Unit 4 Notes By Neha Chhabra

Quality control: Meaning, process control, SQC control charts, single, double and sequential sampling, Introduction to TQM.

QUALITY CONTROL

DEFINITION OF QUALITY:

- The meaning of "Quality" is closely allied to cost and customer needs. "Quality" may simply be defined as fitness for purpose at lowest cost.
  - ✓ The component is said to possess good quality, if it works well in the equipment for which it is meant. Quality is thus defined as fitness for purpose.
- Quality is the 'totality of features and characteristics' both for the products and services that can satisfy both the explicit and implicit needs of the customers.
- "Quality" of any product is regarded as the degree to which it fulfills the requirements of the customer.
- "Quality" means degree of perfection. Quality is not absolute but it can only be judged or realized by comparing with standards. It can be determined by some characteristics namely, design, size, material, chemical composition, mechanical functioning, workmanship, finish and other properties.

MEANING OF CONTROL

Control is a system for measuring and checking (inspecting) a phenomenon. It suggests when to inspect, how often to inspect and how much to inspect. In addition, it incorporates a feedback mechanism which explores the causes of poor quality and takes corrective action.

Control differs from 'inspection', as it ascertains quality characteristics of an item, compares the same with prescribed quality standards and separates defective items from non-defective ones. Inspection, however, does not involve any mechanism to take corrective action.

MEANING OF QUALITY CONTROL

Quality Control is a systematic control of various factors that affect the quality of the product. The various factors include material, tools, machines, type of labour, working conditions, measuring instruments, etc.

Quality Control can be defined as the entire collection of activities which ensures that the operation will produce the optimum Quality products at minimum cost.

As per A.Y. Feigorbaum Total Quality Control is: "***An effective system for integrating the quality development, Quality maintenance and Quality improvement efforts of the various groups in an***

organization, so as to enable production and services at the most economical levels which allow full customer satisfaction"

In the words of Alford and Beatly, ***"Quality Control" may be broadly defined as that "Industrial management technique means of which products of uniform accepted quality are manufactured." Quality Control is concerned with making things right rather than discovering and rejecting those made wrong.***

In short, we can say that quality control is a technique of management for achieving required standards of products.

FACTORS AFFECTING QUALITY

In addition to **men, materials, machines and manufacturing conditions** there are some other factors which affect the product quality. These are:

- Market Research i.e. indepth into demands of purchaser.
- Money i.e. capability to invest.
- Management i.e. Management policies for quality level.
- Production methods and product design.

Modern quality control begins with an evaluation of the customer's requirements and has a part to play at every stage from goods manufactured right through sales to a customer, who remains satisfied.

OBJECTIVES OF QUALITY CONTROL

- To decide about the standard of quality of a product that is easily acceptable to the customer and at the same time this standard should be economical to maintain.
- To take different measures to improve the standard of quality of product.
- To take various steps to solve any kind of deviations in the quality of the product during manufacturing.

FUNCTIONS OF QUALITY CONTROL DEPARTMENT

- Only the products of uniform and standard quality are allowed to be sold.
- To suggest method and ways to prevent the manufacturing difficulties.
- To reject the defective goods so that the products of poor quality may not reach to the customers.
- To find out the points where the control is breaking down and to investigate the causes of it.
- To correct the rejected goods, if it is possible. This procedure is known as rehabilitation of defective goods.

ADVANTAGES OF QUALITY CONTROL

- Quality of product is improved which in turn increases sales.
- Scrap rejection and rework are minimized thus reducing wastage. So the cost of manufacturing reduces.
- Good quality product improves reputation.
- Inspection cost reduces to a great extent.
- Uniformity in quality can be achieved.
- Improvement in manufacturer and consumer relations.

STATISTICAL QUALITY CONTROL (S.Q.C):

- **Statistics**: Statistics means data, a good amount of data to obtain reliable results. The science of statistics handles this data in order to draw certain conclusions.

- **S.Q.C:** This is a quality control system employing the statistical techniques to control quality by performing inspection, testing and analysis to conclude whether the quality of the product is as per the laid quality standards.

Using statistical techniques, S.Q.C. collects and analyses data in assessing and controlling product quality. The technique of S.Q.C. was though developed in 1924 by Dr.WalterA.Shewartan American scientist; it got recognition in industry only second world war. The technique permits a more fundamental control.

"Statistical quality control can be simply defined as an economic & effective system of maintaining & improving the quality of outputs throughout the whole operating process of specification, production & inspection based on continuous testing with random samples." ***-YA LUN CHOU***

"Statistical quality control should be viewed as a kit of tools which may influence decisions to the functions of specification, production or inspection. ***-EUGENE L. GRANT***

The fundamental basis of S.Q.C. is the theory of probability. According to the theories of probability, the dimensions of the components made on the same machine and in one batch (if measured accurately) vary from component to component. This may be due to inherent machine characteristics or the environmental conditions. The chance or condition that a sample will represent the entire batch or population is developed from the theory of probability.

Relying itself on the probability theory, S.Q.C. evaluates batch quality and controls the quality of processes and products. S.Q.C. uses three scientific techniques, namely;

- Sampling inspection
- Analysis of the data, and
- Control charting

ADVANTAGES OF S.Q.C

S.Q.C is one of the tool for scientific management, and has following main advantages over 100 percent inspection:

- **Reduction in cost:** Since only a fractional output is inspected, hence cost of inspection is greatly reduced.
- **Greater efficiency:** It requires lesser time and boredom as compared to the 100 percent inspection and hence the efficiency increases.
- **Easy to apply:** Once the S.Q.C plan is established, it is easy to apply even by man who does not have extensive specialized training.
- **Accurate prediction**: Specifications can easily be predicted for the future, which is not possible even with 100 percent inspection.
- **Can be used where inspection is needs destruction of items:** In cases where destruction of product is necessary for inspecting it, 100 percent inspection is not possible (which will spoil all the products), sampling inspection is resorted to.
- **Early detection of faults:** The moment a sample point falls outside the control limits, it is taken as a danger signal and necessary corrective measures are taken. Whereas in 100 percent inspection, unwanted variations in quality may be detected after large number of defective items have already been produced. Thus by using the control charts, we can know from graphic picture that how the production is proceeding and where corrective action is required and where it is not required.

PROCESS CONTROL

Under this the quality of the products is controlled while the products are in the process of production.

The process control is secured with the technique of control charts. Control charts are also used in the field of advertising, packing etc. They ensure that whether the products confirm to the specified quality standard or not.

Process Control consists of the systems and tools used to ensure that processes are well defined, performed correctly, and maintained so that the completed product conforms to established requirements. Process Control is an essential element of managing risk to ensure the safety and reliability of the Space Shuttle Program. It is recognized that strict process control practices will aid in the prevention of process escapes that may result in or contribute to in-flight anomalies, mishaps, incidents and non-conformances.

The five elements of a process are:

- People – skilled individuals who understand the importance of process and change control
- Methods/Instructions – documented techniques used to define and perform a process
- Equipment – tools, fixtures, facilities required to make products that meet requirements
- Material – both product and process materials used to manufacture and test products
- Environment – environmental conditions required to properly manufacture and test products

PROCESS CONTROL SYSTEMS FORMS

Process control systems can be characterized as one or more of the following forms:

- **Discrete** – Found in many manufacturing, motion and packaging applications. Robotic assembly, such as that found in automotive production, can be characterized as discrete process control. Most discrete manufacturing involves the production of discrete pieces of product, such as metal stamping.
- **Batch** – Some applications require that specific quantities of raw materials be combined in specific ways for particular durations to produce an intermediate or end result. One example is the production of adhesives and glues, which normally require the mixing of raw materials in a heated vessel for a period of time to form a quantity of end product. Other important examples are the production of food, beverages and medicine. Batch processes are generally used to produce a relatively low to intermediate quantity of product per year (a few pounds to millions of pounds).
- **Continuous** – Often, a physical system is represented through variables that are smooth and uninterrupted in time. The control of the water temperature in a heating jacket, for example, is an example of continuous process control. Some important continuous processes are the production of fuels, chemicals and plastics. Continuous processes in manufacturing are used to produce very large quantities of product per year (millions to billions of pounds).

STATISTICAL PROCESS CONTROL (SPC)

SPC is an effective method of monitoring a process through the use of control charts. Much of its power lies in the ability to monitor both process center and its variation about that center. By collecting data from samples at various points within the process, variations in the process that may affect the quality of the end product or service can be detected and corrected, thus reducing waste as well as the likelihood that problems will be passed on to the customer. It has an emphasis on early detection and prevention of problems.

CONTROL CHARTS

Since variations in manufacturing process are unavoidable, the control chart tells when to leave a process alone and thus prevent unnecessary frequent adjustments. Control charts are graphical representation and are based on statistical sampling theory, according to which an adequate sized random sample is drawn from each lot. Control charts detect variations in the processing and warn if there is any departure from the specified tolerance limits. These control charts immediately tell the undesired variations and help in detecting the cause and its removal.

In control charts, where both upper and lower values are specified for a quality characteristic, as soon as some products show variation outside the tolerances, a review of situation is taken and corrective step is immediately taken.

If analysis of the control chart indicates that the process is currently under control (i.e. is stable, with variation only coming from sources common to the process) then data from the process can be used to predict the future performance of the process. If the chart indicates that the process being monitored is not in control, analysis of the chart can help determine the sources of variation, which can then be eliminated to bring the process back into control. A control chart is a specific kind of run chart that allows significant change to be differentiated from the natural variability of the process.

The control chart can be seen as part of an objective and disciplined approach that enables correct decisions regarding control of the process, including whether or not to change process control parameters. Process parameters should never be adjusted for a process that is in control, as this will result in degraded process performance.

In other words, control chart is:

- A device which specifies the state of statistical control,
- A device for attaining statistical control,
- A device to judge whether statistical control has been attained or not.

PURPOSE AND ADVANTAGES:

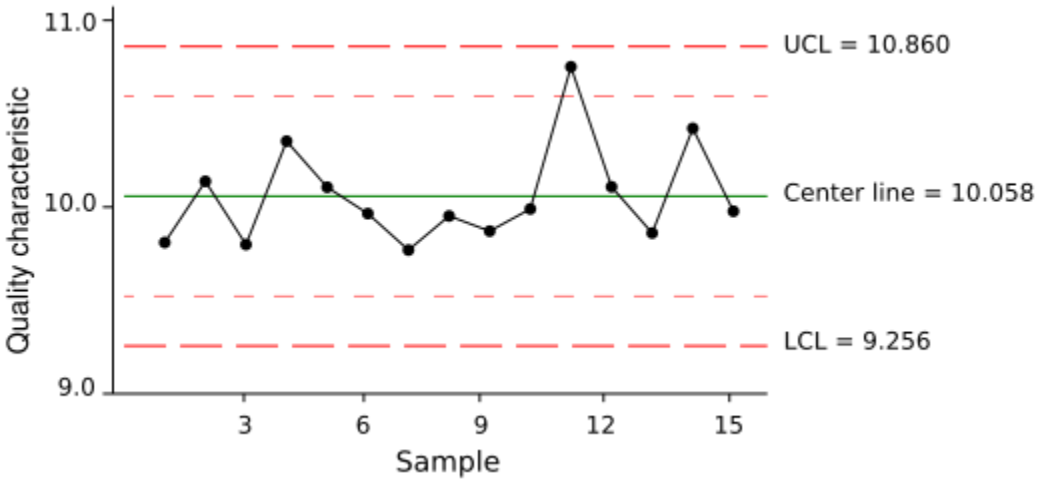
1. A control charts indicates whether the process is in control or out of control.
2. It determines process variability and detects unusual variations taking place in a process.
3. It ensures product quality level.
4. It warns in time, and if the process is rectified at that time, scrap or percentage rejection can be reduced.
5. It provides information about the selection of process and setting of tolerance limits.
6. Control charts build up the reputation of the organization through customer's satisfaction.

A control chart consists of:

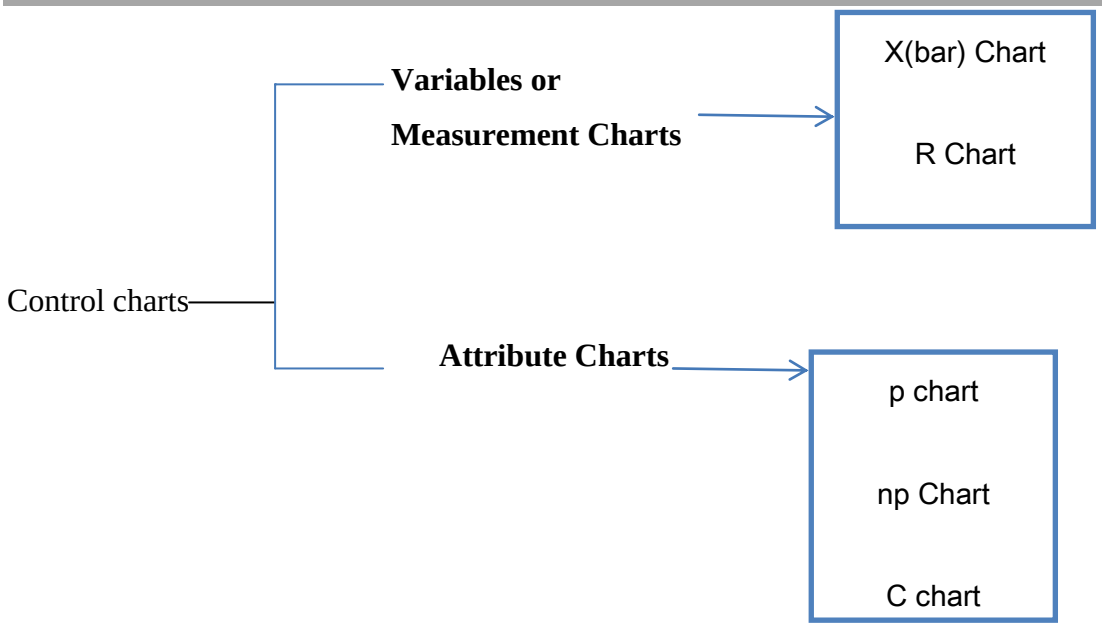
- Points representing a statistic (e.g., a mean, range, proportion) of measurements of a quality characteristic in samples taken from the process at different times [the data]
- The mean of this statistic using all the samples is calculated (e.g., the mean of the means, mean of the ranges, mean of the proportions)
- A center line is drawn at the value of the mean of the statistic
- The standard error (e.g., standard deviation/sqrt(n) for the mean) of the statistic is also calculated using all the samples
- Upper and lower control limits (sometimes called "natural process limits") that indicate the threshold at which the process output is considered statistically 'unlikely' are drawn typically at 3 standard errors from the center line

The chart may have other optional features, including:

- Upper and lower warning limits, drawn as separate lines, typically two standard errors above and below the center line
- Division into zones, with the addition of rules governing frequencies of observations in each zone
- Annotation with events of interest, as determined by the Quality Engineer in charge of the process's quality



TYPES OF CONTROL CHARTS



Control charts can be used to measure any characteristic of a product, such as the weight of a cereal box, the number of chocolates in a box, or the volume of bottled water. The different characteristics that can be measured by control charts can be divided into two groups: **variables** and **attributes.**

- A ***control chart for variables*** is used to monitor characteristics that can be measured and have a continuum of values, such as height, weight, or volume. A soft drink bottling operation is an example of a variable measure, since the amount of liquid in the bottles is measured and can take on a number of different values. Other examples are the weight of a bag of sugar, the temperature of a baking oven, or the diameter of plastic tubing.
- A ***control chart for attributes***, on the other hand, is used to monitor characteristics that have discrete values and can be counted. Often they can be evaluated with a simple yes or no decision. Examples include color, taste, or smell. The monitoring of attributes usually takes less time than that of variables because a variable needs to be measured (e.g., the bottle of soft drink contains 15.9 ounces of liquid). An attribute requires only a single decision, such as yes or no, good or bad, acceptable or unacceptable (e.g., the apple is good or rotten, the meat is good or stale, the shoes have a defect or do not have a defect, the lightbulb works or it does not work) or counting the number of defects (e.g., the number of broken cookies in the box, the number of dents in the car, the number of barnacles on the bottom of a boat).

CONTROL CHARTS FOR VARIABLES VS. CHARTS FOR ATTRIBUTES

A comparison of variable control charts and attribute control charts are given below:

- Variables charts involve the measurement of the job dimensions and an item is accepted or rejected if its dimensions are within or beyond the fixed tolerance limits; whereas as attribute chart only

differentiates between a defective item and a non-defective item without going into the measurement of its dimensions.

- Variables charts are more detailed and contain more information as compared to attribute charts.
- Attribute charts, being based upon go and no go data (which is less effective as compared to measured values) require comparatively bigger sample size.
- Variables charts are relatively expensive because of the greater cost of collecting measured data.
- Attribute charts are the only way to control quality in those cases where measurement of quality characteristics is either not possible or it is very complicated and costly to do so—as in the case of checking colour or finish of a product, or determining whether a casting contains cracks or not. In such cases the answer is either yes or no.

ADVANTAGES OF ATTRIBUTE CONTROL CHARTS

Attribute control charts have the advantage of allowing for quick summaries of various aspects of the quality of a product, that is, the engineer may simply classify products as acceptable or unacceptable, based on various quality criteria. Thus, attribute charts sometimes bypass the need for expensive, precise devices and time-consuming measurement procedures. Also, this type of chart tends to be more easily understood by managers unfamiliar with quality control procedures; therefore, it may provide more persuasive (to management) evidence of quality problems.

ADVANTAGES OF VARIABLE CONTROL CHARTS

Variable control charts are more sensitive than attribute control charts. Therefore, variable control charts may alert us to quality problems before any actual "unacceptables" (as detected by the attribute chart) will occur. Montgomery (1985) calls the variable control charts *leading indicators* of trouble that will sound an alarm before the number of rejects (scrap) increases in the production process.

COMMONLY USED CHARTS

1. (X-Bar) and R charts, for process control.
2. P chart, for analysis of fraction defectives
3. C chart, for control of number of defects per unit.

- **Mean (x-Bar) ($\bar{x}$) Charts**

A mean control chart is often referred to as an ***x-bar chart.*** It is used to monitor changes in the mean of a process. To construct a mean chart we first need to construct the center line of the chart. To do this we take multiple samples and compute their means. Usually these samples are small, with about four or five

observations. Each sample has its own mean. The center line of the chart is then computed as the mean of all sample means, where _ is the number of samples:

1. It shows changes in process average and is affected by changes in process variability.
2. It is a chart for the measure of central tendency.
3. It shows erratic or cyclic shifts in the process.
4. It detects steady progress changes, like tool wear.
5. It is the most commonly used variables chart.
6. When used along with R chart:
    a. It tells when to leave the process alone and when to chase and go for the causes leading to variation;
    b. It secures information in establishing or modifying processes, specifications or inspection procedures;
    c. It controls the quality of incoming material.
7. X-Bar and R charts when used together form a powerful instrument for diagnosing quality problems.

- **Range (R) charts**

These are another type of control chart for variables. Whereas x-bar charts measure shift in the central tendency of the process, range charts monitor the dispersion or variability of the process. The method for developing and using R-charts are the same as that for x-bar charts. The center line of the control chart is the average range, and the upper and lower control limits are computed. The R chart is used to monitor process variability when sample sizes are small (n<10), or to simplify the calculations made by process operators. This chart is called the R chart because the statistic being plotted is the sample range.

1. It controls general variability of the process and is affected by changes in process variability.
2. It is a chart for measure of spread.
3. It is generally used along with X-bar chart.

- **Plotting of $\bar{X}$ and R charts:**

A number of samples of component coming out of the process are taken over a period of time. Each sample must be taken at random and the size of sample is generally kept as 5 but 10 to15 units can be taken for sensitive control charts. For each sample, the average value $\bar{X}$of all the measurements and the range R are calculated. The grand average $\overline{\overline{X}}$ (equal to the average value of all the average $\bar{X}$) and $\bar{R}$ ($\bar{R}$ is equal to the average of all the ranges R) are found and from these we can calculate the control limits for the $\bar{X}$ and R charts. Therefore,

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \cdots + \bar{x}_m}{m}$$

$$\bar{R} = \frac{R_1 + R_2 + \cdots + R_m}{m}$$

Variables Data ($\bar{x}$ and R Control Charts)

$\bar{x}$ Control Chart

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

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

CL = $\bar{\bar{x}}$

R Control Chart

UCL = $\bar{R}\,D_4$

LCL = $\bar{R}\,D_3$

CL = $\bar{R}$

Here the factors A_2, D_4 and D_3 depend on the number of units per sample. Larger the number, the close the limits. The value of the factors A_2, D_4 and D_3 can be obtained from S.Q.C tables. However for ready reference these are given below in tabular form:

n	A_2	D_3	D_4	d_2
2	1.880	0.000	3.267	1.128
3	1.023	0.000	2.574	1.693
4	0.729	0.000	2.282	2.059
5	0.577	0.000	2.114	2.326
6	0.483	0.000	2.004	2.534
7	0.419	0.076	1.924	2.704
8	0.373	0.136	1.864	2.847
9	0.337	0.184	1.816	2.970
10	0.308	0.223	1.777	3.078

Notation:

n or m= sample size

Example

Piston for automotive engine are produced by a forging process. We wish to establish statistical control of inside diameter of the ring manufactured by this process using *x* and *R* charts.

Twenty-five samples, each of size five, have been taken when we think the process is in control. The inside diameter measurement data from these samples are shown in table.

Sample Number	Observations					$\bar{x}_i$	R_i
1	74.030	74.002	74.019	73.992	74.008	74.010	0.038
2	73.995	73.992	74.001	74.011	74.004	74.001	0.019
3	73.988	74.024	74.021	74.005	74.002	74.008	0.036
4	74.002	73.996	73.993	74.015	74.009	74.003	0.022
5	73.992	74.007	74.015	73.989	74.014	74.003	0.026
6	74.009	73.994	73.997	73.985	73.993	73.996	0.024
7	73.995	74.006	73.994	74.000	74.005	74.000	0.012
8	73.985	74.003	73.993	74.015	73.988	73.997	0.030
9	74.008	73.995	74.009	74.005	74.004	74.004	0.014
10	73.998	74.000	73.990	74.007	73.995	73.998	0.017
11	73.994	73.998	73.994	73.995	73.990	73.994	0.008
12	74.004	74.000	74.007	74.000	73.996	74.001	0.011
13	73.983	74.002	73.998	73.997	74.012	73.998	0.029
14	74.006	73.967	73.994	74.000	73.984	73.990	0.039
15	74.012	74.014	73.998	73.999	74.007	74.006	0.016
16	74.000	73.984	74.005	73.998	73.996	73.997	0.021
17	73.994	74.012	73.986	74.005	74.007	74.001	0.026
18	74.006	74.010	74.018	74.003	74.000	74.007	0.018
19	73.984	74.002	74.003	74.005	73.997	73.998	0.021
20	74.000	74.010	74.013	74.020	74.003	74.009	0.020
21	73.982	74.001	74.015	74.005	73.996	74.000	0.033
22	74.004	73.999	73.990	74.006	74.009	74.002	0.019
23	74.010	73.989	73.990	74.009	74.014	74.002	0.025
24	74.015	74.008	73.993	74.000	74.010	74.005	0.022
25	73.982	73.984	73.995	74.017	74.013	73.998	0.035
						$\Sigma = 1850.028$	0.581
						$\bar{\bar{x}} = 74.001$	$\bar{R} = 0.023$

So,

$$\bar{\bar{X}} = 74.001$$

$$\bar{R} = 0.023$$

From S.Q.C tables (Fig.3) for sample size 5

A_2=0.58, D_4=2.11 and D_3= 0

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

= 74.001+ 0.58(0.023)

= 74.01434

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

= 74.001- 0.58(0.023)

= 73.98766

UCL (R chart) = $D_4\bar{R}$

= 2.11*0.023

= 0.04853

LCL (R chart) = $D_3\bar{R}$

= 0*0.023

= 0

Now $\bar{\bar{X}}$ and R charts are plotted on the plot as shown in Fig.1 and Fig.2

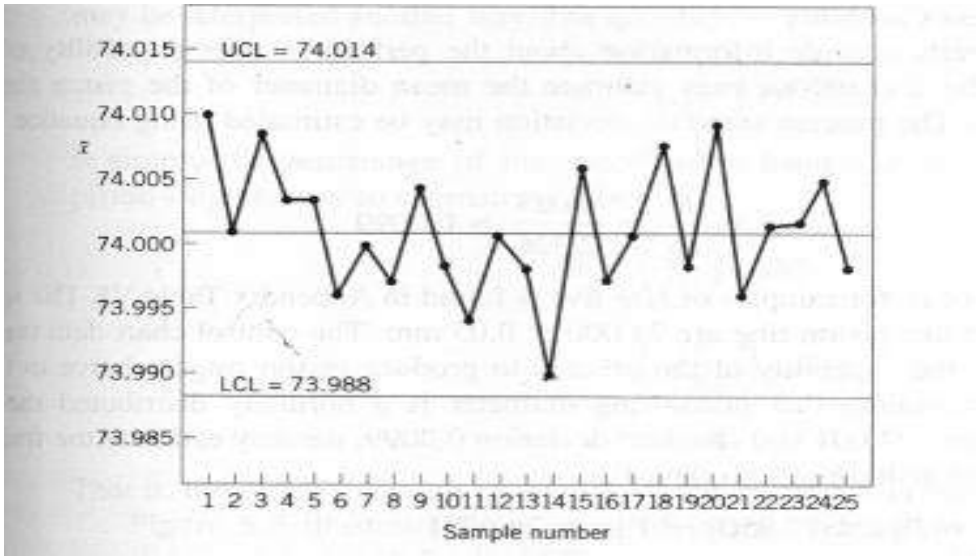


Fig.1: $\bar{X}$ Chart

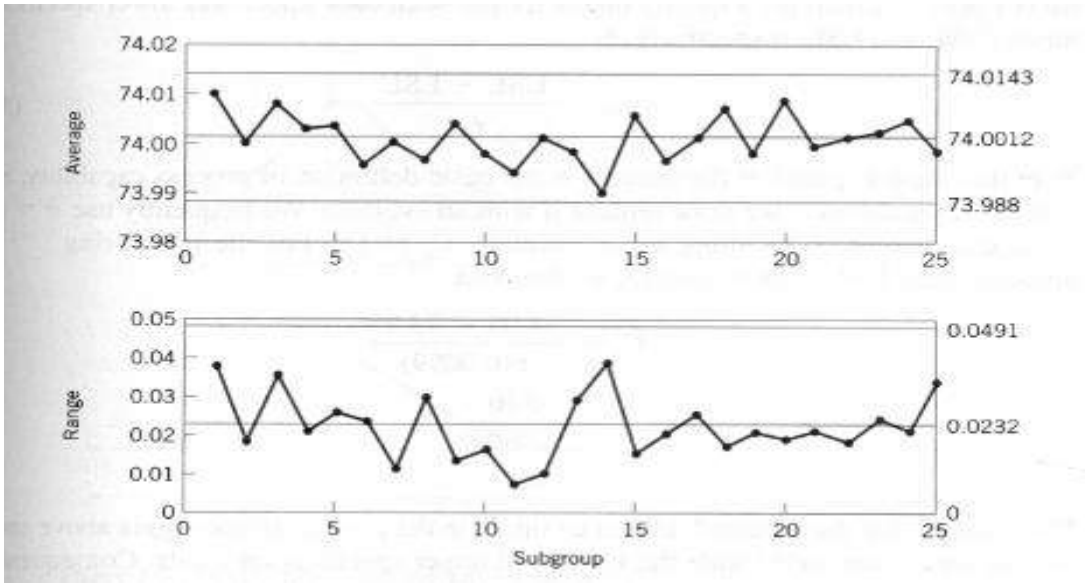


Fig.2: R Chart

Inference:

In the $\bar{X}$ chart, all of the time the plotted points representing average are well within the control limits but if some samples fall outside the control limits then it means something has probably gone wrong or is about to go wrong with the process and a check is needed to prevent the appearance of defective products.

Observations in Sample, n	Chart for Averages: Factors for Control Limits A		A_3	Chart for Standard Deviations: Factors for Center Line c_4	$1/c_4$	Factors for Control Limits B_3	B_4	B_5	B_6	Chart for Ranges: Factors for Center Line d_2	$1/d_2$	Factors for Control Limits d_3	D_1	D_2	D_3	D_4
2	2.121	1.880	2.659	0.7979	1.2533	0	3.267	0	2.606	1.128	0.8865	0.853	0	3.686	0	3.267
3	1.732	1.023	1.954	0.8862	1.1284	0	2.568	0	2.276	1.693	0.5907	0.888	0	4.358	0	2.574
4	1.500	0.729	1.628	0.9213	1.0854	0	2.266	0	2.088	2.059	0.4857	0.880	0	4.698	0	2.282
5	1.342	0.577	1.427	0.9400	1.0638	0	2.089	0	1.964	2.326	0.4299	0.864	0	4.918	0	2.114
6	1.225	0.483	1.287	0.9515	1.0510	0.030	1.970	0.029	1.874	2.534	0.3946	0.848	0	5.078	0	2.004
7	1.134	0.419	1.182	0.9594	1.0423	0.118	1.882	0.113	1.806	2.704	0.3698	0.833	0.204	5.204	0.076	1.924
8	1.061	0.373	1.099	0.9650	1.0363	0.185	1.815	0.179	1.751	2.847	0.3512	0.820	0.388	5.306	0.136	1.864
9	1.000	0.337	1.032	0.9693	1.0317	0.239	1.761	0.232	1.707	2.970	0.3367	0.808	0.547	5.393	0.184	1.816
10	0.949	0.308	0.975	0.9727	1.0281	0.284	1.716	0.276	1.669	3.078	0.3249	0.797	0.687	5.469	0.223	1.777
11	0.905	0.285	0.927	0.9754	1.0252	0.321	1.679	0.313	1.637	3.173	0.3152	0.787	0.811	5.535	0.256	1.744
12	0.866	0.266	0.886	0.9776	1.0229	0.354	1.646	0.346	1.610	3.258	0.3069	0.778	0.922	5.594	0.283	1.717
13	0.832	0.249	0.850	0.9794	1.0210	0.382	1.618	0.374	1.585	3.336	0.2998	0.770	1.025	5.647	0.307	1.693
14	0.802	0.235	0.817	0.9810	1.0194	0.406	1.594	0.399	1.563	3.407	0.2935	0.763	1.118	5.696	0.328	1.672
15	0.775	0.223	0.789	0.9823	1.0180	0.428	1.572	0.421	1.544	3.472	0.2880	0.756	1.203	5.741	0.347	1.653
16	0.750	0.212	0.763	0.9835	1.0168	0.448	1.552	0.440	1.526	3.532	0.2831	0.750	1.282	5.782	0.363	1.637
17	0.728	0.203	0.739	0.9845	1.0157	0.466	1.534	0.458	1.511	3.588	0.2787	0.744	1.356	5.820	0.378	1.622
18	0.707	0.194	0.718	0.9854	1.0148	0.482	1.518	0.475	1.496	3.640	0.2747	0.739	1.424	5.856	0.391	1.608
19	0.688	0.187	0.698	0.9862	1.0140	0.497	1.503	0.490	1.483	3.689	0.2711	0.734	1.487	5.891	0.403	1.597
20	0.671	0.180	0.680	0.9869	1.0133	0.510	1.490	0.504	1.470	3.735	0.2677	0.729	1.549	5.921	0.415	1.585
21	0.655	0.173	0.663	0.9876	1.0126	0.523	1.477	0.516	1.459	3.778	0.2647	0.724	1.605	5.951	0.425	1.575
22	0.640	0.167	0.647	0.9882	1.0119	0.534	1.466	0.528	1.448	3.819	0.2618	0.720	1.659	5.979	0.434	1.566
23	0.626	0.162	0.633	0.9887	1.0114	0.545	1.455	0.539	1.438	3.858	0.2592	0.716	1.710	6.006	0.443	1.557
24	0.612	0.157	0.619	0.9892	1.0109	0.555	1.445	0.549	1.429	3.895	0.2567	0.712	1.759	6.031	0.451	1.548
25	0.600	0.153	0.606	0.9896	1.0105	0.565	1.435	0.559	1.420	3.931	0.2544	0.708	1.806	6.056	0.459	1.541

For $n > 25$.

$$A = \frac{3}{\sqrt{n}} \qquad A_3 = \frac{3}{c_4\sqrt{n}} \qquad c_4 \cong \frac{4(n-1)}{4n-3}$$

$$B_3 = 1 - \frac{3}{c_4\sqrt{2(n-1)}} \qquad B_4 = 1 + \frac{3}{c_4\sqrt{2(n-1)}}$$

$$B_5 = c_4 - \frac{3}{\sqrt{2(n-1)}} \qquad B_6 = c_4 + \frac{3}{\sqrt{2(n-1)}}$$

Fig.3

PROCESS OUT OF CONTROL

After computing the control limits, the next step is to determine whether the process is in statistical control or not. If not, it means there is an external cause that throws the process out of control. This cause must be traced or removed so that the process may return to operate under stable statistical conditions. The various reasons for the process being out of control may be:

1. Faulty tools
2. Sudden significant change in properties of new materials in a new consignment
3. Breakout of lubrication system
4. Faults in timing of speed mechanisms.

PROCESS IN CONTROL

If the process is found to be in statistical control, a comparison between the required specifications and the process capability may be carried out to determine whether the two are compatible.

Conclusions:

When the process is not in control then then the point fall outside the control limits on either $\bar{x}$ or R charts. It means assignable causes (human controlled causes) are present in the process. When all the points are inside the control limits even then we cannot definitely say that no assignable cause is present but it is not economical to trace the cause. No statistical test can be applied. Even in the best manufacturing process, certain errors may develop and that constitute the assignable causes but no statistical action can be taken.

CONTROL CHARTS FOR ATTRIBUTES

Control charts for attributes are used to measure quality characteristics that are counted rather than measured. Attributes are discrete in nature and entail simple yes-or-no decisions. For example, this could be the number of nonfunctioning lightbulbs, the proportion of broken eggs in a carton, the number of rotten apples, the number of scratches on a tile, or the number of complaints issued. Two of the most common types of control charts for attributes are p-charts and c-charts.

- **P-charts** are used to measure the proportion of items in a sample that are defective. Examples are the proportion of broken cookies in a batch and the proportion of cars produced with a misaligned fender. P-charts are appropriate when both the number of defectives measured and the size of the total sample can be counted. A proportion can then be computed and used as the statistic of measurement.

1. It can be a fraction defective chart.
2. Each item is classified as good (non-defective) or bad (defective).
3. This chart is used to control the general quality of the component parts and it checks if the fluctuations in product quality (level) are due to chance alone.

Plotting of P-charts: By calculating, first, the fraction defective and then the control limits.

The process is said to be in control if fraction defective values fall within the control limits. In case the process is out of control an investigation to hunt for the cause becomes necessary.

The mean proportion defective ($\bar{p}$):

$$\bar{p} = \frac{\text{Total Number of Defectives}}{\text{Total Number Inspected}}$$

The standard deviation of p:

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

where n = sample size.

Control Limits are:

$$UCL = \bar{p} + Z*\sigma_{\bar{p}} \qquad LCL = \bar{p} - Z*\sigma_{\bar{p}}$$

or

$$UCL = \bar{p} + Z*\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \qquad LCL = \bar{p} - Z*\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

Usually the Z value is equal to 3 (as was used in the X and R charts), since the variations within three standard deviations are considered as natural variations. However, the choice of the value of Z depends on the environment in which the chart is being used, and on managerial judgment.

- **C-charts** count the actual number of defects. For example, we can count the number of complaints from customers in a month, the number of bacteria on a petri dish, or the number of barnacles on the bottom of a boat. However, we cannot compute the proportion of complaints from customers, the proportion of bacteria on a petri dish, or the proportion of barnacles on the bottom of a boat.

Defective items vs individual defects

The literature differentiates between *defect* and *defective,* which is the same as differentiating between *nonconformity* and *nonconforming units*. This may sound like splitting hairs, but in the interest of clarity let's try to unravel this man-made mystery.

Consider a wafer with a number of chips on it. The wafer is referred to as an "item of a product". The chip may be referred to as "a specific point". There exist certain specifications for the wafers. When a particular wafer (e.g., the item of the product) does not meet at least one of the specifications, it is classified as a nonconforming item. Furthermore, each chip, (e.g., the specific point) at which a specification is not met becomes a defect or nonconformity.

So, a nonconforming or defective item contains at least one defect or nonconformity. It should be pointed out that a wafer can contain several defects but still be classified as conforming. For example, the defects may be located at noncritical positions on the wafer. If, on the other hand, the number of the so-called

"unimportant" defects becomes alarmingly large, an investigation of the production of these wafers is warranted.

Control charts involving counts can be either for the *total number* of nonconformities (defects) for the sample of inspected units, or for the *average number* of defects per inspection unit.

Defect vs. Defective

- 'Defect' – a single nonconforming quality characteristic.
- 'Defective' – items having one or more defects.

C charts can be plotted by using the following formulas:

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

$$\bar{c} = \frac{\text{total number of defects}}{\text{total number of samples}}$$

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

THE PRIMARY DIFFERENCE BETWEEN USING A P-CHART AND A C-CHART IS AS FOLLOWS.

A P-chart is used when both the total sample size and the number of defects can be computed.

A C-chart is used when we can compute *only* the number of defects but cannot compute the proportion that is defective.

ACCEPTANCE SAMPLING

"Acceptance Sampling is concerned with the decision to accept a mass of manufactured items as conforming to standards of quality or to reject the mass as non-conforming to quality. The decision is reached through sampling."

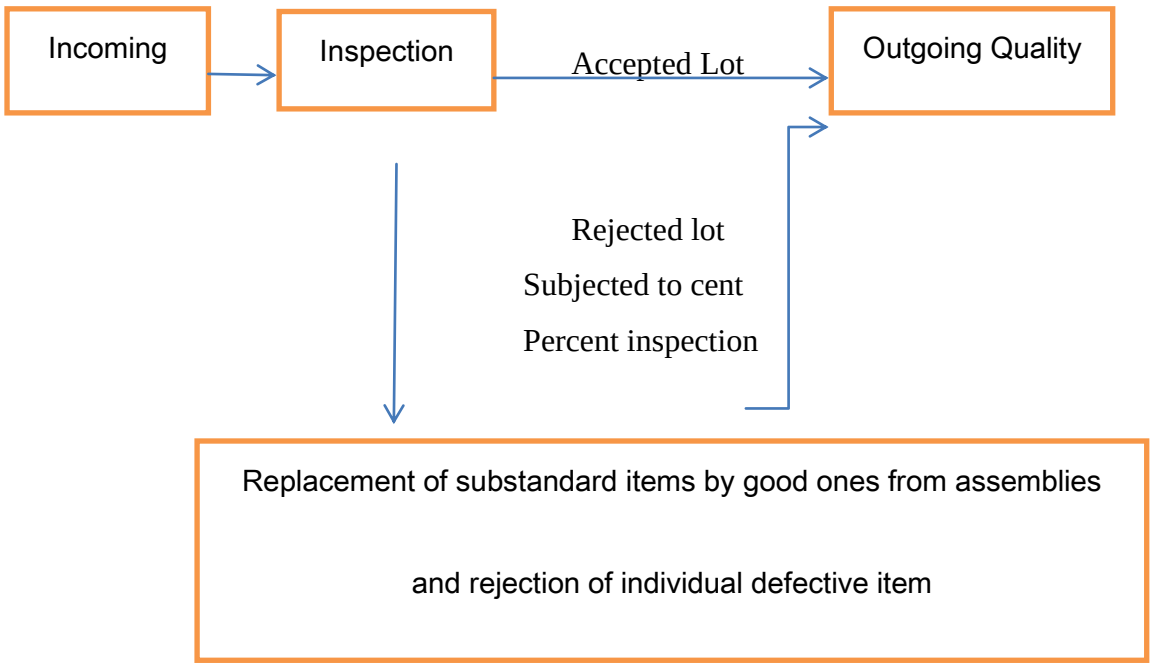
- SIMPSON AND KAFKA

Acceptance sampling uses statistical sampling to determine whether to accept or reject a production lot of material. It has been a common quality control technique used in industry and particularly the military for contracts and procurement. It is usually done as products leave the factory, or in some cases even within the factory. Most often a producer supplies a consumer a number of items and decision to accept or reject the lot is made by determining the number of defective items in a sample from the lot. The lot is accepted if the number of defects falls below where the acceptance number or otherwise the lot is rejected

For the purpose of acceptance, inspection is carried out at many stages in the process of manufacturing. These stages may be: inspection of incoming materials and parts, process inspection at various points in the manufacturing operations, final inspection by a manufacturer of his own product and finally inspection of the finished product by the purchaser.

Inspection for acceptance is generally carried out on a sampling basis. The use of sampling inspection to decide whether or not to accept the lot is known as Acceptance Sampling. A sample from the inspection lot is inspected, and if the number of defective items is more than the stated number known as acceptance number, the whole lot is rejected.

The purpose of Acceptance Sampling is, therefore a method used to make a decision as to whether to accept or to reject lots based on inspection of sample(s).



Acceptance sampling is the process of randomly inspecting a sample of goods and deciding whether to accept the entire lot based on the results. Acceptance sampling determines whether a batch of goods should be accepted or rejected.

Acceptance Sampling is very widely used in practice due to the following merits:

1. Acceptance Sampling is much less expensive than 100 percent inspection.
2. It is general experience that 100 percent inspection removes only 82 to 95 percent of defective material. Very good 100 percent inspection may remove at the most 99 percent of the defectives, but still cannot reach the level of 100 percent. Due to the effect of inspection fatigue involved in 100 percent inspection, a good sampling plan may actually give better results than that achieved by 100 percent inspection.
3. Because of its economy, it is possible to carry out sample inspection at various stages.

Inspection provides a means for monitoring quality. For example, inspection may be performed on incoming raw material, to decide whether to keep it or return it to the vendor if the quality level is not what was agreed on. Similarly, inspection can also be done on finished goods before deciding whether to make the shipment to the customer or not. However, performing 100% inspection is generally not economical or practical, therefore, sampling is used instead.

Acceptance Sampling is therefore a method used to make a decision as to whether to accept or to reject lots based on inspection of sample(s). The objective is not to control or estimate the quality of lots, only to pass a judgment on lots.

Using sampling rather than 100% inspection of the lots brings some risks both to the consumer and to the producer, which are called the consumer's and the producer's risks, respectively. We encounter making decisions on sampling in our daily affairs.

Operating Characteristic Curve

The Operating Characteristic Curve (OC Curve) shows you the probability that you will accept lots with various levels of quality. It is the working plan of acceptance sampling.

AQL – Acceptance Quality Level

The AQL (Acceptance Quality Level), the maximum % defective that can be considered satisfactory as a process average for sampling inspection

RQL – Rejectable Quality Level

The RQL (Rejectable Quality Level) is the % defective. t is also known as the Lot Tolerance Percent Defective (LTPD).

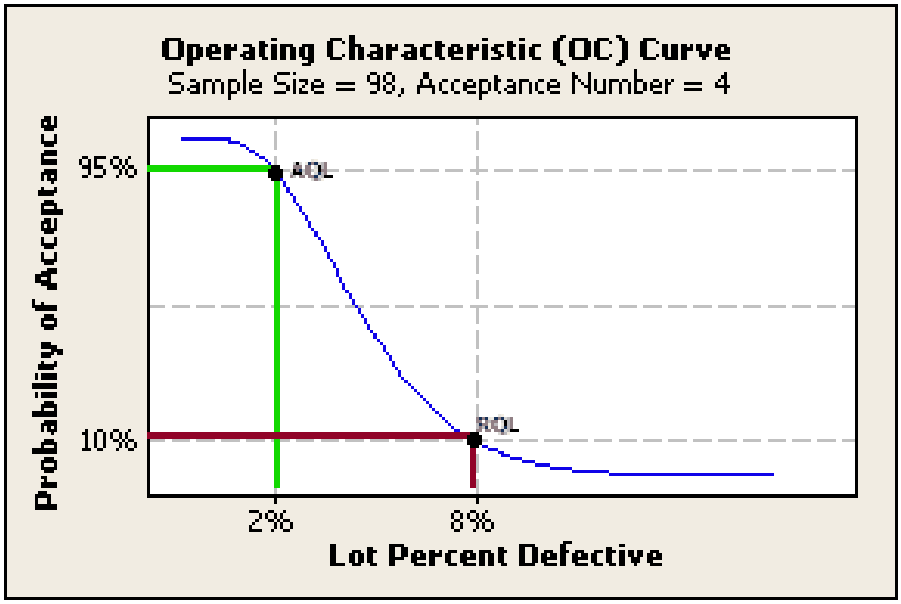
LTPD – Lot Tolerance Percent Defective

The LTPD of a sampling plan is a level of quality routinely rejected by the sampling plan. It is generally defined as that level of quality (percent defective, defects per hundred units, etc.) which the sampling plan will accept 10% of the time.

Risks in Acceptance sampling

1. Producer's risk-: Sometimes inspite of good quality, the sample taken may show defective units as such the lot will be rejected, such type of risk is known as producer's risk.

2. Consumer's Risk-: Sometimes the quality of the lot is not good but the sample results show good quality units as such the consumer has to accept a defective lot, such a risk is known as consumer's risk.



ACCEPTANCE SAMPLING PLANS

A **sampling plan** is a plan for acceptance sampling that precisely specifies the parameters of the sampling process and the acceptance/rejection criteria. The variables to be specified include the size of the lot (*N*), the size of the sample inspected from the lot (*n*), the number of defects above which a lot is rejected (*c*), and the number of samples that will be taken.
There are different types of sampling plans.

- Single Sampling (Inference made on the basis of only one sample)
- Double Sampling (Inference made on the basis of one or two samples)
- Sequential Sampling (Additional samples are drawn until an inference can be made) etc.

Single Sampling Plan

In single sampling plan, the decision regarding the acceptance or rejection is made after drawing a sample from a bigger lot. Inspection is done and if the defectives exceed a certain number the lot is rejected. Otherwise, the lot is accepted when the number of defectives is less than the acceptance number.

Double Sampling Plan

In this, a small sample is first drawn. If the number of defectives is less than or equal to the acceptance number (C1) the lot is accepted. If the number of defectives is more than another acceptance number (C2) which is higher, then C1 then the lot is rejected. If in case, the number in the inspection lies between C2 and C1, then a second sample is drawn. The entire lot is accepted or rejected on the basis of outcome of second inspection.

Sequential Sampling Plan

Sequential sampling plan is used when three or more samples of stated size are permitted and when the decision on acceptance or rejection must be reached after a stated number of samples.

A first sample of n1 is drawn, the lot is accepted if there are no more than c1 defectives, the lot is rejected if there are more than r1 defectives. Otherwise a second sample of n2 is drawn. The lot is accepted if there are no more than c2 defectives in the combined sample of n1 + n2. The lot is rejected if there are more than r2 defectives in the combined sample of n1 + n2. The procedure is continued in accordance with the table below.

Sample	*Sample Size*	*Size*	*Acceptance Number*	*Rejection Number*
First	n_1	n_1	c_1	r_1
Second	n_2	$n_1 + n_2$	c_2	r_2
Third	n_3	$n_1 + n_2 + n_3$	c_3	r_3
Fourth	n_4	$n_1 + n_2 + n_3 + n_4$	c_4	r_4
Fifth	n_5	$n_1 + n_2 + n_3 + n_4 + n_5$	c_5	$c_5 + 1$

If by the end of fourth sample, the lot is neither accepted nor rejected, a sample n5 is drawn. The lot is accepted if the number of defectives in the combined sample of n1 + n2 + n3 + n4 + n5 does not exceed c5. Otherwise the lot is rejected.

A sequential sampling plan involves higher administrative costs and use of experienced inspectors

AN INTRODUCTION TO TOTAL QUALITY MANAGEMENT (TQM)

At its core, Total Quality Management (TQM) is a management approach to long-term success through customer satisfaction.

In a TQM effort, all members of an organization participate in improving processes, products, services and the culture in which they work.

Total Quality Management (TQM) is an approach that seeks to improve quality and performance which will meet or exceed customer expectations. This can be achieved by integrating all quality-related functions and processes throughout the company. TQM looks at the overall quality measures used by a company including managing quality design and development, quality control and maintenance, quality improvement, and quality assurance. TQM takes into account all quality measures taken at all levels and involving all company employees.

TQM can be defined as the management of initiatives and procedures that are aimed at achieving the delivery of quality products and services.

PRINCIPLES OF TQM

A number of key principles can be identified in defining TQM, including:

- Executive Management – Top management should act as the main driver for TQM and create an environment that ensures its success.
- Training – Employees should receive regular training on the methods and concepts of quality.
- Customer Focus – Improvements in quality should improve customer satisfaction.
- Decision Making – Quality decisions should be made based on measurements.
- Methodology and Tools – Use of appropriate methodology and tools ensures that non-conformances are identified, measured and responded to consistently.
- Continuous Improvement – Companies should continuously work towards improving manufacturing and quality procedures.
- Company Culture – The culture of the company should aim at developing employees ability to work together to improve quality.
- Employee Involvement – Employees should be encouraged to be pro-active in identifying and addressing quality related problems.

A core concept in implementing TQM is Deming's 14 points, a set of management practices to help companies increase their quality and productivity:

1. Create constancy of purpose for improving products and services.
2. Adopt the new philosophy.
3. Cease dependence on inspection to achieve quality.
4. End the practice of awarding business on price alone; instead, minimize total cost by working with a single supplier.
5. Improve constantly and forever every process for planning, production and service.
6. Institute training on the job.
7. Adopt and institute leadership.
8. Drive out fear.
9. Break down barriers between staff areas.
10. Eliminate slogans, exhortations and targets for the workforce.
11. Eliminate numerical quotas for the workforce and numerical goals for management.
12. Remove barriers that rob people of pride of workmanship, and eliminate the annual rating or merit system.
13. Institute a vigorous program of education and self-improvement for everyone.
14. Put everybody in the company to work accomplishing the transformation.

TEAM APPROACH

TQM stresses that quality is an organizational effort. To facilitate the solving of quality problems, it places great emphasis on teamwork. The use of teams is based on the old adage that "two heads are better than one."Using techniques such as brainstorming, discussion, and quality control tools, teams work regularly to correct problems. The contributions of teams are considered vital to the success of the company. For this reason, companies set aside time in the workday for team meetings.

Teams vary in their degree of structure and formality, and different types of teams solve different types of problems. One of the most common types of teams is the **quality circle,** a team of volunteer production employees and their supervisors whose purpose is to solve quality problems. The circle is usually composed of eight to ten members, and decisions are made through group consensus. The teams usually meet weekly during work hours in a place designated for this purpose. They follow a preset process for analyzing and solving quality problems. Open discussion is promoted, and criticism is not allowed. Although the functioning of quality circles is friendly and casual, it is serious business. Quality circles are not mere "gab sessions." Rather, they do important work for the company and have been very successful in many firms.

THE SEVEN TOOLS OF QUALITY CONTROL

1. Cause and effect analysis
2. Flowcharts
3. Checklists
4. Control techniques including Statistical quality control and control charts.
5. Scatter diagram
6. Pareto analysis which means identification of vital few from many at a glance. This is used for fixing the priorities in tackling a problem.
7. Histograms.

Cause-and-Effect Diagrams

Cause-and-effect diagrams are charts that identify potential causes for particular quality problems. They are often called fishbone diagrams because they look like the bones of a fish. A general cause-and-effect diagram is shown in Figure 5-8. The "head" of the fish is the quality problem, such as damaged zippers on a garment or broken valves on a tire. The diagram is drawn so that the "spine" of the fish connects the "head" to the possible cause of the problem. These causes could be related to the machines, workers, measurement, suppliers, materials, and many other aspects of the production process. Each of these possible causes can then have smaller "bones" that address specific issues that relate to each cause. For example, a problem with machines could be due to a need for adjustment, old equipment, or tooling problems. Similarly, a problem with workers could be related to lack of training, poor supervision, or fatigue.

Cause-and-effect diagrams are problem-solving tools commonly used by quality control teams. Specific causes of problems can be explored through brainstorming.

The development of a cause-and-effect diagram requires the team to think through all the possible causes of poor quality.

Flowcharts

A flowchart is a schematic diagram of the sequence of steps involved in an operation or process. It provides a visual tool that is easy to use and understand.

By seeing the steps involved in an operation or process, everyone develops a clear picture of how the operation works and where problems could arise.

Checklists

A checklist is a list of common defects and the number of observed occurrences of these defects. It is a simple yet effective fact-finding tool that allows the worker to collect specific information regarding the

defects observed. The checklist in Figure 5-7 shows four defects and the number of times they have been observed.

It is clear that the biggest problem is ripped material. This means that the plant needs to focus on this specific problem—for example, by going to the source of supply or seeing whether the material rips during a particular production process.

A checklist can also be used to focus on other dimensions, such as location or time.

For example, if a defect is being observed frequently, a checklist can be developed that measures the number of occurrences per shift, per machine, or per operator. In this fashion we can isolate the location of the particular defect and then focus on correcting the problem.

Control Charts

Control charts are a very important quality control tool. We will study the use of control charts at great length in the next chapter. These charts are used to evaluate whether a process is operating within expectations relative to some measured value such as weight, width, or volume. For example, we could measure the weight of a sack of flour, the width of a tire, or the volume of a bottle of soft drink.When the production process is operating within expectations, we say that it is "in control."

To evaluate whether or not a process is in control, we regularly measure the variable of interest and plot it on a control chart. The chart has a line down the center representing the average value of the variable we are measuring. Above and below the center line are two lines, called the upper control limit (UCL) and the lower control limit (LCL). As long as the observed values fall within the upper and lower control limits, the process is in control and there is no problem with quality. When a measured observation falls outside of these limits, there is a problem.

Scatter Diagrams

Scatter diagrams are graphs that show how two variables are related to one another. They are particularly useful in detecting the amount of correlation, or the degree of linear relationship, between two variables. For example, increased production speed and number of defects could be correlated positively; as production speed increases, so does the number of defects. Two variables could also be correlated negatively, so that an increase in one of the variables is associated with a decrease in the other. For example, increased worker training might be associated with a decrease in the number of defects observed.

The greater the degree of correlation, the more linear are the observations in the scatter diagram. On the other hand, the more scattered the observations in the diagram, the less correlation exists between the variables. Of course, other types of relationships can also be observed on a scatter diagram, such as an inverted. This may be the case when one is observing the relationship between two variables such as oven temperature and number of defects, since temperatures below and above the ideal could lead to defects.

Pareto Analysis

Pareto analysis is a technique used to identify quality problems based on their degree of importance. The logic behind Pareto analysis is that only a few quality problems are important, whereas many others are not critical. The technique was named after Vilfredo Pareto, a nineteenth-century Italian economist who determined that only a small percentage of people controlled most of the wealth. This concept has often been called the 80–20 rule and has been extended too many areas. In quality management the logic behind Pareto's principle is that most quality problems are a result of only a few causes. The trick is to identify these causes.

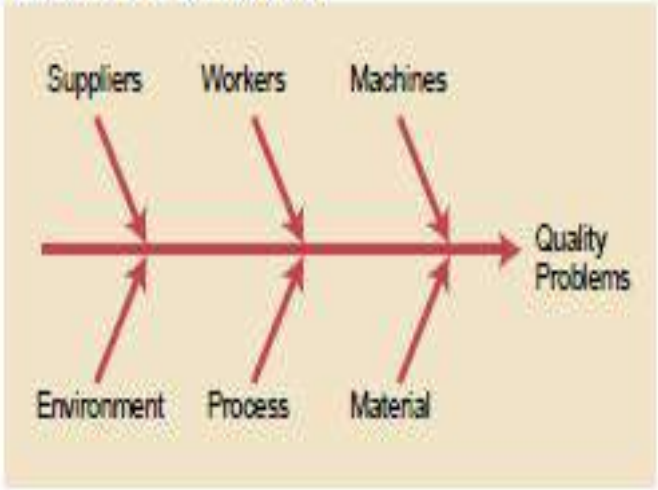
One way to use Pareto analysis is to develop a chart that ranks the causes of poor quality in decreasing order based on the percentage of defects each has caused. For example, a tally can be made of the number of defects that result from different causes, such as operator error, defective parts, or inaccurate machine calibrations. Percentages of defects can be computed from the tally and placed in a chart like those shown in Figure 5-7.We generally tends to find that a few causes account for most of the defects.

Histograms

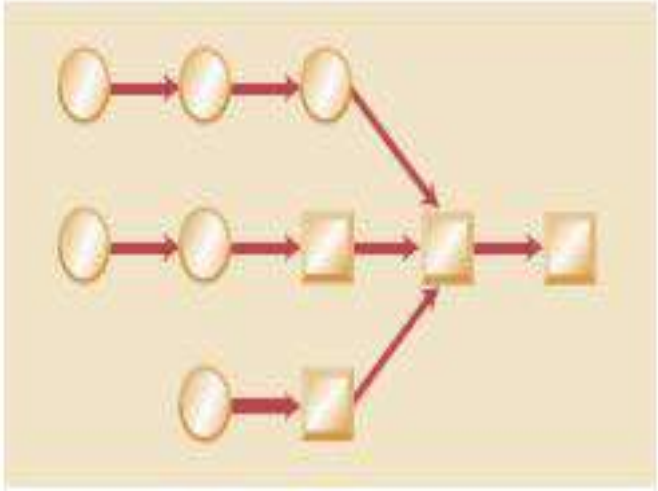
A **histogram** is a chart that shows the frequency distribution of observed values of a variable. We can see from the plot what type of distribution a particular variable displays, such as whether it has a normal distribution and whether the distribution is symmetrical.

In the food service industry the use of quality control tools is important in identifying quality problems. Grocery store chains, such as Kroger and Meijer, must record and monitor the quality of incoming produce, such as tomatoes and lettuce. Quality tools can be used to evaluate the acceptability of product quality and to monitor product quality from individual suppliers. They can also be used to evaluate causes of quality problems, such as long transit time or poor refrigeration.
Similarly, restaurants use quality control tools to evaluate and monitor the quality of delivered goods, such as meats, produce, or baked goods.

1. Cause-and-Effect Diagram



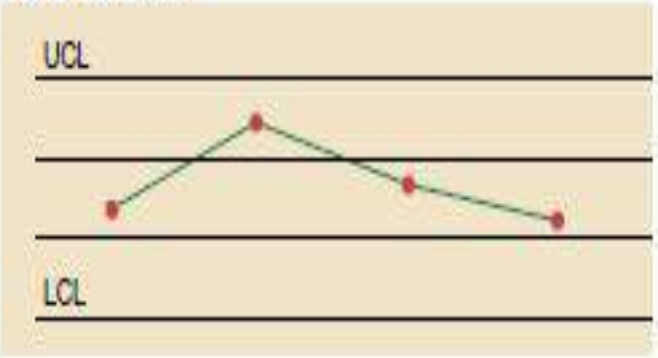
2. Flowchart



3. Checklist

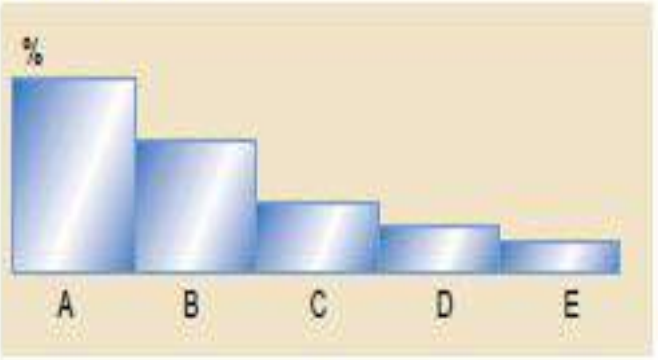
Defect Type	No. of Defects	Total
Broken zipper	✓✓✓	3
Ripped material	✓✓✓✓✓✓✓	7
Missing buttons	✓✓✓	3
Faded color	✓✓	2

4. Control Chart



5. Scatter Diagram

6. Pareto Chart



7. Histogram

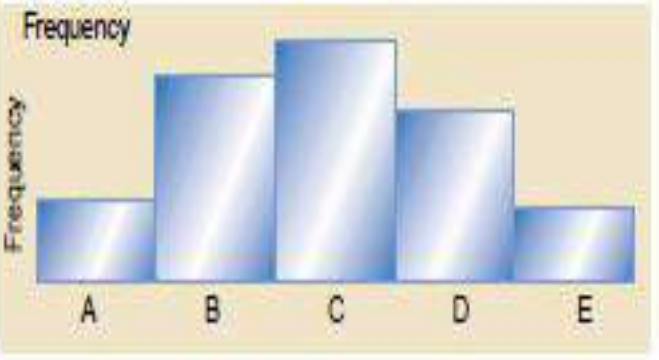


FIGURE 5-7

The seven tools of quality control

Techniques of TQM

ISO 9000 Standards

Increases in international trade during the 1980s created a need for the development of universal standards of quality. Universal standards were seen as necessary in order for companies to be able to objectively document their quality practices around the world. Then in 1987 the International Organization for Standardization (ISO) published its first set of standards for quality management called ISO 9000. The International

Organization for Standardization (ISO) is an international organization whose purpose is to establish agreement on international quality standards. It currently has members from 91 countries, including the United States. To develop and promote international quality standards, ISO 9000 has been created. ISO 9000 consists of a set of standards and a certification process for companies. By receiving ISO 9000 certification, companies demonstrate that they have met the standards specified by the ISO.

The standards are applicable to all types of companies and have gained global acceptance. In many industries ISO certification has become a requirement for doing business. Also, ISO 9000 standards have been adopted by the European Community as a standard for companies doing business in Europe.

In December 2000 the first major changes to ISO 9000 were made, introducing the following three new standards:

• **ISO 9000:2000**–Quality Management Systems–Fundamentals and Standards: Provides the terminology and definitions used in the standards. It is the starting point for understanding the system of standards.

• **ISO 9001:2000**–Quality Management Systems–Requirements: This is the standard used for the certification of a firm's quality management system. It is used to demonstrate the conformity of quality management systems to meet customer requirements.

• **ISO 9004:2000**–Quality Management Systems–Guidelines for Performance: Provides guidelines for establishing a quality management system. It focuses not only on meeting customer requirements but also on improving performance.

These three standards are the most widely used and apply to the majority of companies.

However, ten more published standards and guidelines exist as part of the ISO 9000 family of standards.

To receive ISO certification, a company must provide extensive documentation of its quality processes. This includes methods used to monitor quality, methods and frequency of worker training, job descriptions, inspection programs, and statistical process-control tools used. High-quality documentation of all processes is critical.

The company is then audited by an ISO 9000 registrar who visits the facility to make sure the company has a well-documented quality management system and that the process meets the standards. If the registrar finds that all is in order, certification is received.

Once a company is certified, it is registered in an ISO directory that lists certified companies. The entire process can take 18 to 24 months and can cost anywhere from $10,000 to $30,000. Companies have to be recertified by ISO every three years.

One of the shortcomings of ISO certification is that it focuses only on the process used and conformance to specifications. In contrast to the Baldrige criteria, ISO certification does not address questions about the product itself and whether it meets customer and market requirements. Today there are over 40,000 companies that are ISO certified. In fact, certification has become a requirement for conducting business in many industries.

ISO 14000 Standards

The need for standardization of quality created an impetus for the development of other standards. In 1996 the International Standards Organization introduced standards for evaluating a company's environmental responsibility. These standards, termed ISO 14000, focus on three major areas:

• Management systems standards measure systems development and integration of environmental responsibility into the overall business.
• Operations standards include the measurement of consumption of natural resources and energy.
• Environmental systems standards measure emissions, effluents, and other waste systems.

With greater interest in green manufacturing and more awareness of environmental concerns, ISO 14000 may become an important set of standards for promoting environmental responsibility.

Benchmarking

Benchmarking is the process of comparing one's business processes and performance metrics to industry bests or best practices from other industries. Dimensions typically measured are quality, time and cost. In the process of best practice benchmarking, management identifies the best firms in their industry, or in another industry where similar processes exist, and compares the results and processes of those studied (the "targets") to one's own results and processes. In this way, they learn how well the targets perform and, more importantly, the business processes that explain why these firms are successful.

Benchmarking is used to measure performance using a specific indicator (cost per unit of measure, productivity per unit of measure, cycle time of x per unit of measure or defects per unit of measure) resulting in a metric of performance that is then compared to others

Also referred to as "best practice benchmarking" or "process benchmarking", this process is used in management and particularly strategic management, in which organizations evaluate various aspects of their processes in relation to best practice companies' processes, usually within a peer group defined for the purposes of comparison. This then allows organizations to develop plans on how to make improvements or

adapt specific best practices, usually with the aim of increasing some aspect of performance. Benchmarking may be a one-off event, but is often treated as a continuous process in which organizations continually seek to improve their practices.

Six Sigma

Six Sigma is a set of tools and strategies for process improvement originally developed by Motorola in 1985. Six Sigma became well known after Jack Welch made it a central focus of his business strategy at General Electric in 1995, and today it is used in different sectors of industry.

Six Sigma seeks to improve the quality of process outputs by identifying and removing the causes of defects (errors) and minimizing variability in manufacturing and business processes. It uses a set of quality management methods, including statistical methods, and creates a special infrastructure of people within the organization ("Champions", "Black Belts", "Green Belts", "Orange Belts", etc.) who are experts in these very complex methods.

Each Six Sigma project carried out within an organization follows a defined sequence of steps and has quantified value targets, for example; process cycle time reduction, customer satisfaction, reduction in pollution, cost reduction and/or profit increase. The term *Six Sigma* originated from terminology associated with **manufacturing**, specifically terms associated with statistical modeling of manufacturing processes. The maturity of a manufacturing process can be described by a *sigma* rating indicating its yield or the percentage of defect-free products it creates.

A six sigma process is one in which 99.99966% of the products manufactured are statistically expected to be free of defects (3.4 defects per million), although, as discussed below, this defect level corresponds to only a 4.5 sigma level. Motorola set a goal of "six sigma" for all of its manufacturing operations, and this goal became a byword for the management and engineering practices used to achieve it.

Methods

Six Sigma projects follow two project methodologies inspired by Deming's Plan-Do-Check-Act Cycle. These methodologies, composed of five phases each, bear the acronyms DMAIC and DMADV.[11]

- DMAIC is used for projects aimed at improving an existing business process.
- DMADV is used for projects aimed at creating new product or process designs.

DMAIC

The DMAIC project methodology has five phases:

- ***D****efine* the problem, the voice of the customer, and the project goals, specifically.
- ***M****easure* key aspects of the current process and collect relevant data.
- ***A****nalyze* the data to investigate and verify cause-and-effect relationships. Determine what the relationships are, and attempt to ensure that all factors have been considered. Seek out root cause of the defect under investigation.

- ***I**mprove* or optimize the current process based upon data analysis using techniques such as design of experiments, poka yoke or mistake proofing, and standard work to create a new, future state process. Set up pilot runs to establish process capability.
- ***C**ontrol* the future state process to ensure that any deviations from target are corrected before they result in defects. Implement control systems such as statistical process control, production boards, visual workplaces, and continuously monitor the process.

Some organizations add a ***R**ecognize* step at the beginning, which is to recognize the right problem to work on, thus yielding an RDMAIC methodology.

DMADV or DFSS

The DMADV project methodology, known as DFSS ("**D**esign **F**or **S**ix **S**igma"),features five phases:

- ***D**efine* design goals that are consistent with customer demands and the enterprise strategy.
- ***M**easure* and identify CTQs (characteristics that are **C**ritical **T**o **Q**uality), product capabilities, production process capability, and risks.
- ***A**nalyze* to develop and design alternatives
- ***D**esign* an improved alternative, best suited per analysis in the previous step
- ***V**erify* the design, set up pilot runs, implement the production process and hand it over to the process owner(s).

Quality circle

A **quality circle** is a volunteer group composed of workers (or even students), usually under the leadership of their supervisor (or an elected team leader), who are trained to identify, analyze and solve work-related problems and present their solutions to management in order to improve the performance of the organization, and motivate and enrich the work of employees. When matured, true quality circles become self-managing, having gained the confidence of management.

Quality circles are an alternative to the rigid concept of division of labor, where workers operate in a more narrow scope and compartmentalized functions. Typical topics are improving occupational safety and health, improving product design, and improvement in the workplace and manufacturing processes. The term *quality circles* derives from the concept of PDCA (Plan, Do, Check, Act) circles developed by Dr. W. Edwards Deming.

Quality circles are typically more formal groups. They meet regularly on company time and are trained by competent persons (usually designated as facilitators) who may be personnel and industrial relations specialists trained in human factors and the basic skills of problem identification, information gathering and analysis, basic statistics, and solution generation. Quality circles are generally free to select any topic they wish (other than those related to salary and terms and conditions of work, as there are other channels through which these issues are usually considered).

Quality circles have the advantage of continuity; the circle remains intact from project to project

Note : Study Inspection method for quality control from book

G Acceptance Sampling Plans

LEARNING GOALS

After reading this supplement, you should be able to:

1. Distinguish between single-sampling, double-sampling, and sequential-sampling plans and describe the unique characteristics of each.
2. Develop an operating characteristic curve for a single-sampling plan and estimate the probability of accepting a lot with a given proportion defective.
3. Construct a single-sampling plan.
4. Compute the average outgoing quality for a single-sampling plan.

Acceptance sampling is an inspection procedure used to determine whether to accept or reject a specific quantity of material. As more firms initiate total quality management (TQM) programs and work closely with suppliers to ensure high levels of quality, the need for acceptance sampling will decrease. The TQM concept is that no defects should be passed from a producer to a customer, whether the customer is an external or internal customer. However, in reality, many firms must still rely on checking their materials inputs. The basic procedure is straightforward.

1. A random sample is taken from a large quantity of items and tested or measured relative to the quality characteristic of interest.
2. If the sample passes the test, the entire quantity of items is accepted.
3. If the sample fails the test, either (a) the entire quantity of items is subjected to 100 percent inspection and all defective items repaired or replaced or (b) the entire quantity is returned to the supplier.

We first discuss the decisions involved in setting up acceptance sampling plans. We then address several attribute sampling plans.

my**om**lab and the Companion Website at **www.pearsonhighered.com** contain many tools, activities, and resources designed for this supplement.

Acceptance Sampling Plan Decisions

acceptance sampling
An inspection procedure used to determine whether to accept or reject a specific quantity of materials.

Acceptance sampling involves both the producer (or supplier) of materials and the consumer (or buyer). Consumers need acceptance sampling to limit the risk of rejecting good-quality materials or accepting bad-quality materials. Consequently, the consumer, sometimes in conjunction with the producer through contractual agreements, specifies the parameters of the plan. Any company can be both a producer of goods purchased by another company and a consumer of goods or raw materials supplied by another company.

Quality and Risk Decisions

acceptable quality level (AQL)
The quality level desired by the consumer.

producer's risk (α)
The risk that the sampling plan will fail to verify an acceptable lot's quality and, thus, reject it (a type I error).

Two levels of quality are considered in the design of an acceptance sampling plan. The first is the **acceptable quality level (AQL)**, or the quality level desired by the *consumer*. The producer of the item strives to achieve the AQL, which typically is written into a contract or purchase order. For example, a contract might call for a quality level not to exceed one defective unit in 10,000, or an AQL of 0.0001. The **producer's risk (α)** is the risk that the sampling plan will fail to verify an acceptable lot's quality and, thus, reject it—a type I error. Most often the producer's risk is set at 0.05, or 5 percent.

Although producers are interested in low risk, they often have no control over the consumer's acceptance sampling plan. Fortunately, the consumer also is interested in a low producer's risk because sending good materials back to the producer (1) disrupts the consumer's production process and increases the likelihood of shortages in materials, (2) adds unnecessarily to the lead time for finished products or services, and (3) creates poor relations with the producer.

lot tolerance proportion defective (LTPD)
The worst level of quality that the consumer can tolerate.

consumer's risk (β)
The probability of accepting a lot with LTPD quality (a type II error).

The second level of quality is the **lot tolerance proportion defective (LTPD)**, or the worst level of quality that the consumer can tolerate. The LTPD is a definition of bad quality that the consumer would like to reject. Recognizing the high cost of defects, operations managers have become more cautious about accepting materials of poor quality from suppliers. Thus, sampling plans have lower LTPD values than in the past. The probability of accepting a lot with LTPD quality is the **consumer's risk (β)**, or the type II error of the plan. A common value for the consumer's risk is 0.10, or 10 percent.

Sampling Plans

All sampling plans are devised to provide a specified producer's and consumer's risk. However, it is in the consumer's best interest to keep the average number of items inspected (ANI) to a minimum because that keeps the cost of inspection low. Sampling plans differ with respect to ANI. Three often-used attribute sampling plans are the single-sampling plan, the double-sampling plan, and the sequential-sampling plan. Analogous plans also have been devised for variable measures of quality.

single-sampling plan
A decision to accept or reject a lot based on the results of one random sample from the lot.

Single-Sampling Plan The **single-sampling plan** is a decision rule to accept or reject a lot based on the results of one random sample from the lot. The procedure is to take a random sample of size (n) and inspect each item. If the number of defects does not exceed a specified acceptance number (c), the consumer accepts the entire lot. Any defects found in the sample are either repaired or returned to the producer. If the number of defects in the sample is greater than c, the consumer subjects the entire lot to 100 percent inspection or rejects the entire lot and returns it to the producer. The single-sampling plan is easy to use but usually results in a larger ANI than the other plans. After briefly describing the other sampling plans, we focus our discussion on this plan.

double-sampling plan
A plan in which management specifies two sample sizes and two acceptance numbers; if the quality of the lot is very good or very bad, the consumer can make a decision to accept or reject the lot on the basis of the first sample, which is smaller than in the single-sampling plan.

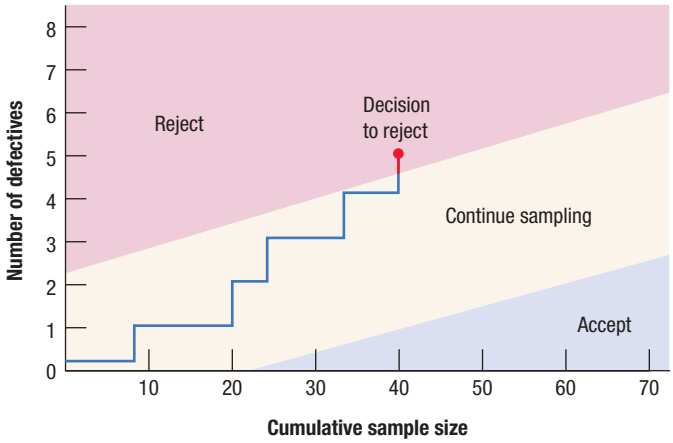
Double-Sampling Plan In a **double-sampling plan**, management specifies two sample sizes (n_1 and n_2) and two acceptance numbers (c_1 and c_2). If the quality of the lot is very good or very bad, the consumer can make a decision to accept or reject the lot on the basis of the first sample, which is smaller than in the single-sampling plan. To use the plan, the consumer takes a random sample of size n_1. If the number of defects is less than or equal to (c_1), the consumer accepts the lot. If the number of defects is greater than (c_2), the consumer rejects the lot. If the number of defects is between c_1 and c_2, the consumer takes a second sample of size n_2. If the combined number of defects in the two samples is less than or equal to c_2, the consumer accepts the lot. Otherwise, it is rejected. A double-sampling plan can significantly reduce the costs of inspection relative to a single-sampling plan for lots with a very low or very high proportion defective because a decision can be made after taking the first sample. However, if the decision requires two samples, the sampling costs can be greater than those for the single-sampling plan.

sequential-sampling plan
A plan in which the consumer randomly selects items from the lot and inspects them one by one.

Sequential-Sampling Plan A further refinement of the double-sampling plan is the **sequential-sampling plan**, in which the consumer randomly selects items from the lot and inspects them one by one. Each time an item is inspected, a decision is made to (1) reject the lot,

(2) accept the lot, or (3) continue sampling, based on the cumulative results so far. The analyst plots the total number of defectives against the cumulative sample size, and if the number of defectives is less than a certain acceptance number (c_1), the consumer accepts the lot. If the number is greater than another acceptance number (c_2), the consumer rejects the lot. If the number is somewhere between the two, another item is inspected. Figure G.1 illustrates a decision to reject a lot after examining the 40th unit. Such charts can be easily designed with the help of statistical tables that specify the accept or reject cut-off values c_1 and c_2 as a function of the cumulative sample size.

The ANI is generally lower for the sequential-sampling plan than for any other form of acceptance sampling, resulting in lower inspection costs. For very low or very high values of the proportion defective, sequential sampling provides a lower ANI than any comparable sampling plan. However, if the proportion of defective units falls between the AQL and the LTPD, a sequential-sampling plan could have a larger ANI than a comparable single- or double-sampling plan (although that is unlikely). In general, the sequential-sampling plan may reduce the ANI to 50 percent of that required by a comparable single-sampling plan and, consequently, save substantial inspection costs.



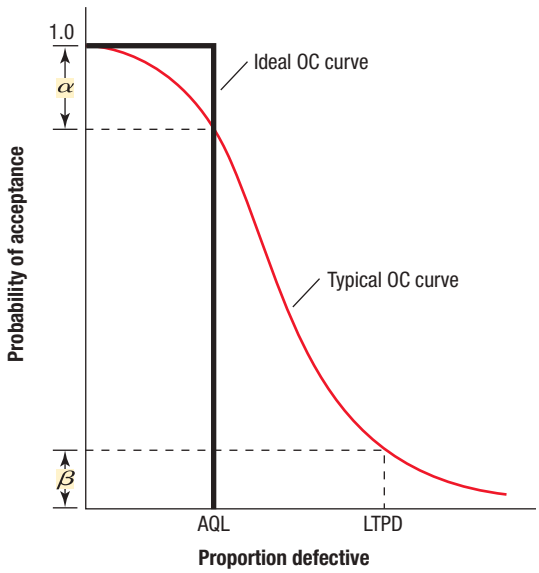
◀ **FIGURE G.1**
Sequential-Sampling Chart

Operating Characteristic Curves

Analysts create a graphic display of the performance of a sampling plan by plotting the probability of accepting the lot for a range of proportions of defective units. This graph, called an **operating characteristic (OC) curve**, describes how well a sampling plan discriminates between good and bad lots. Undoubtedly, every manager wants a plan that accepts lots with a quality level better than the AQL 100 percent of the time and accepts lots with a quality level worse than the AQL 0 percent of the time. This ideal OC curve for a single-sampling plan is shown in Figure G.2. However, such performance can be achieved only with 100 percent inspection. A typical OC curve for a single-sampling plan, plotted in red, shows the probability a of rejecting a good lot (producer's risk) and the probability β of accepting a bad lot (consumer's risk). Consequently, managers are left with choosing a sample size n and an acceptance number c to achieve the level of performance specified by the AQL, α, LTPD, and β.

operating characteristic (OC) curve
A graph that describes how well a sampling plan discriminates between good and bad lots.

▼ **FIGURE G.2**
Operating Characteristic Curves



Drawing the OC Curve

The sampling distribution for the single-sampling plan is the binomial distribution because each item inspected is either defective (a failure) or not (a success). The probability of accepting the lot equals the probability of taking a sample of size n from a lot with a proportion defective of p and finding c or fewer defective items. However, if n is greater than 20 and p is less than 0.05, the Poisson distribution can be used as an approximation to the binomial to take advantage of tables prepared for the purpose of drawing OC curves (see Table G.1 on pp. G.9–G.11). To draw the OC curve, look up the probability of accepting the lot for a range of values of p. For each value of p,

1. multiply p by the sample size n.
2. find the value of np in the left column of the table.
3. move to the right until you find the column for c.
4. record the value for the probability of acceptance, P_a.

When p = AQL, the producer's risk, α, is 1 minus the probability of acceptance. When (p = LTPD), the consumer's risk, β, equals the probability of acceptance.

EXAMPLE G.1 Constructing an OC Curve

myomlab

Tutor G.1 in myomlab provides a new example for constructing an OC curve.

The Noise King Muffler Shop, a high-volume installer of replacement exhaust muffler systems, just received a shipment of 1,000 mufflers. The sampling plan for inspecting these mufflers calls for a sample size $n = 60$ and an acceptance number $c = 1$. The contract with the muffler manufacturer calls for an AQL of 1 defective muffler per 100 and an LTPD of 6 defective mufflers per 100. Calculate the OC curve for this plan, and determine the producer's risk and the consumer's risk for the plan.

SOLUTION

Let $p = 0.01$. Then multiply n by p to get 60(0.01) = 0.60. Locate 0.60 in Table G.1 (pp. G.9–G.11). Move to the right until you reach the column for $c = 1$. Read the probability of acceptance: 0.878. Repeat this process for a range of p values. The following table contains the remaining values for the OC curve.

Values for the Operating Characteristic Curve with $n = 60$ and $c = 1$

Proportion Defective (p)	np	Probability of c or Less Defects (P_a)	Comments
0.01 (AQL)	0.6	0.878	$\alpha = 1.000 - 0.878 = 0.122$
0.02	1.2	0.663	
0.03	1.8	0.463	
0.04	2.4	0.308	
0.05	3.0	0.199	
0.06 (LTPD)	3.6	0.126	$\beta = 0.126$
0.07	4.2	0.078	
0.08	4.8	0.048	
0.09	5.4	0.029	
0.10	6.0	0.017	

DECISION POINT

Note that the plan provides a producer's risk of 12.2 percent and a consumer's risk of 12.6 percent. Both values are higher than the values usually acceptable for plans of this type (5 and 10 percent, respectively). Figure G.3 shows the OC curve and the producer's and consumer's risks. Management can adjust the risks by changing the sample size.

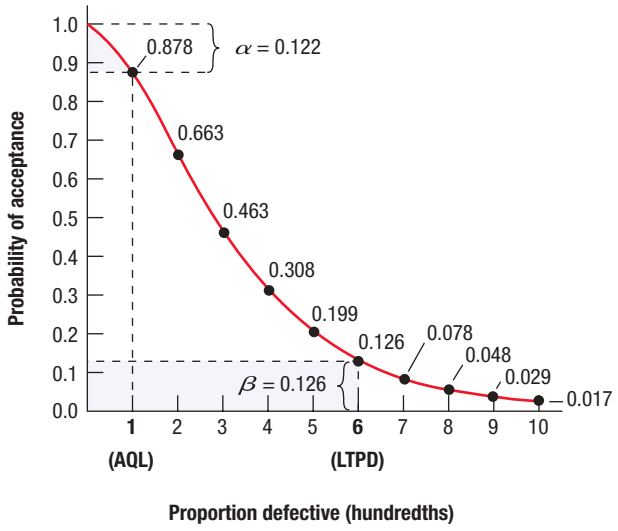


FIGURE G.3 ▶
The OC Curve for Single-Sampling Plan with $n = 60$ and $c = 1$

Explaining Changes in the OC Curve

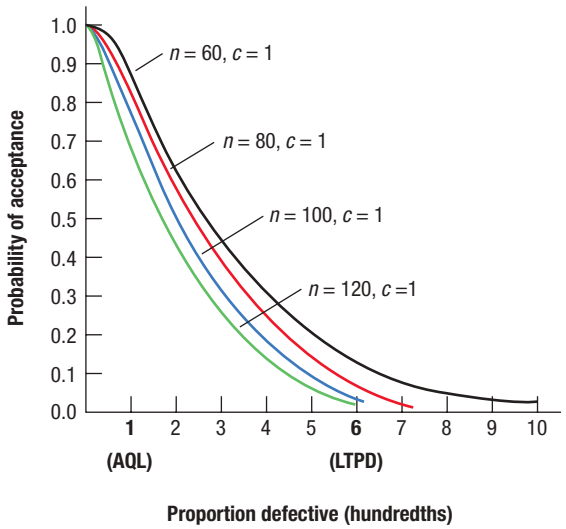
Example G.1 raises the question: How can management change the sampling plan to reduce the probability of rejecting good lots and accepting bad lots? To answer this question, let us see how *n* and *c* affect the shape of the OC curve. In the Noise King example, a better single-sampling plan would have a lower producer's risk and a lower consumer's risk.

Sample Size Effect What would happen if we increased the sample size to 80 and left the acceptance level, *c*, unchanged at 1? We can use Table G.1 (pp. G.9–G.11). If the proportion defective of the lot is p = AQL = 0.01, then np = 0.8 and the probability of acceptance of the lot is only 0.809. Thus, the producer's risk is 0.191. Similarly, if p = LTPD = 0.06, the probability of acceptance is 0.048. Other values of the producer's and consumer's risks are shown in the following table:

n	Producer's Risk (p = AQL)	Consumer's Risk (p = LTPD)
60	0.122	0.126
80	0.191	0.048
100	0.264	0.017
120	0.332	0.006

These results, shown in Figure G.4, yield the following principle: *Increasing* n *while holding* c *constant increases the producer's risk and reduces the consumer's risk.* For the producer of the mufflers, keeping c = 1 and increasing the sample size makes getting a lot accepted by the customer tougher—only two bad mufflers will get the lot rejected. And the likelihood of finding those 2 defects is greater in a sample of 120 than in a sample of 60. Consequently, the producer's risk increases. For the management of Noise King, the consumer's risk goes down because a random sample of 120 mufflers from a lot with 6 percent defectives is less likely to have only 1 or fewer defective mufflers.

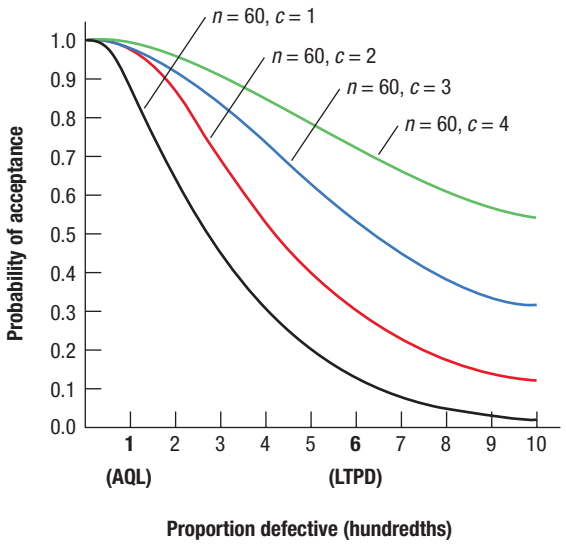
▼ **FIGURE G.4**
Effects of Increasing Sample Size While Holding Acceptance Number Constant



Acceptance Level Effect Suppose that we keep the sample size constant at 60 but change the acceptance level. Again, we use Table G.1 (pp. G.9–G.11).

c	Producer's Risk (p = AQL)	Consumer's Risk (p = LTPD)
1	0.122	0.126
2	0.023	0.303
3	0.003	0.515
4	0.000	0.706

The results are plotted in Figure G.5. They demonstrate the following principle: *Increasing* c *while holding* n *constant decreases the producer's risk and increases the consumer's risk.* The producer of the mufflers would welcome an increase in the acceptance number because it makes getting the lot accepted by the consumer easier. If the lot has only 1 percent defectives (the AQL) with a sample size of 60, we would expect only 0.01(60) = 0.6 defect in the sample. An increase in the acceptance number from one to two lowers the probability of finding more than two defects and, consequently, lowers the producer's risk. However, raising the acceptance number for a given sample size increases the risk of accepting a bad lot. Suppose that the lot has 6 percent defectives (the LTPD). We would expect to have 0.6(60) = 3.6 defectives in the sample. An increase in the acceptance number from one to two increases the probability of getting a sample with two or fewer defects and, therefore, increases the consumer's risk.



▲ **FIGURE G.5**
Effects of Increasing Acceptance Number While Holding Sample Size Constant

Thus, to improve Noise King's single-sampling acceptance plan, management should increase the sample size, which reduces the consumer's risk, *and* increase the acceptance

number, which reduces the producer's risk. An improved combination can be found by trial and error using Table G.1 (pp. G.9–G.11). Alternatively, a computer can be used to find the best combination. For any acceptance number, the computer determines the sample size needed to achieve the desired producer's risk and compares it to the sample size needed to meet the consumer's risk. It selects the smallest sample size that will meet both the producer's risk and the consumer's risk. The following table shows that a sample size of 111 and an acceptance number of 3 are best. This combination actually yields a producer's risk of 0.026 and a consumer's risk of 0.10 (not shown). The risks are not exact because c and n must be integers.

Acceptance Sampling Plan Data

	AQL Based		LTPD Based	
Acceptance Number	Expected Defectives	Sample Size	Expected Defectives	Sample Size
0	0.0509	5	2.2996	38
1	0.3552	36	3.8875	65
2	0.8112	81	5.3217	89
3	1.3675	137	6.6697	111
4	1.9680	197	7.9894	133
5	2.6256	263	9.2647	154
6	3.2838	328	10.5139	175
7	3.9794	398	11.7726	196
8	4.6936	469	12.9903	217
9	5.4237	542	14.2042	237
10	6.1635	616	15.4036	257

Average Outgoing Quality

We have shown how to choose the sample size and acceptance number for a single-sampling plan, given AQL, α, LTPD, and β parameters. To check whether the performance of the plan is what we want, we can calculate the plan's **average outgoing quality (AOQ)**, which is the expected proportion of defects that the plan will allow to pass. We assume that all defective items in the lot will be replaced with good items if the lot is rejected and that any defective items in the sample will be replaced if the lot is accepted. This approach is called **rectified inspection**. The equation for AOQ is

average outgoing quality (AOQ)
The expressed proportion of defects that the plan will allow to pass.

rectified inspection
The assumption that all defective items in the lot will be replaced with good items if the lot is rejected and that any defective items in the sample will be replaced if the lot is accepted.

$$\text{AOQ} = \frac{p(P_a)(N - n)}{N}$$

where

p = true proportion defective of the lot
P_a = probability of accepting the lot
N = lot size
n = sample size

The analyst can calculate AOQ to estimate the performance of the plan over a range of possible proportion defectives in order to judge whether the plan will provide an acceptable degree of protection. The maximum value of the average outgoing quality over all possible values of the proportion defective is called the **average outgoing quality limit (AOQL)**. If the AOQL seems too high, the parameters of the plan must be modified until an acceptable AOQL is achieved.

average outgoing quality limit (AOQL)
The maximum value of the average outgoing quality over all possible values of the proportion defective.

EXAMPLE G.2 Calculating the AOQL

Suppose that Noise King is using rectified inspection for its single-sampling plan. Calculate the average outgoing quality limit for a plan with $n = 110$, $c = 3$, and $N = 1{,}000$. Use Table G.1 (pp. G.9–G.11) to estimate the probabilities of acceptance for values of the proportion defective from 0.01 to 0.08 in steps of 0.01.

myomlab

Tutor G.2 in myomlab provides a new example for calculating the AOQL.

SOLUTION

Use the following steps to estimate the AOQL for this sampling plan:

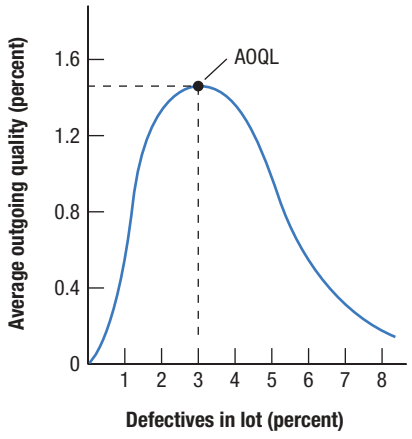
Step 1: Determine the probabilities of acceptance for the desired values of p. These are shown in the following table. However, the values for $p = 0.03$, 0.05, and 0.07 had to be interpolated because the table does not have them. For example, P_a for $p = 0.03$ was estimated by averaging the P_a values for $np = 3.2$ and $np = 3.4$, or $(0.603 + 0.558)/2 = 0.580$.

Proportion Defective (p)	np	Probability of Acceptance (P_a)
0.01	1.10	0.974
0.02	2.20	0.819
0.03	3.30	$0.581 = (0.603 + 0.558)/2$
0.04	4.40	0.359
0.05	5.50	$0.202 = (0.213 + 0.191)/2$
0.06	6.60	0.105
0.07	7.70	$0.052 = (0.055 + 0.048)/2$
0.08	8.80	0.024

Step 2: Calculate the AOQ for each value of p.

For $p = 0.01$: $0.01(0.974)(1000 - 110)/1000 = 0.0087$
For $p = 0.02$: $0.02(0.819)(1000 - 110)/1000 = 0.0146$
For $p = 0.03$: $0.03(0.581)(1000 - 110)/1000 = 0.0155$
For $p = 0.04$: $0.04(0.359)(1000 - 110)/1000 = 0.0128$
For $p = 0.05$: $0.05(0.202)(1000 - 110)/1000 = 0.0090$
For $p = 0.06$: $0.06(0.105)(1000 - 110)/1000 = 0.0056$
For $p = 0.07$: $0.07(0.052)(1000 - 110)/1000 = 0.0032$
For $p = 0.08$: $0.08(0.024)(1000 - 110)/1000 = 0.0017$

The plot of the AOQ values is shown in Figure G.6.



◀ **FIGURE G.6**
Average Outgoing Quality Curve for the Noise King Muffler Service

Step 3: Identify the largest AOQ value, which is the estimate of the AOQL. In this example, the AOQL is 0.0155 at $p = 0.03$.

KEY EQUATION

$$\text{Average outgoing quality: AOQ} = \frac{p(P_a)(N - n)}{N}$$

SOLVED PROBLEM

An inspection station has been installed between two production processes. The feeder process, when operating correctly, has an acceptable quality level of 3 percent. The consuming process, which is expensive, has a specified lot tolerance proportion defective of 8 percent. The feeding process produces in batch sizes; if a batch is rejected by the inspector, the entire batch must be checked and the defective items reworked. Consequently, management wants no more than a 5 percent producer's risk and, because of the expensive process that follows, no more than a 10 percent chance of accepting a lot with 8 percent defectives or worse.

a. Determine the appropriate sample size, n, and the acceptable number of defective items in the sample, c.

b. Calculate values and draw the OC curve for this inspection station.

c. What is the probability that a lot with 5 percent defectives will be rejected?

SOLUTION

a. For AQL = 3 percent, LTPD = 8 percent, $\alpha = 5$ *percent*, and $\beta = 10$ percent, use Table G.1 (pp. G.9–G.11) and trial and error to arrive at a sampling plan. If $n = 180$ and $c = 9$,

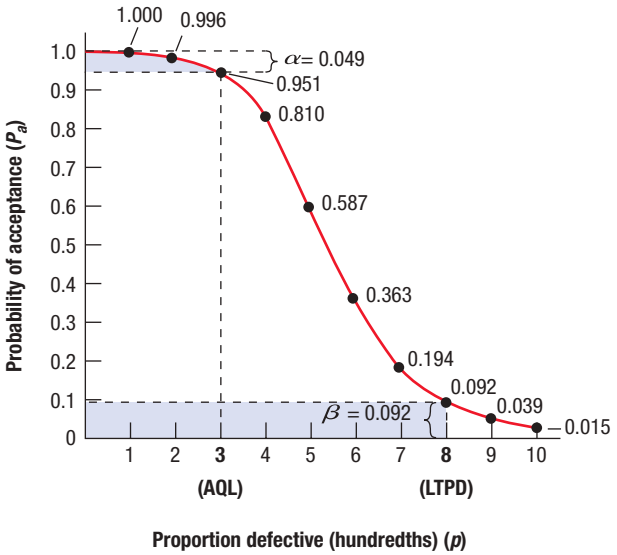
$$np = 180(0.03) = 5.4$$
$$\alpha = 0.049$$
$$np = 180(0.08) = 14.4$$
$$\beta = 0.092$$

Sampling plans that would also work are $n = 200$, $c = 10$; $n = 220$, $c = 11$; and $n = 240$, $c = 12$.

b. The following table contains the data for the OC curve. Table G.1 (pp. G.9–G.11) was used to estimate the probability of acceptance. Figure G.7 shows the OC curve.

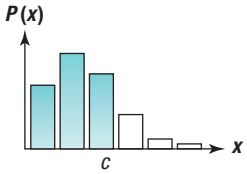
c. According to the table, the probability of accepting a lot with 5 percent defectives is 0.587. Therefore, the probability that a lot with 5 percent defects will be rejected is 0.413, or 1.00 − 0.587.

▼ FIGURE G.7



Proportion Defective (*p*)	*np*	Probability of *c* or Less Defects (P_a)	Comments
0.01	1.8	1.000	
0.02	3.6	0.996	
0.03 (AQL)	5.4	0.951	$\alpha = 1 - 0.951 = 0.049$
0.04	7.2	0.810	
0.05	9.0	0.587	
0.06	10.8	0.363	
0.07	12.6	0.194	
0.08 (LTPD)	14.4	0.092	$\beta = 0.092$
0.09	16.2	0.039	
0.10	18.0	0.015	

TABLE G.1 | CUMULATIVE POISSON PROBABILITIES



$$P(x \le c) = \sum_{x=0}^{x=c} \frac{\lambda^x e^{-\lambda}}{x!}$$

	c													
np	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
.05	.951	.999	1.000											
.10	.905	.995	1.000											
.15	.861	.990	.999	1.000										
.20	.819	.982	.999	1.000										
.25	.779	.974	.998	1.000										
.30	.741	.963	.996	1.000										
.35	.705	.951	.994	1.000										
.40	.670	.938	.992	.999	1.000									
.45	.638	.925	.989	.999	1.000									
.50	.607	.910	.986	.998	1.000									
.55	.577	.894	.982	.998	1.000									
.60	.549	.878	.977	.997	1.000									
.65	.522	.861	.972	.996	.999	1.000								
.70	.497	.844	.966	.994	.999	1.000								
.75	.472	.827	.959	.993	.999	1.000								
.80	.449	.809	.953	.991	.999	1.000								
.85	.427	.791	.945	.989	.998	1.000								
.90	.407	.772	.937	.987	.998	1.000								
.95	.387	.754	.929	.984	.997	1.000								
1.0	.368	.736	.920	.981	.996	.999	1.000							
1.1	.333	.699	.900	.974	.995	.999	1.000							
1.2	.301	.663	.879	.966	.992	.998	1.000							
1.3	.273	.627	.857	.957	.989	.998	1.000							
1.4	.247	.592	.833	.946	.986	.997	.999	1.000						
1.5	.223	.558	.809	.934	.981	.996	.999	1.000						
1.6	.202	.525	.783	.921	.976	.994	.999	1.000						
1.7	.183	.493	.757	.907	.970	.992	.998	1.000						
1.8	.165	.463	.731	.891	.964	.990	.997	.999	1.000					
1.9	.150	.434	.704	.875	.956	.987	.997	.999	1.000					
2.0	.135	.406	.677	.857	.947	.983	.995	.999	1.000					
2.2	.111	.355	.623	.819	.928	.975	.993	.998	1.000					
2.4	.091	.308	.570	.779	.904	.964	.988	.997	.999	1.000				
2.6	.074	.267	.518	.736	.877	.951	.983	.995	.999	1.000				
2.8	.061	.231	.469	.692	.848	.935	.976	.992	.998	.999	1.000			
3.0	.050	.199	.423	.647	.815	.916	.966	.988	.996	.999	1.000			
3.2	.041	.171	.380	.603	.781	.895	.955	.983	.994	.998	1.000			
3.4	.033	.147	.340	.558	.744	.871	.942	.977	.992	.997	.999	1.000		
3.6	.027	.126	.303	.515	.706	.844	.927	.969	.988	.996	.999	1.000		
3.8	.022	.107	.269	.473	.668	.816	.909	.960	.984	.994	.998	.999	1.000	
4.0	.018	.092	.238	.433	.629	.785	.889	.949	.979	.992	.997	.999	1.000	

(continued)

TABLE G.1 (CONT.)

	c													
np	0	1	2	3	4	5	6	7	8	9	10	11	12	13
4.2	.015	.078	.210	.395	.590	.753	.867	.936	.972	.989	.996	.999	1.000	
4.4	.012	.066	.185	.359	.551	.720	.844	.921	.964	.985	.994	.998	.999	1.000
4.6	.010	.056	.163	.326	.513	.686	.818	.905	.955	.980	.992	.997	.999	1.000
4.8	.008	.048	.143	.294	.476	.651	.791	.887	.944	.975	.990	.996	.999	1.000
5.0	.007	.040	.125	.265	.440	.616	.762	.867	.932	.968	.986	.995	.998	.999
5.2	.006	.034	.109	.238	.406	.581	.732	.845	.918	.960	.982	.993	.997	.999
5.4	.005	.029	.095	.213	.373	.546	.702	.822	.903	.951	.977	.990	.996	.999
5.6	.004	.024	.082	.191	.342	.512	.670	.797	.886	.941	.972	.988	.995	.998
5.8	.003	.021	.072	.170	.313	.478	.638	.771	.867	.929	.965	.984	.993	.997
6.0	.002	.017	.062	.151	.285	.446	.606	.744	.847	.916	.957	.980	.991	.996
6.2	.002	.015	.054	.134	.259	.414	.574	.716	.826	.902	.949	.975	.989	.995
6.4	.002	.012	.046	.119	.235	.384	.542	.687	.803	.886	.939	.969	.986	.994
6.6	.001	.010	.040	.105	.213	.355	.511	.658	.780	.869	.927	.963	.982	.992
6.8	.001	.009	.034	.093	.192	.327	.480	.628	.755	.850	.915	.955	.978	.990
7.0	.001	.007	.030	.082	.173	.301	.450	.599	.729	.830	.901	.947	.973	.987
7.2	.001	.006	.025	.072	.156	.276	.420	.569	.703	.810	.887	.937	.967	.984
7.4	.001	.005	.022	.063	.140	.253	.392	.539	.676	.788	.871	.926	.961	.980
7.6	.001	.004	.019	.055	.125	.231	.365	.510	.648	.765	.854	.915	.954	.976
7.8	.000	.004	.016	.048	.112	.210	.338	.481	.620	.741	.835	.902	.945	.971
8.0	.000	.003	.014	.042	.100	.191	.313	.453	.593	.717	.816	.888	.936	.966
8.2	.000	.003	.012	.037	.089	.174	.290	.425	.565	.692	.796	.873	.926	.960
8.4	.000	.002	.010	.032	.079	.157	.267	.399	.537	.666	.774	.857	.915	.952
8.6	.000	.002	.009	.028	.070	.142	.246	.373	.509	.640	.752	.840	.903	.945
8.8	.000	.001	.007	.024	.062	.128	.226	.348	.482	.614	.729	.822	.890	.936
9.0	.000	.001	.006	.021	.055	.116	.207	.324	.456	.587	.706	.803	.876	.926
9.2	.000	.001	.005	.018	.049	.104	.189	.301	.430	.561	.682	.783	.861	.916
9.4	.000	.001	.005	.016	.043	.093	.173	.279	.404	.535	.658	.763	.845	.904
9.6	.000	.001	.004	.014	.038	.084	.157	.258	.380	.509	.633	.741	.828	.892
9.8	.000	.001	.003	.012	.033	.075	.143	.239	.356	.483	.608	.719	.810	.879
10.0	0	.000	.003	.010	.029	.067	.130	.220	.333	.458	.583	.697	.792	.864
10.2	0	.000	.002	.009	.026	.060	.118	.203	.311	.433	.558	.674	.772	.849
10.4	0	.000	.002	.008	.023	.053	.107	.186	.290	.409	.533	.650	.752	.834
10.6	0	.000	.002	.007	.020	.048	.097	.171	.269	.385	.508	.627	.732	.817
10.8	0	.000	.001	.006	.017	.042	.087	.157	.250	.363	.484	.603	.710	.799
11.0	0	.000	.001	.005	.015	.038	.079	.143	.232	.341	.460	.579	.689	.781
11.2	0	.000	.001	.004	.013	.033	.071	.131	.215	.319	.436	.555	.667	.762
11.4	0	.000	.001	.004	.012	.029	.064	.119	.198	.299	.413	.532	.644	.743
11.6	0	.000	.001	.003	.010	.026	.057	.108	.183	.279	.391	.508	.622	.723
11.8	0	.000	.001	.003	.009	.023	.051	.099	.169	.260	.369	.485	.599	.702
12.0	0	.000	.001	.002	.008	.020	.046	.090	.155	.242	.347	.462	.576	.682

(continued)

TABLE G.1 (CONT.)

	c													
np	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
12.2	0	0	0.000	0.002	0.007	0.018	0.041	0.081	0.142	0.225	0.327	0.439	0.553	0.660
12.4	0	0	0.000	0.002	0.006	0.016	0.037	0.073	0.131	0.209	0.307	0.417	0.530	0.639
12.6	0	0	0.000	0.001	0.005	0.014	0.033	0.066	0.120	0.194	0.288	0.395	0.508	0.617
12.8	0	0	0.000	0.001	0.004	0.012	0.029	0.060	0.109	0.179	0.269	0.374	0.485	0.595
13.0	0	0	0.000	0.001	0.004	0.011	0.026	0.054	0.100	0.166	0.252	0.353	0.463	0.573
13.2	0	0	.000	.001	.003	.009	.023	.049	.091	.153	.235	.333	.441	.551
13.4	0	0	.000	.001	.003	.008	.020	.044	.083	.141	.219	.314	.420	.529
13.6	0	0	.000	.001	.002	.007	.018	.039	.075	.130	.204	.295	.399	.507
13.8	0	0	.000	.001	.002	.006	.016	.035	.068	.119	.189	.277	.378	.486
14.0	0	0	0	.000	.002	.006	.014	.032	.062	.109	.176	.260	.358	.464
14.2	0	0	0	.000	.002	.005	.013	.028	.056	.100	.163	.244	.339	.443
14.4	0	0	0	.000	.001	.004	.011	.025	.051	.092	.151	.228	.320	.423
14.6	0	0	0	.000	.001	.004	.010	.023	.046	.084	.139	.213	.302	.402
14.8	0	0	0	.000	.001	.003	.009	.020	.042	.077	.129	.198	.285	.383
15.0	0	0	0	.000	.001	.003	.008	.018	.037	.070	.118	.185	.268	.363
15.2	0	0	0	.000	.001	.002	.007	.016	.034	.064	.109	.172	.251	.344
15.4	0	0	0	.000	.001	.002	.006	.014	.030	.058	.100	.160	.236	.326
15.6	0	0	0	.000	.001	.002	.005	.013	.027	.053	.092	.148	.221	.308
15.8	0	0	0	0	.000	.002	.005	.011	.025	.048	.084	.137	.207	.291
16.0	0	0	0	0	.000	.001	.004	.010	.022	.043	.077	.127	.193	.275
16.2	0	0	0	0	.000	.001	.004	.009	.020	.039	.071	.117	.180	.259
16.4	0	0	0	0	.000	.001	.003	.008	.018	.035	.065	.108	.168	.243
16.6	0	0	0	0	.000	.001	.003	.007	.016	.032	.059	.100	.156	.228
16.8	0	0	0	0	.000	.001	.002	.006	.014	.029	.054	.092	.145	.214
17.0	0	0	0	0	.000	.001	.002	.005	.013	.026	.049	.085	.135	.201
17.2	0	0	0	0	.000	.001	.002	.005	.011	.024	.045	.078	.125	.188
17.4	0	0	0	0	.000	.001	.002	.004	.010	.021	.041	.071	.116	.176
17.6	0	0	0	0	0	.000	.001	.004	.009	.019	.037	.065	.107	.164
17.8	0	0	0	0	0	.000	.001	.003	.008	.017	.033	.060	.099	.153
18.0	0	0	0	0	0	.000	.001	.003	.007	.015	.030	.055	.092	.143
18.2	0	0	0	0	0	.000	.001	.003	.006	.014	.027	.050	.085	.133
18.4	0	0	0	0	0	.000	.001	.002	.006	.012	.025	.046	.078	.123
18.6	0	0	0	0	0	.000	.001	.002	.005	.011	.022	.042	.072	.115
18.8	0	0	0	0	0	.000	.001	.002	.004	.010	.020	.038	.066	.106
19.0	0	0	0	0	0	.000	.001	.002	.004	.009	.018	.035	.061	.098
19.2	0	0	0	0	0	0	.000	.001	.003	.008	.017	.032	.056	.091
19.4	0	0	0	0	0	0	.000	.001	.003	.007	.015	.029	.051	.084
19.6	0	0	0	0	0	0	.000	.001	.003	.006	.013	.026	.047	.078
19.8	0	0	0	0	0	0	.000	.001	.002	.006	.012	.024	.043	.072
20.0	0	0	0	0	0	0	.000	.001	.002	.005	.011	.021	.039	.066

PROBLEMS

1. For $n = 200$, $c = 4$, AQL = 0.5 percent, and LTPD = 4 percent, find α and β.

2. You are responsible for purchasing bearings for the maintenance department of a large airline. The bearings are under contract from a local supplier, and you must devise an appropriate acceptance sampling plan for them. Management has stated in the contract that the acceptable quality level is 1 percent defective. In addition, the lot tolerance proportion defective is 4 percent, the producer's risk is 5 percent, and the consumer's risk is 10 percent.
   a. Specify an appropriate acceptance sampling plan that meets all these criteria.
   b. Draw the OC curve for your plan. What is the resultant producer's risk?
   c. Determine the AOQL for your plan. Assume a lot size of 3,000.

3. The Sunshine Shampoo Company purchases the label that is pasted on each bottle of shampoo it sells. The label contains the company logo, the name of the product, and directions for the product's use. Sometimes the printing on the label is blurred or the colors are not right. The company wants to design an acceptance sampling plan for the purchased item. The acceptable quality level is 5 defectives per 500 labels, and the lot tolerance proportion defective is 5 percent. Management wants to limit the producer's risk to 5 percent or less and the consumer's risk to 10 percent or less.
   a. Specify a plan that satisfies those desires.
   b. What is the probability that a shipment with 3 percent defectives will be rejected by the plan?
   c. Determine the AOQL for your plan. Assume that the lot size is 2,000 labels.

4. Your company supplies sterile syringes to a distributor of hospital supplies. The contract states that quality should be no worse than 0.1 percent defective, or 10 parts in 10,000. During negotiations, you learned that the distributor will use an acceptance sampling plan with $n = 350$ to test quality.
   a. If the producer's risk is to be no greater than 5 percent, what is the lowest acceptance number, c, that should be used?
   b. The syringe production process averages 17 defective parts in 10,000. With $n = 350$ and the acceptance level suggested in part (a), what is the probability that a shipment will be returned to you?
   c. Suppose that you want a less than 5 percent chance that your shipment will be returned to you. For the data in part (b), what acceptance number, c, should you have suggested in part (a)? What is the producer's risk for that plan?

5. A buyer of electronic components has a lot tolerance proportion defective of 20 parts in 5,000, with a consumer's risk of 15 percent. If the buyer will sample 1,500 of the components received in each shipment, what acceptance number, c, would the buyer want? What is the producer's risk if the AQL is 10 parts per 5,000?

6. Consider a certain raw material for which a single-sampling attribute plan is needed. The AQL is 1 percent, and the LTPD is 4 percent. Two plans have been proposed. Under plan 1, $n = 150$ and $c = 4$; under plan 2, $n = 300$ and $c = 8$. Are the two plans equivalent? Substantiate your response by determining the producer's risk and the consumer's risk for each plan.

7. You currently have an acceptance sampling plan in which $n = 40$ and $c = 1$, but you are unsatisfied with its performance. The AQL is 1 percent, and the LTPD is 5 percent.
   a. What are the producer's and consumer's risks for this plan?
   b. While maintaining the same 1:40 ratio of *c:n* (called the *acceptance proportion)*, increase c and n to find a sampling plan that will decrease the producer's risk to 5 percent or less *and* the consumer's risk to 10 percent or less. What producer's and consumer's risks are associated with this new plan?
   c. Compare the AOQLs for your plan and the current plan. Assume a lot size of 1,000 units.

8. For AQL = 1 percent, LTPD = 4 percent, and $n = 400$, what value(s) of the acceptance number, c, would result in the producer's risk and the consumer's risk *both* being under 5 percent?

9. For AQL = 1 percent and $c = 2$, what is the largest value of n that will result in a producer's risk of 5 percent? Using that sample size, determine the consumer's risk when LTPD = 2 percent.

10. For $c = 10$ and LTPD = 5 percent, what value of n results in a 5 percent consumer's risk?

11. Design a sampling plan for AQL = 0.1 percent, LTPD = 0.5 percent, producer's risk $\leq$ 5 percent, and consumer's risk $\leq$ 10 percent.

12. Design a sampling plan for AQL = 0.01 percent (100 parts per million), LTPD = 0.05 percent (500 ppm), producer's risk $\leq$ 5 percent, and consumer's risk $\leq$ 10 percent. Observe the similarity of this problem to Problem 11. As AQL decreases by a factor of K, what is the effect on the sample size, n?

13. Suppose that AQL = 0.5 percent, $\alpha = 5$, LTPD = 2 percent, $\beta = 6$ percent, and $N = 1{,}000$.
   a. Find the AOQL for the single-sampling plan that best fits the given parameter values.
   b. For each of the following experiments, find the AOQL for the best single-sampling plan. Change only the parameter indicated, holding all others at their original values.
      i. Change N to 2,000.
      ii. Change AQL to 0.8 percent.
      iii. Change LTPD to 6 percent.
   c. Discuss the effects of changes in the design parameters on plan performance, based on the three experiments in part (b).

14. Peter Lamb is the quality assurance manager at an engine plant. The summer intern assigned to Lamb is a student in operations management at a local university. The intern's first task is to calculate the following parameters, based on the SPC information at the engine plant:

$$\text{AQL} = 0.02 \text{ percent}, \beta = 1 \text{ percent}, \alpha = 2 \text{ percent}, N = 1000, \text{LTPD} = 2.5 \text{ percent}$$

a. Find the AOQL for the single-sampling plan that best fits the given parameter values.

b. For each of the following experiments, find the AOQL for the best single-sampling plan. Change only the parameter indicated, holding all others at their original values.

i. Change N to 2,000.
ii. Change AQL to 0.3 percent.
iii. Change LTPD to 4 percent.

c. Discuss the effects of changes in the design parameters on plan performance, based on the three experiments in part (b).

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Reliability

-Lecture 5

Reliability

- (informal definition)Reliability is a measure of how long the item performs its intended function.
- (informal definition)Reliability is a measure of the *probability* that an item will perform its *intended function* for a specified interval under *stated conditions.*
- "Engineering Reliability" is derivative of these. Engineering reliability is the probability that a product, device or equipment will give failure free performance of its intended functions for the required duration of time.
- Need for Reliability Engineering:
  - Advances in technology: new products with new features & complex
  - Subcontracting system grew up
  - Reliability in maintenance job: Workmanship reliability, reliability of inputs used (spares, sub-assemblies, tools, consumables etc.)
  - Failure of one components does not always mean failure of the system or a project or a mission.

Reliability

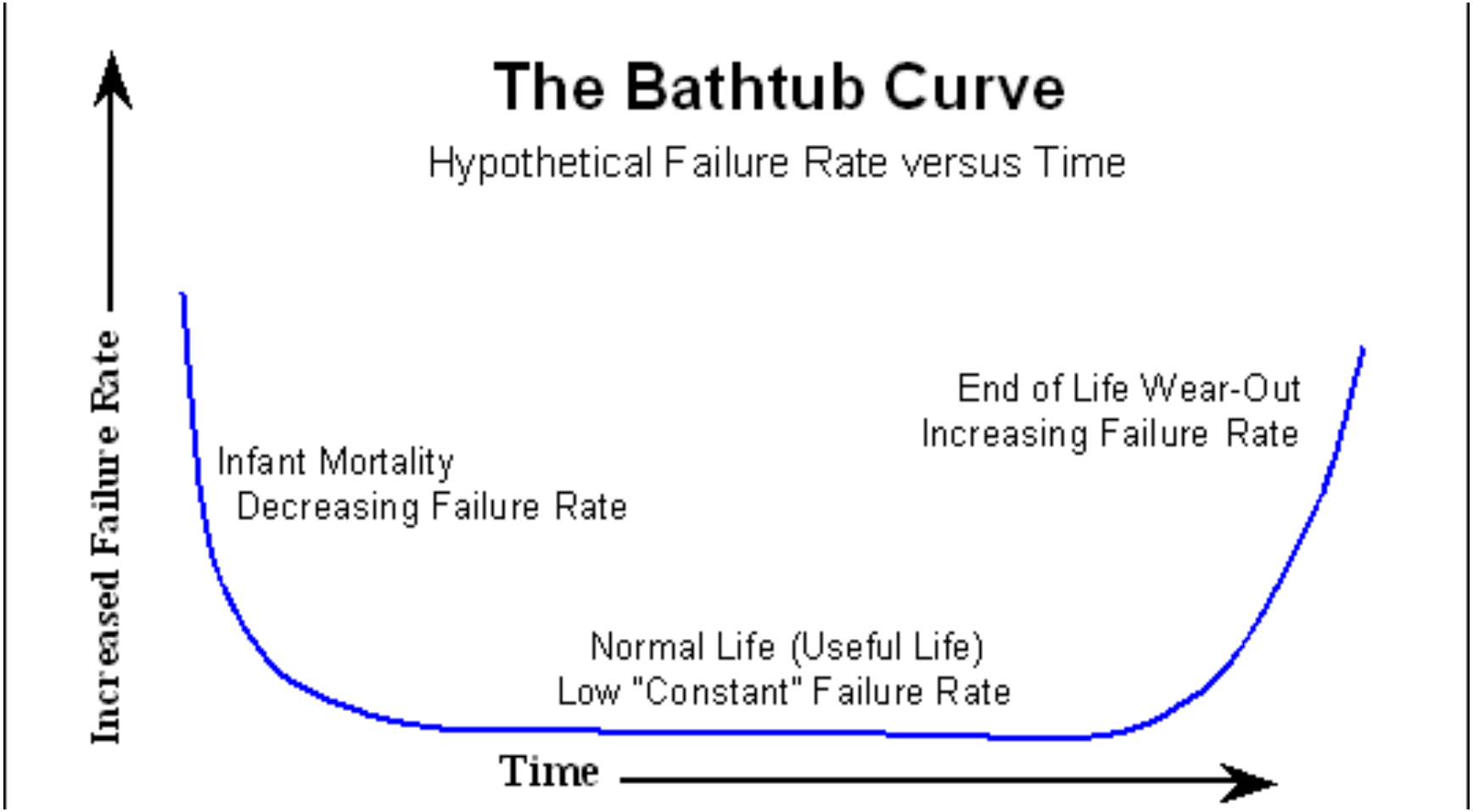
- Types of Failures
  - Functional failure – failure that occurs at the start of product life due to manufacturing or material detects
  - Reliability failure – failure after some period of use
- Types of Reliability
  - Inherent reliability – predicted by product design
  - Achieved reliability – observed during use
- Two commonly used measures of reliability
  - Mean Time between Failure (MTBF), defined as

$$MTBF = \frac{Total\ time\ in\ service}{Number\ of\ failures}$$

  - Failure rate (λ), defined as

$$\lambda = \frac{Number\ of\ failures}{Total\ time\ in\ Service}$$

Bath tub curve



Mean Time Between Failures (MTBF)

- Reliability is quantified as MTBF (Mean Time Between Failures) for repairable product and MTTF (Mean Time To Failure) for non-repairable product. A correct understanding of MTBF is important. A power supply with an MTBF of 40,000 hours does not mean that the power supply should last for an average of 40,000 hours
- An MTBF of 40,000 hours, or 1 year for 1 module, becomes 40,000/2 for two modules and 40,000/4 for four modules.

MTTF is stands for Mean Time To Failure.

- To distinguish between the two, the concept of suspensions must first be understood. In reliability calculations, a suspension occurs when a destructive test or observation has been completed without observing a failure.
- MTBF calculations do not consider suspensions whereas MTTF does. MTTF is the number of total hours of service of all devices divided by the number of devices. It is only when all the parts fail with the same failure mode that MTBF converges to MTTF

MTBF vs MTTF

$$\theta = T/R.$$

θ = MTBF
T = total time
R = number of failures

$$\gamma = T/N$$

γ = MTTF
T = total time
N = Number of units under test.

Suppose 10 devices are tested for 500 hours. During the test 2 failures occur. The estimate of the MTBF is:

= 10*500/2
= 2500 hours/failure

= 10*500/10
= 500 hours/failure

Reliability process & Improvement

- Reliability Engineering is the technology concerned with predictions, controls, measurements, continuous improvements in materials and technologies and thus continuous reduction of equipment failure rates.
- Reliability control and assurance involve proper surveillance (use of techniques for measurement, evaluation and control/monitor etc.).
- Reliability is different from quality as reliability places more emphasis on the activities of design, manufacturing and operation in the field.
- Generally, in industries, reliability does not necessarily mean failure free operation. Of course, failure free operation is important for one shot devices (missiles, unmanned spacecraft) and non-repairable systems like aircraft, high hazard equipment's or lifesaving equipments etc.

Reliability process & Improvement

- The following processes are essential in reliability study programme:
  - The reliability programme starts in the conceptual phase of the product or equipment and continues throughout the design, development, production, testing, field evaluation and service stages etc.
  - Adequate management and organisational support should be there. Involvement of all departmental units, that affect reliability, is essential.
  - Proper failure reporting system from all concerned agencies has to be built up. Necessary signal measuring devices should be installed and their feedback to be monitored.
  - Proper action plans, specifying responsibilities, procedures, schedules and budgets (if necessary) to be issued and followed up.
  - The execution of programme is both technical and managerial function. The programme should include necessary controls to detect and report deviations for taking corrective actions.

Reliability process & Improvement

- Few design aspects for reliability improvements for industrial equipment's are given below
  - ***Massive Over-design***
  - ***Simplicity and Standardization***
  - ***De-rating of Equipment's***
  - ***Human Engineering and Maintainability Considerations,*** *Making the design in* such a way that using incorrectly or fitting incorrect parts are very difficult.

Identifying critical components/parts having less reliability and taking necessary actions is also one of the main tasks of reliability improvement. 80-20 concept can be applied here also *i.e., 20% of parts amount for 80% of failures/problems.*

Use of Reliability

- Availability of reliability information's (MTBF, MTTF and probability of service etc.) are beneficial in the following ways
  - *For Maintenance Personnel:* Knowledge of life expectancy and wear-out characteristics of the components and equipment's help in development of –
    - Good maintenance frequencies,
    - Estimated need of spare parts and stand-bye equipment's/assemblies,
    - Proper replacement plans.
  - *For Assessing Equipment Availability:* Equipment availability depends on reliability and maintainability. Also equipment effectiveness = Reliability x Availability.

Use of Reliability(Contd.)

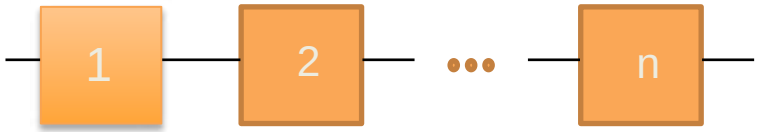
- *Mission Success: Reliability permits evaluation of the success likelihood of a* mission or project.
- *Cost Control: Cost of product or equipment also depends on extent of reliability* essentially required. For industrial products or equipment's, a balance is struck between cost and reliability needed.
- *Safety: Only by knowing the reliability of components, equipment can be built for* maximum safety.

Reliability assurance & testing

- Reliability Assurance means how to assure that the products or equipment's have the required degree of reliability for their intended functions of mission.
  - Abbreviated life tests: chance failure
  - Failure-Repair runs:
    - The equipment or component is run till failure.
    - With few such trials, failure mode and pattern is established
    - However, this may be time consuming. Although an equipment may be non-repairable in actual application, it is often feasible to repair during reliability testing at higher cost.
  - Accelerated test
    - Ingenious methods and techniques are implemented to compress the time and creating nearly same number of stresses and failure chances in that compressed time as would have existed in actual life cycle.
  - Test for increased severity
  - Test for large sample size

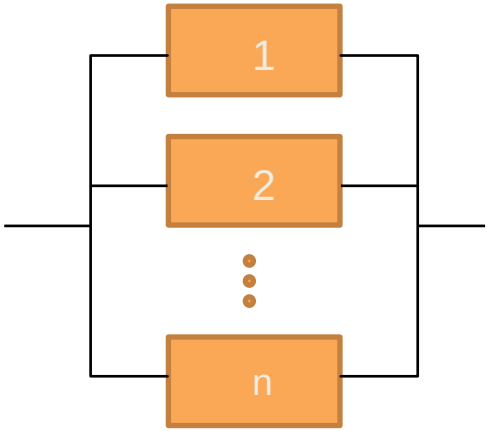
System Reliability

Series Systems



$R_S = R_1 * R_2 * \ldots * R_n$

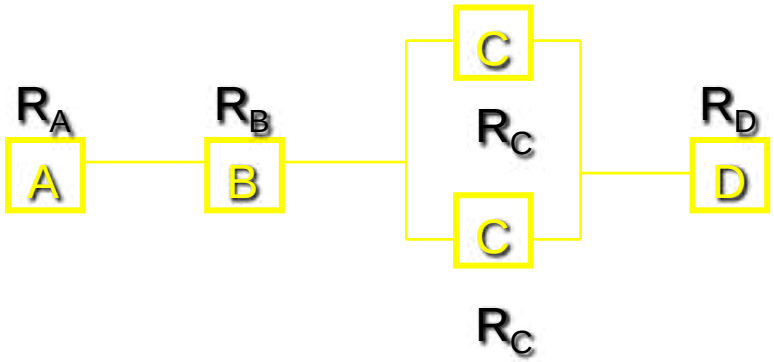
Parallel Systems



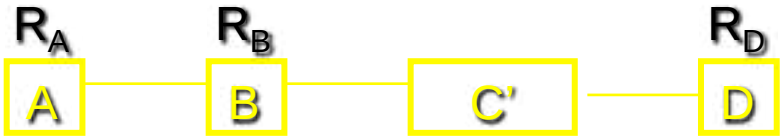
$R_S = 1 - (1 - R_1)$

$(1 - R_2) \ldots (1 - R_n)$

Series-Parallel Systems



Convert to equivalent series system

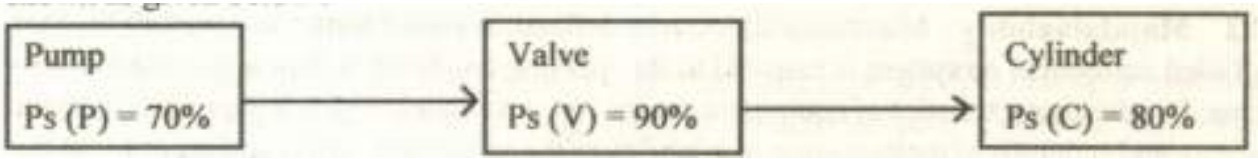


$R_{C'} = 1 - (1-R_C)(1-R_C)$

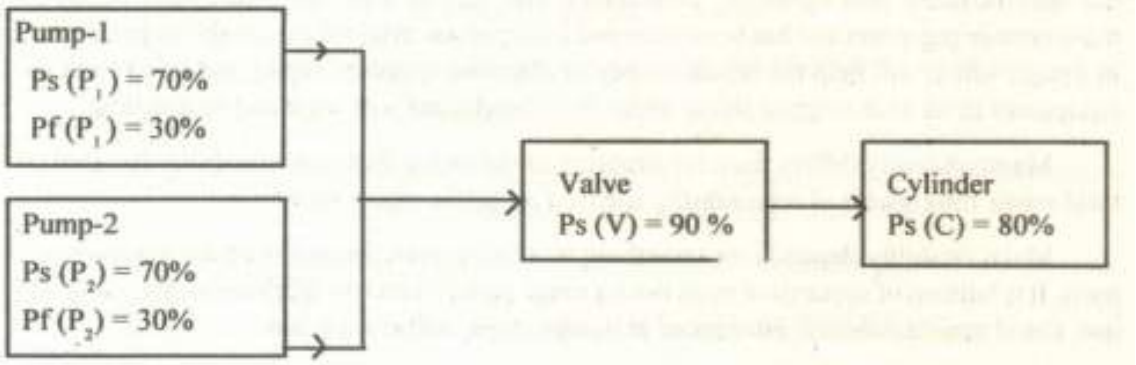
Reliability through redundancy

- In a system where there are many sub-systems, reliability or each element should be improved to near 100% reliability to achieve good reliability.
  - 400 elements having 98% reliability has 2% as system reliability
- If cannot improve sub-system reliability further, still we can improve the system reliability by redundancy
  - i.e. we can duplicate, or triplicate sub-systems which are not functionally needed & most of the

Reliability through redundancy (Contd.)



$$Ps\ (System) = 70\% \times 90\% \times 80\% = 50\%$$



$$\therefore\ Ps\ (\text{at least one pump}) = 100\% - Pf(P_1) \times Pf(P_2)$$
$$= 100\% - (30\% \times 30\%) = 91\%$$
$$\therefore\ Ps\ (System) = Ps\ (\text{at least one pump}) \times Ps\ (V) \times Ps\ (C)$$
$$= 91\% \times 90\% \times 80\% = 66\%$$

Similarly if we triplicate the pump units (in parallel)

$$Ps\ (System) = [100\% - Pf(P_1) \times Pf(P_2) \times Pf(P_3)] \times Ps\ (V) \times Ps\ (C)$$
$$= 97.3\% \times 90\% \times 80\% = 70\%$$

Reliability through redundancy (Contd.)

- Thus by redundancy, the system reliability can be improved.
- But this is a very costly process and also takes lot of additional space which may not be possible in some equipment's or systems.
- In addition to cost and space limitations, there are some additional constraints in reliability through redundancy, such as-
  - Parallel equipment's are, sometimes, connected through a change-over switch (for automatic change-over) which may not be fail-proof and may introduce another reliability factor.
  - With duplication or triplication of components, non-working failed components may cause adverse effect

Maintenance Productivity Measurements (Contd.)

- Two models for defining & fixing of maintenance performance are
  - **Manufacturing based model.**
    - Productivity of maintenance productivity solely dependent on two factors
      - Plant output
      - Maintenance input costs (e.g., man-hour, material, facilities and services etc.) associated with that class like mechanical, electrical, instrumentation etc.,
    - Some of **the advantages** of such model are
      - The data are mainly cost-related and easily available in organization.
      - Measurement methodology is easy and easily acceptable by management.
      - Interplant comparison is possible.
    - **Limitations of the model**
      - It does not inform or help in determining the effectiveness of maintenance operations/jobs in enhancing production outputs or reducing downtimes of plants and machineries.
      - Further, values of most of the measures are determined generally at the total plant level and so productivity measures of individual department and group levels become little difficult.

Maintenance Productivity Measurements (Contd.)

- Two models for defining & fixing of maintenance performance are
  - Service based Model.
    - Plant and organization level as well as for department and group levels of an organization structure.
    - The model is essentially based on monitoring and controlling performance separately for each of the two inter-related classes of activities.
    - These are again of two types:
      - Quality-based performance parameters:
        - » These include parameters/attributes of quality characteristics which are related to production or operation departments such as reliability, availability and waiting time etc.
      - Operation-based performance parameters:
        - » These include parameters/attributes related to maintenance department or group such as backlog of work, overtime, repair mean time and maintenance cost, etc.

Performance Measuring Parameters/Indices

- Quality based parameters
  - Equipment Reliability: It is the probability that an equipment will not fail in service.
    - Reliability data are plotted in the form of a survival curve. One way of expressing the equipment reliability is
    - Mean time between shutdown's (MTBS)
      - Operating runs, terminating in scheduled inspections or major overhauls, are not normally included.
      - **Higher** MTBS means reliability is **better** and **lowe**r MTBS means operating stresses are **higher** or more corrosive conditions prevail or inadequate preventive maintenance etc.
    - Failure rate (λ):
      - MTBF is reciprocal of failure rate. It is the average time between two successive failures.
      - Higher the MTBF, greater is the reliability of the equipment/system.
      - MTBF is generally used for repairable systems.

Performance Measuring Parameters/ Indices (Contd.)

1. Equipment Maintainability:
   - It is defined as the probability that a failed equipment can be repaired within a given period of time.
   - It is designated by Mean Time Down (MTD) and is calculated as given below

   - Here again, the downtime for scheduled inspection and major overhauls are normally not included.
   - Lower MTD indicates better maintainability and greater MID indicates poor maintainability.

2. Equipment Availability
   - It is the probability that the equipment is available for use over a given calendar period and is calculated from MTBS and MTD.
   - The MTBS is a measure of equipment's operability or up-time and MTD is a measure of its inoperability or downtimes and, so, total time is sum of MTBS and MTD.

Performance Measuring Parameters/ Indices (Contd.)

3. Equipment Utilization
    - *Equipment utiliztion=Hours equipment ran @capacity+weekly off+Yearly major repair/ Total calender hours during evaluaiton time*
4. Man-power efficiency
    - *Man Power efficiency=Total man hour actually worked on the jobs/Total man hour scheduled for these jobs*
5. Emergency (Breakdown) Repair percentage or ratio
    - *Man Hour %=Total hours worked on emergency jobs /Total hours worked on all jobs during*

Machine Availability

- Availability is a measure of the % of time the equipment is in an operable state.
  - Presumably, if the equipment is available 85% of the time, we are producing at 85% of the equipment's technical limit.
  - Of course quality and machine speed need to be considered in order to have a proper representation of how close we are to this technical limit.
  - Availability can be measured as:

$$Availability = \frac{Uptime}{Total\ Time} = \frac{Uptime}{Uptime + Downtime}$$

  - Equates to the financial performance of the asset

Overall Availability & Availability Rate

- Availability is the actual time that the machine or system is capable of production as a percent of total planned production time.

- Availability rate should not be confused with overall availability. The latter is calculated using total calendar time as the divisor, not planned production time

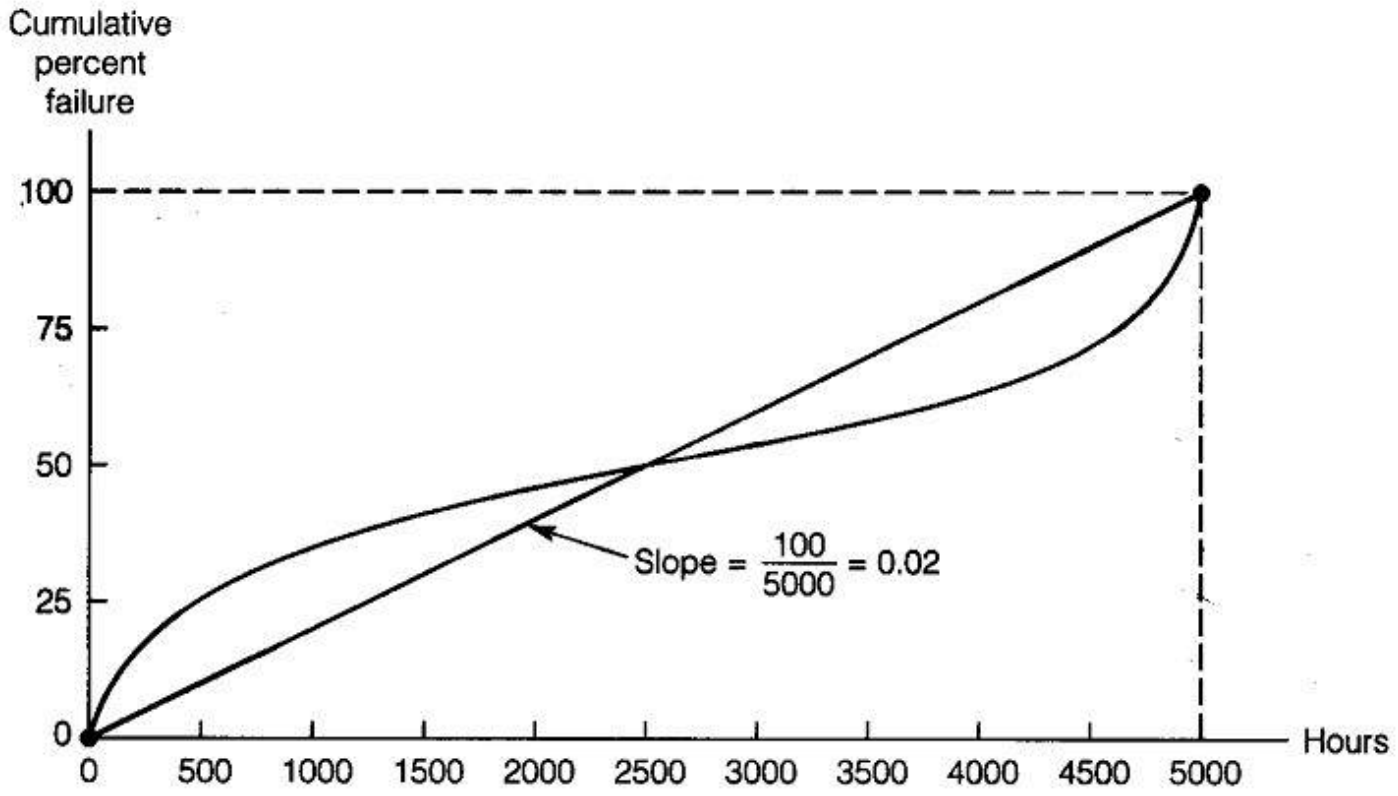
Reliability & Machine Availability

- A piece of equipment can be available but not reliable
- For example the machine is down 6 minutes every hour

$$Availability = \frac{54}{60} = \frac{54}{54+6} = 90\%$$

- *This translates into an availability of 90% but a reliability of less than 1 hour*
- That may be okay in some circumstances but what if this is a *paper machine*? It will take at least 30 minutes of run time to get to the point

Average Failure Rate



Reliability Function

- Probability density function of failures $f(t) = \lambda e^{-\lambda t}$ for $t > 0$
- Probability of failure from (0, T)

  $F(t) = 1 - e^{-\lambda T}$
- Reliability function

  $R(T) = 1 - F(T) = e^{-\lambda T}$

Reliability Engineering

- Standardization
- Redundancy
- Physics of failure
- Reliability testing
- Burn-in
- Failure mode and effects analysis
- Fault tree analysis

Maintenance Economics

Lecture 9

Introduction

- Maintenance cost is generally the total cost incurred in doing the maintenance jobs and keeping a maintenance organization.
- Costs of inadequate maintenance or no maintenance are in the nature of "opportunity“ costs which are not recorded in any system of cost accounting as part of regular reporting system. These "Opportunity" costs are in the form of
  - lower rate of output,
  - poor quality of products,
  - wastages, defectives, damage to equipment's
  - and reduction in the useful life of the equipment's etc.
- As such a well-conceived maintenance policy must minimize the total maintenance cost and also costs of inadequate maintenance.

Maintenance cost behaviour

- For planning and control purposes, generally the costs are divided into following two categories depending on the behavior of such costs in relation to some measure of quantity like production, sales etc.
  - Fixed Cost.
    - The cost of maintaining "ready to serve" men and facilities are fixed costs which have little relationship with the actual amount of maintenance work done during a given period of time
  - Variable Cost
- Maintenance costs consist of some amount of both, fixed and variable costs and so maintenance costs generally fall into the grey area of semi-variable costs.

Factors of Availability

- Measure of the ability of power plants, a unit or a plant section to perform its operational function. A distinction is to be made between equipment availability and energy availability:
- Equipment availability is the ratio of available time (operating and standby time) to the calendar period. Equipment availability characterizes the reliability of a plant.
- Energy availability is the ratio of available energy to theoretically possible energy in the period under report. Characterizes the reliability of a plant in general considering all complete and partial outages.

MTBF MTTR & MWT

Lecture 5

Mean time to Failure (MTTF)

- Mean Time To Failure (MTTF) : average time between two failures (ignoring fix time for a while) caused by some defect.
- For failure incidents of f1, f2, through fn, measure the time from one failure to the next failure (e.g. between fm and f (m+1)) t1, t2 through tn. The average of t1 through tn is the the MTTF.
- With the MTTF, we are interested in the prediction of what the t (n+1) may be.
- Reliability is the estimated probability of t (n+1), based on MTTF.
- There are other metrics use for reliability such as defects/ loc or defects /function point.

Mean time to Repair (MTTR)

- Mean Time to Repair (MTTR): the average time required to locate and fix the problem.
  - This is the time that the system is down and getting repaired; therefore the system is not available.
  - Maintainability is sometimes measured with MTTR.
- Mean Time Between Failure (MTBF): this time between failure takes into account of the average time that the system is under repair or MTBF = MTTF + MTTR.
- Availability of the system may be measured with a ratio such as MTTF/MTBF

Another Way to Use the 3 Metrics

- M. Shooman used the same metrics and characterized reliability, availability and maintainability with a standard scale between 0 and 1. (the closer to 1 --- the better)
- Reliability = MTBF/(1+MTBF)
- looking for big MTBF
- Availability = MTBF/(MTBF + MTTR)
- looking for big MTBF and small MTTR
- Maitainability = 1/(1 + MTTR)
- looking for small MTTR --- close to zero

Mean waiting time?(MWT)

Reliability & Machine Availability

Lecture 4

Reliability

- Reliability Definition: The *reliability of a product (system) is the probability that the item will perform* its intended function throughout a specified time period when operated in a normal(or stated) environment
- There are two commonly used measures of reliability:
  - Mean Time Between Failure (MTBF), which is defined as: total time in service / number of failures.
  - Failure Rate (λ), which is defined as: number of failures / total time in service.
- Reliability Theory: deals with the interdisciplinary use of probability, statistics, and stochastic modeling, combined with engineering insights into the design and the scientific understanding of the failure mechanisms, to study the various aspects of reliability

As such, it encompasses issues such as (i) reliability modeling, (ii) reliability analysis and optimization, (iii) reliability engineering, (iv) reliability science,(v) reliability technology, and (vi) reliability management.

Tools & Techniques for Reliability

- Tools used in the design stage for identifying failures and determining their consequences are as follows:
- **Failure modes and effects analysis (FMEA):** FMEA is a technique for analysis of a system in terms of its subsystems, assemblies, and so on, down to the part level, to determine failure causes. The analysis addresses issues such as how parts can conceivably fail, the mechanisms producing each failure mode, how the failures are detected, and what can be done to compensate for the failure.
- **Failure modes and effects and criticality analysis (FMECA):** This is FMEA in which criticality of each possible failure is also assessed.
- **Fault tree analysis:** A fault tree is a logic diagram that shows the relationship between a potential event affecting the system and the possible underlying causes for this event. Causes may be part or component failures, human error, environmental conditions, or combinations of these. The fault tree specifies the state (working or failed) of the system in terms of the states of its components.

Availability

- Reliability is often confused with Availability
- Availability is a measure of the % of time the equipment is in an operable state while reliability is a measure of how long the item performs its intended function.
- If the equipment is available 85% of the time, we are producing at 85% of the equipment's technical limit. This usually equates to the financial performance of the asset.
- Of course quality and machine speed need to be considered in order to have a proper representation of how close we are to this technical limit.
- Availability can be measured as: Uptime / Total time (Uptime + Downtime).

Reliability Vs Availability

- A piece of equipment can be available but not reliable. For example the machine is down 6 minutes every hour. This translates into an availability of 90% but a reliability of less than 1 hour. That may be okay in some circumstances but what if this is a paper machine? It will take at least 30 minutes of run time to get to the point that we are producing good paper.
- Generally speaking a reliable machine has high availability but an available machine may or may not be very reliable.

CHAPTER - 1

RELIABILITY ENGINEERING BASICS AND OPTIMIZATION TECHNIQUES

Table of Contents

CHAPTER - 1

1.1 INTRODUCTION

For a company to succeed in today's highly competitive & complex environment, it is necessary to know the reliability of it's product and to control it in order to manufacture the product at an optimal reliability level. This results in the product's cost to be minimum and minimize lifecycle cost for the consumer without compromise on the product's quality and reliability.

"Reliability is the probability and capability of components, parts, equipment, products and systems to perform their necessary function for desired period of time without failure in specified environments and with desired confidence". System reliability can be enhanced through provision of redundant parts in parallel or by incremental improvement in part reliability which results in enhancing the system cost. It may be useful to increase the part reliability to some degree and provide redundancy at that point i.e. the tradeoff between these two options.

The typical producer does not actually identify how satisfactorily his products are performing because of lack of reliability-wise viable malfunction reporting system. A practical investigation, interpretation and feedback structure in all business areas that deal with the manufactured products from its birth to its death is vital. If the manufacturer's products are functioning truly and satisfactorily, because they maybe unnecessarily over-designed and hence they are not designed optimally. As a result, the goods may be costing more

than required and lowering profits. Goods are becoming more complex yearly, with the accumulation of more features and components to match competitors' goods. This means that goods with currently acceptable reliabilities should be monitored continuously as the addition of features and goods may decrease the product's overall reliability. If the company does not design its goods with quality and reliability in mind, someone else will design.

The increasing dependence on technology requires that the goods that make up our everyday lives work successfully for the designed-in or desired time period. It is not enough that a component works for a time period shorter than its mission but at the same time it is not necessary to design a system to operate over its intended life, as it would impose extra costs on the company. In today's complex world where many significant operations are performed with automated machinery, we are dependent on the successful function of these equipment (*i.e*. their reliability) and on their quick restoration to function (*i.e*. their maintainability) if they fail.

Component failures have varying effects which range from those which cause minor damage, such as the malfunction of a T.V's remote control (which can become a major irritation, if not a catastrophe, depending on the most interesting event schedule of the day), to a catastrophic failure causing loss of property and life, such as a flight accident. Reliability engineering was born out of the requirement to avoid such catastrophic events which can lead to the unnecessary loss of life and property. Boeing was one of the foremost commercial

companies to implement reliability engineering whose success can be seen in the safety of today's commercial air travel.

Today, reliability engineering can be applied to many products. The earlier example of a remote control which has failed does not have any major life and death consequences to the costumer. However, it may pose a life risk to a non-biological unit: the company that manufactured it. Today's consumer is more clever and product-aware than the end user of years past. The modern customer will no longer tolerate goods that do not perform in a reliable way, or as promised or advertised. Customer disappointment with a product's reliability can have catastrophic financial consequences to a firm. Statistics show that when a customer is content with a product he might tell seven other people; however, a discontented customer will tell 23 people, on an average.

The important applications with which many recent products are entrusted create their reliability a factor of vital importance. For example, the failure of a computer part will have more negative consequences now than it did twenty years back. This is because twenty years ago the technology was relatively new and not extremely widespread, and one most likely had endorsement paper copies somewhere. Now, as computers are commonly the only medium in which lots of computational and clerical functions are performed, the malfunction of a computer component will have a greater effect.

Basic kinds of a system performance measurement:

1) Reliability

2) Availability

3) Percentile life

4) Mean time to failure

Reliability has been extensively used and carefully studied as a performance measure for non-maintained systems. Availability, which describes the percentage of time which the system really function is used for a maintained system.

1.2 RELIABILITY

Reliability is a rapid developing branch changing the approach of the people/ engineers towards the design. “Reliability is the probability and capability of parts, components, equipment, products and systems to perform their required function for desired periods of time without failure”.

If ‘T’ is the time for the system to fail, then the system reliability can be expressed as

$$R(t) = p(T>t)$$

Thus, reliability is a function of time as well on the environmental conditions, which may or may not vary with time. The numerical value of reliability always lies between 0 and 1 i.e.

$$R(\infty) = 0 \text{ and}$$

$$R(0) = 1.$$

“Quality is defined as the extent to which the product satisfies the user’s requirements”. Product quality is a significant function of design and in conformity with design specifications. Reliability is

associated with design where as quality depends on adherence to manufacturing procedures and tolerances and on production system. General principles of design for higher reliability are:

1. Element / Component Selection: The element to be used should be adequate and free from failure rate limit. The technologies which are well established should be used especially in the field of electrical/electronic visualizing the reliability aspect of one over the other.
2. Factor of Safety: It is an important factor for the design of equipment/components where loads/ stresses are of unstable nature. A system is likely to have early failures if subjected to over loading. For an electronic circuit, the voltage stress rate has to be kept well below 0.7 to reduce its failures and in case of mechanical element/ component a safety margin more than 5.0 should be used to minimize its failures.
3. Environment: The failure rates are significantly dependent on the environment. Therefore, environmental factor should be considered and components/ elements with a high quality level that are capable of withstanding the environmental conditions shall be used. Such components will have less failure rate and thus compensate for a high capital cost involved in their manufacture, if any.
4. System complexity: In series reliability model, the failure rate is added depending upon the number of components used. Thus, the number of elements / components in the system should be as

minimum as possible to execute its function. In electronic systems, reliability can be enhanced by using integrated circuits, which substitute many hundreds of basic devices. The malfunction rate of integrated circuit is generally lesser than the total of the failure rate of the components it replaces.

5. Redundancy: A parallel system increases the reliability of the overall system. This must be considered only where certain components/ elements have very high failure rates as it adds to cost.
6. Diversity: When a common power supply is shared by all the components, the breakdown of one component causes breakdown of other components. Failure of power supply will cause all other circuits to fail. When the probability of common mode failure restricts the reliability of the entire system, the use of equipment diversity must be considered. Here, a given task is performed by two systems that are parallel with different operating principles but each system is made up of dissimilar elements. A temperature measurement system using pneumatic and electronic systems may differ in failure patterns.
7. Reliability calculation: Based on failure rates of the components/elements, the overall system reliability is calculated depending upon their arrangement viz. parallel or series or parallel- series as the case might be. The evaluated reliability/ failure rate of the overall system is then compared with the desired value. If the evaluated value is not found within the preferred

limits; the design should be adjusted till the target value is reached.

The system, therefore, is so designed that the failure rate is the least i.e. the failure free period is the highest. The techniques of Failure Mode and Effect Analysis [FMEA] and failure tree analysis [FTA] can be used.

1.3 RELIABILITY ANALYSIS

Evaluation of reliability of the system from its fundamental elements is one of the most significant aspects of reliability analysis. The system consists of a set of items with proper coordinated function that leads to the correct functioning of the system. The physical configuration of a component that belongs to a system is frequently used to model system reliability. In few cases, the way in which the system fails is considered for system reliability analysis. The various modeling schemes for reliability analysis are success tree, fault tree and block diagrams methods.

A system designer while designing and planning a system with reliability as basic design parameter of the system, often faces several conflicting problems. Owing to growing automation and intricacy of tasks entrusted to various sub-systems, they are frequently composed of an increasing number of elements that lead to the decline in overall system reliability. On the other hand, the growing importance of the tasks performed by such systems imposes severe reliability requirements. Resolution of this conflict requires a careful

investigation of many aspects of the problem of raising the system reliability. Reliability cannot be improved without investing money and achieving this objective requires both systematic and scientific analysis and specific material expenditure.

The vital tasks of a reliability designer would be estimation of the safety characteristics and system reliability, assessment of specific characteristics of different designs independently and location of weak spots (elements or subsystems) in the design and assessment of their effects to the unreliability of system.

The above considerations require a systematic reliability analysis at the design phase of the system. In order to carry out an efficient and effective reliability analysis, the following tools and aids are to be used.

As reliability is considered as a way to estimate the effectiveness of a system, an accurate and systematic method is very important for doing a persistent reliability analysis.

The quantitative analysis starts with a physical model i.e., a depiction of the functional relationship among various subsystems and components and the mathematical models for probable failures are developed. A quantitative analysis should be carried out for establishing a rational physical model which entails the disintegration of a particular system into components and subsystems and system working states consistent with the reliability criteria and rules.

1.4 DESIGNING FOR HIGHER RELIABILITY

A numerous techniques are present to improve the system reliability. A few important methods are:

1. Use of overrated components
2. Effective and creative design
3. Parts improvement method
4. Structural redundancy
5. System simplification
6. Maintenance and repair

In the parts improvement method, the reliability of all the constituent components is enhanced or at least the most critical components are recognized and their reliabilities are enhanced. This involves use of improved manufacturing techniques and automation which is a costly and complicated means of achieving reliability. However, it is quite efficient up to certain level. Since the production of an ideal component is almost impractical and the cost of the part improvement is very high, the approach becomes cumbersome when one deals with complex and large systems.

The design engineer has to think of an effective and creative design approach to create a novel and improved system or circuit with better reliability.

When the systems are badly designed and highly complex, the correct use of the components and decreasing the complexity can prove to be a significant technique for increasing the system

reliability. However, over simplification can lead to poor efficiency and quality of the system.

The failure rates of the components can be reduced significantly by the application of overrated components as almost all components change with their operating conditions. The extent of enhancement depends upon the kind of components. The use is limited by the availability of components with the necessary ratings.

Structural redundancy is a very helpful means of increasing system reliability which involves duplication of paths at the subsystem or component level. It is the only solution when overrated components do not exist.

Repairs and maintenance, wherever possible certainly improve the system reliability. A redundancy system when combined with maintenance can have a reliability of nearly one.

1.5 SYSTEM RELIABILITY

In practice, any electronic or electrical or mechanical system consists of plenty of components interrelated in different ways. A few simple system may consist of sub-systems in series and some systems may consist of sub-systems in parallel. “If there are both serial and parallel paths in the system, then the systems are called complex systems”. Failure-free operation is desired for any system. “System reliability is the probability of failure free operation within the stipulated time and stated conditions”.

1.6 REDUNDANCY TECHNIQUES

"Redundancy is the provision of alternative means or parallel paths in a system for carrying out a given task such that all means must fail before causing the system failure". Use of redundancy in system design is seen in almost all types of systems because of numerous advantages over other methods of improving system reliability.

A few important advantages are :

a) Any desired degree of reliability can be achieved. The increase in reliability per unit resource spent is maximum when the optimal redundancy techniques are employed.
b) Relatively less skill is required by the designer for designing the system through redundancy.
c) This technique can be used in the event of failure of all other techniques which provide a quick solution.

The different approaches for introducing redundancy in the system are

1. In unit redundancy approach, a duplicate path is provided for the entire system itself. To the existing system, a complete parallel system is provided which enhances the reliability of the overall system in the unit redundancy.
2. In component redundancy approach, redundant paths for each component are provided individually. Components are added in

parallel to the active components which enhances the redundancy of the system. The redundancy is provided at the component level only.

3. The third approach suggests that weak components should be recognized and strengthened for reliability. This approach can be helpful when reliability and cost optimization problems are considered.

   In practical situations, it may not be feasible to have higher redundancy in the circuit due to cost constraints, weight limitations and space limitation, etc. The objective then becomes “to optimize redundancy satisfying some restrictions” and in some cases it may not be possible to have parallel components or parallel paths in the circuits, as the circuit constants may vary with the presence of redundant units. In such cases, redundant units can be stocked individually so that when active components do not function, they are replaced with the redundant units by a switching mechanism or manually. Then these redundant units are known as the standby units, as they are not active when the original system is operating.

4. In the last approach, the above techniques are appropriately mixed depending upon the reliability requirements and system configuration which is known as mixed redundancy.

The application of a particular approach is dependent up on many constraints such as the system’s weight, size and initial cost or the operating characteristics of the component.

The different forms of redundancy – standby (cold) redundancy, active (hot) redundancy, warm redundancy, system redundancy, component redundancy, hierarchical redundancy etc. - can be engaged in a system, depending on the possibility. One has to select an appropriate form considering the factors such as resources available, the type of components, reliability requirements, type of systems, etc.

Some examples of such systems are :

- Data processing systems
- Protective systems for nuclear reactors
- Satellite communication systems
- Interconnected power systems
- Aircraft propulsion systems
- Temperature control systems for space vehicles
- Ignition systems for rocket engines

1.7 RELIABILITY AND COST

The reliability can be achieved by various methods whose costs will vary according to the following

- Component type
- Maintenance Cost
- Product accessibility for maintenance
- Manpower and time available for design and constraints for instance volume, weight etc.

A cost-effective study may be required prior to choosing one particular method. The reliability can be increased to a certain extent for any product by using quality components. The initial cost increases but the operating cost decreases with the reliability, and hence there exists a value of reliability for which the cost is minimum.

Design and development costs will rise with the improved reliability because of the necessity to be more accurate in designing and the requirement for more extensive testing of the product. For improving the reliability, superior components are used and the process, inspection and testing procedures are monitored closely which increases the production cost. With improved reliability, costs of repair and maintenance fall and the producer has to bear these costs that occur during the guarantee period, but good reliability increase sales.

1.8 MAINTAINABILITY AND AVAILABILITY

No product can be perfectly reliable, inspite of the designer's best efforts. The product is probable to fail during its function, which might be expensive in terms of money, time or safety. Therefore maintenance has become a significant consideration in long-term performance of the product. The product requires preventive maintenance for avoiding any possible failure during its operation. Maintenance is a performance index related with such systems or equipments on which maintenance operation is performed.

“Maintainability can be defined as the probability that failed equipment is restored to operable condition in a specified time (called ‘downtime’) when the maintenance is performed under stated conditions”. It characterizes the flexibility of the product to the recognition and elimination of failures as well as their prevention.

“Reliability and maintainability are the two most important factors that decide the worth of a product. These two concepts have close relation with complexity, cost, weight and operational requirements. The higher the reliability and maintainability, the shorter it’s down time and the rarer it fails”.

Availability is another measure of performance of the maintained equipments. “Availability integrates both reliability and maintainability parameters and depends on the number of failures that occur and on how quickly any faults are rectified”.

Availability = {up time / (up time + down time)}.

The up time is the real time for which the product is available for utilization. The denominator indicates the total time for which the product is necessary to function. The down time is the sum of active repair time, administrative, delays related repairing etc.

1.9 OPTIMIZATION

“Optimization is an act of obtaining the best results under given circumstances”. Engineers have to take many managerial and technological decisions at several stages in construction, design and maintenance of any production system. The eventual goal of all such

decisions is to either maximize the desired benefit or minimize the effort required. “Optimization can be defined as the process of finding the condition that gives the maximum (benefit desired) or the minimum (effort or cost required) value of the certain decision variables of a function”. Optimization problems cannot be solved efficiently by using a single method. For solving diverse types of optimization problems, numerous optimization methods have been developed.

The optimum seeking methods are also called mathematical programming techniques, which are a part of operations research. “Operations Research is a branch of mathematics, which is concerned with the application of scientific methods and techniques to decision-making problems and with establishing the best optimal solution”. Different mathematical programming techniques are:

- Non-linear programming
- Geometric programming
- Calculus of variations
- Quadratic programming
- Stochastic programming
- Calculus methods
- Dynamic programming
- Integer programming
- Linear programming
- Game theory
- Multi-objective programming

- Separable programming
- Network methods: CPM and PERT

"The mathematical programming techniques are useful in finding the minimum of a function of several variables under a prescribed set of constrains".

1.10 ENGINEERING APPLICATIONS OF OPTIMIZATION

Optimization can be applied for solving many engineering problems. Some typical applications from various engineering disciplines are:

- Optimum design of electrical networks.
- Inventory control.
- Design of aerospace structure for air craft with minimum weight.
- Travelling salesman visiting different cities during one tour by taking shortest route.
- Design of material handling equipment like cranes, trucks, and conveyers for least cost.
- Design of civil engineering structures like bridges, foundations, towers, frames, chimneys and dams for minimum cost.
- Optimal production, planning, scheduling and controlling.
- Maintenance planning and replacement of components/ products to reduce operating costs.
- Planning the paramount strategy to obtain highest profit in the existence of a competitor.

- Design of Optimal control systems.

Distribution of resources between several activities to maximize the profit, reducing the waiting and idle times in queuing in production lines to decrease the cost.

1.11 CLASSIFICATION OF OPTIMIZATION PROBLEMS

Optimization problems can be classified as below:

Classification based on the existence of constraints: Any optimization problem can be classified based on whether it is constrained or not as constrained or an unconstrained problem.

Classification based on the nature of decision variables: Based on the nature of the design /decision variables identified, optimization problems can be divided into two broad categories. (a) The problem is to find values to a set of decision parameters which make some specified function of these parameters minimum subject to certain constraints; (b) The objective is to find a set of decision parameters, which are all continuous functions of some other variables that minimize an objective function subject to the specified constraints.

Classification based on the body structure of the problem: Depending upon the physical structure of the problem, optimization problems can be divided as optimal control and non-optimal control problems. “Optimal control problem is usually described by two variables, namely, the control (design) and the state variables. The control variables govern the evolution of the system from one stage to

the next, while the state variables describe the behavior of the system in any stage. The problem is to find a set of control or design variables such that the total objective function over certain number of stages is minimized subject to certain constraints on the state and the control variables."

Classification based on the nature of equations involved: According to this division, optimization problem can be classified as linear, nonlinear, geometric and quadratic programming problems. This classification is extremely useful from the computational point of view, as there are many methods developed solely for the efficient solution of a particular class of problems. Thus the first task of the designer would be to investigate the class of problem formulated. This will, in many cases, dictate the type of solution procedures to be adopted in solving the problem.

1.12 DYNAMIC PROGRAMMING

In many decision making problems, decisions have to be made sequentially at different instances of time, at different points in space and at different levels. "If the decisions are taken sequentially, then such problems are called sequential decision problems. Since these decisions are to be made at a number of stages, they are also referred to as multistage decision problems. Dynamic programming is a mathematical technique well suited for the optimization of multistage decision problems".

"The dynamic programming technique decomposes a multistage decision problem into a series of single stage decision problems. Thus, an 'N' variable problem is represented as a sequence of 'N' single variable problems, which are solved successively. The decomposition to 'N' sub-problems is done in such a way that the optimal solution for the original 'N' variable problem can be obtained from the optimal solution of the 'N' one dimensional problem".

"Dynamic programming can deal with non-convex, discrete variables, non-differentiable and non-continuous functions. By a simple modification of the deterministic procedure, stochastic variability can also be taken into account. The major drawback of dynamic programming technique is the dimensionality. It is very appropriate for the solution in several areas of decision making for a wide range of complex problems".

1.13 STOCHASTIC PROGRAMMING

"Stochastic or probabilistic programming deals with situations where some or all parameters of the optimization problem are described by stochastic or random or probabilistic variables. A stochastic optimization problem is known as stochastic linear or non linear, dynamic linear or non-linear programming problem depending on the type of equations (in terms of random variables) involved in the problem. The stochastic programming problem is solved by converting the stochastic problem into the corresponding deterministic problem by using the familiar techniques like geometric, linear, dynamic and

non-linear programming and then solving the resulting deterministic problem".

1.14 SIMULATION

Simulation technique involves using a computer to imitate the operation of an entire process or system. Simulation is extensively used to mimic or imitate the operation of entire process or system. It is widely used to investigate stochastic systems that will operate continuously. The computer arbitrarily generates and records the occurrence of diverse events that drive the system same as physically operating. The performance of simulated operation of the system for various alternative designs or operating procedures are recorded which enables to evaluate and compare before choosing any one of these alternatives. Simulation model synthesizes the system by building it up component by component and event by event.

Reasons for using simulation

1. To solve cumbersome problems: The simulation technique is advantageously used to solve the majority of the difficult problems which cannot be solved mathematically using quantitative methods.
2. Study the long term effect: It enables the manager to study the long-term effect in a quick manner.
3. To test anticipated analytical solution: It must be stressed that by using simulation technique, the optimum solution proposed can't be tested.

4. Experimentation: Simulation technique helps the manager to experiment the behavior of the existing system without disturbing the inherent character.
5. Stability: A model once developed can be used repeatedly and in any types of situations.
6. Modification: Simulation model is closely identical to conducting sampling experiments on the factual system. Model can be modified for accommodating the varying environments of existent situation.
7. Study the long term effect: It enables the analyst to understand and evaluate the long-term effect in a swift manner.
8. Generation of data: The conclusions drawn from one experiment can be used to generate data for further analysis.
9. No interference: Experiments on the factual system may be too disruptive but the experiments done with the model are not.
10. Bifurcation system: A complex system can be bifurcated into subsystems each of the subsystem individually or jointly**.**
11. Time saving: with one model only we can get all the results. For example effects of consumer ordering behavior or other policies of several years can be computed in a short time by using simulation.
12. Last resort: Simulation sometime is the last resort to solve impossible problem, if we are unable to observe the actual environments on the planet Mars simulation be needed.

Disadvantages

1. Nontransferable solution: The inferences of a solution to a model cannot be transferable to other problems as each solution model is unique.
2. No optimum solution: Simulation is trial and error approach and to a similar problem it may give different solution. Hence, simulation does not produce an optimal solution.
3. Not precise: Simulation model is not precise and it does not give a solution but provides a set of the system in different conditions.
4. Inefficient: Solution obtained through quantitative methods are more efficient than simulation models.
5. Expensive: Developing a simulation model is a complicated process and can be very expensive. Sometimes, it may take years to develop a model. Hence huge expenditure is involved.

1.15 CONCLUSIONS

The historical development of reliability has been dealt in this chapter and moreover this chapter also presented an overview of all the aspects of reliability engineering which includes the techniques used to improve the system reliability, cost effects of reliability, optimization methods used for reliability evaluation and simulation studies in assessing the reliability.

Product development lifecycle

. Introduction

Once a product has been developed, the first stage is its introduction stage. In this stage, the product is being released into the market. When a new product is released, it is often a high-stakes time in the product's life cycle - although it does not necessarily make or break the product's eventual success.

During the introduction stage, marketing and promotion are at a high - and the company often invests the most in promoting the product and getting it into the hands of consumers. This is perhaps best showcased in Apple's famous launch presentations, which highlight the new features of their newly (or soon to be released) products.

It is in this stage that the company is first able to get a sense of how consumers respond to the product, if they like it and how successful it may be. However, it is also often a heavy-spending period for the company with no guarantee that the product will pay for itself through sales.

Costs are generally very high and there is typically little competition. The principle goals of the introduction stage are to build demand for the product and get it into the hands of consumers, hoping to later cash in on its growing popularity.

2. Growth

By the growth stage, consumers are already taking to the product and increasingly buying it. The product concept is proven and is becoming more popular - and sales are increasing.

Other companies become aware of the product and its space in the market, which is beginning to draw attention and increasingly pull in revenue. If competition for the product is especially high, the company may still heavily invest in advertising and promotion of the product to beat out competitors. As a result of the product growing, the market itself tends to expand. The product in the growth stage is typically tweaked to improve functions and features.

As the market expands, more competition often drives prices down to make the specific products competitive. However, sales are usually increasing in volume and generating revenue. Marketing in this stage is aimed at increasing the product's market share.

3. Maturity

When a product reaches maturity, its sales tend to slow or even stop - signaling a largely saturated market. At this point, sales can even start to drop. Pricing at this stage can tend to get competitive, signaling margin shrinking as prices begin falling due to the weight of outside pressures like competition or lower demand. Marketing at this point is targeted at fending off competition, and companies will often develop new or altered products to reach different market segments.

Given the highly saturated market, it is typically in the maturity stage of a product that less successful competitors are pushed out of competition - often called the "shake-out point."

In this stage, saturation is reached and sales volume is maxed out. Companies often begin innovating to maintain or increase their market share, changing or developing their product to meet with new demographics or developing technologies.

The maturity stage may last a long time or a short time depending on the product. For some brands, the maturity stage is very drawn out, like Coca-Cola

4. Decline

Although companies will generally attempt to keep the product alive in the maturity stage as long as possible, decline for every product is inevitable.

In the decline stage, product sales drop significantly and consumer behavior changes as there is less demand for the product. The company's product loses more and more market share, and competition tends to cause sales to deteriorate.

Marketing in the decline stage is often minimal or targeted at already loyal customers, and prices are reduced.

Eventually, the product will be retired out of the market unless it is able to redesign itself to remain relevant or in-demand. For example, products like typewriters, telegrams and muskets are deep in their decline stages (and in fact are almost or completely retired from the market).

Examples of the Product Life Cycle

The life cycle of any product always carries it from its introduction to an inevitable decline, but what does this cycle practically look like, and what are some examples?

Typewriter

A classic example of the scope of the product life cycle is the typewriter.

When first introduced in the late 19th century, typewriters grew in popularity as a technology that improved the ease and efficiency of writing. However, new electronic technology like computers, laptops and even smartphones have quickly replaced typewriters - causing their revenues and demand to drop off.

Overtaken by the likes of companies like Microsoft , typewriters could be considered at the very tail end of their decline phase - with minimal (if existent) sales and drastically decreased demand. Now, the modern world almost exclusively uses desktop computers, laptops or

smartphones to type - which in turn are experiencing a growth or maturity phase of the product life cycle.

RELIABILITY IMPROVEMENT TECHNIQUES

Reliability Modelling

Reliability Modelling is a success-oriented network drawing and calculation tool used to model specific functions of complex systems by using a series of images (blocks). When used to model a system, each component within the system is represented by a block and the connections between the blocks are used to indicate that each component is properly performing its intended function. If a connection exists between the two end points of the diagram, it is said that the system is performing its intended function or that some specified failure mode is not occurring.

Reliability Modelling can be used to:

- Assist in selecting design alternatives with high dependability,
- Evaluate and quantify the reliability of alternative designs and configurations,
- Test and quantify the impact on overall system reliability of making changes to the reliability of one component within that system,
- Provide quantitative information for other analysis techniques such as Reliability Centred Maintenance and Event Tree Analysis.

Failure Modes and Effect Analysis (FMEA) and Failure Modes and Criticality Analysis (FMECA)

- All potential failure modes of the various parts of a system,
- The effects these failures may have on the system,
- The mechanisms of failure, and
- How to avoid the failures, and/or mitigate the effects of the failures on the system.

Failure Modes, Effects and Criticality Analysis (FMECA) extends an FMEA so that each fault mode identified is ranked according to its importance or criticality.

FMEA/FMECA can be used to:

- Assist in selecting design alternatives with high dependability,
- Ensure that all failure modes of systems and processes, and their effects on operational success have been considered,
- Identify human error modes and effects,
- Provide a basis for planning testing and maintenance of physical systems,
- Improve the design of procedures and processes,
- Provide qualitative or quantitative information for other analysis techniques such as Reliability Centred Maintenance and Fault Tree Analysis.

Reliability Centred Maintenance (RCM) and PM Optimisation (PMO)

Reliability Centred Maintenance (RCM) is used to develop an applicable and effective preventive maintenance program for equipment in accordance with the safety, environmental, operational and economic consequences of identifiable failures and the degradation mechanism responsible for those failures.

RCM is a semi-quantitative approach to maintenance task development. In general, the information required for effective decision-making in most organisations is typically not captured in formal information systems, and so it tends to rely (to a greater or lesser extent) on input from those familiar with the operation and maintenance of the equipment during its

application. This can tend to be time and resource-intensive, and for these reasons in many industries, RCM is used sparingly, most often when dealing with highly critical equipment.

PM Optimisation (PMO), like RCM, is used to develop an applicable and effective preventive maintenance program for equipment. Unlike RCM, there are no formal international standards for PMO, and so the approach taken may vary from vendor to vendor.

In the approach taken by Assetivity, PMO uses the same decision-making process as that used in RCM, but differs in the way that failure modes are identified for analysis. Instead of using a FMEA process to identify failure modes, instead the first four questions of the RCM process are replaced by the following questions:

- *Current PM tasks - what are the current PM tasks being performed?*
- *Failure Modes* - what failure modes are these addressing?
- *In-service Failures* – what in-service failures are currently being experienced, and what are their causes?
- *Hidden Failures* - what protective devices and systems are in place and what are the potential failure modes associated with these?
    - The answers to these questions are then used to develop the failure modes used for decision-making. In practice, this approach is typically quicker (especially for existing assets with mature preventive maintenance programs already in place), as the answers to these questions can be more easily answered, and the resulting failure modes are more likely to be those commonly experienced in practice (unlike in an FMEA process, where some failure modes identified may rarely or never, in practice, be experienced). Because a smaller number of failure modes are identified, then the decision-making process can also be performed more quickly.
    - While the process is quicker, in most applications, there is no loss of quality in outcomes, so long as appropriate rigour is applied in identifying the failure modes. However, there is a slight chance that some extremely rare failure modes may be missed when using the PMO process. If this is concerning to you, then the RCM process may be better for you than PMO.
    - Like RCM, PMO is also a semi-quantitative approach to maintenance task development, and relies on input from those familiar with the operation and maintenance of the equipment. However, because it is quicker to apply, it tends to be less resource-intensive when applying this process.

Root Cause Analysis (RCA)

Root cause analysis (RCA) is a method of problem solving used for:

- Identifying the root causes of faults or problems instead of dealing only with the immediately obvious symptoms
- Developing and implementing solutions that prevent occurrence/recurrence of the fault or problem.

The process involves the use of structured analysis techniques such as: ‘5 whys’ , FMEA, FTA, Fishbone diagrams, Pareto analysis, cause and effect mapping.

Focusing on the identification and elimination of the causes of equipment failure assists with:

- Maximising Equipment Uptime and Throughput
- Reducing the risk of future Safety and Environmental incidents
- Maximising the proportion of planned maintenance work
- Minimising Maintenance Costs

The following are the steps involved with performing a RCA.

Step 1: Prepare for the Analysis

- Define the Problem.
- Preserve and Collect Data.
- Minimise Further Consequences.
- Arrange the Analysis Team.

Step 2: Perform the Analysis

- *Identify the Causes.* There are typically three types of causes that can contribute to a problem/failure:
  - *Physical Causes*. Tangible, or component level causes.
  - *Human Causes*. Intended or unintended errors made by people.
  - *Organisational/System Causes*. The organisation's processes, procedures, systems and culture. Addressing these causes is most likely to lead to long-term, sustainable change.
- *Establish relationships between Causes and Effects.*
- *Verify Hypotheses and Validate Causes*.
- *Develop Solutions.*

Step 3: Implement the Recommended Solution(s)

- *Obtain Approvals*.
- *Assign accountability for implementation*.
- *Track implementation progress*.
- *Ensure all Management of Change processes are followed*.
- *Check that the solution is delivering the expected results*.

Root Cause Analysis is most applicable after equipment has entered service, and tends to be reactive in nature – it is generally only applied after an equipment failure event. While it is a highly valuable tool for encouraging and implementing continuous improvement in reliability performance, there are other tools (such as those mentioned earlier) that are more effective in ensuring that failure events don't occur in the first place. Nevertheless, all high performing organisations tend to have formal processes in place for Root Cause Analysis and Failure Elimination.