Chapter 5: Motion Study

- Work study is a technique which is employed to ensure the best possible use of men, machine, materials and energy in carrying out a specific activity. It deals with the techniques of method study and work measurement.

Method study (Motion study) | Work measurement (Time study)

- Work study is based on the principle that for every job, there is:
    a) One best way of doing it.
    b) A scientific method is the best and surest way of finding this best way. — Motion study
    c) The time taken for doing the job by the best way can be measured and set as standards. — Time study

5.1 Motion study:

- ➢ It is defined as a systematic and critical study of existing method of doing a task with a view to evolve the most efficient and economic method of doing it.
- ➢ It is a method for setting up employee productivity standards in which:
    - A complex job is broken down into small or simple steps.
    - The sequence of movements taken by the employee in performing those steps is carefully observed to detect and eliminate wasteful motion.
    - Precise time taken for each correct movement is measured.

From these measurements, production and delivery times and prices are computed and incentive schemes are devised. Generally it is appropriate only for repetitive tasks. Time and motion studies were pioneered by the US industrial engineer Frederick Winslow Taylor (1856-1915) and developed by the husband and wife team of Frank Gilbreth (1868-1924) and Dr. Lillian Gilbreth (1878-1972).

Objectives of motion study

The objectives of motion study are:
- To improve the procedure of doing a work.
- To improve the workplace layout (ultimately plant layout).
- To minimize the human motion for minimum fatigue of operators.
- To maximize the utility of resources (men, m/c, materials).
- To improve the overall working environment.

5.2 Principles of motion economy

- Analysis of an operation when carried out in terms of individual motion of a worker is known as Motion analysis.
- The purpose of motion analysis is to design an improved method which would eliminate unnecessary motion and employs human effort more productively. In doing so, the Principle of motion economy is very much helpful.
- It consists of a set of rules designed by Gilbreth and later rearranged and amplified by others (Branes Lowry et al) to develop better methods.

(i) It is classified into following 04 categories: Rules concerning human body, workplace layout and material handling, Tools and Equipment Design and time conservation.

(ii) Rules concerning human body

1. Both hands should be used for productive work.
2. Both hands should start and finish their motion at the same time.
3. Except for the rest period, the two hands should not be idle at one time.
4. Motion of both the hands and arms are symmetrical, simultaneous and opposite to each other.
5. Motions should be simple and involve minimum number of limbs. (The purpose-shortest duration and minimum fatigue)
6. Motion should be smooth and continuous. There should not be sharp direction change and frequent stop.
7. It is desirable for a worker to employ momentum to assist him.
8. A worker may use mechanical aids to assist him to overcome muscular effort.

(iii) Rules concerning workplace layout and material handling

1. There should be a definite, fixed and easy accessible location for materials and tools.
2. As far as possible, materials, tools and other mechanical devices should be kept close to work place.
3. Gravity should preferably be employed wherever feasible with a conveyor for transportation and delivering materials at the workplace between various workstations and departments.
4. An assembled and final product should preferably be dropped on a conveyor near the workplace so that gravity delivers the job at the required place.
5. Tools and materials should preferably be located in the order/sequence in which they will be required for use.
6. Good illumination is required for proper seeing, fast operating and reducing the accidents.
7. In order to impart rest to some of the limbs, an operator may sometimes sit or stand while working. This necessitates a relationship between his chair, height of table or workpiece.
8. In order to reduce fatigue, the sitting arrangement of the worker should be comfortable and adjustable.
9. All heavy parts should be lifted by mechanical devices.

(iv) Rules concerning Tools and Equipment Design

1. Jigs, fixtures and foot operated devices should be employed to reduce the work load on hand.
2. Tools should be multipurpose and easy to handle.
3. Foot-operated switches and controls should be designed as far as possible to reduce the workload on the hands.
4. Tools and materials should be properly arranged and located near the workpiece.
5. Tools and materials should be located in the order of their use.
6. There should be maximum surface contact between the tool handle and hand. It helps proper application of hand force and minimizes fatigue.
7. Gravity should be used for delivery of materials and finished goods.
8. Where the work is supposed to be carried out by fingers, the load distribution on each finger should be as per normal capacity of finger.
9. A worker should have the flexibility to stand or sit comfortably while working.
10. A worker should be able to operate levers and handles without changing the body position.
11. The workplace should have proper ergonomics in terms of illumination, proper conditions of heat, cold and humidity, reduced dust and noise, etc.

(v) Rules concerning time conservation

1. Even temporary ceasing of work by a man or m/c should not be encouraged.
2. Machine should not run idle as it leads to loss of production and power.
3. Two or more jobs should be done at the same time, or two or more operations should be carried out on a job simultaneously.
4. Number of motions involved in completing a job should be minimized.
5. The loading and unloading of the job and the cycle time should be synchronized in such a manner that one operator can be multi-functional or can simultaneously operate a number of machines.

6 Procedure in Motion Analysis

The steps in motion analysis are as follows:

a) Select: Select the work to be studied.
b) Record: Record all the relevant facts of the proposed work by direct observation.
c) Examine: Examine the facts critically in sequence, using special critical examination sheet.
d) Develop: Develop the best method i.e. the most practical, economic and effective method under prevailing circumstances using the principle of motion economy.
e) Install: install that method as standard practice.
f) Maintain: maintain that standard practice by regular routine check.

Recording

The recording may trace the movements of men, material or details of various processes. The principle is to use the simplest technique which will contain all relevant information needed for investigation.

The different recording techniques are charts, diagrams, models and photographic aids. The most commonly used recording techniques to cover most of the activities are shown in Table 5.1. The different symbols which are used in process charts are shown in Table 5.2.

Table 5.1 Recording Techniques

Recording Technique	**Information Recorded**
(a) Charts	
1. Outline process chart	Principle operations and inspection of the processes.
2. Flow process chart	Activities of men, material or equipment are analyzed into five events viz., operation, transport, inspection, delay and storage.
3. Two-handed process chart	Movements of two hands or limbs of the operator.
4. Multiple activity chart	Simultaneous/interrelated activities of operators and/or machines on a common time scale.
5. Simultaneous Motion Cycle Chart (SIMO)	Movement of body members of the operator, expressed in terms of therbligs on a common time scale.
(b) Diagrams and Models	
1. Flow diagram	Path of men, materials and equipments on a scale model.
2. String diagram	Same as above except for the variation that it uses string to trace the path.
(c) Photographic aids	
1. Cyclegraph	Movement of hand obtained by exposing a photographic plate to the light emitted from small bulbs attached to the operator's fingers.
2. Chrono-cyclegraphs	Modification of cyclegraph in which recording is made using flash light.

Table 5.2 Symbols used in Process Chart

Symbol	Activity	Purpose for which it is used
◯	Operation	Indicates the main steps in a process, method of procedure, usually the part, material or product concerned which is modified or changed during the operation.
→	Transport	Indicates movement of workers, material or equipment from place to place.
□	Inspection	Indicates any type of inspection, check, measurement, visual scrutiny for quality and/or quantity.
D	Temporary storage or delay	Indicates a delay in the sequence of events.
▽	Storage	Indicates a controlled storage in which material is received into or issued from stores under some form of authorization or an item is retained for reference purposes.

5.3Time study

- It was proposed by Frederick Taylor and later modified to include a performance rating (PR) adjustment.
- Once the method is established, the next objective is to set the standard time for the work. This aspect of work study is called Time study (or Work measurement).
- The main objectives of time study are:

1) To determine the standard time for various operations which helps in fixing wage rates and incentives.
2) To estimate the cost of product accurately.
3) To predict accurately the duration for a particular work and customer is promised accordingly.
4) To determine the number of machines an operator can run.
5) To determine the optimum number of men and machine.
6) To provide information for planning and scheduling.
7) To balance the work of all workers working in a group.
8) To compare the work efficiency of different workers/operators.

Work measurement techniques

1. Time study using stop watch.
2. Predetermined motion time system (PMTS).
3. Work sampling.
4. Analytical estimating.

The following table shows the application of each technique and unit of measurement.

Technique	Application	Unit of measurement
Time study using stop watch	Short cycle repetitive jobs	Centiminute (0.01 min)
PMTS	Manual operations confined to one work centre	TMU (I TMU = 0.006 min)
Work sampling	Long cycle jobs/ Heterogeneous operation	Minute
Analytical estimating	Short cycle non-repetitive job	Minute

Time study using stop watch is the most popular technique for determining standard time. The first task of the analyst is to divide the work/job into smaller work elements in such a way that the time for each element should not be less than 3 seconds because for such elements, recording time is difficult. The steps of time study are as follows:

Step 1: First select the job to be studied. Breakdown the work content of the job into smallest possible elements. Then, inform the worker and define the best method.

Step 2: Observe the time for appropriate number of cycles (such as 25 to 50).
Step 3: Determine the average cycle time (CT)

$$CT = \frac{\sum \text{Times}}{\text{No. of cycles}}$$

Step 4: Determine the normal time (NT)

NT = CT (PR)

Where, PR is the performance rating.

Step 5: Determine the standard time using the following formula.

$$ST = NT\ (AF) \text{ where } AF = \frac{1}{1 - \%\ \text{Allowance}}$$

AF being the allowance factor.

5.4 Selection of job for Time Study

Time Study is conducted on a job

- which has not been previously time-studied.
- for which method change has taken place recently.
- for which worker(s) might have complained as having tight time standards.

5.5 Selection of Worker for Time Study

The worker on which time study should be conducted must

- have necessary skill for the job.
- have sufficient experience with the given method on the job (that is, he should have crossed the learning stage).
- be an ‘average' worker as regards the speed of working.
- be temperamentally suited to the study (those who can't work in normal fashion when watched, are not suitable for the study).
- have knowledge about the purpose of study.

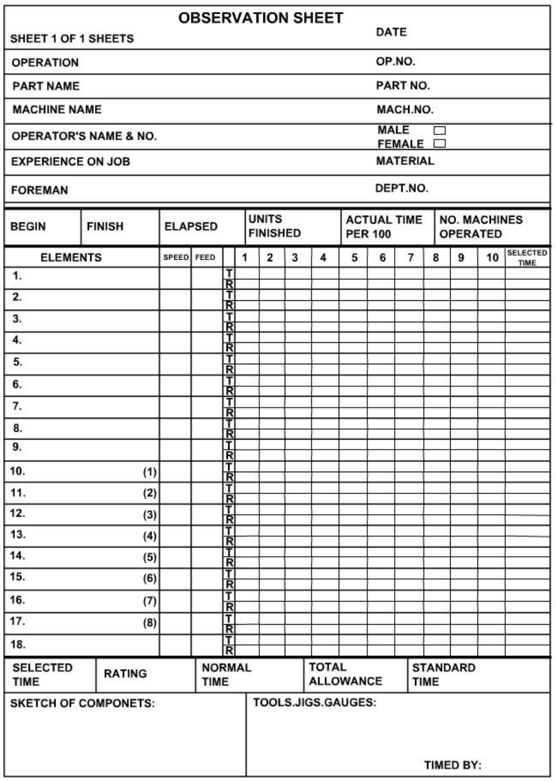
5.6Time Study Equipment

The following equipment is needed for time study work.

- Timing device
- Time study observation sheet
- Time study observation board
- Other equipment

Timing Device. The stop watch is the most widely used timing device used for time study, although electronic timer is also sometimes used. The two perform the same function with the difference that electronic timer can measure time to the second or third decimal of a second and can keep a large volume of time data in memory.

Time Study Observation Sheet. It is a printed form with spaces provided for noting down the necessary information about the operation being studied, like name of operation, drawing number, and name of the worker, name of time study person, and the date and place of study. Spaces are provided in the form for writing detailed description of the process (element-wise), recorded time or stop-watch readings for each element of the process, performance rating(s) of operator, and computation. Fig. 5.1 shows a typical time study observation sheet.



OBSERVATION SHEET

SHEET 1 OF 1 SHEETS	DATE
OPERATION	OP.NO.
PART NAME	PART NO.
MACHINE NAME	MACH.NO.
OPERATOR'S NAME & NO.	MALE ☐ FEMALE ☐
EXPERIENCE ON JOB	MATERIAL
FOREMAN	DEPT.NO.

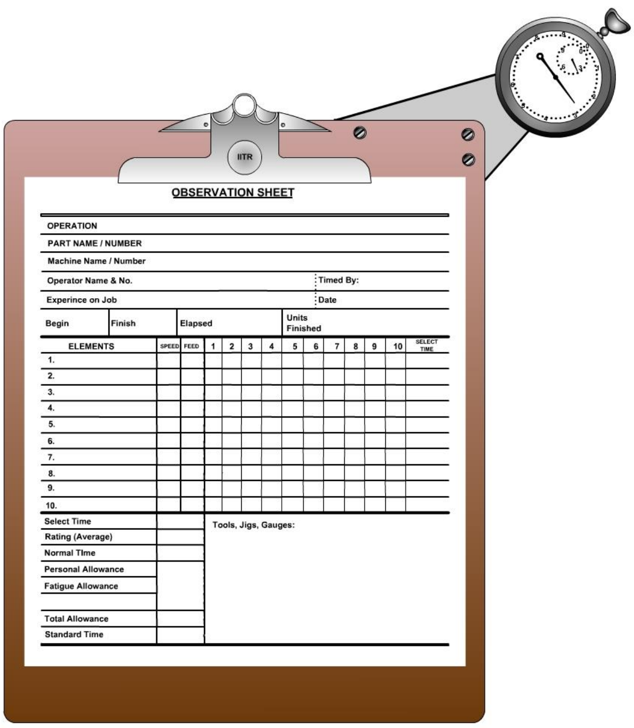
BEGIN	FINISH	ELAPSED	UNITS FINISHED	ACTUAL TIME PER 100	NO. MACHINES OPERATED

ELEMENTS	SPEED	FEED		1	2	3	4	5	6	7	8	9	10	SELECTED TIME
1.			T R											
2.			T R											
3.			T R											
4.			T R											
5.			T R											
6.			T R											
7.			T R											
8.			T R											
9.			T R											
10. (1)			T R											
11. (2)			T R											
12. (3)			T R											
13. (4)			T R											
14. (5)			T R											
15. (6)			T R											
16. (7)			T R											
17. (8)			T R											
18.			T R											

SELECTED TIME	RATING	NORMAL TIME	TOTAL ALLOWANCE	STANDARD TIME

SKETCH OF COMPONETS:	TOOLS.JIGS.GAUGES: TIMED BY:

Time Study Board. It is a light -weight board used for holding the observation sheet and stopwatch in position. It is of size slightly larger than that of observation sheet used. Generally, the watch is mounted at the center of the top edge or as shown in Figure near the upper right-hand corner of the board. The board has a clamp to hold the observation sheet. During the time study, the board is held against the body and the upper left arm by the time study person in such a way that the watch could be operated by the thumb/index finger of the left hand. Watch readings are recorded on the observation sheet by the right hand.



Other Equipment. This includes pencil, eraser, device like tachometer for checking the speed, etc.

5.7 Why Dividing Work into Short Elements is essential?

For the purpose of time study, the task is normally broken into short elements and each element is timed separately for the following reasons:

- To separate unproductive part of task from the productive one.
- To improve accuracy in rating. The worker may not work at the same speed throughout the cycle. He may perform some elements faster and some slower. Breaking of task into short elements permits rating of each element separately which is more realistic than just rating once for the complete cycle.
- To identify elements causing high fatigue. Breaking of task into short elements permits giving appropriate rest allowances to different elements.
- To have detailed job specifications. This helps in detection of any variation in the method that may occur after the time standard is established.
- To prepare standard data for repeatedly occurring elements.

The following guidelines should be kept in mind while dividing a task into elements.

(1) The elements should be of as short duration as can be accurately timed.

(This in turn, depends on the skill of the time study man, method of timing and recording, and many other factors. Generally, with the stop watch, elements of duration less than 0.03 to 0.05 minute are difficult to time accurately. The elements should not normally be longer than 0.40 min.).

(2) Manually performed elements should be separated from machine paced elements.

(Time for machine paced elements can be determined by calculation). Machine elements are not rated against a normal. This rule also helps in recognition of delays.

(3)Constant elements should be separated from variable elements.

(Constant elements are those elements which are independent of the size, weight, length, or shape of the workpiece. For example, the time to pick screw driver from its place and bring it to the head of a screw is constant, whereas the time to tighten or loosen the screw is a variable, depending upon the length and size of the screw).

(4) The beginnings and endings of elements should be easily distinguishable. These should preferably be associated with some kind of sound.

(5) Irregular elements, those not repeated in every cycle, should be separated from regular elements. For example, if the jig is cleaned off after every ten parts produced, "cleaning" is an irregular element, and its time should be spread over ten cycles.

(6) Unnecessary motions and activities should be separated from those considered essential.

(7) Foreign or accidental elements should be listed separately. Such elements are generally of non-repetitive type.

5.8 Number of cycles to be timed.

The following general principles govern the number of cycles to get the representative average cycle time.

(1) Greater the accuracy desired in the results, larger should be the number of cycles observed.

(2) The study should be continued through sufficient number of cycles so that occasional elements such as setting-up machine, cleaning of machine or sharpening of tool are observed for a good number of times.

(3) Where more than one operator is doing the same job, short study (say 10 to 15 cycles) should be conducted on each of the several operators than one long study on a single operator.

It is important that enough cycles are timed so that reliable average is obtained.

5.9 Following techniques are used to determine the number of cycles to be timed.

(i) Use of Tables: On the consideration of the cost of obtaining the data and the desired accuracy in results, most companies have prepared their own tables for the use of time study, which indicate the number of cycles to be timed as a function of the cycle time and the frequency of occurrence of the job in the company.

(ii) Statistical methods: On the basis of the requirements of the particular situation involved, *accuracy* and *confidence level* are decided (An accuracy of a confidence level of 95% is considered reasonable in most cases). A preliminary study is conducted in which some (say *N)* cycles are timed. Standard deviation o of these *(N)* observations is calculated as

$$\sigma = \sqrt{\left[\frac{1}{N}(t-T)^2\right]} = \frac{1}{N}\sqrt{N(\Sigma t^2) - (\Sigma t^2)}$$

Where t = each watch reading

T = average of N watch reading

n = number of watch readings in the preliminary study.

Now, to find M.the number of cycles to time. the following statistical method can be used.

calculated standard error of mean ε from the equation

$$X.\varepsilon = A.T$$

Where A = accuracy desired

t = average of N watch reading

X = a factor corresponding to confidence level desired. Its values is 1 for 68%, 2 for 95%, and 3 for 99% confidence level.

Determine the required sample size M from the equation

$$\varepsilon = \frac{\sigma}{\sqrt{M}}$$

5.10 Performance Rating

It is a process of comparing the performance rate of a worker against standard performance. The standard performance is different for different jobs. Te rating factor is used to convert the observed time into normal time.

$$\text{Normal time} = \text{Observed time} \times \frac{\text{Performance level of worker}}{\text{Standard performance level}}$$

5.11 Allowances

Allowances are added to normal time in order to arrive at standard time. The various allowances are:

1. **Process allowance:** This is an allowance provided to compensate for enforced idleness during a process. This includes loss of time due to (i) no work (ii) power failure (iii) faculty material (iv) faculty tool or equipment.

2. **Personal and Rest allowance**: This is allowed to compensate for the time spent by worker in meeting the physical needs, for instance a periodic break in the production routine. The amount of personal time required by operator varies with the individual more than with the kind of work, though it is seen that workers need more personal time when the work is heavy and done under unfavorable conditions.

   The amount of this allowance can be determined by making all-day time study or work sampling. Mostly, a 5 % allowance for personal time (nearly 24 minutes in 8 hours) is considered appropriate.

   Rest allowance is a relaxation allowance to a worker to overcome fatigue incurred during working. Excessive fatigue badly affects the performance of worker. This rest/relaxation may vary from 12% to 20% of normal time from light to heavy.

3. **Special Allowances**: These allowances are given under certain special circumstances. Some of these allowances and the conditions under which they are given are:

   Policy Allowance: Some companies, as a policy, give an allowance to provide a satisfactory level of earnings for a specified level of performance under exceptional circumstance. This may be allowed to new employees, handicap employees, workers on night shift, etc. The value of the allowance is typically decided by management.

   Small Lot Allowance: This allowance is given when the actual production period is too short to allow the worker to come out of the initial learning period. When an operator completes several small-lot jobs on different setups during the day, an allowance as high as 15 percent may be given to allow the operator to make normal earnings.

   Training Allowance: This allowance is provided when work is done by trainee to allow him to make reasonable earnings. It may be a sliding allowance, which progressively decreases to zero over certain length of time. If the effect of learning on the job is known, the rate of decrease of the training allowance can be set accordingly.

   Rework Allowance: This allowance is provided on certain operation when it is known that some percent of parts made are spoiled due to factors beyond the operator's control. The time in which these spoiled parts may be reworked is converted into allowance.

4. **Policy allowance:** It depends on the policy of an organization controlled by workers union.

Problem 1: In a welding shop, a direct time study was done on a welding operation. One inexperienced industrial engineer and one experienced industrial engineer conducted the study simultaneously. They agreed precisely on cycle time but their opinion on rating the worker differed. The experienced engineer rated the worker 100% and the other engineer rated the worker 120%. They used a 10% allowance.

Cycle time (in minutes)	Number of times observed
20	2
24	1
29	1
32	1

From the above statement,

(a) Determine the standard time using the experienced industrial engineer's worker rating.
(b) Find the standard time using the worker rating of inexperienced industrial engineer.

Solution:

(a) Rating of worker at 100% by the experienced industrial engineer

Cycle time (CT) = $(20\times2+24\times1+29\times1+32\times1)/5 = 25$ min

Normal time (NT) = CT×PR = $25\times100\% = 25$ min

Standard time (ST) = NT/(1-%A) = $25/(1-0.10) = 27.78$ min

(b) Rating of worker at 120% by the inexperienced industrial engineer

Cycle time (CT) = $(20\times2+24\times1+29\times1+32\times1)/5 = 25$ min

Normal time (NT) = CT×PR = $25\times120\% = 30$ min

Standard time (ST) = NT/(1-%A) = $30/(1-0.10) = 33.33$ min

WORK STUDY + Theory BOOKS(NE)

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a) Method or Motion b) Time or Work Measurement

Work study analyse the work into smaller parts in order to rearrange these parts to increase productivity & to find a standard time for each job.

It is divided into 2 parts:-

1. Method or Motion study: It is a set of techniques developed to create new alternate methods of doing the job at a lesser effort & more effectiveness

Steps of Method Study:-

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SELECT → a Job

RECORD → all the data related to the job

EXAMINE → Recorded data

DEVELOP → Few alternate methods

INSTALL → best alternate

MAINTAIN → the installed alternate

→ Recording Techniques:- These are designed to simplify & Standardize, the recorded work. The most generally used recording techniques are:-

1 Process Charts (P.C)

a) outline P.C b) Flow P.C c) Two handed P.C

2. Time Scale
a) Multiple activity chart
b)(i) SIMO } micro motion
(ii) PMTS }

3 Diagrams
a) Flow   c) Travel chart   e) Chromocycle graph
b) String   d) cycle graph   f) 2-D & 3-D Models & Templates.

1. <u>Process Chart (P.C)</u>: It indicates the sequence of operation & the process chart symbols use are

○ - Operation   △ - Storage

□ - Inspection   ⇨ - Transportation

D - Delay or Temporary storage.

a) <u>Outline P.C</u>: These charts are used to get a little bit of information about the process & it uses only 2 symbols i.e Operation & Inspection

*b) Flow P.C: These are of 3 types: Man, Material & Machine types. These chart are much detailed & carry additional informations. All the five symbols are used. These charts are normally used alongwith corresponding flow diagrams to give complete picture.

c) <u>Two handed P.C</u>: In this chart, activities of Left Hand & the Right hand of an operator are recorded on a common

Date :

time scale related to each other. All the Five symbols are used and these are prefered for short cycle. repetitive sitting jobs which are repeated many times a day

.2 Time Scale:

a) MULTIPLE ACTIVITY CHART (86)

Time	Operator	Machine	Remark
1.5 min			Job Loading
5 min			M/C working
0.5 min			Job Unloading

▨ working   ☐ Idle

Operator utilisation = $\frac{2}{7} \times 100$, cycle Time = 7 min

M/C Utilisation = $\frac{5}{7} \times 100$

In these Charts, the activities of more than 1 item are arranged on a common time scale to show their inter-relationship, the study of these charts makes it possible to rearrange these activities so that their utilisation is optimised.

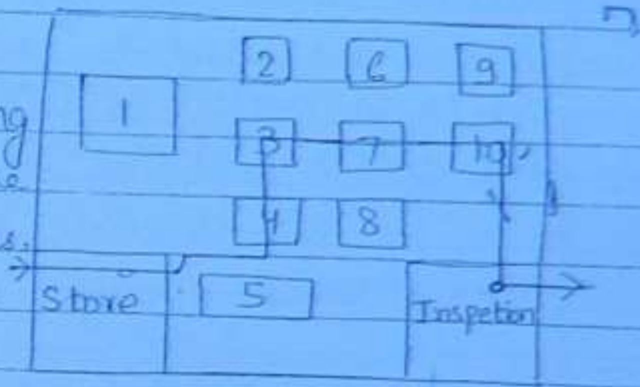
Gang Process chart: It is the form of multiple activity chart in which the activities of Gang or group of workers is synchronised on a common time scale while performing a similar task.

eg Formula-1 Racing car, after 1 lap.

3 Diagrams

a) Flow Diagram

There are upto scale drawing of working area showing the different facilities, Machines, equipments etc. with there numbered symbols.



Scale 1 cm = 2m

These diagram are used along with associated flow process chart to give complete picture of working area.

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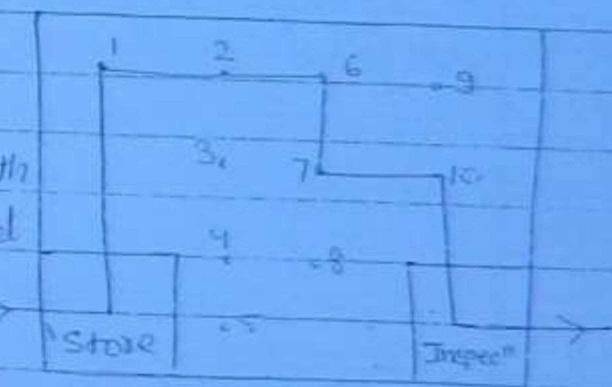
b) String Diagram

In SD are used to trace path of Minimum distance travelled on a upto scale drawing of working area with the help of thread or string.



Scale 1 cm = 2m

It also helps to avoid back-tracking.

c) Travel Chart

4-2-5-3-1

Movement from →

	1	2	3	4	5
1			4		
2				1	
3					3
4					
5		2			

It is a tabular Movement record for presenting Quantitative data about the movements of workes & Material. The travel chart is always square & Each square represents a work station.

to ~~from~~ ↓

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2. Time Scale :

b) MicroMotion Study :
These are used to breakdown a job into smaller parts in order to rearrange those parts to increase the effectiveness of operator.
This is done by Film analysis to facilitate micromotion study.

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Gilbreth divided all the basic human movement into 17 fundamental Hand & Eye movement to which one was added later on. So, Now there are 18 Therbligs and each therbligs has a specific symbol, letter & colour for recording purpose b.1) SIMO CHART

Simultaneous Motion Cycle Chart (Assembly work)

Wink Counter	Left Hand			Right Hand		
	Activity	therblig	Time	Activity	therblig	Time
	$\boxed{1 \text{ wink} = \frac{1}{2000} \text{ minute}}$					

It is micromotion form of 2handed process chart in which the activities of two-hands are related to each other. All the 18 symbols of therbligs are used & are prefered for short duration, repetitive, sitting jobs. The time is measured in Wink counter.

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3 Diagram

d) Cyclegraph: In this method a continuous source of light like a bulb is attached to the hand of an operator and the movement of light is recorded by a camera. The study is performed in a dark room.

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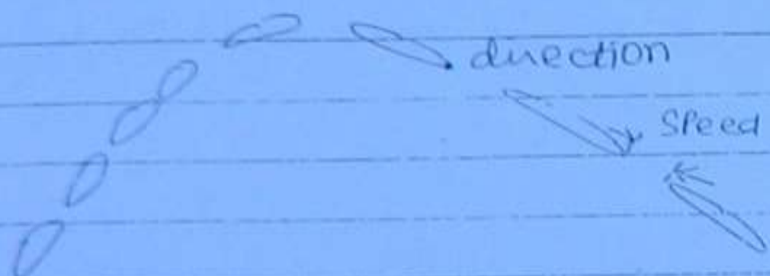
e) Cronocyclegraph: In these graph the light source is interrupted so that the path appears as a series of dots. The pointed end indicates the direction of motion (movement) and the spacing b/w the dots indicates the speed of movement.



TIME STUDY

Date :

- DIRECT
  - StopWatch
  - Work Sampling
- INDIRECT
  - Synthetic or Standard data
  - Analytical Estimation
  - PMTS
    - WF
    - MTM

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I. DIRECT

1. StopWatch:

a) Observed or Elemental time: It is the time measured or observed by an observer using some measuring device like stopwatch.

b) Normal time: It is the time required to complete a job by a normal average worker under normal working conditions.

$$\boxed{\text{Normal Time} = \text{Observed Time} \times \text{Performance Rating factor}}$$

NOTE: Rating factor is always applied to manual controlled operation & is never applied on Machine Element.

c) Standard time: It is the time in which a job is completed after taking all uncertainties & allowances into consideration.
It is the time in which a job is completed when the operator works Continuously for long duration

$$\boxed{\text{Standard Time} = \text{Normal Time} + \text{Allowances}}$$

If nothing is given for allowances, Then always take it equal to Normal Time.

d) Allowances: These are the extra-time provided to qualified workers when they work for long duration. Few of the allowances are rest & personal allowance, contingency allowance, policy allowance, fatigue allowance etc. Delay allowance.
Contigency: Power cut, Failure in system

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2. Work sampling
It is also called as Activity sampling or Ratio Delay study. It is a work measurement technique in which large no of observations are taken at random intervals over a specified period of time on a group of workers or machines.
Larger the no of observations better will be the results as it is based on probability theory and theory of sampling.

It is the best technique for finding the allowances needed for operators

a. No of observations, $\boxed{N = \frac{Z^2 P(1-P)}{L^2}}$

$$\boxed{N = \frac{Z^2 P\% (100 - P\%)}{(L\%)^2}}$$

where,
P is % or fraction of occurance of an activity
L is limit of accuracy and
Z is standard normal variate

Z	Confidence level
1.96	95%
2	95.45%
3	99.74%

b. Confidence precision factor = Z/L

take $z \approx 2$ for 95% [for objective]

$$\boxed{N = \frac{4P(1-P)}{L^2}}$$

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31/8/11
Happy EID.

Quality Control

Quality is defined as fitness for use where fitness is defined by the customer who is using that product.

Quality of a product refers to the degree to which the product meet the customer's expectation. Quality has no specific meaning unless related to a specific function or object.

Cost of Quality or Quality Cost

Failure cost — Appraisal cost — Preventive cost

Failure cost: Internal, External (customers who are using)

etailers, distributers)

All the Expenditure that is associated with preven-ting a production of effective product & the cost associated with companies quality functions like finding, repairing and replacing defective prod-uct can be termed as Cost of Quality.

1. Failure Cost: It is the cost of producing defective product in the production system.

Johnson Taguchi
Jason(+ve) (-ve)

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2. Appraisal Cost : It is the cost associated with evaluating, measuring and finding out defective product within the production system.

3. Preventive cost : All the cost that is associated with minimising failure & appraisal cost can be termed as preventive cost.

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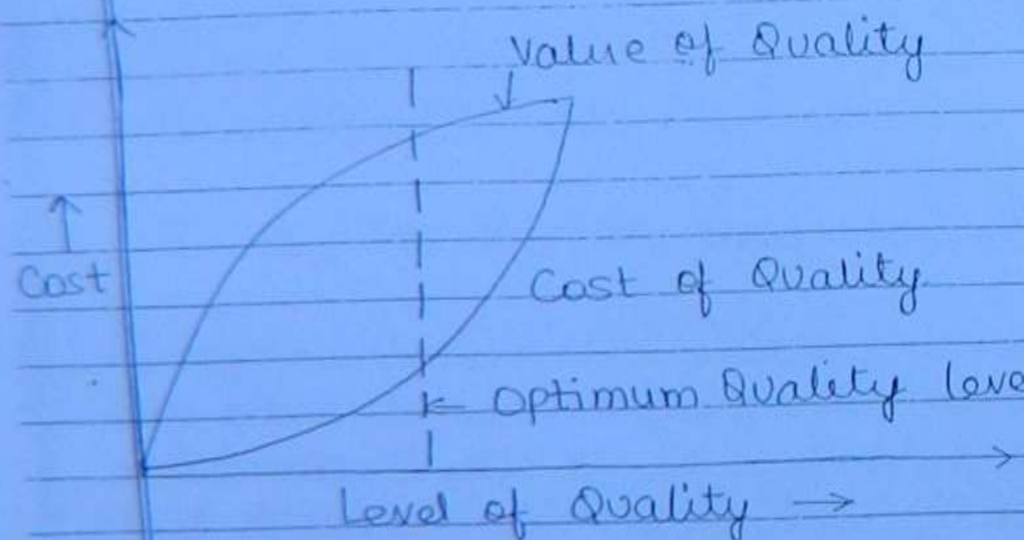
Value of Quality

The return direct or indirect gained by an organisation due to quality control mission is called Value of Quality.

Good quality can earn Market share, good response from the customer, firm price and policy, higher percentage of successful bids and other benefits to the income of organisation.



Quality Control & Inspection

Inspection is an act of checking & sorting out defective product whereas Q.C is a broad term which include

7 many factors including inspection and regulates the quality of future production.
Quality control find out the reasons behind a defective product & also include steps that may be taken so that defective parts may not be repeated in future.

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TYPES OF VARIATION

i. Chance or Common or Random: They are difficult to control & difficult to trace even under best conditions of production. These variations are of Lower magnitude & each component show different variation [This is desirable (in limit)].

2. Assignable Variation: In these variations, Variations are of greater magnitude as compared to common or chance variation and these can be easily traced & detected. They may be due to M/c setting change, tool wear, M/c play, improper training of worker or any other factor.
[This is undesirable, out of limits].

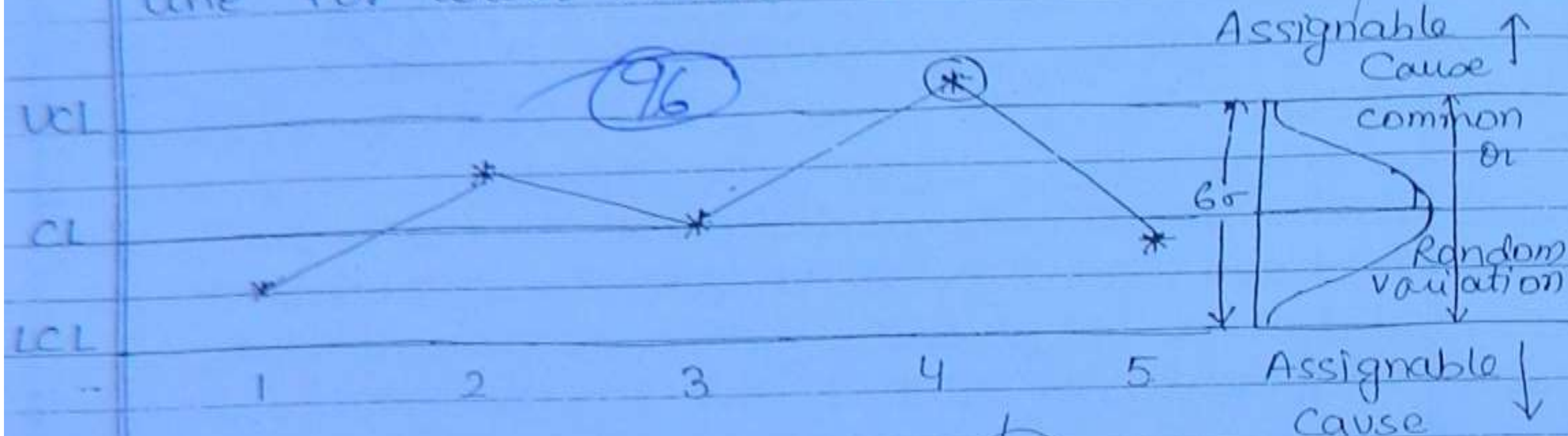
TYPES OF ERROR

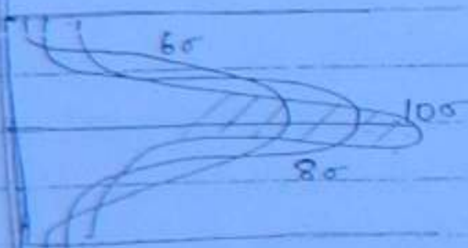
1. TYPE I ERROR: If there is no assignable cost of variation and still we predict that there is some assignable cost, it is called type I error.

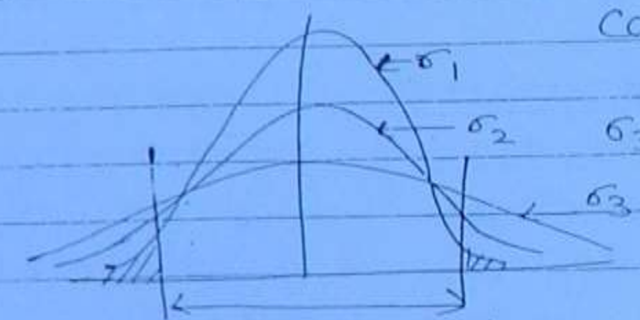
2. TYPE II ERROR: If we conclude that the Universe has not changed, but it really has change

CONTROL CHART

Control Chart is a graph used to study how a process changes over time. Data are plotted in time order a control chart has a central line for the average an upper line for upper control limit and a lower line for lower control limit







$\sigma_3 > \sigma_2 > \sigma_1$

$x = n\uparrow \ \sigma\downarrow$

e.g $\bar{x}$, x_1, x_2, x_3, x_4

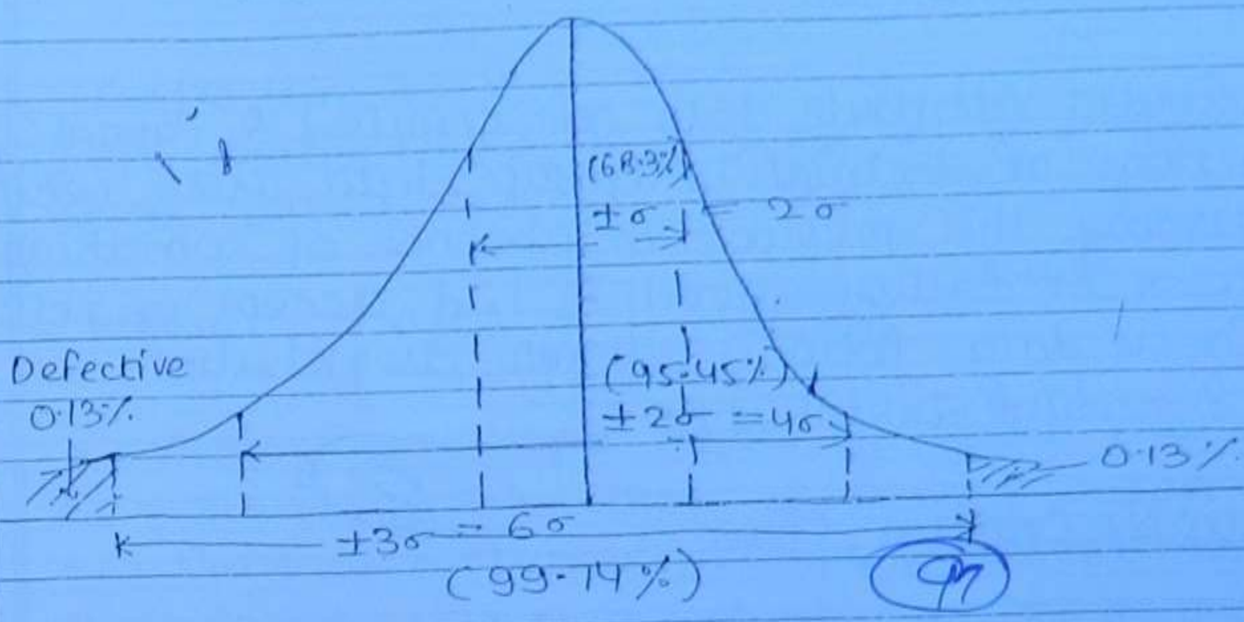
$$\sigma = \sqrt{\frac{(x_1-\bar{x})^2+(x_2-\bar{x})^2+(x_3-\bar{x})^2+(x_4-\bar{x})^2}{n=4}}$$

$\sigma\uparrow$, Non-defective $\downarrow$ — $3\sigma = 6\sigma$, $\sigma = 5$

$\sigma\downarrow$, Defective $\downarrow$ — $3\sigma = 8\sigma$, $\sigma = 3.75$

N.Defective $\uparrow$ — $3\sigma = 10\sigma$, $\sigma = 3$

CONTROL LIMITS   σ is same



Normally, ±3σ control limits are selected most of the time for plotting control charts. Therefore, such charts are called 3σ Control Charts. Since, 99.74% of items fall within this region. So, only 0.26% defective items are produced on a longer run (3 out of 1000).

3.2 for 6σ units, means 3.2 out of 1 million units

TYPES OF CONTROL CHART

- Variable (Measured)
  - Mean or $\bar{X}$ chart
  - Range or R-chart
- Attribute (Counted)
  - P chart
  - np-chart
  - C-chart

1. Variable: These charts are applied to data that follow a continuous distribution. Variable data are measured on a continuous scale & it can be

measured in fractions or decimals. It follows
Normal distribution.

2. Attribute: Attribute data are counted & cannot have fractions or decimals. Attribute data arise while determing the presence or absence of something like success or failure, good or bad, accept or reject etc. These data follow Discrete distribution. (Binomial Distribution)

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1. Variable Control Chart

$\boxed{n}$	$\boxed{n}$	- - -	$\boxed{n}$
1	2	- - -	N
$\overline{X}_1$	$\overline{X}_2$	- - -	$\overline{X}_N$
R_1	R_2	- - -	R_N

$$\overline{\overline{X}} = \frac{\overline{X}_1 + \overline{X}_2 + \ldots + \overline{X}_N}{N} = \sum_{i=1}^{N} \frac{\overline{X}_i}{N}$$

$$\overline{R} = \frac{R_1 + R_2 + \ldots + R_N}{N} = \sum_{i=1}^{N} \frac{R_i}{N}$$

a) $\overline{X}$ - Chart: It shows the centering of the process or in other words it shows the variation in the average of sample.

b) R - Chart: It shows the variation in the range of sample. This chart is a measure of spread of the samples.

a) $\bar{X}$ - control limits:

Centre line = $\bar{\bar{X}}$

Upper control line = $\bar{\bar{X}} + 3 \cdot \sigma_{\bar{X}} = \bar{\bar{X}} + \frac{3 \cdot \sigma}{\sqrt{n}}$

Lower control line = $\bar{\bar{X}} - 3 \cdot \sigma_{\bar{X}} = \bar{\bar{X}} - \frac{3 \cdot \sigma}{\sqrt{n}}$

Where $\boxed{\sigma_{\bar{X}} = \frac{\sigma}{\sqrt{n}}}$ 99

$\bar{\bar{X}}$ = Average of sample mean or ~~Grantt~~ grand average

$\sigma_{\bar{X}}$ = Standard deviation of sample mean.

σ = Universe or process standard deviation

n = Sample size or No. of observation in each sample

$$\bar{R} = \sigma d_2 \Rightarrow \sigma = \frac{\bar{R}}{d_2}$$

$$\boxed{\begin{aligned} U.C.L &= \bar{\bar{X}} + \frac{3 \cdot \bar{R}}{d_2 \sqrt{n}} \\ L.C.L &= \bar{\bar{X}} - \frac{3 \cdot \bar{R}}{d_2 \sqrt{n}} \end{aligned}}$$

U.C.L = $\bar{\bar{X}} + A_2 \bar{R}$

L.C.L = $\bar{\bar{X}} - A_2 \bar{R}$, where $\boxed{A_2 = \frac{3}{d_2 \sqrt{n}}}$

Where, d_2 & A_2 are constant factors whose value depends only upon the sample size 'n'

b) R - Control limits

C L = $\bar{R} = \sigma d_2$

U.C.L = $\sigma \cdot d_2 + 3 \cdot \sigma d_3$

L.C.L = $\sigma d_2 - 3 \sigma d_3$

Now as $\boxed{\bar{R} = \sigma d_2}$ or $\boxed{\sigma = \bar{R}/d_2}$

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$C.L = \bar{R} = \sigma \cdot d_2$

$$U.C.L = \bar{R} + \frac{3 \cdot \bar{R} \cdot d_3}{d_2}$$

$$L.C.L = \bar{R} - \frac{3 \cdot R d_3}{d_2}$$

$$U.C.L = \bar{R}\left[1 + \frac{3d_3}{d_2}\right]$$

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$$L.C.L = \bar{R}\left[1 - \frac{3d_3}{d_2}\right]$$

$\boxed{U.C.L = D_4 \cdot \bar{R}}$ - $\boxed{L.C.L = D_3 \cdot \bar{R}}$

Where $D_4 = \left[1 + \frac{3d_3}{d_2}\right]$ & $D_3 = \left[1 - \frac{3d_3}{d_2}\right]$

where, $\begin{bmatrix} d_2 \,\&\, d_3, \\ D_3 \,\&\, d_4 \end{bmatrix}$ are the constant factors whose value depends upon sample size 'n'.

and for $n < 7$, $D_3 = 0$

2. <u>Attribute Control Chart</u>

a) <u>P- Chart</u> : It is also known as fraction or proportion defective chart. It is used for the situation where sample size is not constant.

Sample No.	Sample size	No. of Defective	Proportion defective $(P_i = d_i / n_i)$
1	n_1	d_1	$P_1 = d_1/n_1$
2	n_2	d_2	$P_2 = d_2/n_2$
¦	¦	¦	
N	n_N	d_N	$P_N = d_N/n_N$

$$\bar{P} = \frac{P_1 + P_2 + \dots + P_N}{N} = \sum_{i=1}^{N} \frac{P_i}{N}$$

$$\bar{n} = \frac{n_1 + n_2 + \dots n_N}{N} = \sum_{i=1}^{N} \frac{n_i}{N}$$

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

$$UCL = \bar{P} + 3\sqrt{\frac{\bar{P}(1-\bar{P})}{\bar{n}}}, \quad LCL = \bar{P} - 3\sqrt{\frac{\bar{P}(1-\bar{P})}{\bar{n}}}$$

(or)

$CL = \bar{P}$

$UCL = \bar{P} + 3\sigma_{\bar{p}}$

$LCL = \bar{P} - 3\sigma_{\bar{p}}$

Where,

$\bar{P}$ = Average proportion defective

$\sigma_{\bar{p}}$ = standard deviation of average proportion defective

$\bar{n}$ = Average sample size.

) np-chart: It is also known as No of defective chart & is used for the situation where sample size is constant.

Sample No.	Sample size	No. of defective	Proportion defective ($P_i = d_i/n$)
1	n	d_1	$P_1 = d_1/n$
2	n	d_2	$P_2 = d_2/n$
N	n	d_n	$P_N = d_N/n$

$CL = n\bar{P}$ $\qquad \sigma_p = \sqrt{\frac{\bar{P}(1-\bar{P})}{n}}$

$UCL = n\bar{P} + 3\sqrt{n\bar{P}(1-\bar{P})}$

$LCL = np - 3\sqrt{n\bar{P}(1-\bar{P})}$

$U.CL = \bar{P} + 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}} \qquad L.C.L = \bar{P} - 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}}$

p, np → defective (Binomial)
c → defect (Poisson)

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c) C-Chart: It is also known as Doubt of Defect chart and it is used when we can compute only the no of defects but cannot compute the proportion that is defective.

It follows poisson's distribution & as in Poisson's distribution variance equals to mean

i.e Variance = Mean.

$$\sigma^2 = \bar{c}$$

$$\boxed{\sigma = \sqrt{\bar{c}}}$$

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$CL = \bar{c}$
$UCL = \bar{c} + 3\sqrt{\bar{c}}$
$LCL = \bar{c} - 3\sqrt{\bar{c}}$

ACCEPTANCE SAMPLING

It refers to the process of randomly inspecting certain no of items from a lot in order to decide whether to accept or reject the entire lot. It is used when inspecting every item is either physically not possible or would be very expensive.

It is the only method of inspection where testing is done through destuctive manner.

Sampling Plan

1. Single Sampling Plan: In this plan 'n' sample are taken randomly once and if no. of defective is equal to or less than acceptance no. (C). Then the entire lot is accepted otherwise rejected.

$$\text{Max. } Z = c_1x_1 + c_2x_2 + \dots + c_nx_n$$

$$a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \le b_1$$

$$a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \le b_2$$

$$a_{m1}x_1 + a_{m2}x_2 + \dots + a_{mn}x_n \le b_m$$

$$x_1, x_2 \dots x_n \ge 0$$

variables = n, C equations = m (103)

If there 'm' equality constraints & 'n' is the no. of variable. ~~Then,~~ & $n > m$, Then we need to put '$n-m$' variable = 0 and solve the remaining 'm' variables with 'm' equality constraints.

The $n-m$ variables which are put equal to zero are called Non-basic variables and the remaining 'm' variables are called Basic variables which gives basic solution.

This step reduces the no of alternatives for optimal solution whose maximum limit is given by $\boxed{{}^nC_m = \frac{n!}{m!(n-m)!}}$

$n=5$, $m=3$, $n-m=2 \Rightarrow$ Non basic, $m=3$ – basic

Definitions :-

Feasible Solution : A solution which satisfy the ggiven constraints along with non-negative condition is called feasible solution

Basic solution : The solution of 'm' basic variable when each of '$n-m$' Non-basic variable is put equal to zero is called basic solution