The various definitions of quality
- The transcendent approach views quality as synonymous with innate excellence.
- The manufacturing-based approach assumes quality is all about making or providing error-free products or services.
- The user-based approach assumes quality is all about providing products or services that are fit for their purpose.
- The product-based approach views quality as a precise and measurable set of characteristics.
- The value-based approach defines quality in terms of “value”.

Defining Quality in Service
- It is the degree to which the bundle of service attributes as a whole satisfies the user. This is called the expectations-to-perception match.
Attributes of Service Quality

- Reliability
- Responsiveness
- Competence
- Access
- Courtesy
- Communication
- Credibility
- Security
- Understanding/knowing the customer
- Tangibles

The perception-expectation gap

<table>
<thead>
<tr>
<th>Gap</th>
<th>Action required to ensure high perceived quality</th>
<th>Main organizational responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap 1</td>
<td>Ensure consistency between internal quality specification and the expectations of customers.</td>
<td>Marketing, operations, product/service development</td>
</tr>
<tr>
<td>Gap 2</td>
<td>Ensure internal specification meets its intended concept of design.</td>
<td>Marketing, operations, product/service development</td>
</tr>
<tr>
<td>Gap 3</td>
<td>Ensure actual product or service conforms to its internally specified quality level.</td>
<td>Operations</td>
</tr>
<tr>
<td>Gap 4</td>
<td>Ensure that promises made to customers concerning the product or service can really be delivered.</td>
<td>Marketing</td>
</tr>
</tbody>
</table>

Defining Product Quality

- Product quality is often defined as grade, fitness for purpose and consistency.
- Grade classifies some major characteristics making up the product into groupings such as high, medium or low or 1, 2, 3 and so on.
- Fitness for purpose is the degree to which the service satisfies the user.
- Consistency refers to a lack of variability in the service provided.

Quality characteristics of goods and services

- Functionality - how well the product or service does the job for which it was intended.
- Appearance - aesthetic appeal, look, feel, sound and smell of the product or service.
- Reliability - consistency of product or services performance over time.
- Durability - the total useful life of the product or service.
- Recovery - the ease with which problems with the product or service can be rectified or resolved.
- Contact - the nature of the person-to-person contacts that take place.
Statistical Quality Control (SQC)

The application of statistical techniques to control quality. Often the term statistical process control is used interchangeably with statistical quality control, although statistical quality control includes acceptance sampling as well as statistical process control.

Statistical Process Control (SPC)

The application of statistical techniques to monitor and adjust an operation.

Statistical Quality Control (SQC)

- Measures performance of a process
- Uses mathematics (i.e. statistics)
- Involves collecting, organizing, & interpreting data
- Objective: provide statistics when assignable causes of variation are present
- Used to
  - Control the process as products are produced
  - Inspect samples of finished products

The Process in SQC
Routes in SQC

Statistical Quality Control

Process Control

Acceptance Sampling

Variables Charts

Attributes Charts

Variables

Attributes

Quality Characteristics

Variables

- Characteristics that you measure, e.g., weight, length
- May be in whole or in fractional numbers
- Continuous random variables

Attributes

- Characteristics for which you focus on defects
- Classify products as either ‘good’ or ‘bad’, or count # defects
  - e.g., radio works or not
- Categorical or discrete random variables

Statistical Process Control (SPC)

- Statistical technique used to ensure process is making product to standard
- All process are subject to variability
  - Natural causes: Random variations
  - Assignable causes: Correctable problems
    - Machine wear, unskilled workers, poor material
- Objective: Identify assignable causes
- Uses process control charts

Process Control:
Three Types of Process Outputs

(a) In control and capable of producing within control limits. A process with only natural causes of variation and capable of producing within the specified control limits.

(b) In statistical control, but not capable of producing within control limits. A process with only natural causes of variation and capable of producing within the specified control limits.

(c) Out of control. A process out of control having assignable causes of variation.
The Relationship Between Population and Sampling Distributions

Three population distributions:
- Beta
- Uniform
- Normal

Distribution of sample means:
- Mean of sample means = \( \mu \)
- Standard deviation of the sample means = \( \sigma / \sqrt{n} \)

- 95.5% of all sample values lie within \( \pm \sigma \)
- 99.7% of all sample values lie within \( \pm 3\sigma \)

Sampling Distribution of Means and Process Distribution

Sampling distribution of the means
Process distribution of the sample

\[ \mu = \bar{X} \]

Process Control Charts

Plot of Sample Data Over Time

Control Chart Purposes

- Show changes in data pattern
  - e.g. trends
  - Make corrections before process is out of control
- Show causes of changes in data
  - Assignable causes
    - Data outside control limits or trend in data
  - Natural causes
    - Random variations around average
Theoretical Basis of Control Charts

Central Limit Theorem

As sample size gets large enough, sampling distribution becomes almost normal regardless of population distribution.

Properties of normal distribution

95.5% of all $\bar{x}$ fall within $\pm 2\sigma_x$

99.7% of all $\bar{x}$ fall within $\pm 3\sigma_x$

Mean

$\bar{x} = \mu$

Standard deviation

$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$

Control Chart Types

Continuous Numerical Data

Control Charts

Variables Charts

$R$ Chart $\bar{x}$ Chart

Attributes Charts

$P$ Chart $C$ Chart

Categorical or Discrete Numerical Data
Produce Good Service
Take Sample
Inspect Sample
Create Control Chart

Start

Produce Good Service

No

Assign Causes?

Yes

Stop Process

Find Out Why

Statistical Process Control Steps

• Type of variables control chart
  – Interval or ratio scaled numerical data
• Shows sample means over time
• Monitors process average
• Example: Weigh samples of coffee & compute means of samples; Plot

$\bar{x}$ Chart

Factors for Computing Control Chart Limits

<table>
<thead>
<tr>
<th>Sample Size, n</th>
<th>Mean Factor, $A_2$</th>
<th>Upper Range, $D_4$</th>
<th>Lower Range, $D_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.880</td>
<td>3.268</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1.023</td>
<td>2.574</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0.729</td>
<td>2.282</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0.577</td>
<td>2.115</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0.483</td>
<td>2.004</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0.419</td>
<td>1.924</td>
<td>0.076</td>
</tr>
<tr>
<td>8</td>
<td>0.373</td>
<td>1.864</td>
<td>0.136</td>
</tr>
<tr>
<td>9</td>
<td>0.337</td>
<td>1.816</td>
<td>0.184</td>
</tr>
<tr>
<td>10</td>
<td>0.308</td>
<td>1.777</td>
<td>0.223</td>
</tr>
</tbody>
</table>
**R Chart**

- Type of variables control chart
  - Interval or ratio scaled numerical data
- Shows sample ranges over time
  - Difference between smallest & largest values in inspection sample
- Monitors variability in process
- Example: Weigh samples of coffee & compute ranges of samples; Plot

**R Chart Control Limits**

\[
\begin{align*}
UCL_R &= D_4 \bar{R} \\
LCL_R &= D_3 \bar{R}
\end{align*}
\]

\[\bar{R} = \frac{\sum_{i=1}^{n} R_i}{n}\]

**Example**

Plot a Mean chart and an R chart for the following tread wear data. Comment the quality level and what action should be taken.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Tread Wear</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>37</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>55</td>
</tr>
<tr>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>43</td>
</tr>
<tr>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
</tr>
</tbody>
</table>

**Steps to Follow When Using Control Charts**

- Collect 20 to 25 samples of \( n=4 \) or \( n=5 \) each from a stable process and compute the mean.
- Compute the overall means, set approximate control limits, and calculate the preliminary upper and lower control limits. If the process is not currently stable, use the desired mean instead of the overall mean to calculate limits.
- Graph the sample means and ranges on their respective control charts and determine whether they fall outside the acceptable limits.
Steps to Follow When Using Control Charts - continued

- Investigate points or patterns that indicate the process is out of control. Assign causes for the variations.
- Collect additional samples and revalidate the control limits.

Which Charts to use?

- **Type of attributes control chart**
  - Nominally scaled categorical data
  - e.g. good-bad
  - Shows % of nonconforming items
- Example: Count # defective chairs & divide by total chairs inspected; Plot
  - Chair is either defective or not defective

\[ \text{p Chart} \]

- Type of attributes control chart
  - Nominally scaled categorical data
  - e.g. good-bad
  - Shows % of nonconforming items
- Example: Count # defective chairs & divide by total chairs inspected; Plot
  - Chair is either defective or not defective

\[ p \text{ Chart} \]

\[ \begin{align*}
\text{p Chart} \\
\text{Control Limits} \\
\text{UCL}_p &= \bar{p} + z \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \\
\text{LCL}_p &= \bar{p} - z \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \\
\bar{p} &= \frac{\sum_{i=1}^{k} \bar{p}_i}{k} \quad \text{and} \quad \bar{p}_i = \frac{\sum_{j=1}^{n_i} x_j}{n_i} \\
\text{Size of each sample} \\
\text{No. of sample} \\
\text{Total Size of sample i} \\
\text{z = 2 for 95.5% limits; z = 3 for 99.7% limits} \\
\end{align*} \]
Example
A sample of 5 commercial websites are selected in a study to examine the error found in using such e-business tool. One hundred visits to each website were carried out. The following table shows the number of errors found in each website. Assume a 99.7% of random variation in the web design when it is in control. Use a p chart to study the proportion of errors made and suggest a possible course of action.

<table>
<thead>
<tr>
<th>Sample No</th>
<th>No. of errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

Solution

Example
A hospital receives several complaints per day regarding their service on timely delivery of meals and medication. Over a week, they received the following numbers of complaints: 5, 7, 2, 8, 8, 13, 10 for a total of 53 complaints. Compute their control limits (using 95.5%).

Solution

\[
UCL = \bar{c} + 3 \sqrt{\bar{c}} \\
LCL = \bar{c} - 3 \sqrt{\bar{c}}
\]
What should we do about these?

Process Capability

The ability of a process to produce parts that conform to (engineering) specifications. Process Capability relates to the inherent variability of a process that is in a state of statistical control.

Process Capability Index $C_{pk}$

$C_{pk} = \min \left\{ \frac{\text{Upper Specification Limit} - \bar{x}}{3\sigma}, \frac{\bar{x} - \text{Lower Specification Limit}}{3\sigma} \right\}$

where $\bar{x}$ = process mean
$\sigma$ = standard deviation of the process population

Assumes that the process is:
- under control
- normally distributed

Meanings of $C_{pk}$ Measures

- $C_{pk}$ = negative number
- $C_{pk}$ = zero
- $C_{pk}$ = between 0 and 1
- $C_{pk}$ = 1
- $C_{pk}$ > 1
What Is Acceptance Sampling?

- Form of quality testing used for incoming materials or finished goods
  - e.g. purchased material & components
- Procedure
  - Take one or more samples at random from a lot (shipment) of items
  - Inspect each of the items in the sample
  - Decide whether to reject the whole lot based on the inspection results

What Is an Acceptance Plan?

- Set of procedures for inspecting incoming materials or finished goods
- Identifies
  - Type of sample
  - Sample size ($n$)
  - Criteria ($c$) used to reject or accept a lot
- Producer (supplier) & consumer (buyer) must negotiate

Operating Characteristics (OC) Curve

- Shows how well a sampling plan discriminates between good & bad lots (shipments)
- Shows the relationship between the probability of accepting a lot & its quality

OC Curve 100% Inspection

- Shows the relationship between the probability of accepting a lot & its quality
**OC Curve with Less than 100% Sampling**

1. **P(Accept Whole Shipment)**
   - Probability is not 100%: Risk of keeping bad shipment or returning good one.

2. **Cut-Off vs. % Defective in Lot**
   - 0% to 100% on the x-axis
   - P(Keep whole shipment) and P(Return whole shipment) on the y-axis

3. **Probability of Acceptance**
   - Bad lots
   - Indifference zone
   - Good lots

**AQL & LTPD**

- **Acceptable Quality Level (AQL)**
  - Is the poorest level of quality we are willing to accept
  - Producer (supplier) does not want lots with fewer defects than AQL rejected
  - For example, if an acceptable quality level is 20 defects in a lot of 1000 parts, then AQL is 20/1000 = 2% defective

- **Lot Tolerance Percent Defective (LTPD)**
  - Is the quality level of a lot we consider bad
  - Consumer (buyer) does not want lots with more defects than LTPD accepted
  - For example, if an unacceptable quality level is 70 defects in a lot of 1000 parts, then the LTPD is 70/1000 = 7% defective

**Producer’s & Consumer’s Risk**

- **Producer’s risk (α)**
  - Probability of rejecting a good lot
  - Probability of rejecting a lot when fraction defective is AQL

- **Consumer’s risk (β)**
  - Probability of accepting a bad lot
  - Probability of accepting a lot when fraction defective is LTPD

**An Operating Characteristic (OC) Curve Showing Risks**

- Probability of Acceptance vs. Defective Rate
- Good lots
- Indifference zone
- LTPD
- Bad lots
- 0.05 producer’s risk for AQL
**OC Curves for Different Sampling Plans**

<table>
<thead>
<tr>
<th>Sampling Plan</th>
<th>n</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 50</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>n = 100</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

**Average Outgoing Quality (AOQ)**

The expected average quality level of outgoing product for a given value of incoming product quality

**Average Outgoing Quality Equation**

\[
AOQ = \frac{(P_d)(P)(N-n)}{N}
\]

Where:
- \( P_d \) = true percent defective of the lot
- \( P_a \) = probability of accepting the lot
- \( N \) = number of items in the lot
- \( n \) = number of items in the sample

**Tool Box**

- Mean Chart
- C Chart
- AQL
- Range Chart
- P Chart
- LTPD
- AOQ
- Cpk
- Service Quality Attributes
- Service Quality Gap Model