CHAPTER 11

Work Study and Ergonomics

11.1 INTRODUCTION

Work study is a process of investigation of the works done in an organization and finding the most effective way of doing the job with efficient utilization of the available resources (man, material, money and machinery) within least possible time. Work study consists of two broad studies, i.e. method study and time study as shown in Figure 11.1. Method study is concerned with the way of performing a job and time study is concerned with measuring the time to complete the job.

Work study is a generic term for techniques, particularly method study and work measurement, which are used for the examination of human work in all its contexts, and which lead systematically to an investigation of all the factors which affect the efficiency and economy of the situation being reviewed, in order to seek improvements. (Adebayo 2007; ILO 1981)

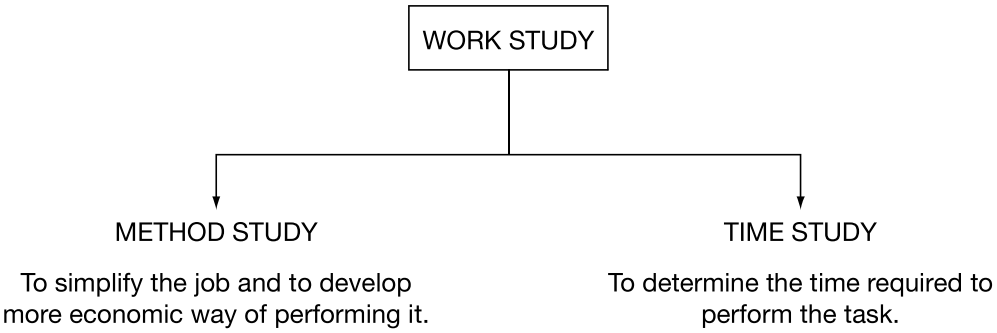

Figure 11-1: Classification of work study

Purposes of Work Study

The following are the purposes of conducting work study:

1. To standardize the method of doing a task.
2. To determine the standard time for doing a task, for use in the wage payment/ determination.
3. To minimize the unit cost of production by selecting proper machine tools, optimum cutting parameters and proper process.

4. To minimize the materials movement and idle time of the workers and machines by proper layout of the plant.
5. To eliminate the unnecessary human motions in performing a task.
6. To utilize the facilities such as man, machine and materials most effectively.

11.2 METHOD OR MOTION STUDY

Methods engineering grew out of the pioneering developments of Frank B. Gilbreth, and his wife, Lillian M. Gilbreth, who developed many of the tools of 'motion study' as a part of formulating a systematic approach to the analysis of work methods. Frank B. Gilbreth first became interested in methods, analysis as an outgrowth of his observations of bricklaying work.

Methods engineering is a necessary function to ensure the most efficient methods. This activity is most frequently performed by industrial engineers; however, all engineers should be concerned with work methods. It is related to the study of methods for performing a job to design effective and efficient work system in order to achieve process improvements, improved layout, better working environment and reduced fatigue. Method study is associated with the reduction of the work content of a job or operation, while work measurement (WM) is mostly concerned with the investigation and reduction of time consumption or any ineffective time associated with it. Mundel (1946) published the method engineering with several studies in his textbook *Systematic Motion and time study.* Method study and time study are interrelated to each other. To know the effectiveness of a method, one of the important parameters is time consuming by the method which can be known by time study or work measurement.

Steps to Conduct Method Study

Select: In this step, a job or process is selected which is to be considered for method study.

Record: All the relevant facts/information about the process or the job is collected through data collection or direct observation.

Examine: All the data collected in second step are examined properly.

Develop: Some of the efficient and economical methods of doing that job or process are developed.

Evaluate or Measure: Results of different alternative methods are evaluated and the best one is selected.

Define: New method among the alternative is defined and presented.

Install: New method as standard practice is installed and persons in applying it are trained to use the new method.

Maintain: Control procedure is established and maintained.

Objectives of Method Study

The following are the objectives of method study:

1. To improve the process of doing the work.
2. To improve the plant layout.

3. To minimize the human motions and fatigue of the operators.
4. To maximize the utility of man, machine and material.
5. To improve the overall working environment.

Factors Influencing the Method Study

In method study, an industrial engineer has to consider the following factors:

1. Motion economy factors.
2. Economic factors.
3. Technical factors.
4. Human factors.
5. Operational complexity.
6. Delays.

Motion economy factors: When a job is considered for method study, one has to think of whether there is a possibility of reducing the unnecessary motions. The jobs that are performed regularly, the micro-motion studies may expose such unnecessary motions. By economizing these motions, we can save human energy and utilize it for higher productivity.

Economic factors: Before conducting the study, one has to think is it worth to conduct motion or micro-motion study? If a work selected for investigation results in a very small economy, it is suggested that the study should not be conducted. One may have to consider the economy in removing the bottlenecks in movements and process such as movement of materials in one operation to the other, layout of machines, operational sequences, etc.

Technical factors: When a new method is developed and implemented, it is required to check availability of adequate technical knowledge and resources required in the method. This is a constraint for development of new methods. In most of the cases, technical factors and economic factors are interlinked.

Human factors: This factor is difficult to evaluate because it is associated with physiological, psychological and anatomical features of human beings. But these difficulties can be overcome to some extent through scientific methods such as ergonomics. If workers and their representatives are allowed to participate in problem formulation and implementation, the problem can be eliminated. The full and active participation from the workers' side and a due consideration to their views from the management side would reduce the difficulties and gives an impression among the workers that the new methods are for their betterment.

Operational complexity: When a method study is taken up for a job, most often the managers forget to take such operational complexity/flexibility into consideration. It is the industrial engineer's responsibility to bring out detailed description about the operational flexibility or complexity, so that the critical examination can be facilitated to check under these constraints.

Delays: There are three types of delays—unavoidable delay, avoidable delay and planned rest pauses. In unavoidable delay, operators cannot avoid the delay, for example, operator inevitably waits for the material to come or for his turn to do the job; heat-treated products have to be cooled

before an operation on a certain machine; welded joints are allowed to cool before taking for operation, etc. The avoidable delays can be avoided by proper planning. For example, a machinist need not have to wait if cleaning is done prior to his arrival. The third type of delay is planned rest pauses. These are also inevitable but somewhat flexible to change their schedules or duration in accordance with ergonomics studies. The industrial engineers who conduct method study must take these delays into consideration while developing the new method. Method study uses the symbols mentioned in Figure 11.2.

S. No.	Activity	Symbol	Remarks
1.	Operation		Indicates the main process, method or operation.
2.	Inspection		Indicates an inspection for quality and/or check for quantity.
3.	Transport		Indicates the movement of workers, materials or equipment from place to place.
4.	Temporary storage or delay		Indicates a delay in the sequence of events: for example, work waiting between consecutive operations, or any object laid aside temporarily without record until required.
5.	Permanent storage		Indicates a controlled storage in which material is received into or issued from a store under some form of authorization; or an item is retained for reference purposes.

Figure 11-2: Symbols used in method study

Tools Used in Method Study

The tools used for method study may be classified under three heads as discussed below:

- Charts;
- Diagrams; and
- Photographic aids.

There are two types of charts: A-type and B-type. A-type charts indicate the sequence of events happening in the order in which events occur irrespective of time scale, whereas B-type charts indicate the sequence of happening in the order in which events occur on a time scale. Some of the charts in common use are discussed in the following subsections.

11.2.1 Operation Process Chart

Operation process chart is a graphical representation of a process containing the name of the product, assembly or sub-assembly, name of person making chart, date, a sketch of the product, sequence of operations, the name of the department, drawing number and summary. The operation process chart is shown in Figure 11.3.

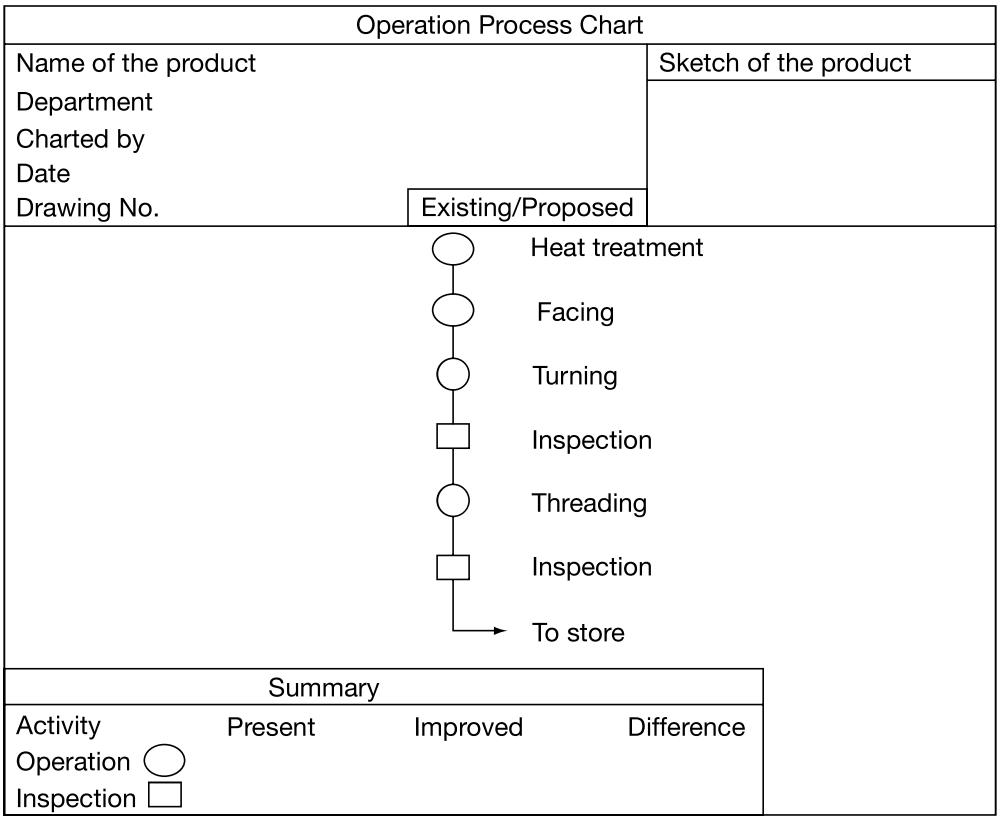

Figure 11-3: Operation process chart

Advantages of Operation Process Chart

There are following advantages of operation process chart:

1. It represents basic activities and summarizes overall picture of an operation.
2. It visualizes the process and makes easy to understand.
3. It gives a scope for improvement of operations or their sequence by combination or rearrangement or elimination.
4. It helps in identifying the stages of inspection and thus provides an idea for better layout of the workplace.
5. It shows a way to think of improvements in material handling and reducing the material movements.

Limitations of Operation Process Chart

The following information is not given in operation process chart:

1. Distance between workstations or shops.
2. Time to travel between workstations or shops.
3. Any interference or delays between two workstations.
4. Back tracking, if any.

11.2.2 Flow Process Chart

The flow process chart was introduced by Frank Gilbreth to members of ASME in 1921 as the presentation *Process Charts, First Steps in Finding the One Best Way to Do Work* (Gilbreth 1921). It is an improved version of the operation process chart, which is set out sequence of flow of a product, man or machine or material by recording all events in its process, in terms of appropriate symbols. Flow process chart is shown in Figure 11.4. It has advantages over operation process chart due to having following extra information:

1. Distance between workstations or shops.
2. Time to travel between the workstations or shops.
3. Any interference during transportations and possible causes.
4. Backtracking, if any.
5. Mode of transport between two workstations.

Flow Process Chart

Name of the product
Department
Charted by
Date
Drawing No.

Existing/Proposed

Sketch of the product

	Distance (m)	Time (min.)	Remarks
Mild steel rod from store			
To heat treatment lab.	25	30	Hand trolley
Heat treatment			
To lathe machine	30	32	Hand trolley
Facing			
Turning			
Inspection			
Threading			
Inspection			
To store	28	29	Hand trolley
Store			

Summary

Activity	Present	Improved	Difference
Operation			
Inspection			
Transportation			
Delay			
Storage			

Figure 11-4: Flow process chart

11.2.3 Two-hand Process Chart

This chart is used to study the motions of two hands of workers and bring out the effectiveness and hence the efficiency. It is defined as a process chart in the activities of a worker's both hands recorded in relationship to each other. This technique is widely used for micro-motion study. The purposes of two-hand process chart are:

1. To balance the motions of both hands and reduce fatigue.
2. To reduce or eliminate non-productive motions.
3. To shorten the duration of productive motions.
4. To train new operators in the ideal method.
5. To sell the proposed method.

A structure of two-hand process chart is shown in Figure 11.5.

Method : Existing/Proposed Operation : Operator : Start of Activity : Department :		Machine No. : Operation No. : Charted by : End of Activity : Date :	
Description Left Hand	Symbol	Symbol	Description Right Hand
	○⇨▽D□	○⇨▽D□	

Summary

Activity/Symbol	Existing		Proposed		Saving
	LH	RH	LH	RH	
Operation (○)					
Transportation (⇨)					
Storage (▽)					
Delay (D)					
Inspection (□)					
Distance in Mtrs.					

Figure 11-5: Two-hand process chart

11.2.4 Multiple Activity Chart

In all the above charts, they represent only one of resource like a worker or an equipment or material, etc. But the relation between a man and machine or man and material, etc. is not shown. The multiple activity charts can show all these relationships in a very compact manner. This chart enables the industrial engineer to study whether any unnecessary waiting times can be eliminated. A multiple activity chart is a chart in which the activities of more than one subject (worker, machine or item of equipment) are recorded on a common time scale to show their interrelationship. Using separate vertical columns or bars to represent the activities of different operatives, machines against a common time scale, the chart shows clearly the periods of idleness on the chart on the part of any of the subjects during the process.

The multiple activity charts are prepared in one of the four ways as: one man–one machine chart, two men–one machine chart, one man–two machine chart, and two or more men–one or more machine chart. The main advantages of this chart are to use as a tool for finding the optimum number of men and machines, capacity calculations, incentive calculations, manpower planning, material planning, job scheduling, etc. For example, multiple activity charts concerning operation and a man–machine process charts are shown in Figures 11.6 and 11.7, respectively.

11.2.5 SIMO Chart

It is one of the recording techniques of micro-motion study and records simultaneously the different therbligs performed by different parts of the body of one or more operators simultaneously. 'SIMO' stands for 'Simultaneous Motion Cycle Chart'. It is used to show the simultaneous nature of motions; more generally, a therblig chart for two-hand work with motion symbols is plotted vertically with respect to time, showing the therblig and a brief description for each activity, and individual time's values and body-member detail. A two-hand SIMO chart is shown in Figure 11.8.

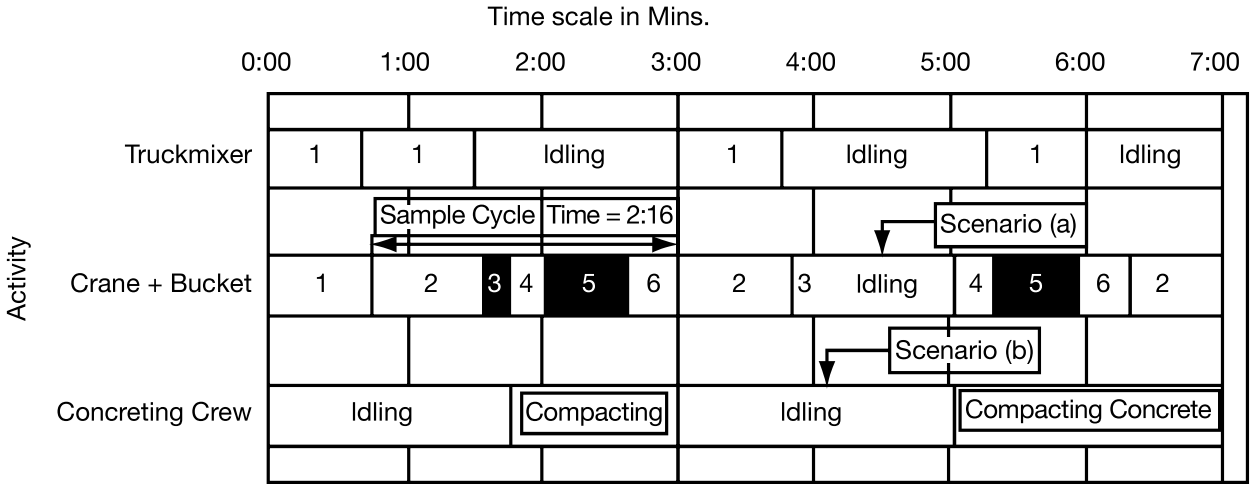

Figure 11-6: Multiple activity chart for concern operation

Operator Name :
Department :
Activity :
Org. No. :
Method :

Summary

	Man	Machine
Idle time		
Working time		
Total cycle time		
Utilization	Operator utilization	Machine utilization

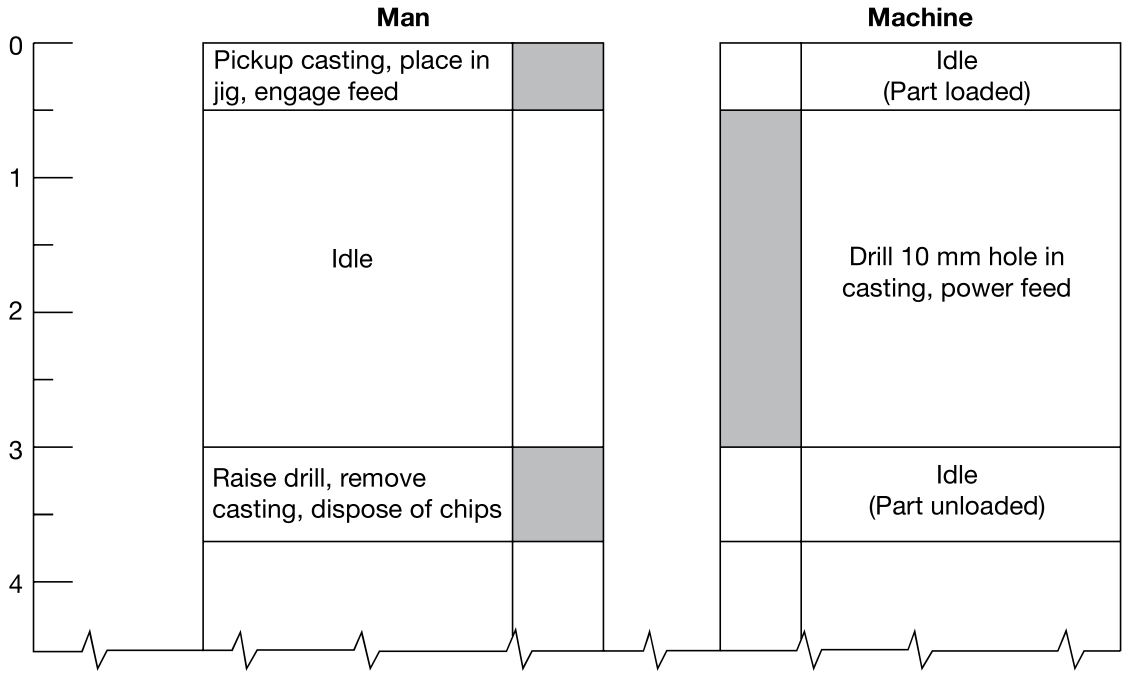

Figure 11-7: Man–machine process chart

SIMO CHART

OPERATION : **FILM NO. :**

Method : **OPERATION NO. :**

Charted by : **Date :**

LEFT HAND	TH	AB	TIME	RIGHT HAND	TH	AB	TIME
To bolt		TE	12	To nut		TE	12
Grasp bolt		G	10	Grasp nut		G	10
Move to assembly		TL	10	Move to assembly		TL	10
Head bold		H	10	Put nut over the bolt		H	10

Figure 11-8: SIMO Chart

The SIMO chart represents the following features:

1. The cycle time.
2. Percentage utilization of the hands or the part of the body taking operation.
3. Total working time of the part of the body.
4. Total idle time of the part of the body.
5. Total time for which two or more parts of the body are involved simultaneously.

11.2.6 Flow Diagram

It is an effective tool for layout of single or multiple products. It uses all the symbols used in a flow process chart, but it is better than the operation process chart and flow process chart as it is easy to draw. In this technique, a scaled drawing of the plant is used on the drawing sheet. Therefore, the actual distance between workstations and the total distance travelled by the work piece could be shown on a certain scale. A sample flow diagram is shown in Figure 11.9. A square shows the position of the machine or workstation.

11.2.7 String Diagram

This is very simple and easy to use. It can be used for single or multiple products. In the case of multiple products, multicolours of strings are used. In this technique, no symbol is used. It uses a drawing sheet. In place of squares (as in flow diagram), pins are used. Pin represents the workstations. The pins are connected by the strings showing the path of movement with distance. An example of string diagram is shown in Figure 11.10.

11.2.8 Travel Chart or Trip Frequency Chart

A travel chart is a tabular record for presenting quantitative data about movements of workers, materials or equipments between any numbers of places, workstations or departments over any given period of time. The string diagrams take rather a long time to construct and when frequent

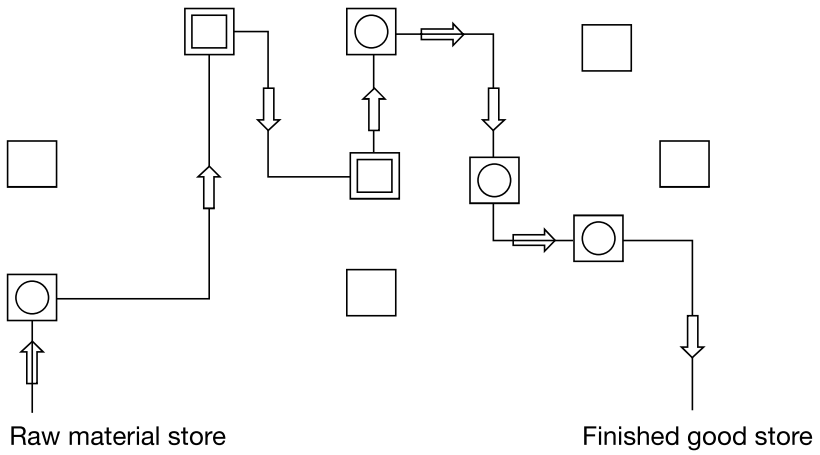

Figure 11-9: Flow diagram

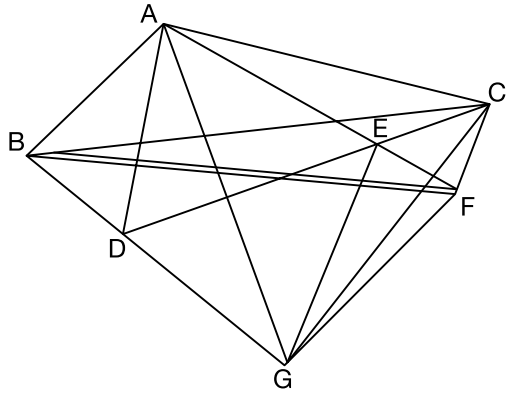

Figure 11-10: String diagram

movements along complex paths are involved, the diagram becomes very complex. Travel chart is a quicker and an easier recording technique. The travel chart is always a square and each small square represents a workstation. If, for example, there are 10 workstations, then the travel chart will have $10 \times 10 = 100$ small squares. The squares from left to right along the top of the chart represent the places from where movement takes place; those down the left-hand edge represent the stations to which the movement is made. For example, consider a movement from station 2 to station 8. To record this, the study man enters the travel chart at the square numbered 2 along the top of the chart, runs his pencil down vertically through all the squares underneath this one until he reaches the square which is horizontally opposite the station marked 8 on the left-hand edge. This is the terminal square, and he will mark in that square to indicate his journey from station 2 to station 8 at 6 as shown in Figure 11.11. All journeys are recorded in the same way. The travel chart can also be made to indicate the weight/material moved per trip. This is the technique used in plant layout as block diagrams.

From

To	1	2	3	4	5	6	7	8	9	10
1						1				1
2					5	3	2		1	1
3										
4	1	1						1		
5		1	2					2	2	
6	1	1	1						1	
7					1					
8		6					6			
9										
10	1	1				1	1	1		

Summary of number of moves to station	
2	1
12	2
0	3
3	4
7	5
4	6
1	7
12	8
0	9
5	10

3	10	3	0	6	5	9	4	4	2
Summary of number of moves from station									
1	2	3	4	5	6	7	8	9	10

Figure 11-11: Travel chart

11.2.9 Photographic Aids

Still and video photography techniques are employed to record and analyse the operations and procedures to perform a task. There are different types of analysis such as memo-motion and micro-motion studies, cyclographs and chrono-cycle graphs, etc. All are very expensive methods involving special photographic equipment. Photographic aids are used for detailed investigation of very short duration, highly repetitive and high-speed operations. These aids are discussed in the following sections as micro-motion, memo-motion, cycle graph and chrono-cycle graph.

11.3 MICROMOTION STUDY

Micromotion study was proposed by Frank B. Gilbreth. It is a technique of recording and analysing the timing of the fundamental elements of an operation or activity with a view to achieving the best method of performing the operation. Frank B. Gilbreth considered that an operation consists of minute elements or sub-divisions. These elements may be repetitive or non-repetitive. He called these elements *THERBLIG*. Standard symbols and colours of THERBLIG are shown in Figure 11.12.

It is an analysis technique making use of motion pictures (videotape) taken at a constant speed. The film becomes a permanent record of both the methods being used and the time consumed in doing the work. Micromotion study provides a valuable technique for making minute analyses of those operations that are short in the cycle, contain rapid movements and involve high production over a long period of time. Thus, it is very useful in analysing operations such as the sewing of garments, assembly of small parts and a number of similar activities.

Purposes of Micromotion Study

The following are the purposes of micromotion study:

1. To study the nature and path of movements for accomplishing the elements of an operation.
2. To find the most efficient way of accomplishing the elements.
3. To impact training to the operators regarding motion economy principles so that unnecessary motion or movement by the operator may be avoided.
4. To keep a permanent record of the most efficient way of doing a task for new reference.
5. To collect motion time data (MTD) for calculating synthetic time standard for different elements.

11.4 MEMO-MOTION STUDY

Memo-motion study was proposed by M. E. Mundel. It is a special type of micromotion study in which the motion pictures or video tape is taken at slow speeds. With this technique, photograph is also taken of the moving part of the body, as was done in micromotion study. But the speed of the movie camera is kept considerably lower. In micromotion study, the record is made by film operated at the speed of 16 frames per second or by constant speed camera at 1000 frames per minute. In memo-motion study, the photograph is taken by cameras using 50 to 100 frames per minute. The cost of operation is much less compared to that in case of micro-motion study.

Name of symbole	Therblig symbol		Color	Color symbol
Search	Sh		Black	
Select	St		Gray (light)	
Grasp	G		Lake red	
Transport empty	TE		Olive green	
Transport loaded	TL		Green	
Hold	H		Gold ochre	
Release load	RL		Carmine red	
Position	P		Blue	
Pre-position	PP		Sky-blue	
Inspect	I		Burnt ochre	
Assemble	A		Voilet (heavy)	
Disassemble	DA		Voilet (light)	
Use	U		Purple	
Unavoidable delay	UD		Yellow ochre	
Avoidable delay	AD		Lemon yellow	
Plan	Pn		Brown	
Rest	R		Orange	

Figure 11-12: Standard symbols for Therblig

Memo-motion is superior with respect to other forms of time and motion study for the following applications (Norbury 1954):

1. Single operator repetition work
2. The study of a group of men or machines
3. Team studies
4. Utilization studies
5. WM

Memo-motion study has been used to study the flow and handling of materials, crew activities, multi-person and machine relationships, stockroom activities, department store clerks and a variety of other jobs. It is particularly valuable on long-cycle jobs or jobs involving many interrelationships.

Cycle graph: In this method, a small electric bulb is attached to each part of the body which makes movement for carrying out operations. The path of movement is photographed by high-speed camera, such a record is called cycle-graph.

Chronocycle graph: It is an improvement over the previous method. In this method, a bulb is also attached to the moving part of the body, but the bulb is made slowly off and quickly on and photograph is taken. The path of the bulb, i.e. the path of movement appears dotted, the dots taking pear shape. If the movement is fast, the dots are spaced far apart, whereas they are closer if the speed is slow.

11.5 TIME STUDY OR WORK MEASUREMENT

It is related to time measurement of work required for a job, to arrive at the best method of work, improved planning and control. Work Measurement (WM) is a technique of establishing the proper time required in performing a job or work. Since it is concerned with measurement of time, so it is also called time study. WM is concerned with investigating, reducing and eliminating ineffective time, whatever may be the cause. It is the means of measuring the time taken in the performance of an operation or a series of operations in such a way that the ineffective time is shown up and can be separated out. The basic procedure for time study may be summarized below as:

Select: Select the job for study

Divide: Divide the operation into smaller elements.

Measure and Record: Measure and record the time taken by the operator for each element.

Determine the number of observations required: Determine the number of such readings necessary for getting the normal time (NT) for each element.

Rate the performance: Rate the operator's performance; determine the allowances and then finally calculate the standard time.

Objectives of Time Study

There are following objectives of time study:

1. To analyse the activities for doing the job with a view to reducing or eliminating some unnecessary or repetitive activities so that human effort can be minimized.
2. To compare the time of performance by alternative methods.
3. To standardize the efficient method of performing a job.
4. To standardize the conditions for efficient performance.
5. To determine the optimum number of men and machines.
6. To determine man and the machines ratio for effective and efficient utilization of both.
7. To provide information and basis for production, planning and scheduling.
8. To balance the work of all the workers working in a group.
9. To determine the normal time for a job, to be used as a basis for wage incentive schemes for the workers.

Limitations of Time Study

Some of the limitations of time study are given below as:

1. There are variations of the standard time determined by different observers. Even the same observer sets different standard time each time he is asked to conduct the time study.
2. Time study involves an element of subjectivity of the observer. Sufficient judgement has to be used by the observer in the choice of a measure of central tendency, deciding the degree of personal allowance and so on.
3. The standard time determined by time study may not be accurate because of incorrect performance rating of the operator under study.
4. Time study usually has an adverse effect on the workers. They may not show the normal behaviour pattern when they are being observed. Even the trade unions may resist stop watch time studies.

Difference Between Motion Study and Time Study

The differences between the time and motion study are specified in Table 11.1.

Table 11-1: Difference between motion Study and time study

Basis	Motion study	Time study
Purpose	Concerned with the motions or movements of workers performing each operation on the job.	Concerned with the determination of time taken by the workers
Scope	Covers only workers.	Covers both workers and machines.
Procedure	Conducted by photographic procedures.	Conducted with the help of a stopwatch.

11.6 WORK MEASUREMENT TECHNIQUES

Many work measurement techniques have been in use as are discussed in the following subsections:

11.6.1 Direct Time Study

Direct time study (DTS) involves direct observation of a task using a stopwatch or other chronometric device to record the time taken to accomplish the task. The task is usually divided into work elements and each work element is measured separately. While observing the worker, the time study analyst evaluates the worker's performance/pace, and a record of this pace is attached to each work element time. This evaluation of the worker's pace is called performance rating. The observed time is multiplied by the performance rating to obtain the normal time for the element or the task.

$$\text{Normal time} = \text{Observed time} \times (1 + \text{Rating factor})$$
$$\text{Standard time} = \text{Normal time} + \text{Allowance}$$

Number of Readings Required

If an activity is measured by a time measuring device or stop watch, then the question arises that how many readings should be taken. In general, we take readings for ±5 per cent accuracy and 95 per cent confidence level. The number of readings can be calculated as:

$$N = \left[\frac{40\sqrt{n\sum(fx^2) - \left[\sum(fx)\right]^2}}{\sum(fx)} \right]^2$$

where $n = \sum f$ = Number of observations taken

N = Number of observations required for ±5% accuracy and 95% confidence level

x = Value of observations

Example 11.1: For a particular element of a job, 20 observations (as shown in Table 11.2) were taken by an observer using a stopwatch. Check whether these number of observations are sufficient for ±5 per cent accuracy with 95 per cent confidence level. Find the minimum number of observation required.

Table 11-2: Observations

Time *x* (in min.)	0.04	0.05	0.06	0.07	0.08
Frequency	3	2	8	5	2

Solution:

The solution for this problem is shown in Table 11.3.

Table 11-3: Calculation table

***x* (min)**	***f***	***fx***	***x*²**	***fx*²**
0.04	3	0.12	0.0016	0.0048
0.05	2	0.10	0.0025	0.0050
0.06	8	0.48	0.0036	0.0288
0.07	5	0.35	0.0049	0.0245
0.08	2	0.16	0.0064	0.0128
Total	20	1.21	0.0190	0.0759 (≃ 0.076)

$$N = \left[\frac{40\sqrt{n\sum(fx^2) - \left[\sum(fx)\right]^2}}{\sum(fx)} \right]^2 = \left[\frac{40\sqrt{20 \times 0.076 - 1.21^2}}{1.21} \right]^2 = 338.77 \simeq 339$$

Total number of observation is only 20, but the required number of observations is 339.

11.6.2 Westinghouse Rating System

The Westinghouse rating system provides the rating factor for skill, effort, conditions and consistency as shown in Table 11.4. This is used to determine the rating factor in different conditions and situations. These situations are categorized and scaled. This scaling is directly used to calculate the total rating. This rating is used to determine the normal time and hence the standard time.

Table 11-4: Westinghouse performance rating systems

Skill	Effort	Conditions	Consistency
Super A1 = +0.15 A2 = +0.13	Excessive A1 = +0.13 A2 = +0.12	Ideal A = +0.06	Perfect A = +0.04
Excellent B1 = +0.11 B2 = +0.08	Excellent B1 = +0.10 B2 = +0.08	Excellent B = +0.04	Excellent B = +0.03
Good C1 = +0.06 C2 = +0.03	Good C1 = +0.05 C2 = +0.02	Good C = +0.02	Good C = +0.01
Average D = 0.00	Average D = 0.00	Average D = 0.00	Average D = 0.00
Fair E1 = −0.04 E2 = −0.10	Fair E1 = −0.04 E2 = −0.08	Fair E = −0.03	Fair E = −0.02
Poor F1 = −0.16 F2 = −0.22	Poor F1 = −0.12 F2 = −0.17	Poor F = −0.07	Poor F = −0.04

Example 11.2: The following observations (Table 11.5) of the actual time taken by a worker for doing a job repeatedly were taken by a time-study observer. The ratings for that worker are as follows:

Skill: Good C1; Effort: Excellent B1; Condition: Ideal; Consistency: Good.

Calculate the normal time.

Table 11-5: Observations

Observation no.	1	2	3	4	5	6	7	8	9	10
Time (min.)	0.3	0.4	0.7	0.4	0.5	0.6	0.5	0.6	0.6	0.4

Solution:

$$\text{Average time} = \frac{0.3+0.4+0.7+0.4+0.5+0.6+0.5+0.6+0.6+0.4}{10}$$

$$= \frac{5.0}{10} = 0.5\,\text{min}$$

$$\text{Rating factor} = 0.06+0.1+0.06+0.01 = 0.19$$

$$\text{Normal time} = \text{Observed time}\,(1+\text{Rating factor}) = 0.5(1+0.19) = 0.595\ \text{min.}$$

11.6.3 Synthetic Rating

Morrow introduced the system of synthetic rating. An observer records the actual time of performance for an element. Performance times for such elements have been standardized, which are known as 'Predetermined Motion Time Standard (PMTS)' values. The PMTS value of the elements from such tables is noted. The ratio of PMTS value of the element taken from tables to average actual observed time for the same element gives the rating factor.

$$R = \frac{P}{A}$$

where R is performance rating factor, P is PMTS value for the element in minutes (from tables), and A is the average actual time observed for the same element in minutes.

Example 11.3: The average actual times for the five elements of a task were measured and shown in Table 11.6. The predetermined motion times for three elements are also given. Calculate the performance rating factor.

Table 11-6:

Element no.	1	2	3	4	5
Avg. actual time, *A* (min.)	0.12	0.14	0.22	0.34	0.12
Predetermined motion time (*P*)	0.14	—	0.20	—	0.10

Solution:

Performance rating factor for element 1, $R = \frac{P}{A} = \frac{0.14}{0.12} = 116.67\%$

Performance rating factor for element 3, $R = \frac{P}{A} = \frac{0.20}{0.22} = 90.9\%$

Performance rating factor for element 5, $R = \frac{P}{A} = \frac{0.10}{0.12} = 83.33\%$

$$\text{Average, } R = \frac{116.67 + 90.9 + 83.33}{3} = 96.96\%$$

11.6.4 Objective Rating

Objective rating was proposed by M. E. Mundel and is carried out in two steps.

Step 1: The speed or pace or tempo of the operator is rated against an objective pace standard. This objective pace standard is same for all the jobs irrespective of the job difficulties and its limiting effect on the pace. Mundel used the term 'base time' for this, time rated against pace.

$$B = P \times T$$

where B is base time, P is rated pace and T is observed time.

Step 2: Now, the base time obtained in step 1 is appraised by an adjustment factor, which Mundel calls job difficulty factor or job complexity or secondary adjustment. It is expressed as:

$$NT = B \times M$$

where NT is normal time, *B* is base time and *M* is job difficulty factor as given in Table 11.7.

Table 11-7: Job difficulty factor

S. no.	Description	Notation letter	Conditions	Per cent adjustment
1.	Amount of body used	A	Finger used loosely	0
		B	Wrists and Fingers	1
		C	Elbows, wrists and fingers	2
		D	Arms, etc.	5
		E1	Trunks, etc.	8
		E2	List with leg from floor	10
2.	Foot pedals	F	No pedals or one pedal with fulcrum under foot	0
		C	Pedal or pedals with fulcrum outside the foot	5
3.	Bi-manualness	H1	Hands help each other or alternate	0
		H2	Hands work simultaneously doing the same work	18
4.	Eye–hand coordination	I	Rough work, mainly feet	2
		J	Moderate vision	2
		K	Constant but not closed	4
		L	Watchful. fairly close	7
		M	Within 1/64”	10
5.	Handling requirements	N	Can be handled roughly	0
		O	Only roll control	2
		P	Must be controlled but may be squeezed	3
		Q	Handle carefully	4
		R	Fragile	5
6.	Weight		Identified by the actual weight for resistance	

Example 11.4: The observed time for an element is 0.24 min, the pace rating is 90 per cent and the sum of all secondary adjustment (for job complexity) amounts to 40 per cent, find the NT.

Solution:

$$\text{Normal time} = \text{Observed time} \times \text{Pace rating} \times \text{Secondary adjustment}$$

$$= 0.24 \times \frac{90}{100} \times \frac{140}{100} = 0.30 \text{ min}.$$

11.6.5 Skill and Effort Rating

This system was introduced by Charles E. Bedaux. In this system, an observer is supposed to evaluate the work rate or speed of the worker’s movement and how fast he is performing the motions, but not the movements and skill he is applying. Unlike the other methods, Bedaux introduced a unit ‘B’ that represents a standard minute, which is composed of

1. Work component
2. Relaxation component

The procedure follows the following steps:

1. Divide the operation into smallest measurable elements. (Smallest time is greater than or equal to 3 seconds).
2. Measure element with the help of a stopwatch having 60 divisions on its dial.
3. Take a sufficient number of observations and calculate average time.
4. Estimate the efficiency of the operator in terms of B values assuming the average worker must obtain 60 B per hour and maximum B value can be 80 B per hour. Thus, convert the observed time in terms of B's with reference to a standard of 60 B per hour values.
5. Allow the relaxation factors as shown in Table 11.8.

Table 11-8: Relaxation factors

Nature of work	Factor
Light work	1.1 to 1.2
Medium work	1.2 to 1.35
Heavy work	1.35 to 1.5
Very heavy work	1.5 to 3.0

6. Now calculate B values for a work element by the formula.

$$B = \frac{T_b \times V \times R_a}{60 \times 60}$$

where T_b is observed time in seconds, V is speed of work, and R_a is relaxation allowance.
7. The sum of all the values of various work elements gives B values per work piece.
8. Variable time (lost time) and setting are to be recorded regularly and special B values are to be provided accordingly.
9. Irregular times and disturbance are not to be included.
10. Purely machining times where the workman is not involved are evaluated separately and added as a method allowance, since only human effort is measured by the Bedaux system.

11.6.6 Physiological Evaluation of Performance Level

There is a positive relationship between the physical work and the amount of oxygen consumed. It has also been tried out to find the changes in heartbeat for various physical works. This is assumed to be the most reliable measure of muscular activity and studies are still going on by many experts in industrial engineering, bio-medical engineering and physiology.

Allowances: There are following types of allowance that are provided in the calculation of standard time:

Personal allowance: It includes restroom breaks, phone calls, water fountain stops, cigarette breaks (5 per cent typical), etc.

Fatigue allowance: Rest allowance to overcome fatigue due to work-related stress and conditions (5 per cent or more).

Delay allowance: Machine breakdowns, foreman instructions (5 per cent typical).

Contingency allowance: Additional allowance due to a problem with the task (e.g. raw material problem). It cannot be greater than 5 per cent.

Policy allowance: These allowances are intended to cover special work situations that are usually associated with a wage incentive system.

Training allowance: For workers whose responsibilities include teaching other new workers in their jobs.

Learning allowance: For workers who are learning a new task or new employees who are just beginning to work.

Example 11.5: An operator was kept under observation for 20 days. He was found working on 900 occasions and abstaining including idle time was 100. He produced 250 jobs during these days. The observation per day was for 5 hours only and the total number of observations was 1000. Take 110 as performance rating for operator and 20 per cent as allowance. Calculate the standard time.

Solution:

$$\text{Observed time} = \text{Total working time} \times \frac{\text{Percentage of working time}}{100}$$

$$= 20 \text{ days} \times 5 \text{ hours} \times 60 \text{ minutes} \times \frac{90}{100} = 5400 \text{ min}$$

$$\text{Normal time per unit of job} = \text{Observed time} \times \text{Rating factor}$$

$$= \frac{5400 \text{ min}}{250} \times \frac{110}{100} = 23.76 \text{ min}$$

$$\text{Standard time} = \text{Normal time} + \text{Allowance} = 23.76 \times 1.2 = 28.52 \text{ min.}$$

11.7 PREDETERMINED MOTION TIME SYSTEM

It is a work measurement technique. PMTS is the Maynard Operation Sequence Technique (MOST), which was first released in 1972 (Zandin 2003). Manual operations are divided into fundamental elements and time to accomplish each element is tabulated. To get the standard time of any operation, the operation is divided into fundamental elements. The time of performance for each element is taken directly from the database. Therefore, before doing any operation, its standard time could be known. This is the difference with the time study where standard time is finalized after an operation is carried out. The common PMTS systems are mentioned as follows:

Work factor system (WFS): In WFS, the time for an operation is calculated on the basis of the use of some variables such as body member, distance moved, manual control, weight or resistance involved, etc.

Method-time-measurement (MTM): This is a technique of method analysis and additionally it does the work of time study by providing time values for each motion.

Basic motion time study (BMTS): This system was developed by Ralph Presgrave, G. B. Bailey and other members of the staff of J. D. Woods and Gordon Ltd. of Toronto, Canada, and was first used in 1950. The basic motion is defined as a complete movement of a body member, such as saying hand moves from rest and again comes to rest.

11.8 PRINCIPLE OF MOTION ECONOMY

The principles of motion economy can be classified into three groups (Kanawaty 1992; Meyers and Stewart 2002):

1. Principles related to the use of the *human body*;
2. Principles related to the arrangement of the *workplace*; and
3. Principles related to the *design of tools and equipment*.

Every work involves some or all of the THERBLIG. Each THERBLIG consumes time. To reduce the time taken for performing any work, some principles have been propounded by Barnes which are known as principles of motion economy.

Use of Human Body

1. Both the hands should start and finish their motions at the same time.
2. Both the hands should not be made idle simultaneously, except while at rest.
3. Arms' motions should be symmetrical and simultaneous.
4. As far as possible, arrangements should be made for minimum movements of hands and body.
5. Straight-line movements should be availed in the presence of continuous curved movements.
6. Free swinging movements should be preferred over controlled and restricted movements.
7. Work should be arranged to give the operator repetitive nature of motion, i.e. rhythm in motion.
8. Work should be arranged to give minimum eye movement so that THERBLIG 'search' and 'find' take minimum time.
9. Momentum should be used for helping the operator, but the momentum should be minimized if it is to be overcome by the muscular effort of the operator.

Arrangement of the Workplace

1. For all tools and workpieces, definite places should be fixed up.
2. To reduce searching time, tools and workplaces should be prepositioned.
3. The workpiece should be delivered at the nearest to the workstation by gravity feed, or bins, or containers or transfer machines.
4. Tools, materials and controlling levers should be located within easy reach of both the hands of the operators.
5. Tools and workpiece should be arranged according to the sequence of the operations.

6. Arrangement should be made for automatic disposal of the finished goods.
7. Adequate light, a comfortable chair, convenient height of the workpiece should be provided.
8. The workplace and the workpieces should have colour contrast.

Design of Tools and Equipments

1. As far as possible, jig, fixture or foot-operated device should be used instead of hands for 'holding' the workpiece.
2. Tools should be combined, if possible.
3. If fingers are used, load to each finger should be given according to its capacity.
4. Handles of levers, cranes or large screw drivers should be made sufficiently large so that there is maximum contact with the hands.
5. The levers, cross bars, hand wheel, etc. should be so arranged that the operators can use them with the least change in their body position.

11.9 WORK SAMPLING

Work sampling is a method to find the percentage of the day of worker is working and the percentage of the day he is idle. The working and idle time of a worker are used to fix up performance rate, and establish the standard time for an operation. The following types of sampling are used in an industry:

Systematic sampling: If the observations are taken at a fixed interval of time, it is called systematic sampling.

Random sampling: If the observations are taking random spaced time, it is called random sampling.

Stratified sampling: If observations are taken at a random spaced time after a finite number of regularly spaced time intervals, it is called stratified sampling.

Procedure for Work Sampling

Five steps are involved in making a work-sampling study:

(a) Identify the activity or activities that are to be considered for the study. For example, determine the percentage of time that equipment is working, remain idle, or under repair.
(b) Estimate the proportion of time of the activity of interest to the total time (e.g. that the equipment is working 80 per cent of the time). These estimates can be made from the analyst's knowledge, past data, reliable guesses of others, or a pilot work-sampling study.
(c) State the desired accuracy in the study results.
(d) Determine the specific times when each observation is to be made.
(e) After two or three intervals during the study period, recompute the required sample size by using the data collected thus far.
(f) Adjust the number of observations, if appropriate.

Advantages of Work Sampling

The following are the advantages of work sampling over the direct time measurement systems:

1. The activities that are difficult to measure using time study can be easily measured by work-sampling process.
2. The men or machines can be studied in groups with work sampling.
3. Since the observations are taken over a period of days or weeks, therefore, day-to-day variation cannot affect the result appreciably.
4. The chances of getting misleading results are less since the operators are not under direct observation.
5. The study is less time-consuming and less tiring for the observers.
6. No time measuring device is required.
7. The calculation is easy and less time-consuming.

Limitations of Work Sampling

The following are limitations of work sampling:

1. Study of an individual machine or operator is not economical.
2. The operator may change the work pattern in the presence of an observer.
3. This study presents an average result and it cannot give information regarding individual activities.
4. The approach of statistical analysis creates confusion among the workers.
5. Minimum number of observations, randomness in observations, instantaneous observations are essential and must be focused on the accuracy of the results.

Minimum Number of Observations

The number of observations in work sampling affects the accuracy of prediction. For any desired level of accuracy, sufficient number of observations is required. Suppose the desired level of accuracy is given as $\pm e$ per cent and the corresponding value of z for the given confidence level is known, the number of observations can be calculated as:

$$z \times \sigma = e\,(\text{error}) \Rightarrow \sigma = \frac{e}{z}$$

$$N = \frac{pq}{\sigma^2} = \left(\frac{z}{e}\right)^2 pq$$

where z is the corresponding value of confidence level, σ is standard deviation, p is the percentage occurrence of an activity or delay being measured, expressed as a percentage of total number of observations as a decimal, q is the percentage of non-occurrence of an activity, e is accuracy in fraction, and N is the number of observations.

Example 11.6: Calculate the required number of observations necessary for an accuracy of ±3 per cent and confidence level of 98 per cent, if the total number of observations of machines working is 3000 and idle 1000.

Solution:

$$p = 1000/4000 = 0.25;\ q = 3000/4000 = 0.75;$$

z corresponding to 95% confidence level = 1.65

$$N = \frac{pq}{\sigma^2} = \left(\frac{z}{e}\right)^2 pq = \left(\frac{1.65}{0.03}\right)^2 \times 0.25 \times 0.75$$

$$= 567.187 \cong 568 \text{ observations}$$

11.10 JOB DESIGN

Job design is a function of specifying the work activities of an individual or group in an organizational setting. The objective of job design is to develop jobs that meet the requirements of the organization and satisfy the jobholder's personal and individual requirements. This is a complex function to plan and make the strategies that who does what, where, why and how to do a job.

Objectives of Job Design

The objectives of job design are:

1. To establish organizational chart.
2. To develop work assignments or jobs that meet both organizational and the worker needs.
3. To develop job descriptions of the works.
4. To motivate human resource on the job at work place through implementation of job design components and relative worth of a job.

Approaches to Job Design

Mechanistic approach: In this approach, jobs that are simple, routine, repetitive tasks carried out every day such as assembly jobs, packing processes are specialized. Generally, workers are fixed at one specific work location, station, area, such as assembly operators, machine operator, and data entry clerk, crane/tractor operator, etc.

Motivational approach: In this approach, five core dimensions of job such as skills variety, job identity, task significance, task autonomy and feedback are used. Skills variety is a job that requires workers to use a variety of skills and talents. Job identity allows the worker to perceive the job as a whole, from start to finish. Task significance shows that it is important and has an impact on the organization and society and the job is meaningful. Task autonomy provides freedom, independence, discretion, responsibility and accountability to perform the job. Feedback is monitoring activities that a job should provide clear, timely information on performance, roles and functions, status and problems.

The three ways of job expansion are job enrichment, job rotation and job enlargement as discussed below:

Job enrichment is a process of vertical expansion of job where higher levels of tasks are added, increase in job responsibilities and job depth, increase in work autonomy and basic managerial skills, and preparation of a staff for a potential promotion.

Job rotation is a process of worker to be sent to learn and work in another operation on a scheduled basis, to set up a periodic work rotation schedule, giving exposure to other jobs to acquire new skills, knowledge, adds motivation and challenges to job and worker.

Job enlargement is a process of horizontal expansion of job where varied tasks of similar activities are added, the increase in job scope, combines various tasks at a similar level into a job, and allowing workers to perform a whole unit of work.

Biological approach: This approach considers ergonomics factors to design a job that fits the worker's physiological nature, and not to fit the worker to the job.

Perceptual approach: This approach considers mental factors and demands that do not exceed the mental capabilities of the worker.

11.11 JOB RATING OR EVALUATION

It is a process of assessment of the relative worth of a job qualitatively and quantitatively. It is used to differentiate the wages for the workers employed in different types of jobs. This is essential for wage differentials. The jobs are rated on the basis of difficulty to perform, complexity to understand, the responsibility involved, education and training required, and working conditions and environment.

11.12 MERIT RATING

In merit rating, a man is rated based on his performance. There are various criteria used to rate a man; these criteria are attendance, co-operation with another person, dependability, cautiousness during working, leadership ability, appearance, initiative, judgement, versatility, working knowledge and general awareness. Employee rating is used to keep a record of the relative value of each employee, justify and determine the wage differential for the same job, have better information for promotion, transfer, or layoff, and point out the weakness of the employees for self-development.

11.12.1 Wage and Wage Incentives

Wage is the remuneration given to the worker for the work performed. A wage incentive is the amount or facility in terms of monetary given to workers to motivate them for higher production and productivity. Wage incentives may be in the form of financial incentive, leave with pay, free medical facility, free housing, free transportation from residence to workplace and workplace to residence, recreational facilities, leave travel concession, free education to children and higher educational facility for the employee, etc.

11.12.2 Wage Differentials

The differences in wages among the employee having same/different qualification and skill are known as wage differentials. The reasons for wage differentials are enumerated as follows:

1. Difference in marginal productivity of the workers.
2. Difference in qualification, experience and training of the workers.