$ is a sample of size $n$, then the average of this sample is

$$\bar{X} = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

• $\bar{X}$ is normally distributed with mean, $\mu$, and standard deviation, $\sigma_{\bar{X}} = \sigma/\sqrt{n}$

Control Charts for $\bar{X}$ and $R$

Control Limits for the $\bar{X}$ chart

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

Center Line $= \bar{X}$

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

• $A_2$ is found in constants for various values of $n$. 
Control Charts for $\bar{X}$ and R

Control Limits for the R chart

\[ UCL_R = D_4 \bar{R} \]
\[ Center \ Line = \bar{R} \]
\[ LCL_R = D_3 \bar{R} \]

- $D_3$ and $D_4$ are constants for various values of $n$.

Control Charts Constants

<table>
<thead>
<tr>
<th>$D_4$</th>
<th>$D_3$</th>
<th>$B_4$</th>
<th>$B_3$</th>
<th>$A_3$</th>
<th>$A_2$</th>
<th>Sample size $n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.267</td>
<td>0</td>
<td>3.267</td>
<td>0</td>
<td>2.659</td>
<td>1.880</td>
<td>2</td>
</tr>
<tr>
<td>2.575</td>
<td>0</td>
<td>2.568</td>
<td>0</td>
<td>1.954</td>
<td>1.023</td>
<td>3</td>
</tr>
<tr>
<td>2.282</td>
<td>0</td>
<td>2.266</td>
<td>0</td>
<td>1.628</td>
<td>0.729</td>
<td>4</td>
</tr>
<tr>
<td>2.115</td>
<td>0</td>
<td>2.089</td>
<td>0</td>
<td>1.427</td>
<td>0.577</td>
<td>5</td>
</tr>
<tr>
<td>2.004</td>
<td>0</td>
<td>1.970</td>
<td>0.030</td>
<td>1.287</td>
<td>0.483</td>
<td>6</td>
</tr>
<tr>
<td>1.924</td>
<td>0.076</td>
<td>1.882</td>
<td>0.118</td>
<td>1.182</td>
<td>0.419</td>
<td>7</td>
</tr>
</tbody>
</table>
Control Charts for $\bar{X}$ and s

- The sample standards deviation can be a more accurate estimation of the process variability process, especially if the sample size $n>10$.

- In this case control charts for Xbar and S can be used to monitor the process.

Control Charts for $\bar{X}$ and s

- Construction of the control charts for Xbar and S follows the same procedure as for the Xbar-R charts.

- Control Limits for $s$ chart are:
  \[ UCL_s = B_4 \bar{s} \]
  \[ CenterLine = \bar{s} \]
  \[ LCL_s = B_3 \bar{s} \]

- Control Limits for Xbar chart:
  \[ UCL = \bar{x} + A_3 \bar{s} \]
  \[ Center Line = \bar{x} \]
  \[ LCL = \bar{x} - A_3 \bar{s} \]

- $A_3$, $B_3$, $B_4$ are constants.
Example of $\bar{X}$ -R control charts

A component part for a jet aircraft engine is manufactured by an investment casting process.

The vane opening on this casting is an important functional parameter of the part.

We will illustrate the use of $Xbar$ and $R$ control charts to assess the statistical stability of this process.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_3$</th>
<th>$x_4$</th>
<th>$x_5$</th>
<th>$\bar{X}$</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33</td>
<td>29</td>
<td>31</td>
<td>32</td>
<td>33</td>
<td>31.6</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
<td>31</td>
<td>37</td>
<td>31</td>
<td>33</td>
<td>33.4</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>37</td>
<td>33</td>
<td>34</td>
<td>36</td>
<td>35.0</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>31</td>
<td>33</td>
<td>34</td>
<td>33</td>
<td>32.2</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>33</td>
<td>34</td>
<td>35</td>
<td>33</td>
<td>34</td>
<td>33.8</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>38</td>
<td>37</td>
<td>39</td>
<td>40</td>
<td>38</td>
<td>38.4</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>31</td>
<td>32</td>
<td>34</td>
<td>31</td>
<td>31.6</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>29</td>
<td>30</td>
<td>38</td>
<td>39</td>
<td>30</td>
<td>36.8</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>28</td>
<td>33</td>
<td>35</td>
<td>36</td>
<td>43</td>
<td>35.0</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>38</td>
<td>33</td>
<td>32</td>
<td>35</td>
<td>32</td>
<td>34.0</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>28</td>
<td>30</td>
<td>28</td>
<td>32</td>
<td>31</td>
<td>29.8</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>31</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>34</td>
<td>34.0</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>27</td>
<td>32</td>
<td>34</td>
<td>35</td>
<td>37</td>
<td>33.0</td>
<td>10</td>
</tr>
<tr>
<td>14</td>
<td>33</td>
<td>33</td>
<td>35</td>
<td>37</td>
<td>36</td>
<td>34.8</td>
<td>4</td>
</tr>
<tr>
<td>15</td>
<td>35</td>
<td>37</td>
<td>32</td>
<td>35</td>
<td>39</td>
<td>35.6</td>
<td>7</td>
</tr>
<tr>
<td>16</td>
<td>33</td>
<td>33</td>
<td>27</td>
<td>31</td>
<td>30</td>
<td>30.8</td>
<td>6</td>
</tr>
<tr>
<td>17</td>
<td>35</td>
<td>34</td>
<td>34</td>
<td>30</td>
<td>32</td>
<td>33.0</td>
<td>5</td>
</tr>
<tr>
<td>18</td>
<td>32</td>
<td>33</td>
<td>30</td>
<td>30</td>
<td>33</td>
<td>31.6</td>
<td>3</td>
</tr>
<tr>
<td>19</td>
<td>25</td>
<td>27</td>
<td>34</td>
<td>27</td>
<td>28</td>
<td>28.2</td>
<td>9</td>
</tr>
<tr>
<td>20</td>
<td>35</td>
<td>35</td>
<td>36</td>
<td>33</td>
<td>30</td>
<td>33.8</td>
<td>6</td>
</tr>
</tbody>
</table>

$\bar{X} = 33.32 \quad r = 5.8$
Example of $\bar{X}$ -R control charts

Calculate the control limits for the R chart:

- **Upper Control Limit (UCL)**: $D_4 \bar{R} = 12.27$
- **Center Line**: $\bar{R} = 5.80$
- **Lower Control Limit (LCL)**: $D_3 \bar{R} = 0$

<table>
<thead>
<tr>
<th></th>
<th>$D_2$</th>
<th>$D_3$</th>
<th>$B_1$</th>
<th>$B_2$</th>
<th>$A_2$</th>
<th>$L_2$</th>
<th>Sample size n</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.267</td>
<td>0</td>
<td>3.267</td>
<td>0</td>
<td>2.659</td>
<td>1.880</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2.575</td>
<td>0</td>
<td>2.568</td>
<td>0</td>
<td>1.954</td>
<td>1.023</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2.282</td>
<td>0</td>
<td>2.266</td>
<td>0</td>
<td>1.628</td>
<td>0.729</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>1.115</td>
<td>0</td>
<td>2.089</td>
<td>0</td>
<td>1.477</td>
<td>0.577</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>2.004</td>
<td>0</td>
<td>1.970</td>
<td>0.036</td>
<td>1.287</td>
<td>0.483</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>1.924</td>
<td>0.076</td>
<td>1.882</td>
<td>0.118</td>
<td>1.182</td>
<td>0.419</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

Calculate the control limits for the Xbar chart:

- **Upper Control Limit (UCL)**: $\bar{X} + A_2 \bar{R} = 36.67$
- **Center Line**: $\bar{X} = 33.32$
- **Lower Control Limit (LCL)**: $\bar{X} - A_2 \bar{R} = 29.97$

Example of $\bar{X}$ -R control charts

The process is Out of statistical control; it is not stable. Special causes should be investigated using cause and effect diagram and other quality tools.
Other Control Charts for variables

1. Individual Moving Range Charts
2. Exponentially Weighted Mean Average (EWMA) charts
3. Cumulative Sum (CUSUM) chart.

*Student should search on the net for the use of these charts*

---

PART 2

CONTROL CHARTS FOR ATTRIBUTES
Introduction

• Many quality characteristics cannot be conveniently represented numerically.

• In such cases, each item inspected is classified as either conforming or nonconforming to the specifications on that quality characteristic.

• Quality characteristics of this type are called attributes.

Types of Control Charts

Control Charts for Variables Data

- $\bar{X}$ and $R$ charts: for sample averages and ranges.
- $\bar{X}$ and $s$ charts: for sample means and standard deviations.
- $Md$ and $R$ charts: for sample medians and ranges.
- $\bar{X}$ charts: for individual measures; uses moving ranges.

Control Charts for Attributes Data

- $c$ charts: count of nonconformities.
- $p$ charts: proportion of units nonconforming.
- $np$ charts: number of units nonconforming.
- $u$ charts: count of nonconformities per unit.
Control Chart Selection

**Quality Characteristic**

**Variable Attribute**

- \(n > 1?\)
  - yes: \(x\) and \(s\)
  - no: \(x\) and MR

- \(n \geq 10?\)
  - yes: \(x\) and R
  - no: \(x\) and MR

**Defective**

- constant sample size?
  - yes: \(p\) or \(np\)
  - no: p-chart with variable sample size

**Defect**

- constant sampling unit?
  - yes: \(c\)
  - no: \(u\)

Type of Attribute Charts

**c charts**

- This shows the number of defects or nonconformities produced by a manufacturing process.

**p charts**

- This chart shows the fraction of nonconforming or defective product produced by a manufacturing process.
- It is also called the control chart for fraction nonconforming.

**np charts**

- This chart shows the number of nonconforming. Almost the same as the \(p\) chart.

**u charts**

- This chart shows the nonconformities per unit produced by a manufacturing process.
c Chart

- In statistical quality control, the c-chart is a type of control chart used to monitor "count" or 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.
- c: counts of nonconformities.
- Control limits must be calculated (UCL, LCL):

\[
UCL = \bar{c} + 3\sqrt{\bar{c}} \quad LCL = \bar{c} - 3\sqrt{\bar{c}}
\]

\[
\bar{c} = \frac{\sum c}{g} = \text{average count of nonconformities}
\]

Example from Manufacturing

Surface defects have been counted on 25 rectangular steel plates, and the data are shown below.

The control chart for nonconformities (c-chart) is used to study the process stability.

Is the Process under Statistical Control?
The c chart for nonconformities shows that the process is:

**Out of Statistical Control; it is unstable.**
**Special causes must be investigated.**

---

### Example 2

<table>
<thead>
<tr>
<th>Sample</th>
<th>Defects</th>
<th>c-Bar</th>
<th>UCL</th>
<th>LCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2.50</td>
<td>5.66</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2.50</td>
<td>5.66</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2.50</td>
<td>5.66</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>2.50</td>
<td>5.66</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>2.50</td>
<td>5.66</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>2.50</td>
<td>5.66</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>2.50</td>
<td>5.66</td>
<td>0.00</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>2.50</td>
<td>5.66</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>2.50</td>
<td>5.66</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>2.50</td>
<td>5.66</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Process is in Statistical Control and Stable.
$p$ charts

**Application**

$p$ charts are used to analyse proportion of items or events that fall into a specific category. Typical applications include:

- Proportion of rejects/passes/failures after an inspection (e.g. of products and forms).
- Proportion of late deliveries/arrivals/payments.
- Proportion of jobs that are vacant.
- Proportion of rejects due to wrong item delivered, damaged item, no longer required, etc.
- Proportion of patients suffering infection.

$p$ charts

- In this chart, we plot the percent of defectives (per batch, per day, per machine, etc.).
- However, the control limits in this chart are not based on the distribution of rate events but rather on the binomial distribution (of proportions).
Formula

- Fraction nonconforming:
  \[ p = \frac{(np)}{n} \]
- where \( p \) = proportion or fraction nc in the sample or subgroup,
- \( n \) = number in the sample or subgroup,
- \( np \) = number nc in the sample or subgroup.

Example

- During the first shift, 450 inspection are made of book-of-the-month shipments and 5 nc units are found. Production during the shift was 15,000 units. What is the fraction nc?

  \[ p = \frac{(np)}{n} = \frac{5}{450} = 0.011 \]

- The \( p \), is usually small, say 0.10 or less.
- If \( p > 0.10 \), indicate that the organization is in serious difficulty.
p-Chart construction for constant subgroup size

- Select the quality characteristics.
- Determine the subgroup size and method
- Collect the data.
- Calculate the trial central line and control limits.
- Establish the revised central line and control limits.
- Achieve the objective.

Select the quality characteristics

The quality characteristic?
- A single quality characteristic
- A group of quality characteristics
- A part
- An entire product, or
- A number of products.
Determine the subgroup size and method

- The size of subgroup is a function of the proportion nonconforming.
- If $p = 0.001$, and $n = 1000$, then the average number $nc, np = 1$. *Not good, since a large number of values would be zero.*
- If $p = 0.15$, and $n = 50$, then $np = 7.5$, would make a good chart.

Therefore, the selection subgroup size requires some preliminary observations to obtain a rough idea of the proportion nonconforming.

Calculate the trial central line and control limits

- The formula:
  $$UCL = \bar{p} + 3 \sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$$
  $$LCL = \bar{p} - 3 \sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$$

  $\bar{p} = \frac{\sum np}{\sum n}$ = average of $p$ for many subgroups
- $n =$ number inspected in a subgroup
Negative value of LCL is possible in a theoretical result, but not in practical (proportion of nc never negative).
Control Charts for Fraction Nonconforming (p chart) Example 2

Example
• A process that produces bearing housings is investigated. Ten samples of size 100 are selected.

<table>
<thead>
<tr>
<th>Sample #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td># Nonconf.</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

• Is this process operating in statistical control?

Example \( n = 100, m = 10 \)

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

\[
\begin{align*}
UCL &= 0.038 + 3 \sqrt{\frac{0.038(1-0.038)}{100}} = 0.095 \\
CL &= 0.038 \\
LCL &= 0.038 + 3 \sqrt{\frac{0.038(1-0.038)}{100}} = -0.02 \rightarrow 0
\end{align*}
\]
C chart – Example 2

P Chart for C1

u Chart

• The u chart is mathematically equivalent to the c chart.

\[ u = \frac{c}{n} \quad \text{and} \quad \bar{u} = \frac{\sum c}{\sum n} \]

\[ UCL = \bar{u} + 3 \sqrt{\frac{\bar{u}}{n}} \quad \text{and} \quad LCL = \bar{u} - 3 \sqrt{\frac{\bar{u}}{n}} \]
### Example

\[
\bar{u} = \frac{\sum c}{\sum n} = \frac{3389}{2823} = 1.20
\]

<table>
<thead>
<tr>
<th>ID Number</th>
<th>Subgroup</th>
<th>n</th>
<th>c</th>
<th>u</th>
<th>UCL</th>
<th>(u)-Bar</th>
<th>LCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-Jan</td>
<td>1</td>
<td>110</td>
<td>120</td>
<td>1.091</td>
<td>1.51</td>
<td>1.20</td>
<td>0.89</td>
</tr>
<tr>
<td>31-Jan</td>
<td>2</td>
<td>82</td>
<td>94</td>
<td>1.146</td>
<td>1.56</td>
<td>1.20</td>
<td>0.84</td>
</tr>
<tr>
<td>1-Feb</td>
<td>3</td>
<td>96</td>
<td>89</td>
<td>0.927</td>
<td>1.54</td>
<td>1.20</td>
<td>0.87</td>
</tr>
<tr>
<td>2-Feb</td>
<td>4</td>
<td>115</td>
<td>162</td>
<td>1.409</td>
<td>1.51</td>
<td>1.20</td>
<td>0.89</td>
</tr>
<tr>
<td>3-Feb</td>
<td>5</td>
<td>108</td>
<td>150</td>
<td>1.389</td>
<td>1.52</td>
<td>1.20</td>
<td>0.88</td>
</tr>
<tr>
<td>4-Feb</td>
<td>6</td>
<td>56</td>
<td>82</td>
<td>1.464</td>
<td>1.64</td>
<td>1.20</td>
<td>0.76</td>
</tr>
<tr>
<td>28-Feb</td>
<td>26</td>
<td>101</td>
<td>105</td>
<td>1.040</td>
<td>1.53</td>
<td>1.20</td>
<td>0.87</td>
</tr>
<tr>
<td>1-Mar</td>
<td>27</td>
<td>122</td>
<td>143</td>
<td>1.172</td>
<td>1.50</td>
<td>1.20</td>
<td>0.90</td>
</tr>
<tr>
<td>2-Mar</td>
<td>28</td>
<td>105</td>
<td>132</td>
<td>1.257</td>
<td>1.52</td>
<td>1.20</td>
<td>0.88</td>
</tr>
<tr>
<td>3-Mar</td>
<td>29</td>
<td>98</td>
<td>100</td>
<td>1.020</td>
<td>1.53</td>
<td>1.20</td>
<td>0.87</td>
</tr>
<tr>
<td>4-Mar</td>
<td>30</td>
<td>48</td>
<td>60</td>
<td>1.250</td>
<td>1.67</td>
<td>1.20</td>
<td>0.73</td>
</tr>
</tbody>
</table>

**• For January 30:**

\[
\bar{u}_{Jan\ 30} = \frac{c}{n} = \frac{120}{110} = 1.09
\]

\[
UCL_{Jan\ 30} = 1.20 + 3\sqrt{\frac{1.20}{110}} = 1.51
\]

\[
LCL_{Jan\ 30} = 1.20 - 3\sqrt{\frac{1.20}{110}} = 0.89
\]
Control Charts for Variables in Minitab
Home Work

- Study the process stability using the data shown on the table on nonconforming units in the manufacturing process.
Conclusion

"Quality control truly begins and ends with education",

Lecture Finished

Any Question?

Yes

Ask questions

Teachers answers

Train your self (Google, YouTube, course webpage)

End

(See you next lecture)