UNIT 13: QUALITY CONTROL

UNIT STRUCTURE

13.1 Learning Objectives

13.2 Introduction

13.3 Quality Control

13.4 Organization for Quality Control

13.5 Classification of Quality Control techniques

13.6 Process Capability

13.7 Process Variations Distribution

13.8 Type of Data

13.9 Six Sigma

13.10 Let Us Sum Up

13.11 Further Reading

13.12 Answers to Check Your Progress

13.13 Model Questions

13.1 LEARNING OBJECTIVES

After going through this unit, you must be able to:

- explain the basic concept of Quality Control
- explain the various Quality Control techniques
- describe the concept of Acceptance Sampling and Six Sigma

13.2 INTRODUCTION

In this unit, we are going to discuss the concept of Quality Control, its components, its various techniques. Proper implementation of these concepts can play an important role in the quality control of the production

of any goods or in the delivery of any service. In fact, these concepts can lead to effective production process or service delivery process.

13.3 QUALITY CONTROL

Quality refers to the sum of the attributes or properties that describe a product. These are generally expressed in terms of specific product characteristics like length, width, colour, specific gravity etc. Quality Control refers to the activities involved in the assurance that quality creation is performed in such manner that the resulting products will in fact its intended function. It is the staff function concerned in the prevention of defects in manufacturing so that items may be made right at the first time and not to be rejected later. Quality control is different from inspection. Inspection refers to the process of checking material, product or components of products at various stages, with reference to certain pre-determined factors and detecting and sorting out the faulty or defective items. In inspection emphasis is placed on the quality of the past production. Quality Control on the other hand is a broad term. Here emphasis is placed on the quality of future production.

Need for controlling quality: In the absence of quality, the following will result:

(i) No yardstick for comparing the quality of products.

(ii) Difficulty in maintaining consistency in quality

(iii) Dissatisfied customers due to increased maintenance and operating costs of products

(iv) Increased rework cost while manufacturing products/ delivering services.

(v) Reduced life time of products

(vi) Reduced flexibility with respect to the usage of standard spare parts.

Strategic areas of quality control: The Strategic areas of quality control are:

(i) Supplier quality

(ii) Incoming raw material quality

(iii) Process quality

(iv) Final quality

(v) Customer quality

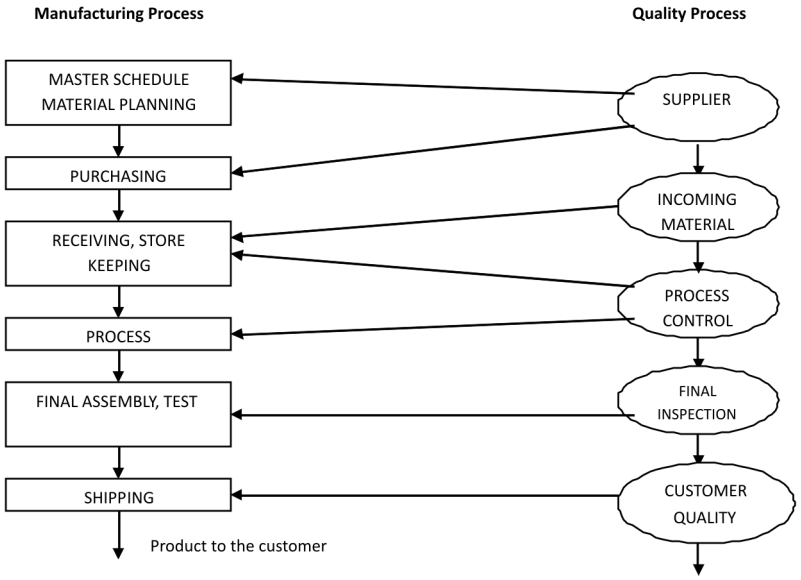


Fig 13.1: Strategic areas of quality control program

13.4 ORGANIZATION FOR QUALITY CONTROL

Operating Quality Costs can be classified as follows:

(i) Costs of control

(a) Costs of prevention

(b) Costs of appraisal

(ii) Costs of failure to control

(a) Costs of internal failure

(b) Cost of external failure

13.5 CLASSIFICATION OF QUALITY CONTROL TECHNIQUES

The various quality control techniques can be classified as follows:

(i) CONTROL CHARTS: They are used to control in-process quality. They can be further classified as follows:

A) For Variables:

(a) $\overline{\overline{X}}$ Chart (Mean Chart): These reveal variations between sample observations.

(b) R Chart (Range Chart): These reveal idea about the dispersion (spread) of the observations.

$\overline{\overline{X}}$ and R Chart:

Control Limits:

Control Limits for $\overline{\overline{X}}$ chart:

Upper Control Limit, $UCL_{\overline{X}}$ = $\overline{\overline{X}}$ + 3 $\sigma_{\overline{X}}$ = $\overline{\overline{X}}$ + 3$\sigma/\sqrt{n}$ = + A_2 $\overline{R}$

Lower Control Limit, $LCL_{\overline{X}}$ = $\overline{\overline{X}}$ - 3 $\sigma_{\overline{X}}$ = $\overline{\overline{X}}$ - 3$\sigma/\sqrt{n}$ = - A_2 $\overline{R}$

Where, $\overline{X}$ is the mean of the sample, $\overline{\overline{X}}$ is the mean of the sample means

R in the range of sample observations and is the mean of sample range $\sigma_{\overline{X}}$ is the sample standard error = $\sigma/\sqrt{n}$, A_2 is a constant

Control Limits for R chart:

Upper Control Limit, UCL_R = + $3\sigma_R$ = D_4

Lower Control Limit, LCL_R = $\overline{\overline{X}}$ - $3\sigma_R$ = D_3

Where, R is the range of sample observations and $\overline{R}$ is the mean of

sample range σ_R is the standard deviation of range, D4 and D3 are constants

Example 13.1: Construct the control chart for mean and range for the following data on the basis of sample of automobile engines, five being taken every hour. Comment on the sate of control. Note that constants A_2= 0.577, D_3= 0, D_4= 2.115.

Sample	1	2	3	4	5	6	7	8	9	10
Mean of engine reading	32	34	36	34	35	33	32	35	33	35
Range of engine reading	4	5	6	3	4	5	4	7	6	3

Solution to Example 13.1: Given, the following data on the basis of sample of automobile engines, five being taken every hour,

Sample	1	2	3	4	5	6	7	8	9	10
Mean of engine reading	32	34	36	34	35	33	32	35	33	35
Range of engine reading	4	5	6	3	4	5	4	7	6	3

Let $\overline{X}$, $\overline{\overline{X}}$, $\overline{R}$, $\Sigma \overline{X}$, ΣR, n and N indicate Mean of engine reading, Mean of Mean of engine reading, Range of engine reading, sum of Mean of engine reading, sum of Range of engine reading, sample size and number of samples respectively.

In the above problem, n= 5, N= 10,

$\Sigma \overline{X}$ = 32+34+36+34+35+33+32+35+33+35 = 339

$\overline{\overline{X}}$ = $\Sigma \overline{X}$ ÷ N = 339 ÷ 10 = 33.9

ΣR = 4+5+6+3+4+5+4+7+6+3 = 47

$\overline{R}$ = ΣR ÷ N = 47 ÷ 10 = 4.7

Control Limits for $\overline{X}$ chart:

Upper Control Limit, UCL $_{\overline{X}}$ = $\overline{\overline{X}}$ + A_2 $\overline{R}$ = 33.9 + (0.577 × 4.7) = 36.62

Lower Control Limit, LCL $_{\overline{X}}$ = $\overline{\overline{X}}$ - A_2 $\overline{R}$ = 33.9 - (0.577 × 4.7) = 31.19

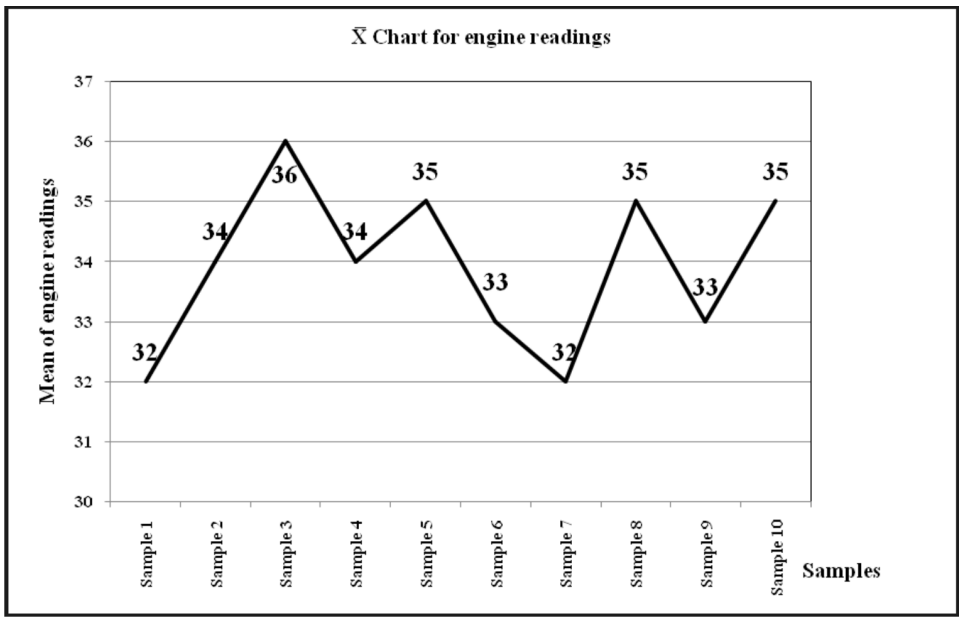


Fig: X? Chart for engine readings

From the above X? Chart for engine readings, it is seen that all the points, i.e., mean of engine readings (X?) are between upper and lower control limits (UCLX? and LCLX? respectively). As such, the process is under presently under control. However, there is noticeable deviation of these points above and below the mean. Therefore, care has to be taken, otherwise, the process may go out of control in the near future.

Control Limits for R chart:

Upper Control Limit, $UCL_R = D_4 \overline{R} = 2.115 \times 4.7 = 9.94$

Lower Control Limit, $LCL_R = D_3 \overline{R} = 0 \times 4.7 = 0$

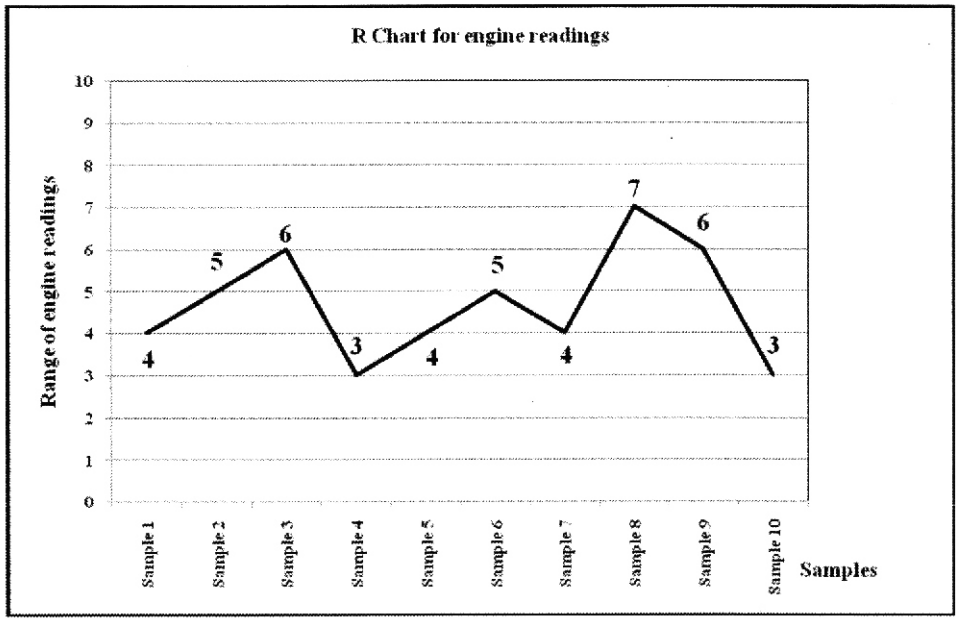


Fig: R Chart for engine readings

From the above R Chart for engine readings, it is seen that all the points, i.e., range of engine readings (R) are between upper and lower control limits (UCLR and LCLR respectively). So, the process is under presently under control. But, there is significant deviation of these points above and below the mean. Therefore, care has to be taken; otherwise, the process may go out of control in the near future.

From the above X? Chart and R Chart for engine readings, it is seen that the process is under presently under control.

B) For Attributes:

(a) P-Chart (Percent defective chart): They are used to discover average proportion of non conforming articles or parts submitted for inspection over a period of time and to bring to the management's attention any change in the average quality level.

Control Limits for P chart:

Upper Control Limit, $UCL_p = \bar{p} + 3\sqrt{\{\bar{p}(1 - \bar{p})/n\}} = \bar{p} + 3\sigma_p$

Lower Control Limit, $LCL_p = \bar{p} - 3\sqrt{\{\bar{p}(1 - \bar{p})/n\}} = \bar{p} - 3\sigma_p$

Where, p is the process percent defective of a sample = (Number of defective items in a sample) /n

is the process mean percent defective,

n is the sample size, k is the number of samples

$_p$ is the standard deviation of percent defectives

Example 13.2: ABC Company manufactures a particular item. At some intermediate point of the production line, 10 samples of size 20 each have been taken. Items within each sample were classified into good or bad. The related data are given in the following data. Construct a p-chart with 3-sigma limit and comment on the process.

Sample Number	Number of Defective Items	Fraction of Defective Items
1	9	0.45
2	12	0.60
3	10	0.50
4	5	0.25
5	6	0.30
6	7	0.35
7	10	0.50
8	9	0.45
9	8	0.40
10	6	0.30

Solution to Example 11.2: Given for ABC Company that manufactures a particular item,

Sample Number	Number of Defective Items	Fraction of Defective Items
1	9	0.45
2	12	0.60
3	10	0.50
4	5	0.25
5	6	0.30
6	7	0.35
7	10	0.50
8	9	0.45
9	8	0.40
10	6	0.30
	$?D = 82$	$?p = 4.10$

Let D, p, , D, p, n and N indicate number of defective items, percent defective, process mean percent defective, total number of defective items, sum of percent defective, sample size and number of samples respectively.

In the above problem, n = 20, N = 10

$\bar{p}$ = ΣD ÷ (n × N) = 82 ÷ (20 × 10) = 0.41 = Σp ÷ N = 4.10 ÷ 10

Control Limits for p-chart:

Upper Control Limit, $UCL_p = \bar{p} + 3\sqrt{\{\bar{p}(1 - \bar{p})/n\}}$ = 0.41 + 3 √{0.41 (1 - 0.41) / 20}= 0.74

Lower Control Limit, $LCL_p = \bar{p} - 3\sqrt{\{\bar{p}(1 - \bar{p})/n\}}$ = 0.41 + 3 √{0.41 (1 - 0.41) / 20}= 0.08

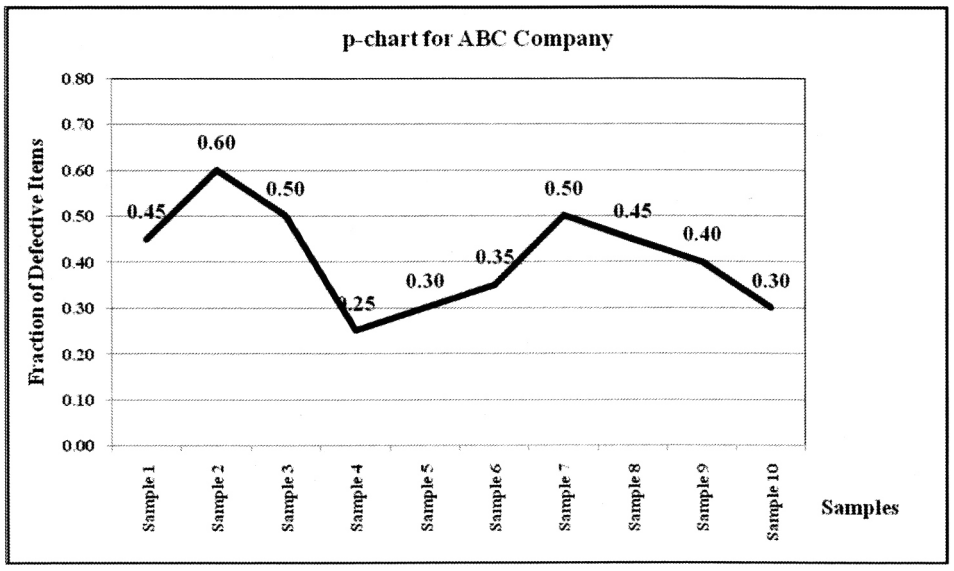


Fig: p-Chart for ABC Company

From the above p- Chart for engine readings, it is seen that all the points, i.e., percent defective in case of ABC Company (p) are between upper and lower control limits (UCLp and LCLp respectively). So, the process is under presently under control. But, there is significant deviation of these points above and below the mean. Therefore, care has to be taken; otherwise, the process may go out of control in the near future.

(b) C-Chart (Non-conformities chart): They are used to discover the number of non-conformities in samples of constant size.

Control Limits for C chart:

Upper Control Limit, $UCL_c = \bar{c} + 3\sqrt{\bar{c}}$

Lower Control Limit, LCLc = $\bar{c}$ - 3 $\sqrt{\bar{c}}$

Where, c is the number of non- conformities, $\bar{c}$ is the mean number of non- conformities.

Example 13.3: The following chart gives the number of missing screws noted in 10 newly manufactured machines. Construct a C-chart? Comment on the state of control.

Machine Number	1	2	3	4	5	6	7	8	9	10
Number of missing screws	12	16	23	21	19	21	13	12	13	17

Solution to Example 13.3: Given for ABC Company that manufactures a particular item,

Machine Number	1	2	3	4	5	6	7	8	9	10	
Number of missing screws (c)	12	16	23	21	19	21	13	12	13	17	$\sum c = 167$

Let c, $\bar{c}$, $\sum c$ and N indicate number of missing screws, mean of the number of missing screws, sum of the number of missing screws, and number of machines (samples) respectively,

$\sum c$= 12+16+23+21+19+21+13+12+13+17 = 167

N= 10,

$\bar{c}$ = $\sum c \div N$ = 167 ÷ 10 = 16.7

Control Limits for C chart:

Upper Control Limit, UCL_c = $\bar{c}$ + 3 $\sqrt{\bar{c}}$ = 16.7 + {3 × $\sqrt{(16.7)}$} = 28.96

Lower Control Limit, LCL_c = $\bar{c}$ - 3 $\sqrt{\bar{c}}$ = 16.7 - {3 × $\sqrt{(16.7)}$} = 4.44

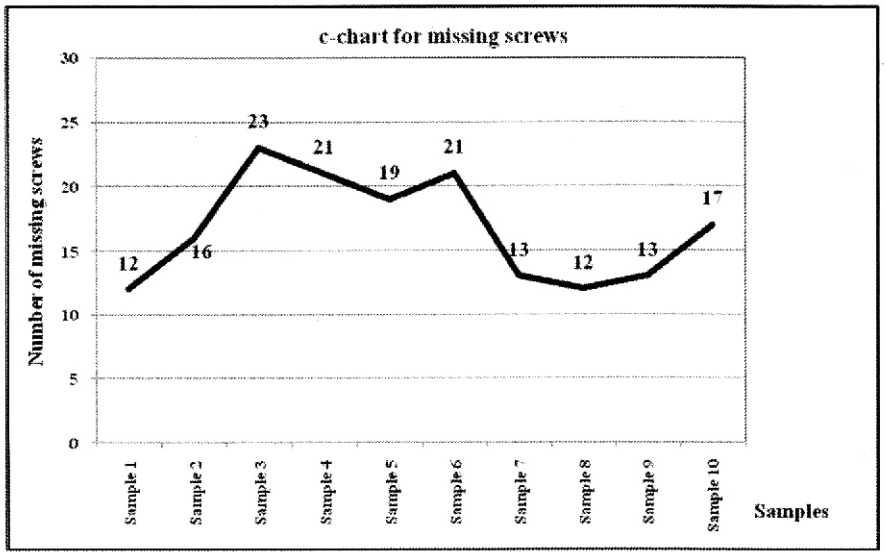


Fig: c-Chart for ABC Company

From the above c-Chart for engine readings, it is seen that all the points, i.e., number of missing screws (c) are between upper and lower control limits (UCLc and LCLc respectively). So, the process is under presently under control. But, there is significant deviation of these points above and below the mean. Therefore, care has to be taken; otherwise, the process may go out of control in the near future.

(ii) Acceptance Sampling: Acceptance Sampling is the process of evaluating a portion of the product/ material in a lot for the purpose of accepting or rejecting a lot as either conforming or non-conforming to a quality inspection. They are used to take decisions whether to accept or reject a lot (raw material/ finished parts) based on sample's characteristics. They are very popular because the cost of data collection for such measure is much less. But acceptance sampling by variables may yield the desired result even with small number of samples. In this process the following two types of errors may occur:

- Type I (α) Error/ Producer's Risk: If lot is really good, but based on sample characteristics the lot is rejected, then the producer/ supplier will be penalized.
- Type II (β) Error/ Consumer's Risk: If lot is really bad, but based

on sample characteristics the lot is accepted, then the consumer will be at loss.

So, both the parties mutually decide about the levels of Producer's Risk (? error) and Consumer's Risk (? error).

NOTE: In 100% inspection all the parts or products are subjected to inspection, whereas in acceptance sampling only a sample is drawn from the lot and inspected. The advantages of Acceptance Sampling are as follows:

(a) The items which are subjected to destructive test must be inspected by sampling inspection only.

(b) The cost and time required for Acceptance Sampling are comparatively less than 100% inspection

(c) Acceptance Sampling involves lesser problem of inspection fatigue

(d) Acceptance Sampling involves smaller inspection staff

(e) Acceptance Sampling involves lesser monotony on the part of the inspector

Acceptance sampling can be further classified as follows:

A) For Variables:

(a) Acceptance sampling plan with α: These involve acceptance sampling plans taking into account Producer's Risk (? error).

(b) Acceptance sampling plan with α and β: These involve acceptance sampling plans taking into account Producer's Risk (? error) and Consumer's Risk (α error).

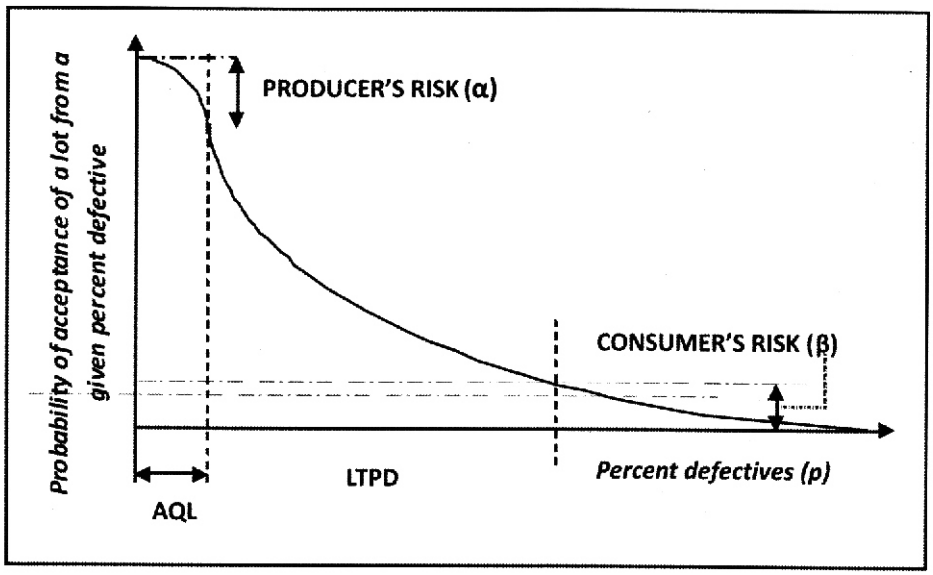


Fig 13.2: Operating Characteristics Curve

Operating Characteristics Curve provides a basis for selecting alternate sample plans for a given value of sample size (n) and acceptance number (C). The value of percent defective indicates the quality level of the lot inspected. AQL means the Acceptable Quality Level. LTPD means Lot Tolerance Percent Defectives. These represent quality levels of the lot submitted for inspection. If the quality level of the lot inspected is at AQL or less than AQL, then the customers are satisfied with the quality of the lot. The corresponding probability of acceptance is called (1 - α). On the other hand, if the quality level is more than or equal to LTPD, the quality of the lot is considered to be inferior from the consumer's viewpoint. The corresponding probability of acceptance of the lot is called β. The quality level in between AQL and LTPD is called indifferent zone. Thereby α, β, AQL and LTPD are used in this case to design a sample plan.

B) For Attributes:

(a) Single Sampling Plan: Here based on the outcome of one sample, a lot may be rejected or accepted. It is designed with a specified producer's risk and consumer's risk with the following required data:

- Producer's Risk (?)
- Consumer's Risk (?)
- Acceptable Quality Level (AQL)
- Lot Tolerance Percent Defectives (LTPD)

The objective of this design is to find out the values for the sample size (n) and the acceptance number (C).

(b) Double Sampling Plan: Here based on the outcome of two samples, a lot may be rejected or accepted. If the outcome of the first sample is not to accept the lot, then one or more samples are drawn. Based on the combined quality level of the samples, the final decision will be made.



CHECK YOUR PROGRESS

Q 1: What is the process of checking material, product or components of products at various stages, with reference to certain pre-determined factors and detecting and sorting out the faulty or defective items called?

(a) Receipt Store (b) Work-in-process

(c) Quality Control (d) Inspection

Q 2: Which of the following quality control charts reveal variations between sample observations?

(a) R Chart (Range Chart) (b) Chart (Mean Chart)

(c) P Chart (d) None of these

Q 3: In Acceptance Sampling, which of the following types of error is associated with if lot is really good, but based on sample characteristics the lot is rejected?

(a) Type I (?) Error/ Producer's Risk (b) Distributor's Risk

(c) Type II (?) Error/ Consumer's Risk (d) None of these

13.6 PROCESS CAPABILITY

Process capability refers to the capability of a production process to meet or exceed specifications that have already been preset. In fact, process capability plays the role of comparing the output of a manufacturing process with the specification limits by using capability indices. This comparison is made by calculating the process capability index (Cp) which is the ratio of the specification width to the process width.

$$C_p = \frac{\text{Specification Width}}{\text{Process Width}} = \frac{\text{USL - LSL}}{6\rho}$$

Here,

Specification width indicates the spread between the process specifications. It is the difference between USL and LSL. USL and LSL indicates the Upper Specification Limit and Lower Specification Limit respectively.

Process width indicates the spread of the process values, as measured by 6 process standard deviation units of the process being monitored.

Process capability is measured by the process capability index, Cp, which is computed as the ratio of the specification width to the width of the process variability:

$$Cp = \frac{\text{Specification Width}}{\text{Process Width}} = \frac{\text{USL - LSL}}{6\rho}$$

The process width is computed as 6 standard deviations (?) of the process being monitored. The reason we use 6 is that most of the process measurement (99.74 percent) falls within 3? standard deviations, which is a total of 6 standard deviations.

Process Variations Distribution:

There are three possible ranges of values for C_p.

C_p= 1: A value of C_p equal to 1 means that the process variability just

meets specifications, as in Figure 13.3. So, it may be concluded that the process is minimally capable.

C_p< 1: A value of C_p below 1 means that the process variability is outside the range of specification, as in Figure 13.3. This means that the process is not capable of producing within specification and the process must be improved.

C_p> 1: A value of C_p above 1 means that the process variability is tighter than specifications and the process exceeds minimal capability, as in Figure 13.3.

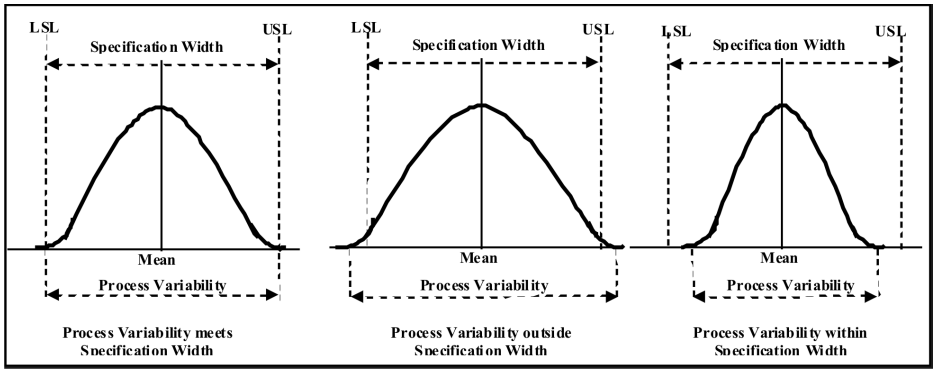


Fig 13.3: Process Variations Distribution

13.7 SIX SIGMA

Six Sigma is a disciplined data-driven approach and methodology for eliminating defects which amounts to driving towards six standard deviations between the mean and the nearer specification limit in a any process (manufacturing/transactional) of products/services. A six Sigma defect is defined as any flaw that inhibits the attainment of customer expectations and specifications. It aims at process improvement and reduction of variation through its application.

Six Sigma level indicates 99.99966% confidence in any process that the product/service delivered is defect free. This means that only 0.00034% of the times the product/service delivered are defect prone.

When 0.0000034 is multiplied by one million, it comes to 3.4 defects per million opportunities (DPMO).

An opportunity is defined as a chance for nonconformance or not meeting the required specifications. This means that we need to be nearly flawless in executing our key processes.

Actual Sigma Level

$$= \frac{\text{Actual number of defects}}{\text{Total number of opportunities for the organisation to make mistakes from the customer angle}} \times 100$$

A process is said to be Six Sigma level provided that the process is not producing more than 3.4 defects per million opportunities.

Approaches for Six Sigma: The approaches for Six Sigma are:

(i) DMAIC: It means Define, Measure, Analyze, Improve and Control. It is a process improvement system for the existing process falling below specifications and looking for incremental improvement.

(ii) DMADV: It means Define, Measure, Analyze, Design and Verify. This process is an improvement system used to develop new processes or products at Six Sigma quality levels.

Types of Six Sigma Belts: The types of Six Sigma Belts are:

(i) Green Belts: These comprise Six Sigma team leaders capable of forming and facilitating Six Sigma teams and managing Six Sigma projects from conception to completion. The desirable skills of Green belts are good problem solving ability, experience in leading a team, expertise in project management, competence to apply basic improvement tools etc.

(ii) Black Belts: These comprise Six Sigma team leaders responsible for measuring, analyzing, improving and controlling key processes

that influence customer satisfaction and /or productivity growth. The desirable skills of Black belts are customer advocacy, self motivation, positive personality, good communication, project management expertise etc.

(iii) Master Black Belts: These comprise Six Sigma team leaders with the highest level of technical and organizational proficiency. The desirable skills of Master Black belts are experience in different areas, analytical and technical competence advanced statistical knowledge, ability to coach Six Sigma leaders etc.

(iv) Six Sigma Champions: These comprise business leaders who lead Six Sigma by sponsoring projects. The desirable skills of Six Sigma Champions are ability to support, align and integrate the Six Sigma launch in their organizations.

Benefits of Six Sigma: The benefits of Six Sigma are:

(i) It ensures enhanced product quality.

(ii) It enables predictable delivery of products.

(iii) It helps to achieve productivity improvement.

(iv) It helps to obtain rapid response to the changing needs of customers.

(v) It also facilitates the development and introduction of new products into the marketplace.



CHECK YOUR PROGRESS

Q 4: Which of the following types of Six Sigma belts comprises of Six Sigma team leaders capable of forming and facilitating Six Sigma teams and managing Six Sigma projects from conception to completion?

(a) Green Belts (b) Black Belts

(c) Master Black Belts (d) None of these

Q 5: In process capability, Cp indicates.

(a) Production capability index (b) Process capability index

(c) Process control index (d) None of these



13.6 LET US SUM UP

Quality refers to the sum of the attributes or properties that describe a product. These are generally expressed in terms of specific product characteristics like length, width, colour, specific gravity etc. Quality Control refers to the activities involved in the assurance that quality creation is performed in such manner that the resulting products will in fact its intended function. The important points under Quality Control discussed above are:

- Acceptance Sampling is the process of evaluating a portion of the product/ material in a lot for the purpose of accepting or rejecting a lot as either conforming or non-conforming to a quality inspection.
- Process capability refers to the capability of a production process to meet or exceed specifications that have already been preset.
- Six Sigma is a disciplined data-driven approach and methodology for eliminating defects which amounts to driving towards six standard deviations between the mean and the nearer specification

limit in a any process (manufacturing/transactional) of products/ services.



13.7 FURTHER READINGS

- Industrial Engineering and Production Management by M.S. Mahajan, Dhanpat Rai and Company Private Limited, pp.780-784.
- Operations Management by M.S. Mahadevan, Pearson Education, pp.474-509.
- Production and Operations Management by E.E.Adam and R.J. Ebert, Prentice Hall of India Private Limited, pp.521-549.
- Production and Operations Management by K. Aswathappa K.S. Bhat, Himalaya Publishing House, pp.294-322.



13.8 ANSWERS TO CHECK YOUR PROGRESS

Ans. to Q. No.1: (d) Inspection

Ans. to Q. No.2: (b) $\overline{X}$ Chart (Mean Chart)

Ans. to Q. No.3: (a) Type I (α) Error/ Producer's Risk

Ans. to Q. No.4: (a) Green Belts

Ans. to Q. No.5: (b) Process capability index



13.9 MODEL QUESTIONS

Q. 1) What is inspection? What is the basic difference between inspection and quality control?

Q. 2) Define quality and quality control? How is quality control different from total quality control?

Q. 3) Explain the concept of cost of quality.

Q. 4) What is meant by value engineering? What is the difference between value analysis and value engineering?

Q. 5) State and explain the advantages and limitations of acceptance sampling over 100% inspection.

Q. 6) Construct the control chart for mean and range for the following data for readings for a sample of engines. Readings of five such engines are being taken every hour (each set of five has been arranged on order of magnitude). Comment on the sate of control:

45	65	65	48	87	43	46	65	71	80
20	24	70	83	83	40	51	64	73	81
42	56	57	59	75	56	79	71	73	122
66	70	74	95	128	23	21	23	34	57

Q. 7) XYZ Company manufactures LED bulbs. At some intermediate point of the production line, 10 samples of size 20 each have been taken. Bulbs within each sample were classified into good or bad. The related data are given in the following data. Construct a p-chart with 3-sigma limit and comment on the process.

Sample Number	Number of Defective Bulbs	Percentage of Defective Bulbs
1	9	0.45
2	10	0.50
3	9	0.45
4	12	0.60
5	2	0.10
6	6	0.30
7	12	0.60
8	13	0.65
9	7	0.35
10	5	0.25

Q. 8) The following chart gives the number of missing joints noted in ten newly fabricated trucks. Construct a C-chart? Comment on the state of control.

Truck Number	1	2	3	4	5	6	7	8	9	10
Number of missing joints (c)	12	18	23	20	11	20	19	11	14	15

** *** **