INTERPRETATION OF CONTROL CHARTS

Variation

◆ Chance or Common Causes of Variation
  – natural or inherent variation caused by the cumulative of variation within the process

◆ Assignable or Special Causes of Variation
  – may be assigned to particular causes such as machining problems, operator errors or defective material etc

Control Charts

◆ When a process only exhibits chance causes of variation it is said to be in statistical control

◆ The variables control chart was developed by Shewhart to monitor the ongoing process for variation and to separate and identify assignable and chance causes of variation
Interpretation of Control Charts

- It is essential to be able to interpret out of control characteristics in control charts such as runs, jumps, cyclical behaviour and associate these directly with their causes within the manufacturing process.

- Delayed or incorrect actions at this stage could cause significant effects on the quality of the output.

The Quality Loop

Out of Control Conditions

- Freaks
- Runs
- Trends
- Jumps
- Stratifications
- Mixtures
- Cycles
Out of Control Conditions

**Freaks**
Points outside the upper and lower control limits

**Runs**
A succession of points (7 or more) one side of the centre line

**Jumps**
A large sudden change between two successive points  
2/3 of UCL and LCL on 2 consecutive points

**Trends**
A succession of points (7 or more) either increasing or decreasing

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Out of Control Conditions

**Stratifications**
Successive points lying very close the mean line  
more than 90% between 1/3 UCL and 1/3 LCL

**Mixtures**
Points falling near to the upper and lower control limits  
less than 40% between 1/3 UCL and 1/3 LCL

**Cycles**
Short trends that occur in repeated patterns

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Out of Control Situations

- Process
- Materials
- Machine / Equipment
- Environment
- Operator
- Inspection
Possible Causes X Charts - Freaks

**Process**
A process carried out before the machine has stabilized may cause large process dispersion in the output mean.

**Material**
Sudden changes in materials or parts. Changes in material dimensions may cause increase/decrease in output mean.

**Machine Equipment**
Tool breakage etc or changeouts may change process mean.

**Operator**
New or inexperienced operator mistakes may cause sudden changes in process mean.

Possible Remedies X Charts - Freaks

**Process**
Give machine sufficient time to stabilize as it starts up, stop production when the machine is being shut down.

**Material**
Take precautions against changes in dimensional changes etc.

**Machine / Equipment**
Check for chipped off/breakage of tool or die changeouts. Adjust process setting accordingly.

**Operator**
Train operator etc. Proper guidance and motivation should be given to help avoiding mistakes.

Statistical Process Control

- One of the principle features of SPC is prevention of defective output using a feedback mechanism, where the results of SQC techniques are interpreted, so that action on the process may lead to an improvement in quality.

- Effective SPC requires the feedback mechanism to be both reliable and rapid.
After all special causes have been corrected and the process is running in statistical control, the process capability can be assessed. If the variation from common causes is excessive, the process cannot produce output that consistently meets customer needs. The process itself must be investigated, and management action must be taken to improve the system.

**Process Capability**

- Process Capability Indices provide a measure of process capability in terms of a numerical index

\[
Cp = \frac{\text{Specified Tolerance}}{\text{Process Spread (6}\sigma)}
\]

- Based on assumption of normality
The main problem with using $C_p$ is that it only takes into account process spread and ignores the process centring. For this reason the $C_{pk}$ value is used in preference to $C_p$.

$$C_{pk} = \frac{Z_{min}}{3}$$

where $Z_{min}$ equals the minimum value of

$$Z_{usl} = \frac{USL - m}{s} \quad \text{and} \quad Z_{lsl} = \frac{m - LSL}{s}$$

$C_{pk}$ therefore relates the scaled distance between the process mean ($m$) and the closest specification limit. Usually the minimum acceptable value for $C_{pk}$ is 1.33.

**PROCESS NOT CAPABLE ($C_{pk} < 1$)**

**PROCESS JUST CAPABLE ($C_{pk} = 1$)**
PROCESS CAPABLE \((Cpk > 1)\)

- Lower specification limit
- Upper specification limit
- Mean
- \(3\sigma\)

Common Values of Cpk

- \(Cpk = 1\) \(\sigma\) limits
  - 99.73% of the distribution lies between \(+3\sigma\)
  - 1 part in 370 defective, \(2700 / \text{million}\)

- \(Cpk = 2\) \(6\sigma\) limits
  - 99.994% of the distribution lies between \(+4\sigma\)
  - 1 part in 16,667 defective, \(60 / \text{million}\)

Off Centre Processes

- Generally if \(Cp = Cpk\), the process is centred at the midpoint of the specifications, and when \(Cpk < Cp\) the process is off-centre.

- The magnitude of \(Cpk\) relative to \(Cp\) is a direct measure of how off-centre the process is operating.
Attribute Data

Results from comparing the process outcome to an acceptance specifications and deciding if it conforms or doesn’t conform:

Outcome is classified:

Conforms: “accept”
Doesn’t conform: “reject”

Attribute Data Examples

- vehicle does not leak
- lamp lights/ does not light
- hole diameter undersized or oversized
- shipment to dealer correct or incorrect
- bubbles in windshield
- paint imperfections
- errors in invoice

example of defective identification in an attribute quality characterisation situation (engine valve seat blank)
Cracks = 3
Holes = 6
Flash = 1
Gate Breakout = 1

Attribute Control Charts

- There are four types of attribute control chart:
  - Control Chart for Fraction of Defective Items (p chart)
  - Control Chart for Number of Defective Items (np chart)
  - Control Chart for Number of Defects per Unit (u chart)
  - Control Chart for Number of Defects per Sample (c chart)
Attribute Control Charts

- The $p$ chart (varied sample size - defective)
- The $np$ chart (constant sample size defective)
- The $u$ chart (varied sample size - defects)
- The $c$ chart (constant sample size defects)

Attribute Data Examples

<table>
<thead>
<tr>
<th>Vehicle does not leak</th>
<th>$p$ chart or $np$ chart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp lights/ does not light</td>
<td></td>
</tr>
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<td>Errors in invoice</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>NUMBER</th>
<th>nonconforming units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple but needs constant sample size</td>
<td>$np$</td>
</tr>
<tr>
<td>PROPORTION</td>
<td>nonconformities</td>
</tr>
<tr>
<td>More complex, but adjusts to understandable proportion and copes varying sample sizes</td>
<td>$c$</td>
</tr>
<tr>
<td></td>
<td>$p$</td>
</tr>
<tr>
<td></td>
<td>$u$</td>
</tr>
</tbody>
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Selection of Attribute Control Chart

1. Is the item a defect rather than a defective unit?
   - Yes
   - No

2. Is the sample size constant?
   - Yes
   - No

- Use p chart
- Use np chart
- Use u chart
- Use c chart

Control Chart for Fraction Defective (p chart) (Variable Sample Size)

Control Chart for Number of Defectives (np chart)
IMPLEMENTING CONTROL CHARTS

Guidelines for Implementing Control Charts

- Choose the proper type of control chart
- Determine which process to control
- Determine where the charts should be implemented
- Take actions to improve the process as a result of the SPC

Choosing the Proper Variable Chart

- A new process, or a new product
- The process is in trouble
- Destructive testing is required
- Reducing acceptance sampling
- Attribute Charts have been unsuccessful
- Very tight tolerances
- Decisions on whether to adjust process
- Change in product specification is desired
- Proc. capability must be continually demonstrated
Choosing the Proper Attribute Chart

- Operators control assignable causes and it is necessary to reduce defects
- Process is a complex assembly operation. Quality is measured in terms of product function
- Process control is necessary but measurement data cannot be obtained
- Historical summary of process performance is required

Determining Which Characteristics to Control and where to put Charts

- In the beginning anywhere believed important
- Charts then removed/added
- Keep information on number & type of chart
- Use of variable charts should increase, attribute charts decrease
- Earlier that control can be established, the better
- Ensure charts are on-line

Actions Taken to Improve a Process

<table>
<thead>
<tr>
<th>Is the Process in Control?</th>
<th>Is the Process capable?</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SPC</td>
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<td>SPC Experimental Design</td>
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Control Charts for Individuals

- Inconvenient or impossible to obtain more than one measurement per sample (or repeat measurements will differ)
- Automated testing and inspection technology used allowing measurement of every unit produced
- Waiting for large amounts of data may be impractical

ADVANCED CHARTING TECHNIQUES

CUSUM CHARTS

- Primary used to maintain control over ongoing process
- Better than standard charts in picking up small shifts in process mean
- Easier to determine point at which shift occurred
- Cumulative sum plotted rather than individual values
Moving Average Charts

- Similar in construction to standard charts except moving average is plotted.
- Useful when:
  - group size is limited,
  - true mean changes slowly,
  - process spread is stable

Exponentially Weighted Moving-Average Charts (EWMA)

- New moving average plotted by forming exponentially weighted of the new value and the previous moving average
- Useful for:
  - one at a time data
  - greater precision is needed to detect small changes

COMMON MISTAKES

WHEN VARIATION IS NOT UNDERSTOOD
### TWO COMMON MISTAKES

- **Mistaking a common cause of variation for a special cause**
  - This is illustrated by Deming through the funnel experiment where he shows four different rules - if there are only special causes acting on a system and there is a state of control then the best thing to do is leave the system alone - ie meddling will only increase variation.

- **Failing to identify special causes of variation**
  - This will occur if the control chart is not interpreted properly for example if runs or trends etc are not identified or if the wrong control chart is used in the wrong situation - eg X-R chart is used when the central limit theorem does not apply for example when taking individual measurements. Advanced charting techniques such as CUSUM or EWMA charts should be used.

### ACCEPTANCE SAMPLING

Acceptance Sampling is the process of evaluating a portion of the product in a lot (ie a population) for the purpose of accepting or rejecting the entire lot of either conforming or not conforming to a quality specification.
**Sampling Plans**

A sampling plan is characterized by the lot size \( N \), the sample size \( n \) and the acceptance number, \( c \).

For example, the sampling plan
\[
N = 1000 \quad n = 125 \quad c = 2
\]
implies that 125 units from a lot of 1000 are inspected. If more than 2 units are nonconforming the lot is rejected.

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**A Single Sampling Plan**

- Lot Size = \( N \)
- Random Sample of Size \( n \)
- Number of defectives = \( d \)

\[
d \leq n \quad d > c
\]

- Accept Lot
- Reject Lot

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**Operating Characteristic Curve**

The Operating Characteristic (OC) Curve measures the performance of an acceptance plan. The curve plots the probability of acceptance against the lot fraction defective. Thus the OC curve displays the discriminatory power of the sampling plan.

The OC Curve can be used to assess other characteristics of a sampling plan such as average outgoing quality, consumers risk and producers risk.
Three Aspects of Sampling

- It is the purpose of acceptance sampling to sentence lots, not to estimate lot quality.

- Acceptance sampling plans do not any direct form of quality control. Acceptance Sampling simply accepts or rejects lots. Process controls are used to control and systematically improve quality, but acceptance sampling does not.

- The most effective use of acceptance sampling is not to “inspect quality into the product” but rather as an audit tool to ensure that the output of the process conforms to requirements.

Three Approaches to Lot Sampling

- Acceptance with no inspection - used when vendors process is “guaranteed” or when it is not economically justifiable.

- 100% Inspection - used when component is extremely critical or when vendors process capability is inadequate.

- Acceptance Sampling is used in situations when:
Testing is destructive

- cost of 100% inspection is very high
- 100% inspection is not technologically feasible or very time consuming
- There are many items and there is a high rate of inspection error
- The vendor has an excellent quality record and a reduction from 100% inspection is desired

Advantages of Acceptance Sampling

- Less expensive and time consuming than 100% inspection
- Reduced chance of damage due to less handling of product
- Applicable to destructive testing
- Fewer personnel involved
- Greatly reduces inspection error
- Rejection of entire lots often provides stronger motivation to the vendor for quality improvements

Disadvantages of Acceptance Sampling

- There is a risk of accepting “bad” lots and rejecting “good” lots
- Less information is usually generated about the product or about the process that manufactured the product
- Acceptance sampling requires planning and documentation of the acceptance sampling procedure whereas 100% inspection does not
....some manufacturers have persuaded their suppliers to install a management tool called statistical process control. Managers and engineers set standards for the quality of the parts or materials, such as the minimum and maximum width of steel sheet. Then products are tested as they are made; when the quality varies too much the process is corrected. That sounds like common sense, but engineers say the mix of computers, statistics and immediate information lets the companies catch the problems as they occur.

Wall Street Journal 1983

The importance of quality in component parts and raw materials has caused many manufacturing organizations to exert considerable pressure on their vendors and suppliers to improve their quality.

The proper use of acceptance sampling plans is an integral part of this activity.

However, quality must be built into the product.

We must rely more on adequate process controls at the vendor level to ensure quality, and use of acceptance sampling as an audit or compliance tool not as a technique for attempting to inspect quality into the product or sort good lots form bad ones.

INSPECTION
DEMING'S FOURTEEN POINTS
1. Constancy of Purpose
2. The New Philosophy
3. Cease Dependence on Inspection
4. End “lowest Tender” Contracts
5. Improve Every Process
6. Institute Training On The Job
7. Institute Leadership
8. Drive Out Fear
9. Break Down Barriers
10. Eliminate Exhortations
11. Eliminate Targets
12. Permit Pride of Workmanship
13. Encourage Education
14. Top Management's Commitment

3. Cease Dependence on Inspection

Eliminate the need for mass inspection as a way to achieve quality.

......by building quality into the product in the first place. Require statistical evidence of built in quality in both manufacturing and purchasing functions

When and Where to Inspect

Inspection depends on the type of process and the value added at each stage. It can take place:

- At the suppliers plant
- On the receipt of goods
- Before costly or irreversible process
- During step by step production process
- When production is complete
- Before shipment

Pareto analysis, Process Flow Charts, Cause and Effect Diagrams etc are used to aid “when and where decision”
Source Inspection

Consistent with the concept of employee empowerment, individual employees self check their work and that of the employees preceding them. This type of “source” inspection may be assisted by the use of controls such as a fail safe device called poka-yoke.

A poka-yoke is a foolproof device or technique that ensures production of good units every time. The idea is to treat the next step in the process as the customer ensuring delivery of a good product to the next “customer”.