INDUSTRIAL ENGINEERING
study material for 6\textsuperscript{th} semester mechanical
2.1 INTRODUCTION

The standard of living of industrialised nations depends upon the economic efficiency of all its industrial enterprises great or small. Economic efficiency is also termed as productivity.

2.2 DEFINITION OF PRODUCTIVITY

Productivity can be defined as the ratio of financial output in a period of time to the financial input in the same period of time. Productivity can thus be measured as:

\[
\text{Productivity} = \frac{\text{Financial output (in a period of time)}}{\text{Financial input (in the same period)}}
\]

In simple terms productivity is the quantitative relationship between what we produce (output) and the resources (inputs) which we used.

Productivity and Production

At the outset let us make a distinction between productivity and production. Production is the process of converting the raw materials into finished products by performing a set of manufacturing operations in a predetermined sequence.

Production refers to absolute output. Thus, if the input increases the output will normally increase in the same proportion. The productivity remains unchanged. If, however, the output increases with the same input of resources or we get the same output with lesser input of the resources, the productivity increases. Production means the output in terms of money (or the number of units produced) without any regard to the input of resources, while productivity is a human attitude to produce more and more with less and less inputs of resources so that the benefits of improved productivity will be distributed to a larger number of people. The aim is to obtain most efficient utilization of the available resources, applying new technologies methods. Before going further into the details of productivity let us first understand the types of production systems.

2.3 TYPES OF PRODUCTION SYSTEMS

A production system consists of plant facilities, equipment and operating methods arranged in a systematic order. This arrangement depends upon the type of product and the strategy that a company employs to serve its customers. There are two major types of production systems:
(e) to compare the actual productivity with the planned productivity.

The problems in the comparative measurement of productivity arise when production systems produce different types of output or production systems use different types of resources. For overcoming these problems we use the same units (in terms of money) for the output and the input both.

Productivity Measures

There are three major types of productivity measures as listed below:

1. Partial productivity measures (PPM)
2. Total factor productivity measures (TFPM)
3. Total productivity measure (TPM)

1. Partial Productivity: Partial productivity is the ratio of output to one class of input among many factors of production. For example, labour productivity measures the productivity of labour. Similarly, material and capital productivities can be defined. Thus,

\[
\text{Labour productivity} = \frac{\text{Output}}{\text{Labour input}}
\]

2. Total Factor Productivity: Total factor productivity is the ratio of net output to the sum of associated labour and capital (factor) inputs. Net output means output minus material, capital, energy and other input expenses. Thus,

\[
\text{Total factor productivity} = \frac{\text{Net output}}{(\text{Labour + capital}) \text{ inputs}}
\]

3. Total Productivity: Total productivity is the ratio of total output to the sum of all input factors. Thus, it represents the joint impact of all the input factors in producing the output.

\[
\text{Total productivity} = \frac{\text{Total tangible output}}{\text{Total tangible input}}
\]

* Tangible means measurable

- Total tangible output = Value of finished goods + value of partially finished units + dividends from securities + interest + other income.
- Total tangible input = Value of human, material, capital, energy and other inputs used in the outputs and inputs of the company must be expressed in a common unit preferably in monetary value, say input value. To compare productivity, indices are to be adjusted to the base year and must be stated in terms of base year input value. This is referred to as deflating year to another year.

\[
\text{Deflator} = \frac{\text{Current year price}}{\text{Base year price}}
\]
Productivity Index

Productivity index is used to compare the productivity during the current year with the productivity during the base year. Base year is any year which the company uses for comparative study.

\[
\text{Productivity Index} = \frac{\text{Productivity during the current year}}{\text{Productivity during the base period}}
\]

2.5 FACTORS AFFECTING PRODUCTIVITY

1. Raw material, its nature and quality
2. Utilization of manpower
3. Utilization of plant, equipment and machinery
4. Efficiency of plant and equipment employed
5. Basic nature of manufacturing process employed
6. Volume, continuity and uniformity of production.

The ways in which the productivity can be increased are summarised as under:

1. Increase manpower effectiveness at all levels
2. Method improvement
3. Improvesimply product design and reduce variety
4. Improve basic production processes by research and development
5. Use better production equipment

The details regarding productivity improvement techniques currently in use are discussed in the following paragraphs.

2.6 PRODUCTIVITY IMPROVEMENT TECHNIQUES

Productivity improvement techniques are as follows:

1. Technology based
   (a) CAD/CAM/CIMS are computer techniques and have profound influence on human productivity
   (b) Robotics
   (c) Laser technology
   (d) Modern maintenance techniques
   (e) Energy technology
   (f) Flexible manufacturing system (FMS).

2. Employee based
   (a) Incentives (financial/non-financial) at individual and group level
   (b) Promotion
(c) Job design, job enlargement, job enrichment
(d) Worker participation
(e) Quality circles, small group activities
(f) Personal development.

3. Material based
   (a) Material planning and control
   (b) Purchasing logistics
   (c) Material storage and retrieval
   (d) Source selection for quality
   (e) Waste elimination
   (f) Recycling and reuse of waste material

4. Process based
   (a) Methods Engineering and work simplification
   (b) Process design
   (c) Human factors engineering

5. Product based
   (a) Value analysis/value engineering
   (b) Product diversification
   (c) Simplification/standardization
   (d) Reliability engineering
   (e) Product mix and promotion

6. Management based
   (a) Management technique
   (b) Communication in the organization
   (c) Work culture
   (d) Motivation
   (e) Promoting group activity

Levels of Productivity Measurements

Productivity can be measured at international, national and industry (sector) levels. It can also be measured at company level and on individual resource level.

2.7 PRODUCTIVITY IMPROVEMENT MODELS

1. Craig and Harris Model: It is also called “Service flow model” because physical inputs are substituted in returns paid for services provided by inputs. Productivity is measured as efficiency of this conversion process.
   Total productivity is thus expressed as
\[ P = \frac{O}{L + C + R + Q} \]

where,
- \( P \) = Total productivity
- \( C \) = Capital input factor
- \( O \) = Output (services rendered)
- \( L \) = Labour input factor
- \( R \) = Raw material and purchased parts
- \( Q \) = Other miscellaneous goods/services.

2. American Productivity Centre (APC) Model. APC has developed a model based on the fact that profitability is a function of productivity and price recovery. Productivity relates to the quantities of output and inputs while price recovery relates to price of output and costs of inputs. Price recovery can be thought of as degree to which input cost increases are passed on to the customers in the form of higher output price. Productivity, profitability and price recovery are related as follows.

\[
\text{Profitability} = \frac{\text{Revenue}}{\text{Cost}} = \frac{\text{Output quantities} \times \text{Sales price}}{\text{Input quantities} \times \text{Unit cost}}
\]

\[
\text{Profitability} = \frac{\text{Output quantities}}{\text{Input quantities} \times \text{Unit cost}} \times \text{Sales price}
\]

Profitability = Productivity \times Price recovery.

The model compares data from base period with the data from the current period.

2.8 NATIONAL AND INTERNATIONAL PRODUCTIVITY MEASURES FOR COMPARISONS

1. Organisation for European Economic Co-operation (OEEC) uses two measures:
   (a) Gross Domestic Product (GDP) per capita and
   (b) GDP per employee civilian

2. Rost (1953) used
   (a) Gross output per one hour of labour
   (b) Physical output per one unit of labour.

3. At National Level the productivity measures used are:
   (a) National Product: Market value of output of final goods and services produced by Nation's economy. Final product means a product that is not resold. Intermediate goods means the products that are resold.
   (b) Gross National Product includes capital consumption allowances (reserves for depreciation, accidental damage to fixed capital).
   (c) Net National Product. It excludes above such allowances. Bureau of Labour Statistics (BLS) use (a) Labour productivity index, (b) Capital productivity index and (c) Labour and capital utility productivity index for this purpose.
Example 2.1: Find the partial productivity and total productivity for M/S ABC Company for which the following data is available:

\( \text{Output} = 15000 \) units, Labour input = Rs 4500, Material input = Rs 3000, Capital input = Rs 1500, Other input expenses = Rs 750. Assume the above values are in constant rupees with respect to a base period.

**Solution:**

- **Labour productivity**
  \[ \frac{\text{Output}}{\text{Labour input}} = \frac{15000}{4500} = 3.3 \]

- **Material productivity**
  \[ \frac{\text{Output}}{\text{Material input}} = \frac{15000}{3000} = 5.0 \]

- **Capital productivity**
  \[ \frac{\text{Output}}{\text{Capital input}} = \frac{15000}{4500} = 3.3 \]

- **Energy productivity**
  \[ \frac{\text{Output}}{\text{Energy input}} = \frac{15000}{1500} = 10.0 \]

- **Other expenses productivity**
  \[ \frac{\text{Output}}{\text{Other expenses input}} = \frac{15000}{750} = 20.0 \]

- **Total factor productivity**
  \[ \frac{\text{Net output}}{\text{Labour + Capital input}} = \frac{15000}{1500 + 4500} = \frac{15000}{6000} = 2.5 \]

Therefore, the total productivity is:
\[ \frac{15000}{6000} = 2.5 \]

**Example 2.2:** Products X and Y are being manufactured by a company using materials A and B. Both materials are equally suitable. Product X is expected to sell at Rs 75 per unit and product Y at Rs 35 per unit. The operating data is given below.

<table>
<thead>
<tr>
<th>Material</th>
<th>Material A</th>
<th>Material B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>200 units</td>
<td>400 units</td>
</tr>
<tr>
<td>Labour</td>
<td>300 units</td>
<td>200 units</td>
</tr>
<tr>
<td>Quantity of raw material usage</td>
<td>1000 kg</td>
<td>1000 kg</td>
</tr>
<tr>
<td>Labour usage</td>
<td>300 man-hrs</td>
<td>250 man-hrs</td>
</tr>
<tr>
<td>Electric energy consumption</td>
<td>1000 kwhr</td>
<td>1200 kwhr</td>
</tr>
<tr>
<td>Cost of raw material/kg</td>
<td>Rs 22</td>
<td>Rs 33</td>
</tr>
<tr>
<td>Labour cost per man-hour</td>
<td>Rs 10</td>
<td>Rs 10</td>
</tr>
<tr>
<td>Electric energy/kwhr</td>
<td>Rs 5.0</td>
<td>Rs 2.0</td>
</tr>
</tbody>
</table>

Compare the productivity of materials A and B. Comment on the relative advantage of using either of the materials.

**Solution:**

**Productivity = \frac{\text{Value of output}}{\text{Value of input}}**

**Sales value of output with material A**

\(- 200 \times 75 = 300 \times 35 = 15000 \times 10 = 500 = 25,500 \)

**Sales value of output with material B**

\(- 400 \times 75 = 200 \times 35 = 30,000 \times 7 = 7,000 = 37,000 \)

The partial productivity of different factors of production are as follows.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Productivity (type)</th>
<th>Material A</th>
<th>Material B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Productivity of raw materials</td>
<td>25,500 - 1.16</td>
<td>37,000 - 1.12</td>
</tr>
<tr>
<td></td>
<td>Value of raw material used</td>
<td>1000 x 22</td>
<td>1000 x 33</td>
</tr>
<tr>
<td>2.</td>
<td>Labour productivity</td>
<td>25,500 - 8.5</td>
<td>37,000 - 14.60</td>
</tr>
<tr>
<td></td>
<td>Value of labour used</td>
<td>300 x 10</td>
<td>250 x 10</td>
</tr>
<tr>
<td>3.</td>
<td>Productivity of energy</td>
<td>25,500 - 12.75</td>
<td>37,000 - 12.30</td>
</tr>
<tr>
<td></td>
<td>Value of electric energy used</td>
<td>1000 x 5</td>
<td>1500 x 2</td>
</tr>
</tbody>
</table>

**Comments:** The productivities of (1) and (2) are nearly the same but lower than material A. Labour is the key factor; use of material B is better as it yields higher productivity 14.6 = 8.5.
Example 2.3: A factory is manufacturing consumer goods. It operates 8 hours per day, 6 days a week and employs 23 operators. The following data is available about the factory:

1. Standard hours per unit of production: 5

   During a particular week:
   - Number of units produced: 50
   - Absentee (man-days): 40
   - Idle time due to load shedding (man-days): 20

   Determine:
   (i) the percentage of absenteeism
   (ii) the percentage of labour utilisation
   (iii) productive efficiency of labour
   (iv) overall productivity of labour is terms of units produced per week per employee.

Solution:

(i) Percentage absenteeism = \( \frac{\text{Absentee man-days/week}}{\text{Total operator man-days/week}} \times 100 \) = \( \frac{40}{23 \times 6} \times 100 = 26.66\% \)

(ii) Labour utilisation = \( \frac{\text{Working man-days/week}}{\text{Attended man-days/week}} \times 100 \)

   = \( \frac{(25 \times 6) - 40 - 20}{(25 \times 6) - 40} \times 100 \)
   = \( \frac{90}{110} \times 100 \)
   = 81.81\%

(iii) Productive efficiency of labour = \( \frac{\text{Standard production man hours/week}}{\text{Actual man hours worked/week}} \times 100 \)

   = \( \frac{50 \times 5}{[(25 \times 6) - 40 - 20] \times 8} \times 100 \)
   = 34.72\%

(iv) Overall productivity of labour = \( \frac{\text{Total production/week (output)}}{\text{Total workers}} \times 20 \) units/week/operator

Productivity Benefit Model

The improvement in total productivity of a product or service reduces total cost per unit which results in two favourable management strategies as follows:

1. Selling price of the product is reduced while profit margin remains the same. Consumer benefits by getting the same or better quality at lower price.

2. Increase profit margin without reducing the selling price. The organization benefits from increase in revenues making it possible to give higher wages to employees and job security.

Both these benefits help the nation to have a healthy economy.

Fig. 2.2 Productivity benefit model

Productivity Cycle

Any organization interested in productivity improvement has to follow productivity cycle which includes:

(a) Productivity measurement
(b) Productivity evaluation
(c) Productivity planning
(d) Productivity improvement

Fig. 2.3 Productivity cycle

Questions

1. Define the term productivity. How is it different from production? Give examples using your own numbers.
1.1. DEFINITION AND CONCEPT OF INDUSTRIAL ENGINEERING

The American Institute of Industrial Engineers (A.I.I.E.) has defined the special field of Industrial Engineering as—

"Industrial Engineering (I.E.) is concerned with the design, improvement and installation of integrated system of people, materials, equipment and energy. It draws upon specialized knowledge and skill in the mathematical, physical and social sciences together with the principles and methods of engineering analysis and design to specify, predict and evaluate the results to be obtained from such systems."

I.E. is engineering approach to the detailed analysis of the use and cost of the resources of an organisation. The main resources are men, money, materials, equipment and machinery. The Industrial Engineer carries out such analysis in order to achieve the objectives (to increase productivity or profits etc.) and policies of the organisation. An Industrial Engineer's technique is to go beyond the mechanical cost factor. He is associated with organization structure, administrative techniques, labour problems and at the same time he understands the relationship between efficiency and consent (of the working group). Essentially the industrial engineer is engaged in the design of a system and his function is primarily that of management. If he is to focus on only one concept to describe his field of interest and objective, it would have to be productivity improvement. Productivity improvement implies:

(a) a more efficient use of resources.
(b) less waste per unit of input supplied
(c) higher levels of output for fixed levels of input supplied and so on.

The input may be:

(a) human efforts
(b) energy in any of its myriad forms
(c) materials
(d) invested capital etc.

In a gist, the mission of I.E. would be to try to produce more or to serve better without increasing the resources being consumed.
1.3. SCOPE OF INDUSTRIAL ENGINEERING

Till 1950 Industrial Engineering was concerned with plant layout, manufacturing facilities, work methods, cost control, production and manufacturing methods. In other words, the scope was limited to the manufacturing field, and the activities were confined to the production of mechanical goods. During this period, relatively small systems were picked up for detailed study. There were two reasons for the limited scope of this subject in the past. First, industrial engineering depended on social sciences like industrial psychology which had not been fully developed in the past. Secondly, in the beginning, industrial application was limited. Development of scientific management by Taylor and the time and motion study by Gilbreth created a new concept called science of ‘operations’. This necessarily meant, the breaking down elements of activities. Thus any activity can be defined by grouping these elemental activities in such a way as to give meaningful ‘operating systems’. When such a system was developed, they remained independent of any specific field and became capable of universal applications. Once this was made possible, the scope of industrial engineering was no more confined to any one area. This enabled industrial engineering to break new horizons of operation covering almost all areas such as industry, state administration, business, utility services, hospital and banks etc. During this period three more developments took place:

- Development of applied mathematics for industrial application such as various Operational Research (OR) techniques like LP, simulation and statistical sampling.
- Development of industrial psychology for business applications as revealed in the Hawthorne studies.
- Development of computers and introduction of electronic data processing in industrial applications.

These developments have immensely increased the scope of industrial engineering and has enabled its application to spread to other fields. Within the manufacturing field itself, it has enabled application of Industrial Engineering to cover all areas under production and operations management. Computers with their tremendous data storage capacity and extremely high speed of computation have made operations of industrial engineers more interesting, meaningful and challenging.
1.6. INDUSTRIAL ENGINEERING TECHNIQUES

(1) Planning techniques.
(2) Process design (process planning).
(3) Human capability analysis.
(4) Control techniques.
(5) Commercial engineering techniques.
(6) Statistical techniques.

The details of these techniques will be discussed later; however, they are summarised here:

1. Planning Techniques. A plan is an organised scheme of doing some profitable business and directed towards the fulfillment of objectives and goals under certain constraints. The execution of this organised scheme is controlled from the viewpoint of bringing coordination between various elements of plan and thus an homogeneous working environment is developed. Some of the techniques commonly employed include the following which assist in decision making:

(i) Various evaluation techniques such as O.R., time study, material-flow analysis, PERT & CPM, etc.
(ii) System modelling techniques such as O.R., Simulation, Organisation, etc.
(iii) Motion study techniques.
(iv) Manufacturing processes techniques.
(v) Various statistical techniques.

2. Process Design. To study, develop, analyse, improve and install more efficient methods (optimised methods) for effective utilisation of resources. If these techniques of methods engineering are fully utilised,
Introduction to Industrial Engineering

more than half of the battle against inefficiency is won. Six elements of method study analysis — what, why, when, how and where are extensively used. It helps to develop optimal route sheets which are best evaluated in terms of time.

3. **Human Capability Analysis.** It is a general notion that man is very flexible element of a man-machine system. Man can change himself according to work and environment, but this notion has very far reaching adverse consequences. This field of study is a new one and referred to as Ergonomics (Ergo = Economics). Ergo means human work.

4. **Control Techniques.** Every system and sub-systems usually carry one or other control system to monitor in terms of its predetermined performance (cost and time). Usually, these are feedback systems to evaluate the performance of each sub-system.

5. **Commercial Engineering Techniques.** Usually, these are economic policies to be adopted in different areas of business system. Some of the activities where logical techniques are applied to optimise the objectives include:

   - (i) Procurement of resources.
   - (ii) Job evaluation and establishing wage plans.
   - (iii) Various incentive and welfare schemes.
   - (iv) Recruitment, training and placement programmes.
   - (v) Cost control and cost reduction programmes.
   - (vi) Economic analysis.

6. **Statistical Techniques.** Owing to fluctuating conditions, it is assumed that nothing is static in business and it is probabilistic. Therefore, every phase of the system has to be tackled statistically.

1.7. **ROLE OF AN INDUSTRIAL ENGINEER IN AN INDUSTRY**

The following are functions of an industrial engineer:

- (a) Advisor/Consultant - available to others for interpretation of data.
- (b) Advocate/Activist - promote actively a process or approach.
- (c) Analyst - separate a whole into parts and examine them to explain insight and characteristics.
- (d) Boundary spanner - bridge the information/interest gap between industrial engineering and user.
- (e) Motivator - provide stimulus and skill availability to a group or individual.
- (f) Decision maker - Select a preference from many alternatives.
- (g) Designer/planner - produce the solution specifications.
- (h) Expert - provide a high level of knowledge, skill and experience in a specialized field.
- (i) Coordinator/Integrator
- (j) Innovator/Inventor - seek to produce a creative or advanced technology.
- (k) Measurer - obtain data and facts about existing conditions.
- (l) Project Manager - operate, supervise and evaluate projects.
- (m) Trainer/educator - in the skill and knowledge of I.E.
- (n) Data gatherer
- (o) Negotiator.
5.8. QUALITIES OF AN INDUSTRIAL ENGINEER

The functions of an industrial engineer are very significant in whole of the industry. There are certain qualifications and qualities of a good industrial engineer. He must be educated to the level that he can grasp the problem and should be capable to understand the principles, procedures and objectives of Industrial Engineering.

Basic Requirements
(a) Good knowledge of methods and various systems of production.
(b) Appreciation of the spirit of work.
(c) Mentally sound and suited to the work.
(d) Objective approach to the industrial engineering problems with good knowledge of workshop practice and work-organization.
(e) Knowledge of different manufacturing processes.
(f) Good practical experience of industries and processes.

Qualities
(a) Mental abilities: Good power of observation, quick understanding, mental alertness, quick in noticing the things, clear in thoughts, clear power of expression, able to convince his superiors and the workmen, open mind, critical outlook, full of ideas with good judgement.
(b) Physical attributes: Normal keenness of vision, normal hearing, feelings of various movements and judgements, uniformity of senses.
(c) Education: Graduate engineer in Mech. Engg/Ind. Engg. leadership potential with good expression of thoughts.
(d) Character requirement: Reliability, thoroughness, will-power, courage, politeness, tactful in handling situation.

5.9. PRODUCTION AND OPERATIONS MANAGEMENT FUNCTION

Production and operations management concerns itself with the conversion of inputs into value-added outputs, (products/services) using physical resources, so as to provide the desired utility of form, place, possession or state or a combination thereof to the customer while meeting the other organizational objectives of effectiveness, efficiency and adaptability.

Its functions are different from other functions such as personnel and marketing etc. by way of its primary concern for 'conversion by using physical resources'. But the use of other resources such as 'information' in production and operation management can also be denied. The management of the use of physical resources for the conversion process is what distinguishes production and operation management from other functional disciplines. The Table 1.2 illustrates the many facets of it.

Product and Services
The output of an operations system (or production system) may be in terms of end-product—physical goods such as automobiles, cement, paper, butter and books etc or rendering a service such as in transportation, hospitals, educational institutions, banks, cinema halls and beauty parlours etc. Rendering a service may involve physical goods (or facilitating goods) such as dental making a set of false teeth while rendering dental care, manufacturer of an automobile giving after-sale service to its purchaser after selling the automobiles...
3.8 WORK CONTENT

Work content means the amount of work contained in a job. It is measured as man-hours or machine hours. Work content has two components:

1. Basic work content: This is the minimum time required (theoretically/ideally) to perform an operation. It cannot be reduced further. The following conditions apply:
   - Job design and specifications are ideal.
   - Manufacturing procedure is exactly followed.
   - No loss of working time due to any of the reasons.
   Thus the basic work content represents the ideal conditions which are not possible to achieve.
2. Excess work content: The actual time required to complete an operation is more than the ideal basic time. This additional portion of work content is called excess work content which is added to the basic work content.

Reasons for Excess Work Content

The excess work content is due to the following reasons:

(a) Work added due to defective design, lack of standardisation of components, incorrect specifications and quality standards.
(b) Work added due to inefficient production methods, incorrect process of manufacture, wrong tools, improper shop layout, and inefficient materials handling.
(c) Work added due to ineffective management, bad work environment, frequent breakdowns, poor planning and control of production operations, unsafe practices, lack of clear instructions, frequent changes in set-up, lack of performance standards, shortage of materials and tools.
(d) Ineffective time within the control of workers unauthorised absence, substandard performance, careless attitude, unnecessary wastage of time.

Management Techniques to Reduce Work Content

(a) Management techniques to reduce work content due to product: product development, variety reduction (standardisation).
(b) Due to process and methods: Process planning, methods improvement.
(c) Due to management: Product standardisation (simplification), product specialisation, component standardisation, production planning and control, material control, plant maintenance, better safety and improved working conditions.
(d) Due to workers: Sound personnel policies, operator training, safety training, financial incentives.
1.1 Introduction
In their efforts to improve productivity and performance, scientists, technicians and behaviourists have developed several techniques. Scientific management has played a key role in the productivity movement. During the scientific management movement many techniques were developed for scientific analysis and solution of problem in industrial operations. Work study is one of these techniques.

As per ILO (International labour organization-Geneva) “Work Study is a generic term for these techniques, particularly method study and work measurement which are used in the examination of human work in all its contents and which lead systematically to the investigations of all the facts which affect the efficiency and economy of the situation being reviewed, in order to effect improvement”. Thus work study is a systematic and analytical study of work process and work methods with the objective of increasing efficiency and reducing costs. The main concern of work study is to improve and maximise productivity of existing jobs and to maximise productivity in the design of future jobs within the constraints. Work study helps to reduce waste through standardization of qualitative and quantitative elements of a job. It aids in increasing industrial productivity through job standardization.

1.2 Objectives of Work Study
Work study is designed to achieve the following objectives
(i) The optimum use of plant and equipment
(ii) The most effective utilization of human effort
(iii) Determination of effective work method
(iv) Evaluation of human work
(v) Establishment of standards of performance.
It is a vital tool of improving productivity and cost effectiveness. It helps in the elimination of inefficient and unnecessary activities and idle time. It results in the simplification and standardization of operations. It saves time and effort and assists management in the optimum utilization of human and physical resources.
Work Study makes improvements in the areas of work environment, plant layout, material handling, employee’s safety and equipment utilization.

1.3 The Techniques of Work Study
A close look at the definition of work study given above reveals that the term “work study” embraces several techniques but in particular the phrase “Work Study” is used to associate two distinct but inter-dependent groups of techniques. These groups are METHOD STUDY and WORK MEASUREMENT respectively (See Figure 1.1. Work Study Components)

1.3.1 Method Study (Definition) - Method study is a systematic recording and developing and applying easier and more effective methods and reducing costs.
1.3.2 Work Measurement (Definition). Work Measurement is the application of techniques designed to establish the time for a qualified worker (a qualified worker is one who is accepted as having the necessary physical attributes, who possesses the required intelligence and education and has acquired the necessary skill and knowledge to carry out the work in hand to satisfactory standards of safety, quantity, and quality) to carry out a specific job at a defined level of performance.

1.4 The Basic Procedure of Work Study
There are eight basic steps in performing a complete work study, some of which are common to both method study (MS) and work measurement (WM):

1. SELECT the job or process to be studied (MS and WM).
2. RECORD from direct observation everything that happens using suitable recording techniques (MS and WM).
3. EXAMINE the recorded facts critically (MS and WM).
4. Develop the most economic method (MS).
5. MEASURE the quantity of work involved in the selected method and determine a standard time for doing it (WM).
6. DEFINE the new method and the related time (WM).
7. INSTALL the new method with the standard time as agreed standard practice (MS).
8. MAINTAIN the standard practice with the help of proper control procedures (MS).

Note: Work study was widely known as "time and motion study" but with the development of the technique and its application to a very wide range of activities it was felt that the older title was insufficiently descriptive. The term "work study" is now generally accepted.

Good relations must be established before conducting a work study. There must be top management support apart from good cooperation from the supervisors/foremen, who must be sounded about the utility of conducting the study. All instructions and questions should preferably have the supervisors' "green signal". Contrary to widely held belief, work study, properly applied, tends to improve industrial relations.

1.5 Method Study
It is primarily concerned with finding better ways of doing things and it improves efficiency by elimination of unnecessary work, reduction of fatigue, avoidable delays and other forms of waste.
1.5.1 Objectives of Method Study

(i) Improved working processes and standardized procedures
(ii) Better work place layout; neat and clean environment and working conditions.
(iii) Less fatigue to operators
(iv) Better quality of products
(v) Effective utilization of men, materials and machinery
(vi) Efficient and fast material handling
(vii) Reduced health hazards
(viii) Efficient planning of the section.

1.5.2 Basic Procedure of Method Study. Steps involved in carrying out a complete method study are as follows:
1. Select the job or process to be studied which is primarily based on:
   (a) Economic considerations
   (b) Technical considerations
   (c) Human considerations

Economic considerations are important. The obvious areas of application of method study are bottlenecks, excessive movement, operation involving repetitive work, excessive work in process and unsafe work condition. In technical considerations, we are to ensure availability of relevant technical knowledge with which to make the study. Human considerations and reactions need to be accounted for too. Method study will be more readily accepted if the first subject/job are the unpopular ones such as dirty jobs having many allied unpleasant features. If the study improves these types of jobs by reducing unpleasantness, effort and fatigue, the method study will be welcomed. If, however, the study of a particular job appears to be leading to unrest or ill feeling, then leave it alone and wait for an appropriate time or switch over to alternative subject.

2. Record all the relevant information pertaining to the existing method (if any). After selecting the job to be studied and before actual commencement of the subsequent steps, it is important to decide on the objectives to be attained, in order of priority. With the objective for the study in mind, it will then be possible to consider the degree of detail that should be gone into. Clearly, no study should be more detailed than it is justified economically and so the selection of a job must be based on an estimate of time and expense needed. When a job has been selected and the detail and extent of the investigation decided, the systematic analysis of the work is begun. A record is to be made of all the relevant facts relating to the present method which would have to be subjected to a critical examination.

Most people find the graphical or pictorial representation of information invaluable when they are faced with a mass of facts that they must study systematically, because there is less chance of overloading any detail. Many types of charts and diagrams form a vital part of the RECORDING STAGE of method study. These charts and diagrams enhance their utility in recording and development stages. Recording can be done with the help of the following aids.

(a) Process charts
   (i) Outline process chart
   (ii) Flow process chart (Man type, Material type and Equipment type)
   (iii) Two handed process chart
   (iv) Multiple activity chart (Man Machine chart)
(b) Diagrams
(i) Flow diagrams
(ii) Cycle graph
(iii) Chronocyclegraph
(iv) Motion Analysis (SIMO chart)
(v) String diagram
(vi) Chronocyclegraph

(c) EXAMINE the recorded facts carefully and critically to see some elements can be eliminated, combined or simplified. This step will reveal defects in existing methods. The purpose, place and sequence of every operation should be critically examined.

(d) DEVELOP the new and improved method. After analysis of all facts, complete, alternative method is developed (considering all the alternatives and then deciding which to follow). Improvement may be brought in any of the following ways:
   (a) better product design and material specifications
   (b) improved layout
   (c) better sequence of operations
   (d) improvement in method
   (e) better tools and equipments

(e) INSTALL the new method with the cooperation of supervisors and operators (and after proper training of operators in the new method, if required)

(f) MAINTAIN the new method as the standard practice and verify with the help of proper control procedures that it is achieving the desired results.

Summary of the procedure of Method study:
1. SELECT the job to be studied.
2. RECORD all the relevant information of it.
3. EXAMINE the recorded facts critically and impartially.
4. DEVELOP the new or improved method out of the many alternatives.
5. INSTALL the new method with the help of all concerned.
6. MAINTAIN the new method as standard practice.

1.5.2.1 Process Charts Symbols: Charts are generally represented by symbols because symbols produce a better picture and quick understanding of the facts. Process charts use the following five basic symbols to record different types of events:

<table>
<thead>
<tr>
<th>Event</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td></td>
<td>Operation represents an action; it is a step in the procedure. An operation involves a change in the location or condition of an item. Example: cutting a bar on a power hacksaw or driving a nail in wood.</td>
</tr>
<tr>
<td>Storage</td>
<td></td>
<td>Storage represents a stage when an item is waiting or material awaits an action or when an item has been completed for quite some time for reference purposes. Storage shows the location of an item. Example:item lying in a store or refrigerator in a stock room.</td>
</tr>
<tr>
<td>Delay or</td>
<td></td>
<td>Delay occurs when something stops the process and the item waits for the next event. It is a temporary halt in the process. Example: power failure, waiting for the lift, a traffic jam.</td>
</tr>
<tr>
<td>Temporary</td>
<td></td>
<td>Transport indicates the movement of an item from one location to another. The item may be material, group of people or equipment. Example: Oil flowing through a pipe, material flying from one city to another, mail order forms being sent from stores to Machine shop, etc.</td>
</tr>
<tr>
<td>Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. Inspection
   Inspection is an act of checking for correctness of the quantity or the quality of the items. Inspection is not normally expected to change the shape or other characteristics of an item. Example: gauging a piston pin or checking the hardness of a carburized mild steel piece.

   In addition to the basic symbols discussed above, there are symbols for combined activities also and they are given below. The important event has the outer symbol.

6. Operation
   Example: Articles are being painted as they are transported by the chain conveyor.

cum-transportation

7. Inspection
   Example: A powder milk tin being weighed (inspection) as it is filled. Both the events occur simultaneously and are controlled automatically.
cum-operation

(a) Process Charts. A chart may be a diagram, a picture or a graph which gives an overall view of the situation say a process. It helps visualising various possibilities of alteration or improvement. A chart representing a process may be called a Process Chart. A process chart records graphically or diagrammatically in sequence, the operations connected with a process with the help of a set of symbols as explained above. Various process charts are discussed below.

(i) Outline process chart (also called an operation process chart). It is the one giving an overall picture by recording in sequence only the main operations and inspections. It provides an overall view, a quick idea of the entire process from beginning to end at a glance. Fig 12 shows on outline process chart of "changing refill of a ball point pen."

<table>
<thead>
<tr>
<th>TASK</th>
<th>CHANGING REFILL OF A BALL POINT PEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chart begins</td>
<td>Unscrew cap</td>
</tr>
<tr>
<td>Chart ends</td>
<td>Screw the cap</td>
</tr>
<tr>
<td>Charted by</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td></td>
</tr>
</tbody>
</table>

```
1. Unscrew cap
2. Unscrew neck
3. Remove the old refill
4. Assemble the spring on new refill
5. Place the refill in the barrel
6. Screw the neck
7. Summary
   1. Check if the ball pen writes
5. Screw the cap
```

Fig. 1.2. Outline Process Chart
(A) Flow process chart (Man) records the activities of an operator i.e. what an operator does. Fig. 1.3 shows this chart.

Job: Polishing the specimen for metallographic study.

1. Start polishing machine.
2. Sprinkle the solution of polishing compound on the rotating table.
3. Hold the specimen in hand.
4. Place the specimen gently on the rotating table and polish it.
5. Wait for a few seconds.
6. Take away the specimen to wash basin.
7. Wash the specimen.
8. Etch the specimen.
9. Wash the specimen again.
10. Dry it.
11. Check under a microscope.
12. Keep the specimen in the container.

(B) Flow process chart (Material) - A material type flow process chart records what happens to the material i.e. how the material undergoes in the process. Fig. 1.4 shows such a type of chart with flow of the cooling.

(C) Flow process chart (Equipment) - An equipment type flow process chart records the manner in which the equipment is used. The equipment type chart is
Fig. 1.4. A Portion of the Flow Process Chart (Material type) showing flow of product

(ii) Two handed process chart. It records the activities of the left hand and the right hand (of an operator) as related to each other. The activities of the two hands can be synchronized by providing a time scale on the chart. Fig. 1.5 shows a two-handed process chart which is also known as Operator Activity Chart and such a chart is generally used for repetitive jobs of short durations.

<table>
<thead>
<tr>
<th>JOB: ASSEMBLING NUT AND BOLT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LEFT HAND</strong></td>
</tr>
<tr>
<td><strong>SYMBOLS</strong></td>
</tr>
<tr>
<td>PICK UP BOLT</td>
</tr>
<tr>
<td>HOLD</td>
</tr>
<tr>
<td>HOLD</td>
</tr>
<tr>
<td>HOLD</td>
</tr>
</tbody>
</table>

Fig. 1.5. Two-handed process chart
(iv) **Multiple activity chart (Man Machine Chart)**

The multi-activity chart is the multiple activity chart (Man Machine Chart) described in §1.6 where the activities of more than one subject (worker, machine or equipment) are recorded on a common time scale to show this inter-relationship.

<table>
<thead>
<tr>
<th>PRODUCT:</th>
<th>Punched Cards</th>
<th>PROCESS:</th>
<th>Read in a deck of cards in Card Reader</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (Seconds)</td>
<td>Man</td>
<td>Man</td>
<td>Machine</td>
</tr>
<tr>
<td>0</td>
<td>Removes rubber band from deck of cards</td>
<td></td>
<td>IDLE</td>
</tr>
<tr>
<td>3</td>
<td>Picks up weight from hopper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Places deck in hopper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Replaces weight on deck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Pushes start button</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Card Reader reads deck of cards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Picks up deck from the output stacker</td>
<td></td>
<td>IDLE</td>
</tr>
<tr>
<td>23</td>
<td>Replaces rubber band on the deck</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SUMMARY**

<table>
<thead>
<tr>
<th>MAN</th>
<th>MACHINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time sec</td>
<td>%</td>
</tr>
<tr>
<td>Work</td>
<td>15</td>
</tr>
<tr>
<td>Idle</td>
<td>8</td>
</tr>
</tbody>
</table>

**Fig. 1.6. Man-Machine Activity Chart**

(b) **Diagrams.** Process charting helps to visualise the sequence of events in a situation but it cannot illustrate the pattern of movement that men, materials and tools have to follow when a job is being done. Here we find that certain types of diagrams are helpful to indicate visually the path of movement. Various such diagrams are discussed below:

(i) **Flow Diagram.** It shows a rough (or scaled) view of the space which shows the location of specific activities carried out, the extent of work areas, machine follow-up by workers, materials or equipment. (See fig 1.7)

(ii) **String Diagram.** It is a scale plan or model on which a thread or string is used to trace and measure the path of workers, materials or equipment during specified sequence of events. String diagram can deal with complex movements throughout a whole building, and by contrast to illustrate the movement of an operator's hand at a work bench. (See fig 1.8)
(iii) Cyclegraph. Some motions (of operator) require very small time and it is difficult to measure time for these motions accurately but the time required by these motions cannot be neglected because they are repeated hundreds of times. Therefore, the motions are taken on picture film with the help of a picture camera. Very small time up to 0.0005 minute can be measured by this system. When picture camera is used, the procedure is known as "Micromotion study".

Small electric bulbs are attached to the fingers, hands, legs, ankles and other parts of the body of the operator and photographs are taken to record the path of the motion. With a still camera, the path of light so photographed is called a "Cyclegraph".

(iv) Chrono-cyclegraph. Referring to the above cyclegraph, if an interrupter is placed in the electric circuit with the bulb and the light is flashed quickly and off slowly, then the path of bulb in the photograph will appear as a dotted line with the space between the dots indicating the direction of motions. The space between the dots will be according to the speed of the hand or finger of the body. Size and shape of the space will show whether body part is in acceleration or in retardation. The number of dots will give the time taken by that part. Such a record is called "Chrono-cyclegraph."
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Therblig</th>
<th>Symbol</th>
<th>Colour</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Assemble</td>
<td>A</td>
<td>Violet</td>
<td>Puts objects together.</td>
</tr>
<tr>
<td>2.</td>
<td>Disassemble</td>
<td>DA</td>
<td>Light violet</td>
<td>Separating different parts of an assembly.</td>
</tr>
<tr>
<td>3.</td>
<td>Avoidable delay</td>
<td>AD</td>
<td>Lemon yellow</td>
<td>A delay which can be avoided.</td>
</tr>
<tr>
<td>4.</td>
<td>Unavoidable delay</td>
<td>UD</td>
<td>Yellow</td>
<td>A delay which cannot be avoided.</td>
</tr>
<tr>
<td>5.</td>
<td>Transport load</td>
<td>TL</td>
<td>Green</td>
<td>Moving an article from one place to another.</td>
</tr>
<tr>
<td>6.</td>
<td>Transport empty</td>
<td>TE</td>
<td>Olive green</td>
<td>Moving empty load from one place to another.</td>
</tr>
<tr>
<td>7.</td>
<td>Search</td>
<td>SH</td>
<td>Black</td>
<td>Hunting for something.</td>
</tr>
<tr>
<td>8.</td>
<td>Plan</td>
<td>RN</td>
<td>Brown</td>
<td>Mental examination of an object.</td>
</tr>
<tr>
<td>9.</td>
<td>Rest</td>
<td>R</td>
<td>Orange</td>
<td>An allowance, diurnal or temporary.</td>
</tr>
<tr>
<td>10.</td>
<td>Position</td>
<td>P</td>
<td>Blue</td>
<td>Turning an object to make a change possible.</td>
</tr>
<tr>
<td>11.</td>
<td>Find</td>
<td>F</td>
<td>Grey</td>
<td>Mental examination of an article.</td>
</tr>
<tr>
<td>12.</td>
<td>Inspect</td>
<td>I</td>
<td>Burnt ochre</td>
<td>Examining an article to determine its quality.</td>
</tr>
<tr>
<td>13.</td>
<td>Proposition</td>
<td>PP</td>
<td>Pale blue</td>
<td>Locating an article in a predetermined position.</td>
</tr>
<tr>
<td>14.</td>
<td>Grasp</td>
<td>G</td>
<td>Red</td>
<td>Manipulating or controlling a tool or other mechanism.</td>
</tr>
<tr>
<td>15.</td>
<td>Use</td>
<td>U</td>
<td>Purple</td>
<td>Retention after grasping.</td>
</tr>
<tr>
<td>16.</td>
<td>Hold</td>
<td>H</td>
<td>Gold ochre</td>
<td>Choosing one object amongst many.</td>
</tr>
<tr>
<td>17.</td>
<td>Select</td>
<td>ST</td>
<td>Light grey</td>
<td>Retaining an object.</td>
</tr>
<tr>
<td>18.</td>
<td>Release load</td>
<td>RL</td>
<td>Carmine red</td>
<td>Releasing an object.</td>
</tr>
</tbody>
</table>
**Man-Machine Chart**

It is similar to the two handed process chart, where the activities of worker and machines are recorded on a common time scale to show inter-relationship. It should have one column for the man and a column each for machine 1 and machine 2.

An example of a man-machine chart showing one operator operating two semi-automatic lathes is shown in figure 3.6.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Machining on two semi-automatic lathes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dept. :</td>
<td>Workshops</td>
</tr>
<tr>
<td>Method :</td>
<td>Existing</td>
</tr>
<tr>
<td>Date</td>
<td></td>
</tr>
<tr>
<td>Scale</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>Load Machine 1</td>
</tr>
<tr>
<td>0.50</td>
<td>Load Machine 2</td>
</tr>
<tr>
<td>0.75</td>
<td>Idle</td>
</tr>
<tr>
<td>1.00</td>
<td>Unload Machine 1</td>
</tr>
<tr>
<td>1.25</td>
<td>Load Machine 1</td>
</tr>
<tr>
<td>1.50</td>
<td>Load Machine 2</td>
</tr>
<tr>
<td>1.75</td>
<td>Unload Machine 1</td>
</tr>
<tr>
<td>2.00</td>
<td>Load Machine 1</td>
</tr>
<tr>
<td>2.25</td>
<td>Load Machine 2</td>
</tr>
<tr>
<td>2.75</td>
<td></td>
</tr>
<tr>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>3.25</td>
<td></td>
</tr>
<tr>
<td>3.50</td>
<td>Unload Machine 1</td>
</tr>
<tr>
<td>3.75</td>
<td>Idle</td>
</tr>
<tr>
<td>4.00</td>
<td>Unload machine 2</td>
</tr>
<tr>
<td>4.25</td>
<td>Summary</td>
</tr>
<tr>
<td>Idle Time</td>
<td>1.25</td>
</tr>
<tr>
<td>Working time</td>
<td>3.00</td>
</tr>
<tr>
<td>Utilisation</td>
<td>$\frac{3}{4}$</td>
</tr>
</tbody>
</table>

*Fig. 3.6. Man-machine chart.*
1.6 Work Measurement

Work measurement refers to the study of work content of a job so as to lay down a "fair day's work". It seeks to provide a quantitative assessment of human work in a specified job and to establish the proper time for the effective performance of that job. The following are main objectives of work measurement.

1.6.1 Objectives of Work Measurement

1. To determine the time required to do a job; thus it compares alternative methods and establishes the fastest method other conditions being same.
2. To balance the work of members of a team so that as far as possible each member has a task which takes equal time to perform.
3. To determine the number of machines an operator can run.
4. To enable schedules of work to be prepared by relating reasonably accurate assessments of human work to plant capacity.
5. As a basis of a realistic and fair incentive scheme.
6. To provide information on the basis of which estimates for tenders, selling prices and delivery schedules may be prepared.
7. As a basis of labour budgeting and budgetary control systems.
8. To enable estimates to be prepared for future labour requirements and costs.
9. To devise schemes for transfer/training for the poor performance.

1.6.2 Basic Procedure of Work Measurement

The steps to be followed sequentially for work measurement are:

1. SELECT the work to be studied after having made a preliminary survey.
2. RECORD all the relevant data pertaining to the circumstances in which the work is being done, the methods and the elements of activities in them.
3. MEASURE each element in terms of time over a sufficient number of cycles of activity to ensure that a representative picture has been obtained.
4. EXAMINE the recorded data and time element critically to ensure that unproductive or random elements are separated from productive elements; also examine the recorded times of each element and determine a representative time for each.
5. COMPARE a time for the operation which will provide a realistic standard of performance and will include time allowances to cover suitable rest, personal needs and contingencies etc.
6. DEFINE precisely the series of activities and method of operation for which the time has been allowed and issue the standard time for the activities and methods specified.

The above steps of work measurement are essentially a three stage procedure of analysis, measurement and synthesis. The analysis stage occurs when the work to be measured is broken down into its constituent parts. Measurement records time for an operator to carry out each element. Synthesis takes place when the available information is gathered together into a suitable form for use. The three stages are closely connected with each other.

1.6.3. Techniques of Work Measurement

The principal techniques of Work Measurement are:

1. Time study.
1.6.3.1 Time study. Definition. Time study is a technique for determining as accurately as possible from a limited number of observations, the time necessary to carry out a given activity at a defined level of performance.

Objective. The objective of time study is to determine by direct observation, the quantity of human work in a specified task and hence to derive the proper time for the task.

Time study procedure. Basic time study equipment or tools consist of a stop watch, a study board, pencils, a pocket calculator, and measuring instruments for distance and speed (such as a ruler tape measure, micrometer and technometer/revolution counter).

![Image of time study equipment]

The basic steps in time study procedure are as follows:

1. **SELECT** the job to be studied (short cycle or long cycle, repetitive or non-repetitive). A job might be selected for a variety of reasons. It could be because of:
   - a new job,
   - a change in method for which a new standard time is needed,
   - a complaint received from workers or their representatives about time allowed for an operation,
   - a bottleneck operation,
   - a change in management policy such as the introduction or withdrawal of an incentive scheme.

2. **RECORD** all the information about the job, the operator and the surrounding conditions which are likely to affect carrying out of the work. Plan the...
programme by which all the constituents can be measured economically and accurately, record a complete description of the method and break down the operation into elements which could be conveniently observed, measured, analysed and synthesised.

(3) MEASURE with a stop watch the time for each element repeated for sufficient number of cycles, so as to provide reliable data covering all expected conditions. Also while observing do not forget to assess the effective speed of the working of the operator relating to a pre-determined ‘normal’ speed. This process is called “Performance Rating” and if it is not reliable enough it could be a bone of contention between the various relevant parties. Now we shall define the term “Performance Rating”.

By definition rating is a comparison of actual performance with some standard notion or normal performance. Normal performance (or pace) is the working rate of the average worker working under capable supervision but without the stimulus of an incentive wage plan. This pace can easily be maintained day after day without undue physical or mental fatigue and is characterised by the fairly steady exertion of reasonable effort.

Some accepted standard or norms are that an average person walks at a speed of about 4 miles per hour or deal a pack of cards (52 cards in 4 hands) in 0.375 minute (= 22.5 secs). But all the activities taking place on the shop floor or even in our domestic house cannot be standardized like this. For example, if one asks what will be the time (normal time without undue exertion) of assembling a connecting rod in the piston of an I.C. engine or what will be the time in sweeping a floor of 15 ft x 12 ft size by a broomstick, we shall be stumped outright. But walking at a speed of 4.5 miles an hour or 3.5 miles an hour will immediately bring a spontaneous answer of 112.5% efficient walk or 87.5% efficiency walk (taking the accepted standard speed of walk of 4 m.p.h. as 100%). Which is why observers (time study engineers) are specially trained in various ways to be able to recognise the normal rate of working and to assess the degree to which a worker's observed speed and effectiveness varies from the 100% concept. The procedure in which this assessment is noted simultaneously with the observed time in taken as performance rating.

The following three scales of rating are in use designated as 60-80 scale, 100-133 scale, and 0-100 scale out of which the 0-100 scale is most extensively used. The following table shows examples of different scales.

<table>
<thead>
<tr>
<th>SCALES</th>
<th>Description</th>
<th>Equivalent Walking Speed (m.p.h.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60-80</td>
<td>0-3</td>
<td>0</td>
</tr>
<tr>
<td>100-133</td>
<td>40-67, 50</td>
<td>2</td>
</tr>
<tr>
<td>0-100</td>
<td>90-100, 75</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>90-133, 100</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>100-167, 125</td>
<td>5</td>
</tr>
</tbody>
</table>

In the scale 0-100 the figure 100 represents standard performance. If the study man decides that the operation he is observing is being performed with less effective speed than his concept of standards, he will use a factor of less than 1.0.
Thus Basic time (or normal time) = Observed time × Standard Rating (100)

For example, if observed time is 0.16 minute and the work is working at a faster rate of 125% then the basic time is:

$$\frac{0.16 \times 125}{100} = 0.20 \text{ minute.}$$

(Performance rating or rating factor is generally taken to be 90 – 120%)

(4) Compile the various basic times for the entire element activities. After establishing the basic time per cycle required by the qualified worker to perform each element at standard rate of working, it is necessary to find out what percent of time should be added to each element to allow for fatigue, personal needs of time, the effects of working in various environments, and other contingencies. RELAXATION ALLOWANCE (RA) is added to the basic time.

(iii) Visual fatigue

(ivii) Other influences of environments.

For the assessment of RA of individual elements, the following Table may serve as a useful guide.

<table>
<thead>
<tr>
<th>FACTORS</th>
<th>Men</th>
<th>RA%</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Constant Allowances</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal needs allowance</td>
<td>5</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Basic fatigue allowance</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>(2) Variable Allowances</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Standing allowance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) Abnormal positions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ii) Slightly awkward</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(iii) Bending</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(iv) Bending (lying, stretching up)</td>
<td>7</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>(d) Weight lifting or use of force</td>
<td>7</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>(i) 5 kg</td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>(ii) 10 kg</td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>(e) Air conditions (excluding climate)</td>
<td>0 to 5</td>
<td>0 to 5</td>
<td></td>
</tr>
<tr>
<td>(f) Visual strain</td>
<td>0 to 5</td>
<td>0 to 5</td>
<td></td>
</tr>
<tr>
<td>(g) Aural strain</td>
<td>0 to 5</td>
<td>0 to 5</td>
<td></td>
</tr>
<tr>
<td>(h) Mental strain</td>
<td>0 to 5</td>
<td>0 to 5</td>
<td></td>
</tr>
<tr>
<td>(i) Fall process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ii) Complex or wide span of attention</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(iii) Very complex</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>(iv) Monotony: mental</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>(v) Monotony: physical</td>
<td>0 to 4</td>
<td>0 to 4</td>
<td></td>
</tr>
</tbody>
</table>

Source: An Introduction to Work Study (1952)
Added to the above is yet another allowance (in %) known as the CONTINGENCY ALLOWANCE (CA) accounting for the following contingencies.

(i) Sharpening of tools
(ii) Obtaining special materials
(iii) Obtaining a special purpose equipment from a central tool room
(iv) Consultation with the supervisor
(v) Consulting a manual or work order for specifications.

And finally any other allowance, which the company thinks fit under its policy decision is added to compute the Standard Times.

Thus Standard Time = Basic time + RA + CA + any other allowance (Fig 1.10)

![Diagram](image)

Fig. 1.10.

(5) DEFINE all the activities covered now and issue the allowed time for a particular job/operation. Obviously, this allowed time should have the approval of the management and the support of the employees and their representatives so that no conflict occurs when the plan is actually put into practice.

It is important, however, for the time study man to have taken sufficient number of readings. This can be determined by using the following formula which is based on a normal distribution for 95% level of confidence and a precision need of predicting the final results within ± 5%.

\[ N_{\text{expected}} = \frac{40}{\sqrt{\frac{\sum X^2 - (\sum X)^2}{2X}}} \]

where \( N \) denotes observations already taken
and \( X \) represents the value of each observation

\( N_{\text{expected}} \) = sufficient no. of readings.

**Illustration:** An observer has taken few observations of an element as shown below and now wants to know as to how many more observations are to be taken for a 95% confidence level and ± 5% precision.

Individual reading in 0.01 min (\( X \)) are 6, 6, 6, 6, 6, 5, 6 i.e. 0.06, 0.05 ... min. etc.

**Solution:**

\[ N_{\text{expected}} = \frac{40}{\sqrt{\frac{7 \times (6^2 + 6^2 + 6^2 + 6^2 + 6^2 + 5^2 + 6^2) - (6 + 6 + 6 + 6 + 6 + 5 + 6)^2}{2 \times (6 + 5 + 6 + 5 + 6)}}} \]

\[ = 46 \text{ i.e. } 46 - 7 = 39 \text{ more observations are to be taken} \]

Thus a total of 46 observations are required for achieving desired accuracy and confidence level.

**Summary of the procedure of Time Study:**

1. **SELECT** the job to be studied.
2. **RECORD** all the information about the job and break the job into small elements.
(3) MEASURE the time for each element of the job
(4) COMPARE all the element times, add the allowances to get standard time
(5) DEFINE all the activities covered and issue the standard time for the job
or operation to be put into practice now.

A time study form (blank) is shown below:

<table>
<thead>
<tr>
<th>Time Study Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product:</td>
</tr>
<tr>
<td>Operation No.:</td>
</tr>
<tr>
<td>Operation description:</td>
</tr>
<tr>
<td>N.o. of cycles: 5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard time found:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Element description</th>
<th>Observed time (Stop watch reading)</th>
<th>Averaged observed time</th>
<th>Rating factor</th>
<th>Normal time</th>
<th>Allowances</th>
<th>Standard time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1.11. Time study form

Standard Data: It is a catalogue of basic time or normal time values for different elements of job or for minute movements involved in different jobs. The catalogue is prepared by compiling the timings of a number of standard elements.

Example 1.1 Find out the standard time using the following data:
- Average time for machine elements = 5 min
- Average time for manual elements = 4 min
- Performance rating = 110%
- Allowances = 10%

Solution: Basic time = Machinery time + manual time × rating

\[
= 6 \times 4 \times \frac{110}{100} = 10.4 \text{ min}
\]

Standard time = Basic time + Allowance

\[
= 10.4 \times 10.4 \times \frac{10}{100} = 10.4 + 1.04 = 11.44 \text{ min}
\]

Example 1.2 A work sampling study was conducted for 100 hours in the machine shop in order to estimate the standard time. The total number of observations recorded were 2500. No working activity could be noticed for 400 observations. The ratio between manual and machine elements was 2:1. Average rating
factor was estimated as 1.15 and the total number of articles produced during the study period were 6000.

Rest and personal allowances may be taken as 12% of the normal time. Compute the standard time in minutes.

Solution: Proportion of working time $= \frac{2500 - 400}{2500} \times 100 = 84\%$

Time taken to make one article $= \left( \frac{100 \times 0.84}{100} \right) \times \frac{60}{5000} = 0.84 \text{ min}$

Out of 0.84 min, the time devoted by manual labour $= 0.84 \times \frac{2}{3} = 0.56 \text{ min}$

and machine time $= 0.84 \times \frac{1}{3} = 0.28 \text{ min}$

Basic time per article $= \text{Machine time} + \text{manual time} \times \text{rating}$

$= 0.28 + 0.56 \times 1.15 = 0.924 \text{ min}$

:. Standard time per article $= \text{Basic time} + \text{Allowances}$

$= 0.924 + 0.924 \times \frac{12}{100} = 0.924 + 0.11088$

$= 1.0349 \text{ minutes. Ans.}$

Time and motion study - Work study was previously widely known as Time and Motion study. Motion study was first devised by Frank Gilbreth who defined it as "science of eliminating wastefulness resulting from ill-directed and inefficient motions". Motion study was a technique which analysed each operation of a given piece of work, very closely and in order to eliminate unnecessary operations and to approach the quickest and easiest method of performing each necessary operation. It included the standardization of equipment, method and working conditions and training of the operator to follow the standard method. Later, on the scope of motion study was enlarged and it was named as 'method study'.

1.6.3.2 Work sampling (or Activity sampling or Ratio Delay or Random Observation Method or Observation Ratio Study): It is based on the statistical method first devised by L.H.C. Tippett in 1934 who used this method for determining the causes of loom stoppages while working for the British Cotton Industry Research Institute. Work sampling is a fact finding tool and a measurement technique for quantitative analysis in terms of time, of the activity of operators, machines or of any observable state or condition of operation.

This tool is particularly useful when information is urgently needed about men or machines, especially in the analysis of non-repetitive or irregularly occurring or machines, especially in the analysis of non-repetitive or irregularly occurring or machines activity where no complete method and frequency description is available. Work sampling can be used to study almost any type of work, repetitive or non-repetitive, factory or office, executive or supervisory, clerical or engineering, handlers, salesmen, nurses and what you have.

Work sampling is a method of randomly observing work, noting state and condition of the object being studied. From the proportion of observations in each category, inferences are drawn concerning the total work activity under study.
Uses of Work Sampling - Work sampling provides a way to:

1. Obtain information about either certain long cycle work or non-repetitive type of jobs for which it would be clearly impractical to use continuous observation methods.
2. Indicate if certain activities should be studied in details.
3. Help design the workload distribution in formulating a new work system.
4. Study any operation for possible methods improvement.
5. Help establish job content as an aid to job evaluation and employment purposes.
6. Aid supervisors to organise their time.
7. Aid appraisal of shop effectiveness, efficiency, safety performance etc.
8. Provide feedback information about compliance to stated management policies.
10. Establish control on labour, material or machine utilization.

The object of the observations may be personnel, equipment or facilities which can be categorised as follows: typical categories applied to people are:

(a) Working
(b) Being idle
(c) Being out of area
(d) Walking
(e) Handling material
(f) Inspecting
(g) Changing tools
(h) Clearing up
(i) Handling clerical tasks
(j) Talking.

Typical categories applied to machines/equipments are:

(a) At work
(b) Idle - no operator
(c) Idle - no stock
(d) Idle - being serviced
(e) Idle - interference.

Fundamental Concept - Based upon the law of probability, it can be said that a sample taken at random from a large group tends to have the same pattern of distribution as the large parent group and if the sample is large enough, the characteristics of the sample will differ very little from the characteristics of the parent group or population. Sampling is the analysis of the characteristics of a population based on the analysis of a small group collected at random from it.

The sampling process should be completely unbiased and each part comprising the population must have an equal chance of being drawn. This can be ensured with the help of random sampling. It is necessary to decide before hand what level of confidence is desired in the final work sampling results. The most commonly used confidence level is 95% which means that one is confident that 95% of the time the random observations will represent the facts and that 5% of the time, they will not.

For 95% confidence level, a relationship exists between number of observations (N), the extent of the phenomenon being observed - expressed as decimal (P) and the accuracy of the sample results (SP). This is given below:

\[
SP = 2 \frac{\sqrt{P(1-P)}}{N} 
\]

For 70% confidence level, SP = \( \frac{P(1-P)}{N} \)

For 99% confidence level, \( SP = 3 \frac{\sqrt{P(1-P)}}{N} \)
Accuracy of Activity Sampling Measurement:

Limits of accuracy (S) refers to the permissible variations of the results of the study from the true mean of the situation. Through the figure of limits of accuracy varies depending upon the objective of the study, it is common practice to pick up the figure between the range from 2% to 5%.

When one determines the degree of accuracy desired in the activity sampling, he is in effect determining the number of observations required. The number of such observations in turn effects the time and cost of making the study. The purpose of the activity sampling study thus should suggest the degree of accuracy of results required.

In designing the work sampling study analyst must size up the entire situation. A proper balance between the accuracy desired and the economics of the study must be struck. Fortunately in a work sampling study the analyst can determine in advance the number of observations needed for a given degree of statistical accuracy using the formula mentioned above.

The steps for an activity sampling study may be described as follows:

1. Define the problem.
2. Get the approval of the supervisor of the department concerned in which the study is to be made to ensure the co-operation of the operators to be studied.
3. Determine the desired accuracy of the final results and the confidence level.
4. Make a preliminary estimate of the percentage occurrence of the activity or delay to be measured.
5. Design the Study.
   (A) Determine the number of observations to be made.
   (B) Determine the number of observers needed.
   (C) Select and instruct these people.
   (D) Determine the number of shifts needed for the study.
   (E) Make a detailed working plan for taking the observations.
   (F) Design the observation form.
6. Make the observations according to the plan.
7. Analyse and summarize the data thus obtained.
8. Check the accuracy or precision of the data at the end of the study.

An example of the type of observation sheet used in activity sampling study may be found at the end of this topic.

Activity Sampling - An Example

Suppose we want to determine the percentage of idle time of the automatic screw machines by activity sampling. Further, assume that a confidence level of 95% and an accuracy of ±5% have been decided upon.

(A) To determine the number of random observations needed to give us the desired results, a trial study is first made of the screw machines to get a first estimate of the percentage of idle time.

Suppose a total of 100 observations were made, and in this percentage study 25 observations showed the machines to be idle. The percentage of idle time would be 25%.

So, N = No. of observations needed (to be determined)

P = idle time = 25% = 0.25 (First estimate)
S = Accuracy ± 5% = ± 0.05

So,

N = \frac{P^2 \times S^2}{(P - S)^2} = \frac{0.25^2 \times 0.05^2}{(0.25 - 0.05)^2} = \frac{0.0625 \times 0.0025}{0.20^2} = \frac{0.00015625}{0.04} = 0.00390625

Therefore, N \approx 4

Would you need to make four observations to get an accurate result of 25% ± 5%?
Substituting the values of \( P \) and \( S \) in the formula:

\[
SP = \frac{P(1-P)}{N} \quad \text{and} \quad S = 0.25 \times 0.75 = 0.1875
\]

we get:

\[
N = 4800
\]

(B) After the work sampling study is under way and 500 observations have been made, a new calculation would be made in order to check our original value of \( N \). Assume that the results were as follows:

- Observations of machines working: 350
- Observation of machine idle: 150

Then \( P = \frac{350}{500} = 0.70 \) (working time)
and \( S = \text{accuracy} = 0.05 \) previously decided.

Recalculation with the same formula shows \( N = 3733 \).

It is advisable to recalculate \( N \) at regular intervals in order to better evaluate the progress of the study.

(C) After the study is completed, a final calculation is made to determine whether the results are within the desired accuracy. This can be done by calculating \( S \) in the formula instead of \( N \) as was previously done.

Assume that the final results of the study were as follows:

- Observations of machines working: 2600
- Observations of machines idle: 1400

Then \( P = \frac{1400}{4000} = 0.35 \) (working time)

Substituting in the formula we get:

\[
S = \pm 4.3\%
\]

Since 4.3% is below the 5% desired accuracy the number of observations is sufficient.

Activity Sampling Observations Sheet

<table>
<thead>
<tr>
<th>Date</th>
<th>Observer</th>
<th>Study No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>2</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>3</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>4</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>5</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>6</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>7</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>8</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>9</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>10</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>11</td>
<td>W</td>
<td>W</td>
</tr>
</tbody>
</table>

A = Operative absent from work place.
1.6.3.3 **Predetermined Motion Time System (PMTS).** Every element of work is composed of some combination of basic human motions. Apart from mental activity, all work can be broken down into elements that are usually a fundamental movement of the body or body members. After this analysis stage, the basic motions that have been isolated have a time allotted to them on the basis of predetermined motion times. This is the measurement (or rather pre-measured) stage. The synthesis stage involves combining the basic motions in specific combinations and frequencies to form basic elements which will go to complete the total work operation. This method is particularly suited to situations where direct observations may not be possible or it may be some entirely new method of working which, however, is composed of work of basic elements which are standard with a new combination or mix. It is suited to both repetitive as well as non-repetitive work.

1.6.3.4 **Analytical Estimating.** After the job has been broken down into its constituent elements in certain types of non-repetitive work, we find that analytical estimating serves as best for measuring work. In the analysis stage we find that usually these basic elements are much larger as compared to the elements in PMTS or time study. For the measuring stage, the time, which will be occupied by the element at a specific speed of working, is estimated. Many values may be obtained from the records of previous studies. The synthesis of all such records or data can be clubbed together for meaningful purpose.

1.6.3.5 **Synthesis from Standard Data.** Now here we find yet another technique of work measurement to obtain synthetic times (or synthesised time standards) that are synthesised from element times previously obtained from direct time studies. The analysis and measurement stages are thus conducted prior to the actual study. The technique primarily focuses on the synthesis stage. Most organisations that have had work studies conducted for some time usually build synthetic tables covering the common elements in their own type of work. You could also refer to some standard tables, but be cautious in adapting it to your own organisations by duly keeping the framework in mind for which the standards might be applicable.

1.6.3.6 **MOST Measurement System.** The work MOST stands for Maynard Operation Sequence Technique. It is yet another work measurement technique. It was conceptualised around 1967 but was formalised only in 1975. The basic assumption here is that for an overwhelming majority of work, there is a common denominator from which work can be studied: the displacement of objects. In fact, all basic units of work are organised for the purpose of accomplishing some useful result by simply, moving objects. MOST is a system to measure work by concentrating on the movement of objects. Consequently, MOST technique is composed of the following basic sequence models:

The General Move Sequence (for the spatial movement of an object freely through the air).

The Controlled Move Sequence (for the movement of an object when it remains in contact with a surface or is attached to another object during the movement).

The Tools Use Sequence (for the use of common hand tools).
Work measurement also provides, at a glance, a clear picture of the activities of all employees. The absence of com-
prises.
(6) **Production Planning for Scheduling**: The knowledge of time standards enables one to fix production norms for each operation or job. This makes it possible for him to plan and schedule production targets for men and machines for optimum utilisation. Similarly, planning and scheduling of maintenance jobs is also possible.
(7) **Rational Basis for Incentives**: Time standard data along with standard performance norms provide a rational basis for introducing financial incentive schemes which are equitable both to the management and the workmen.

## 1.7 Work Study Applications

Work study techniques can be applied in a large number of situations. They are not necessarily confined to manufacturing at the shop floor level. Work study could be applied in office situations in which case the technique is more popularly known as O and M (Organisation and Methods). Work study could be applied in the Building Industry. In fact, Frank Gilbreth developed his ideas on time and motion study in a construction situation. Quite often, repetitive work is to be found on one site, e.g. laying precast concrete floor units, etc. Work study, par-
ticularly method study has, in such cases, been found to be very beneficial.
Again, we could utilise work study in the context of agriculture, which remains largely non-mechanised in our country. Savings in time and effort of farmers can be used to increase their effectiveness and efficiency. Identification and elimination of fatiguing and costly or unproductive activities could be undertaken.

Work study could be used in a hospital setting also. Work study groups can achieve great success in the nursing patterns and staffing, ward design and hospital layout improvement in services such as catering, laundry work, domestic cleaning, typing, secretarial work and documentation etc.

In some countries abroad, work study has been used in national and local government services for maintenance of parks, playing fields, housing schemes, street cleaning, rubbish collection and disposal, post office sorting etc. It can also be used in defence services—both for repair and logistic functions etc. Work study can also be used in hotel management for housekeeping, lines service, kitchen work, reception, preparation, cooking and serving of foods etc.

Work study personnel could also prove to be beneficial if they are included in design teams which require an inter-disciplinary approach for greater effectiveness.

Accordingly, work study people along with value analysts would certainly increase design worthiness.

1.8 Ergonomics (Human motion economy)

1.8.1 Definition. Ergon means ‘Work’ and nomos means ‘Natural Laws’. Ergonomics or its American equivalent ‘Human Engineering’ may be defined as the scientific study of the relationship between man and his working environments. Ergonomics implies ‘Fitting the job to the worker’. Ergonomics combines the knowledge of a psychologist, physiologist, anatomist, engineer, anthropologist and a bio-mechanic.

1.8.2 Objectives. The objectives of the study of ergonomics is to optimize the integration of man and machine in order to increase work rate and accuracy. It involves the design of,

(i) a work place which the needs and requirements of the worker,
(ii) equipment, machinery and controls in such a manner so as to minimize mental and physical strain on the worker thereby increasing the efficiency, and
(iii) a conducive environment for executing the task most effectively.

Both work study and Ergonomics are complementary and try to fit the job to the workers; however, Ergonomics adequately takes care of factors governing physical and mental strains.

1.8.3 Applications. In practice, ergonomics has been applied to a number of areas as discussed below

(A) Working environments,
(B) The workplace, and
(C) Other areas.

(A) Working Environments

(a) The environment aspect includes considerations regarding light, climatic conditions (i.e., temperature, humidity and fresh air circulation), noise, bad odour, smoke, fumes, etc., which affect the health and efficiency of a worker.
(b) Day light should be reinforced with artificial lights, depending upon the nature of work.
(c) The environment should be well-ventilated and comfortable.
(d) Dust and fume collectors should preferably be attached with the equipments giving rise to them.
(e) Glare and reflections coming from glazed and polished surfaces should be avoided.
(f) For better perception, different parts or sub-systems of an equipment should be coloured suitably. Colours also add to the sense of pleasure (paints protect, colours cheer).
(g) Excessive contrast, owing to colour or badly located windows, etc., should be avoided.
(h) Noise, no doubt distracts the attention (thoughts, mind) but if it is slow and continuous, workers become habituated to it. When the noise is high pitched, intermittent or sudden, it is more dangerous and needs to be dampened by isolating the place of noise and through the use of sound absorbing materials.

(B) Work place layout

The workplace is a space in a factory/machine which must accommodate an operator(s), who may be sitting or standing.

Ideally, a workplace should be custom built for the use of one person whose dimensions are known. For general use, however, a compromise must be made to allow for the varying dimensions of humans. Therefore, a workplace should be so proportioned that it suits a chosen group of people.

Adjustment may be provided (on seat heights for example) to help the situations.

Fig 1.12 shows suggested critical dimensions for a group of males using a seated workplace. These dimensions can be obtained quickly and easily and will be quite satisfactory for constructing a mock-up of the proposed design.

---

**Plan View**

Fig 1.12. Critical dimensions for seated male operator

The Fig 1.12 shows the left hand covering the maximum working area and the right hand covering the normal working area.

Normal working area is the space within which a seated or standing worker can reach and use tools, materials and equipment when his elbows fall naturally by the side of the body.
Maximum working area is the space over which a seated or standing worker has to make full length arm movements (i.e., from the shoulder) in order to reach and use tools, materials and equipment.
Assuming the work as some operation requiring equipment, any tools, bins, etc., they should be placed within the area shaded so that they can be seen and reached quickly and easily.
- Fig. 1.13 shows the situation with respect to bench heights and seat heights. In this view, the seat should be adjustable for height and rake. It is not usually convenient to have adjustable benches or work tops and the value of 712 mm to 762 mm is probably the best compromise dimension.

![Diagram of bench and seat heights](image)

- Workbench layout, design of seat, arrangement of different equipment tools and components should not cause discomfort to the worker.
- The seat should be such that the worker is able to adopt different postures, if necessary, for carrying out different operations.
- The height and back of the chair should be adjustable.
- A proper foot rest, arm rest and leg room should be provided. While working, an operator should feel himself natural and comfortable.
- Design and layout of display panels and instrument dials should result in accurate observations. They should preferably form a part of the workplace and the display should be easily readable by all. Also, the display panel should be at right angles to the line of sight of the operator.
— An instrument, with a pointer should be employed for check readings, whereas for quantitative readings, digital type of instruments should be preferred.

— Design and location of various manual controls, knobs, wheels and levers should not cause excessive physical and mental strain to the worker. Levers and controls should be located close to the operator. Hand and foot controls, both, should be employed to advantage.

— All controls should preferably move in one direction for one kind of action. For example, upward movement of the levers should energise the sub-system and downward motion should de-energise and vice versa.

— In the case of tote boxes, bins, loose or portable tools, etc., there should be a definite place for their location within the working area. Hence the operator can develop habitual, confident movements when reaching for equipment often without any need for the eyes to direct the hands. The mental effort and strain are less. For the same reason, material and tools used at the workplace should always be located within the working area to permit the best sequence of operations. (Refer Fig. 1.14)

---

**Fig. 1.14. Workplace layout for assembled part**

The operation shown consists of assembling four parts A, B, C and D (two assemblies at a time) using both hands. As finished assemblies are placed in chutes, parts A are in the next bins as they are required first for the next assembly.

— Where possible, clear access should be given around industrial workplaces to allow for adequate supervision and inspection.

— It is clear that if ergonomic principles are observed in the design of workplaces, then the operator will be more efficient, less strained and tired and consequently less liable to have an accident.

(C) Other areas

Other areas include studies related to fatigue, losses caused due to fatigue, real pauses, amount of energy consumed, shift work and age considerations.
2.1. FACILITY LOCATION (INTRODUCTION)

Traditionally, location has always meant as industrial plant/factory location down the ages, however, the concept of plant location has now been generalised into that of facility location since the facility could include a production operation or service system. The term plant has been used as synonymous to a factory, manufacturing unit or assembly unit which could include fertiliser, steel, paper, cement, rice milling plants, textile, jute, sugar mills, rubber factories, breweries, refineries, thermal or hydro-electric nuclear power station etc. However, with the enlarged scope of a facility, this term can now be used to refer to banks, hospitals, blood banks, fire stations, police stations, warehouses, godowns, depots, recreation centres and beauty parlours etc.

Facility location decisions are strategic, long term and non-repetitive in nature. Without sound and careful location planning in the beginning itself, the new facility may pose continuous operating disadvantages, for the future operation. A right selection of a plant location can make and a wrong one can mar an organisation. Location decisions are affected by many factors such as the technology used, the capacity, the financial position, the work force required and also by economic, political and social conditions in the various localities. The efficiency, effectiveness, productivity and profitability of the facility are also affected by the location decision. The facilities location problem is concerned primarily with the best location depending on the appropriate criteria of effectiveness. The following are some of the important factors affecting plant location.

Factors Affecting Plant Location

(1) Input Considerations
   (a) Material—Quantity, quality, cost and regular supply
   (b) Land—Site availability and costs, cost of construction, constructional regulations.
   (c) Equipment—Availability and cost
   (d) Plant utilities—Gas, electricity, coal, water etc. availability and cost
   (e) Labour—Availability, supply, skill, wage rates, unionization
   (f) Capital—Equity and debt potential, banking facilities

(2) Processing considerations
   (a) Production analysis—Educational and research facilities
   (b) Process analysis—Engineering and consultancy
Facilities Location, Plant Layout, Material Handling and Capacity Planning

(c) Forecasting and scheduling—Data resources and capabilities
(d) Production control—Inventory storage and future expansion
(e) Maintenance—Service and repair facilities
(f) Cost control—Accounting and credit facilities
(g) Presence of related industries

3. Output considerations
(a) Distribution—Distribution and storage facilities
(b) Transportation—Facilities and costs
(c) Present and future market potential
(d) Local rates and taxes

4. Other considerations
(a) Community attitude towards industry and company
(b) Public and community services—educational, recreational, housing, medical and cultural etc.
(c) Stockholder interests
(d) Organizational decentralisation policies
(e) Environmental standards—Air, water, zoning and building codes
(f) Political situation

2.1.1. When Does a Location Decision Arise?

A location decision arises due to the various reasons listed below:

(1) It may arise when a new facility is to be established.
(2) In some cases, the facility or plant operations and subsequent expansion are restricted by a poor site, thereby necessitating the setting up of the facility at a new site.
(3) The growing volume of business makes it advisable to establish additional facilities in new territories.
(4) Decentralisation and dispersal of industries reflected in the Industrial Policy resolution, so as to achieve an overall development of a developing country, would necessitate a location decision at a macro level.
(5) It could happen that the original advantages of the plant have been overweighed due to new developments.
(6) New economic, social, legal or political factors could suggest a change of location of the existing plant.

Whenever the plant location decision arises, it deserves careful attention because of the long term consequences and any mistake in selection of a proper location could prove to be costly. Poor location could be a constant source of

(a) higher cost
(b) higher investment
(c) difficult marketing and transportation
(d) dissatisfied and frustrated employees and consumers
(v) frequent interruptions of production
(vi) abnormal wastages
(vii) delays in committed dates of supply
(viii) substandard quality
(ix) denied advantages of geographical specialization and so on.

Once a facility is set up at a location, it is very difficult to shift later to a better location because of numerous economic, political and sociological reasons.

Economic reasons could include total costs, profits, availability of raw materials, labour, power, transportation facilities and market etc.

Social reasons could include employee welfare and employment opportunities etc.

Political reasons could be because of pursuance of a policy of decentralization regional and developmental planning especially in a developing country like India. There could be security considerations on the risk of military invasion, sabotage from anti-social elements etc. and some may be prone to natural calamities like floods, droughts, and earthquakes etc. Policy matters like anti-pollution etc. would have to be given their due consideration.

**Weber's Analysis**

Alfred Weber's analysis was one of the first attempts to base location decisions on the transport cost of the raw material which was least expensive. He categorized raw materials into (a) Ubiquities—to denote those raw materials which are available almost everywhere like sand, soil and water etc., and (b) Localized materials having specific locations. These are further divided into pure material which contributes nearly the total weight of it to the finished goods and gross material which contributes only a small fraction of total weight to the finished goods. It is obvious that ubiquities hardly influence the decision of location. Weber formulated the following material index:

\[
\text{Material Index (M.I.)} = \frac{\text{Weight of the localised material used in the finished product}}{\text{Weight of the finished product}}
\]

If M.I. > 1, then location should be nearer to the source of the raw material.
If M.I. < 1, then the location should be nearer to the market.

The common-sense involved in the above conclusion is unquestionable but such an approach tacitly assumes the existence of a static point of the lowest transportation cost for the raw material.

**2.1.2 Steps in the Facility Location Study**

In the following two phases the location studies are usually made
(i) the general territory selection phase
(ii) the exact site/community selection phase among those available in the general locale.

The considerations vary at the two levels, though there is substantial overlap shown in the...
Facilities Location, Plant Layout, Material Handling and Capacity Planning

Table 2.1: Overlap of consideration of factors in the two stages of facility location.

<table>
<thead>
<tr>
<th>Location factors</th>
<th>Phase I: General territory selection</th>
<th>Phase II: Particular selection of site and community</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Market</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Raw materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Power</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4) Transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) Climate and fuel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(6) Labour and wages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(7) Laws and taxation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(8) Community services and attitude</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(9) Water and waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(10) Ecology and pollution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(11) Capital availability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(12) Vulnerability to enemy attack</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An interdisciplinary team consisting of economists, accountants, geographers, town planners, lawyers, marketing experts, politicians, executives, industrial engineers, defence analysts and ecologists etc. should be set up for undertaking location studies.

**Phase I: Territory Selection**

The following are some of the important factors that influence the selection decision for the general territory/region/area selection.

(a) **Markets.** There has to be some customer/market for your product/service. The market growth potential and the location of competitors are important factors that could influence the location. Locating a plant or facility near to the market is preferred if promptness in service is required if the product is fragile, or is susceptible to spoilage like glass articles, bakery, ceramic goods, fresh breads, jam, jelly, pickles etc. Moreover, if the product is relatively inexpensive and transportation costs add substantially to the cost, a location close to the market is desirable. Assembly type industries also tend to locate near markets.

(b) **Raw Materials and Supplies.** Sometimes accessibility to vendors/suppliers of raw materials, part supplies, tools, equipment etc. may be very important. The issue here is promptness and regularity of delivery and inward freight cost minimization.

If the raw material is bulky or low in cost, or if it is greatly reduced in bulk viz. transformed into various products and by-products, if it is perishable and processing makes it less so, then location near raw materials sources is important. If raw materials come from a variety of locations, the plant/facility may be situated so as to minimize total transportation costs. The costs vary depending upon specific routes, mode of transportation and specific product classifications.

**Transportation Facilities.** Adequate transportation facilities are essential for the economic operation of a productive system. For companies that produce or buy heavy bulky and low value per ton commodities, water transportation could be an important factor in locating plants. It can be seen that civilizations grew along rivers/ waterways etc. Many facilities/plants are located along river banks.

**Manpower Supply.** The availability of skilled manpower, the prevailing wage pattern, living costs and the industrial relations situation influence the location.
Infrastructure. This factor refers to the availability and reliability of power, water, fuel and communication facilities in addition to transportation facilities.

Legislation and Taxation. Factors such as financial and other incentives for new industries in backward areas or no-industry districts, exemption from certain state and local taxes, etc., are important.

Climate. Climatic factors could dictate the location of certain type of industries like textile industry which requires high humidity levels.

**Phase II. Site/Community Selection**

Having selected the general territory/region, next we would have to go in for site/community selection.

Let us discuss some factors relevant for this stage.

**Community Facilities.** These involve factors such as quality of life which in turn depends on availability of facilities like schools, places of worship, medical services, police and fire stations, cultural and social amenities, recreation opportunities, housing, good streets and good communication and transportation facilities.

**Community Attitudes.** These can be difficult to evaluate. Most communities usually welcome setting up of a new industry especially since it would provide opportunities to the local people directly or indirectly. However, in case of polluting, or 'dirty' industries, they would try their utmost to locate them as far away as possible. Sometimes because of prevailing law and order situation, companies have been forced to relocate their units. The attitude of people as well as the state government has an impact on industrial location.

**Waste Disposal.** The facilities required for the disposal of process waste including solid, liquid and gaseous effluents need to be considered. The plant should be positioned so that prevailing winds carry any fumes away from populated areas and so that waste may be disposed off properly and at reasonable expense.

**Ecology and Pollution.** These days there is a great deal of awareness towards maintenance of natural ecological balance. There are quite a few agencies propagating the concepts to make the society at large more conscious of the dangers of certain avoidable actions.

**Site Size.** The plot of land must be large enough to hold the proposed plant and parking and access facilities and provide room for future expansion. These days a lot of industrial areas/parks are being earmarked in which certain standard sheds are being provided to entrepreneurs (especially small scale ones).

**Topography.** The topography, soil structure and drainage must be suitable. If considerable land improvement is required, low priced land might turn out to be expensive.

**Transportation Facilities.** The site should be accessible by road and rail preferably. The dependability and character of the available transport carriers, frequency of service and freight and terminal facilities are also worth considering.

**Supporting Industries and Services.** The availability of supporting services such as tool rooms, plant services etc. need to be considered.

**Land Costs.** These are generally of lesser importance as they are non-recurring and possibly make up a relatively small proportion of the total cost of locating a new plant. Generally speaking, the site will be in which helps in regional development also. It is seen that once a large industry is set up (or even if a decision is made to locate medium scale industries) the site could be preferably in the suburban/semi-urban areas for the Small-Scale Industries, the location could be somewhat paradoxical as people, with money and means, are usually in the cities and would like to locate the
Some of the industrial needs and characteristics that tend to favour each of these locates are now discussed.

Requirements governing choice of a city location are:
1. Availability of adequate supply of labour force.
2. High proportion of skilled employees.
3. Rapid public transportation and contact with suppliers and customers.
4. Small plant site or multi-floor operations.
5. Processes heavily dependent on city facilities and utilities.
6. Good communication facilities like telephone, telex, post offices.
7. Good banking and health care delivery systems.

Requirements governing the choice of a suburban location are:
1. Large plant site close to transportation or population centre.
2. Free from some common city building zoning (industrial areas) and other restrictions.
3. Freedom from higher parking and other city taxes etc.
4. Labour force required resides close to plant.
5. Community close to, but not in, large population centre.
6. Plant expansion easier than in the city.

Requirements governing the choice of a country/rural location are:
1. Large plant site required for either present demands or expansion.
2. Dangerous production processes.
3. Lesser effort required for anti-pollution measures.
4. Large volume of relatively clean water.
5. Lower property taxes, away from Urban Land Ceiling Act restrictions.
6. Protection against possible sabotage or for a secret process.
7. Balanced growth and development of a developing or underdeveloped area.
8. Unskilled labour force required.
9. Low wages required to meet competition.

2.1.3. Subjective, Quantitative and Semi-Quantitative Techniques of Plant Location

Three subjective techniques used for facility location are:
(i) Industry Precedence
(ii) Preferential Factor
(iii) Dominant factor.

(i) Industry Precedence. Here the basic assumption is that if a location was best for similar forms in the past, it must be the best for us now also and in future too. As such there is no need for conducting a detailed location study and the location choice is thus subject to the principle of precedence—good or bad.

(ii) Preferential Factor. Here the location decision is dictated by a personal factor. It depends on the individual whims and preferences e.g., if one belongs to a particular state, he may like to locate his unit only in that state. Such personal factors may not take into account the factors of cost, investment or profit in making a final decision. This could hardly be called a professional approach though such methods are probably more common in practice in our country than generally recognized.

(iii) Dominant Factor. In some cases of plant location there could be certain dominant factors (in contrast to the preferential factor) which could influence the location decisions. In a true dominant sense, mining or
petroleum drilling operations must be located where the mineral resource is available. The decision in this case is simply whether to locate or not to locate at the source.

We now deal with some of the well-known quantitative and semi-quantitative techniques of plant location.

(A) Composite Measure Method. The basic steps of this method are listed below sequence-wise.

1. Develop a list of all relevant factors.
2. Assign a scale to each factor and designate some minimum.
3. Weigh the factors relative to each other in light of importance towards achievement of system goals.
4. Score each potential location according to the designated scale and multiply the score by the weights.
5. Treat the points for each location and either use them in conjunction with a separate economic analysis or include an economic factor in the list of factors and choose the location on the basis of maximum score.

The following example will illustrate the application:

Example 1. There are three potential sites and five relevant factors like transportation costs per week, labour costs per week, finishing material supply, maintenance facilities and community attitude. The costs are in rupees whereas for the last three factors, points are assigned on 0–100 scale. The data are given below:

<table>
<thead>
<tr>
<th>Factors</th>
<th>Potential Location Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$S_1$</td>
</tr>
<tr>
<td>Transportation cost/week (Rs.)</td>
<td>$F_1$</td>
</tr>
<tr>
<td>Labour cost/week (Rs.)</td>
<td>$F_2$</td>
</tr>
<tr>
<td>Finishing material supply</td>
<td>$F_3$</td>
</tr>
<tr>
<td>Maintenance facilities</td>
<td>$F_4$</td>
</tr>
<tr>
<td>Community attitude</td>
<td>$F_5$</td>
</tr>
</tbody>
</table>

The location analyst has pre-established weights for various factors. This includes a standard of 1.0 for each Rs. 10 a week of economic advantage. Other weights applicable are 2.0 on finishing material supply, 0.5 on maintenance facilities and 2.5 on community attitude. Also the organisation prescribes a minimum acceptable score of 30 for maintenance facilities. Select a suitable site based on the above given data.

Solution. Let us consider the first 2 factors first.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Potential Location Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic Advantage</td>
<td>$S_1$</td>
</tr>
<tr>
<td>Monetary value converted to points</td>
<td>$S_1$ over $S_3$</td>
</tr>
<tr>
<td></td>
<td>320</td>
</tr>
<tr>
<td></td>
<td>$10 \times 1 = 32$</td>
</tr>
</tbody>
</table>

Now we prepare the decision matrix table next.
Table 2.4. Decision Matrix.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Weightage</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined ($F_1  \times F_2$) economic advantage</td>
<td>1.0</td>
<td>0</td>
<td>32</td>
<td>24</td>
</tr>
<tr>
<td>$F_1$ (Finishing material supply)</td>
<td>2.0</td>
<td>30</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>$F_2$ (Maintenance facilities)</td>
<td>0.5</td>
<td>60</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>$F_3$ (Community attitude)</td>
<td>2.5</td>
<td>50</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>Composite site rating</td>
<td>1.0 x 0 +</td>
<td>1.6 x 32 +</td>
<td>1.0 x 24 +</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.0 x 30 +</td>
<td>2.0 x 80 +</td>
<td>2.0 x 70 +</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.5 x 60 +</td>
<td>0.5 x 20 +</td>
<td>0.5 x 30 + 2.5 x 70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.5 x 50 = 215</td>
<td>2.5 x 80 = 400</td>
<td>354</td>
<td></td>
</tr>
</tbody>
</table>

The maximum score of 402 is achieved by site $S_3$ in the decision matrix table and so $S_2$ may be an obvious selection of the preferred site. But it does not satisfy the minimum acceptable score of 30 for maintenance facilities and so it is discarded and the next best score of 354 of site $S_2$ is taken into consideration and $S_2$ is adjudged as the preferred site.

(b) Locational Breakeven Analysis. Sometimes it is useful to draw location breakeven chart which could aid in deciding which location would be optimal. The following example will show you how.

Example 2. A manufacturer of automobile carburetors is considering three locations $P$, $Q$ and $R$ for a new plant. Cost studies indicate that fixed costs per year at the sites are Rs. 30,000, Rs. 60,000 and Rs. 110,000 respectively; and variable costs are Rs. 75 per unit, Rs. 45 per unit and Rs. 25 per unit respectively. The expected selling price of the carburetors produced is Rs. 120. The company wishes to find the most economical location for an expected volume of 2000 units per year.


Solution. For each of the three locations the fixed cost points and total cost (fixed cost + variable cost) lines have been shown in the breakeven chart shown in Fig. 2.1.

![Fig. 2.1. Breakeven Chart.](image)
2.1 Introduction

Layout refers to the arrangement of facilities in a particular work station. It may be plant layout, office layout, auditorium layout or retail store layout.

Plant layout implies the physical arrangement of machines, equipment and other industrial facilities on the factory floor in such a manner that they may be handled efficiently. It may be defined as "Plant layout is the optimum arrangement of different facilities including man, machine, equipment, and material etc., showing the space allocated for material movement, storage and all supporting activities from the receipt of raw material to the shipping of the finished goods for an overall economy of production." It involves a judicious arrangement of production facilities so that work flows in as direct a path as possible. According to the great management expert Riggs, the overall objective of plant layout is to design a physical arrangement that most economically meets the required output, quantity and quality. An optimum layout would permit an uninterrupted flow of work through the work station. It ensures best possible utilization of machines, workers and space.

A plant layout study is required to create an arrangement that will minimise unit production costs. Such a study involves a careful analysis of all factors affecting layout. It is an important decision as it represents a long term commitment. It is also important because it affects the flow of materials and processes, labour efficiency, supervision and control, use of equipment, use of space, expansion possibilities etc. Plant layout covers not only the initial layout of machines and other facilities but encompasses revision or improvement in existing layout in the light of changes in the methods and technique of production.

2.2 Objectives and Advantages

Some of the important objectives of a good plant layout are as follows:

(1) Overall simplification of production process in terms of equipment utilization, minimisation of delays, reducing manufacturing time and better provisions for maintenance.

(2) Overall integration of men, materials, machinery, supporting activities and any other considerations in a way that result in the best compromise.

(3) Minimisation of material handling cost by suitably placing the facilities in the best flow sequence.

(4) Saving in floor space, effective space utilization, and less congestion/confusion.

(5) Increased output and reduced inventories-in-process.

(6) Better supervision and control.

(7) Worker convenience, improved morale and worker satisfaction.

(8) Better working environment, safety of employees and reduced hazards.

(9) Minimisation of waste and higher productivity.
2.3 Evidence of Poor Layout

The following are evidences of a poor layout:
1. Slow movement of materials through the plant.
2. Handing and transportation costs.
3. Crowded stock rooms and production departments.
4. Constricted aisles and workplaces making them safety hazardous.
5. Inconveniently located service departments.
6. In-process materials are frequently damaged, misplaced or lost.

2.4 Principles of Plant Layout

While designing the layout of a plant, the following principles (essentials) should be followed:
1. Principle of Overall Integration. All plant facilities are integrated into one single operating unit considering all the servicing necessary for their operations.
2. Principle of Minimum Distance Moved. Attempts are made to minimize movements as far as possible. However, the principle of overall integration should be considered while planning for the minimum distance moved. In fact, weight-distance moved should be the minimum.
3. Principle of Flow. A layout must arrange the work areas as far as possible, in the same way as the sequence of operations or processes. The basic idea is to move the work towards completion progressively without interference of backtracking with a minimum of interruption or congestion.
4. Principle of Cubic Space. Economy is obtained by using effectively all available space—both vertical and horizontal.
5. Principle of Satisfaction and Safety. Satisfaction of working people is an important factor to be kept in mind. Similarly, due consideration must be given to safety requirements.
6. Principle of Flexibility. The layout must be sufficiently flexible to take care of the necessity of re-arranging production facilities when the need arises.

2.5 Types of Plant Layout

There are four broad categories of plant layout:
1. Product layout (Sequence grouping of machines)
2. Process layout (Functional layout or type grouping of machines)
3. Fixed-position layout (Project layout)
4. Group layout (Cellular layout or Combination layout)

1. Product Layout. In product layout, machines and equipment are arranged in the sequence of the manufacturing operations required for the product. The material or deviation of material. It is called line layout because machines are lined up, the finished product on one end and the raw materials fed at one end and taken out as product layout. However, assume a single line shape, a U-shape or a circular shape. A straight line type of plant layout is shown below.

![Plant Layout](image)

Fig. 2.1: Product layout showing movement of two products

Advantages. Product layout offers the following benefits:
(i) Low cost of material handling due to straight and short path and elimination of backtracking.
(ii) Smooth and uninterrupted operations free from bottlenecks.
(iii) Continuous flow of work permits mechanized handling of materials.
(iv) Lesser investment in inventory and work-in-process.
(v) Special purpose equipment can be operated by semi-skilled labour.
(vi) Optimum use of floor space and less congestion of work in the process.
(vii) Shorter processing, time or quicker output.
(viii) Simple and effective inspection of work and simplified production control.
(ix) Lower cost of manufacturing per unit.

Disadvantages. Product layout suffers from the following drawbacks:
(i) High initial capital investment in special purpose machines.
(ii) Heavy overhead charges.
(iii) Breakdown of one machine results in serious work stoppage of the entire line of machines.
(iv) Less flexibility of the layout cannot be adapted to the manufacture of any other type of product. Fluctuations in rate of production will increase manufacturing cost. Even a minor change in machine arrangement requires a complete change in layout.

Suitability. Product layout is useful under the following conditions:
(a) Mass production of standardized products.
(b) Simple and repetitive manufacturing processes.
(c) Operation time for different processes is more or less equal.
(d) Reasonably stable demand for product.
(e) Interchangeability of parts.
(f) Continuous supply of materials.

Large automobile assembly plants, food-processing chains and continuous process industries are examples where line layout is useful. For instance, a multiple spindle automatic screw machine successfully indexes the work from one machining position to another so that several operations are performed in a continuous flow of material within the machine.

To conclude, line layout best suits those industries which manufacture a large volume of standard products involving repetitive processes. In these industries, line layout reduces inventory handling and supervision costs.
Advantages. Process layout has the following merits:
(a) Lower initial capital investment is required in machines and equipment. The higher degree of machine utilization as a machine is not tied to a single product.
(b) Overhead costs are relatively low.
(c) Change in product design and volume can be more easily adapted to the output of a variety of products.
(d) Breakdown of one machine does not result in complete work stoppage.
(e) Supervision can be made more effective and specialized.
(f) There is greater flexibility and scope for expansion.
(g) Setup and maintenance costs are low.

Disadvantages. Process layout suffers from the following limitations:
(a) Material handling costs are high due to backtracking.
(b) More skilled labour is required resulting in higher labour cost.
(c) Processing time or time lag in production is higher.
(d) Work-in-progress inventory is high requiring greater storage space.
(e) More frequent inspection is needed resulting in costly supervision. As the work has to pass through different departments, it is difficult to definitely trace the final responsibility for the finished product.
(f) Production planning and control become difficult.

Suitability. Process layout is useful when:
(a) Products are not standardized.
(b) Quantity produced is small.
(c) Changes in the design and style of product are frequent.
(d) Job shop type of work is done.
(e) Machines are very expensive.

(3) Fixed Position Layout
- Layout by fixed position of the product is inherent in ship building, aircraft manufacture (Fig. 2.3 and big pressure vessels fabrication.
- In other types of layout discussed earlier, the product moves past stations and equipment are moved to the material which remains at one place and the product is completed at that place where the material lies.

Advantages
(a) There is possibility to assign one or more skilled workers for a project from start to finish in order to ensure continuity of work.
(b) It involves least movement of materials.
(c) There is maximum flexibility for all sorts of changes in product and process.
(d) A number of quite different projects can be taken together with the same layout.

Disadvantages
(a) It usually involves a low content of work in process.
(b) There is a tendency to low utilization of labour and equipment.
(c) It involves high equipment handling costs.

(4) Group Layout (Cellular Layout or Combination Layout). A combination of process and product layouts combines the advantages of the both types of layouts. Moreover, these days pure product or process layouts are rare. Most of the manufacturing sections are arranged in process layout with manufacturing lines occurring here and there (scattered) wherever the conditions permit. A combination layout is possible where an item is being made in different types and sizes. In such cases machinery is arranged in a process layout but the process grouping (a group of number of similar machines) is then arranged in a sequence to manufacture various types and sizes of products. The point to note is that, no matter the product varies in size and type, the sequence of operations remains same or similar. Fig. 2.4 shows a combination type of layout for manufacturing different sized gears.

Fig. 2.4. A combination layout for making different types and sizes of gears.

A combination layout is also useful when a number of items are produced in the same sequence but none of the items are to be produced in bulk and thus no item justifies for an individual and independent production line. For example, files, hack-saws, circular metal saws, wood saws, etc. can be manufactured on a combination type of layout. This is also called hybrid layout.
2.6 Factors Affecting Plant Layout

The following factors should be considered while planning the layout of a plant.

1. Plant Location. Plant layout is intimately connected with plant location. As a matter of fact, the size and shape of the site and its topography influence the general pattern of layout. Plant site also influences the type of building, mode of transport and the scope of expansion which in turn influences layout. Plant layout is generally a compromise between the ideal layout and the limitations of plant size and site and building. A decision to relocate offers an opportunity to improve the arrangement of facilities and services. Thus, plant layout is considerably affected by both the specific site and the general location.

2. Nature of Product. Standardised products require a product layout whereas custom made products may need process layout. A fixed position layout would be required for heavy and bulky products. Products involving hazardous and dangerous operations would require isolation of processes. Similarly, value, fragile, volume and quality of product are important considerations in plant layout.

3. Type of Industry. The nature and type of production process exert considerable influence on plant layout. Generally, product layout is more appropriate in continuous process industry, whereas intermittent production requires process layout. The sequence of operations should also be taken into consideration. Perhaps no one factor influences plant layout as much as the nature of the productive process involved. A synthetic process requires a line layout so that various materials and parts merge into the completed assembly in a fluid. On the other hand, an analytic process takes the form of a tree as it starts out with a single material and spreads out into a variety of resultant materials. A conditioning process requires a layout to accommodate lot or batch manufacture. In such a layout the material undergoes no merging or separation but it is simply subjected to physical conditioning as it flows in separate lots through the variety of operations and processes.

4. Plant Environment. In planning factory layout, heat, light, noise, ventilation and other aspects of plant climate should be given due consideration. For example, paint shops and plating sections should be located on an outside wall so that dangerous fumes may be removed through proper ventilation. Type of machines, materials and equipment used also exercise considerable influence on plant location.

5. Spatial Requirements. The spatial needs for machines, material handling equipment and available floor space are important influences on plant location. Spatial requirements also depend upon the position and needs of workers. Employee facilities and safety should be duly considered.

6. Repairs and Maintenance. Machines and equipment should not be fixed so close to each other that it may create problems in repairs, maintenance and replacement. Access to machine parts for repairs and maintenance should be provided.

7. Balance. Proper balance between processes helps to avoid bottlenecks. The arrangement of machine capacity should be such as to ensure a uniform flow of work. At the same time the layout should be designed in such a manner that there is minimum possible movement of materials and men.

8. Management Policy. Management policies regarding size, quality, employee facilities and delivery schedules should be considered while deciding plant layout.

2.7 Methods of Plant Layout

A layout furnishes details of the building to accommodate various facilities like workers, materials, machinery etc. In addition it integrates various aspects of a design of a production system. The information required for plant layout includes dimensions of workplaces, sequence of operations, flow pattern of materials, storage space for raw materials, in-process inventory and finished goods, offices, aisles, toilets, canteen etc. There is no single universal technique leading to the best layout; the different techniques independently or in conjunction with other techniques may be employed at different stages involved in plant layout. During different development stages of a layout the following methods may be used:

1) Process Flow Charts. They show, how different component parts assemble in sequence of operations to form sub-assemblies which in turn lead to assemblies (finished products). Details about flow charts have been discussed in chapter 1 of Work Study.

2) Material Movement Pattern. The principle of minimum movements (i.e., number of movements and distance travelled in one move) forms the basis for optimum effective flow of each operation or process or material. The principle of minimum movements reduces material handling costs, in-process inventory and space for processing and supervision and control becomes simpler. While designing a new plant layout, generally the flow patterns are decided earlier and then a system of facilities (machinery, material and building) is designed and built around the flow pattern. Various flow patterns that are employed in designing the layouts with their characteristics are shown below (Fig. 2.5):

Flow Pattern Characteristics and Place of Use

- Line flow: Simplest, material enters at one end (X) and leaves at other end (Y). It is preferred in buildings having long length and smaller widths.
- U-type flow: Resembles line flow and is used where buildings are more wide but less long as compared to line flow type building.
- Circular flow: Preferred for rotary handling systems. Different work stations are located along circular path. Raw material enters at X and finished goods come out from Y.
- U-type flow: Supervision is simpler as compared to (a) and (b) above. Raw material entrance and finished goods exit is on the same side. (c) and (d) are preferred in square-shaped buildings.
- S or inverted S: Preferred for production lines longer than (d) and in square shaped buildings. The system is compact, space has been better utilise and supervision is efficient.
2.8 Plant Layout Procedure

The ideal procedure for a plant layout is to build the layout around the productive process and then design the building around the layout. This may not be possible always, because the plant building may already be existing or the shape of the plant site may not permit the construction of a building to house the productive process, etc. Ultimately one has to strike a balance between the two approaches. However, various procedural steps involved in plant layout have been listed below:

(1) Accumulate basic data.
(2) Analyse and coordinate basic data.
(3) Describe the equipment and machinery required.
(4) Select the material handling system.
(5) Sketch plan of the plot for making factory building.
(6) Determine a general flow pattern.
(7) Design the individual work station.
(8) Assemble the individual layout into the total layout.
(9) Calculate storage space required.
(10) Make flow diagrams for work stations and allocate them to areas on plot plan.
(11) Plan and locate service areas.
(12) Make master layout.
(13) Check final layout.
(14) Get official approval of the final layout.
(15) Install the approved layout.

The Systematic Layout Planning (S.L.P.) procedure suggested by Francis and White (1974) is shown below. We see that once the appropriate information is gathered, a flow analysis can be combined with an activity analysis to develop the relationship diagram. Space considerations when combined with the relationship diagram lead to the construction of space relationship diagrams. Based on the space relationship diagram, modifying considerations and practical limitations, a number of alternative layouts are designed and evaluated.
2.9 Work Station Design
(Factors Considered in Designing a Work Station)

The work station design affects the production rates, efficiency and the accuracy with which an operation can be performed. A work station not only needs space for commodation, Space requirements and a few more factors governing a good work station design are discussed below:

(A) Space Requirements

1. Space for the worker to stand, sit (as per requirements) or turn comfortably to operate the machine.

2. Space for the machine, taking into considerations the overhang, projection or a planer.

3. Space for the work if it is projecting out from the machine like a long bar fed to a turret lathe, a long shaft fed to a drill machine for the drilling operation on the ends.

4. Space for bins storing in-coming material and processed goods.

5. Space for necessary tools and supplies required by the worker.

6. Space for additional attachments accessories or jigs and fixtures.

7. Space to load large work on and off the machine.
(B) Besides space requirements as given above, other factors are:
1. Consideration for the space required for the movement of material handling equipment.
2. Easy access to safety stops in case of an emergency.
3. Easy access to machine for inspection, lubrication, maintenance and repair.
5. Aisle space between one machine and the next.
6. Appropriate ventilating, lighting and safety arrangements.

Figure 2.16 below shows a work station layout. Numbers 1, 2, 4 etc refer to those of space requirements as discussed under (A) above.

Fig. 2.16. A work station layout for a cylindrical grinding machine

2.10 Computerised Layout Planning

A recent trend has been the development of computer programmes to assist the layout planner in generating alternative layout designs. Computerised layout planning can improve the search of the layout design process by quickly generating a large number of alternative layouts.

Computer programmes are generally either construction programmes or improvement programmes:

(i) Construction programmes
   (a) Successive selection and placement of activities
(ii) Improvement programmes
   (a) CORELAP (Computerised Relationship Layout Planning)
   (b) ALDEP (Automated Layout Design Programme)
   (c) CRAFT (Computerised Relative Allocation of Facilities Techniques)

(A Complete existing layout is required initially and locations of departments are inter-changed to improve the layout design.)

Both ALDEP and CORELAP are concerned with the construction of a layout based on the closeness ratings given by the REL chart.

CRAFT is concerned with the minimisation of a linear function of the movement between departments. Typically CRAFT employs an improvement procedure to obtain a layout design based on the objective of minimising material handling costs.
activities are compared and the activity with the highest total closeness relationship is selected and located first in the layout matrix. This activity is named TCR count is selected and located first in the layout matrix. This activity is named TCR; an activity which must be close to the winner is selected and placed as close as possible to the winner. This activity is denoted as A (closeness of exactly necessary) and is named Victor. A search of winner's remaining relationships is then made. These are placed, again, as close as possible. If no more A's can be found, the victors become potential winners and their relationships are searched for A's. If an A is found, the victors become the new winner, and the procedure is repeated. When no winners are found, the same procedure is repeated for E's (closeness Especially important), I's (closeness important) and O's (Ordinary closeness not desirable) in the layout. CORELAP also puts a value on the U (closeness Unimportant) and II (closeness not desirable) relationship.

ALDEP
It uses a preference table of relationship values in matrix form to calculate the scores of a series of randomly generated layouts. If for example, activities 11 and 19 are adjacent, the value of the relationship between the two would be added to the layout's score. A modified random selection technique is used to generate alternate layouts. The first activity is selected and located at random. Next, the relationship data are searched to find an activity with a high relationship to the first activity. The activity is placed adjacent to the first. If none is found, a second activity is selected at random and placed next to the first. This procedure is continued until all activities are placed. The entire procedure is repeated to generate another layout. The analyst specifies the number of layouts wanted which must satisfy a minimum score.

CRAFT
It is the only one which uses flow of materials data as the sole basis for development of closeness relationships. Material flow, in terms of some unit of measurement (pounds per day, in terms of skids per week), between each pair of activity areas, forms the matrix to the programme. A second set of input data allows the user to enter cost of moving in terms of cost per unit moved per unit distance. In many cases this cost input is unavailable matrix.

Space requirements are the third set of input data for CRAFT. These take the form of an initial or an existing layout. For new area layouts, best guess or even better, in a quantity approximate to their space requirements. The location of any activity can be fixed in the overall area to 40.

THEORETICAL QUESTIONS
1.0. BREAK-EVEN ANALYSIS

Break-even analysis is also known as cost-volume-profit analysis. It is the study of inter-
relationship among firm’s sales, cost, and profit at various levels of output. It is the method of
representing the effect of changes in volume on profit. It is concerned with finding the point at
which revenues and costs are exactly equal. This point is called break-even point.

1.10.1. Purpose of Break-Even Analysis

The important aims and objectives of break-even analysis are:

(i) To help in deciding profitable level of output, below which losses will occur.
(ii) To compute costs and revenues for all possible volumes of output to fix budgeted sales.
(iii) To take decision regarding make or buy.
(iv) To decide the product mix and promotion mix.
(v) To take plant expansion decisions.
(vi) To take equipment replacement decisions.
(vii) To indicate margin of safety.
(viii) To fix the price of an article to give the desired profit.
(ix) To compare a number of business enterprises.
(x) To compare a number of facility locations.

1.10.2. Assumption in Break-Even Analysis

The break-even analysis is based on the following assumptions:

(i) Selling prices will remain constant at all sales levels \( i.e., \) quantity discounts are not
   available.
(ii) There is a linear relationship between sales volume and costs.
(iii) It assumes that costs are classified into fixed and variable costs, ignoring semi-variable
   costs.
(iv) It considers that production is equal to the sales. \( i.e., \) there is no inventory.
(v) No other factors will influence the cost except the quantity.

1.10.3. Terms used in Break-Even Analysis

Following are the terms used in break-even analysis.

1. Fixed cost: The cost which does not change with the volume of production is called fixed
cost. For example, administrative overhead is fixed cost.
2. Variable cost: The cost which varies with the volume of production is referred as variable cost. For example, raw material cost is a variable cost.
3. Total cost line: The line which comes with the addition of fixed cost and variable cost is called total cost line.

4. Break-even point: The break-even point may be defined as the level of sales at which total revenues and total costs are equal. It is a point at which the profit is zero.

It is also known as "no-profit no-loss point." If a firm produces and sells above the break-even point, it makes profit. In case it produces and sells less than the break-even point, the firm would suffer losses.

1.10.4. Break-Even Chart

Break-even chart is a graphical representation of the relationship between costs and revenue at a given time.

It is a graphic device to determine the break-even point and amount of loss or profit under varying conditions of output and costs.

A break-even chart is illustrated as shown in fig. 1.5.

In break-even chart, cost and revenue in rupees is represented on vertical axis, while output in quantity is represented on horizontal axis.

The fixed cost line is horizontal and parallel to the X-axis. It indicates that fixed cost remains unchanged for any volume.

The variable cost line is superimposed on the fixed cost line to show total costs.

The total sales revenue line is drawn as shown in Fig. 1.5. This line indicates sales income at various levels of output.
The point at which the total revenue line intersects the total cost line is the break-even point.

The shaded area above the Break Even Point (BEP) marks profit to the firm whereas the shaded area below the BEP represents loss to the concern.

The method to plot break-even chart is as under:

(i) The cost and revenue in rupees are plotted on Y-axis.
(ii) The volume of production (in units) is plotted on X-axis.
(iii) Fixed cost plotted by a straight line parallel to horizontal axis.
(iv) The variable cost is superimposed on the fixed cost line. This represents total cost line.
(v) The sales line passes through origin.
(vi) The point of intersection of total cost line and sales line is Break Even Point (BEP).
(vii) The left shaded part BEP is loss and right shaded part is profit.

Margin of safety : Margin of safety is the difference between the existing level of output and the level of output at BEP.

\[ \text{Margin of safety (in %)} = \frac{\text{Sales} - \text{Sales at BEP}}{\text{Sales}} \times 100 \]

Greater value of margin of safety means higher profits to the firm.

If the safety margin is low, then the firm runs the risk of incurring losses.

Angle of incidence : This is an angle at which sales revenue line cuts the total costs line.

(Refer Fig. 1.5.)

A large angle of incidence indicates a high profit rate. A narrow angle shows that even fixed overheads are absorbed and relatively low rate of return.

Profit volume ratio (PV Ratio) : PV ratio measures the profitability in relation to sales. The contribution at a given output is the difference between total sales and total variable costs. The PV ratio is ratio of contribution to sales. It is a measure to compare profitability at different products.

\[ \text{PV ratio} = \frac{\text{Contribution}}{\text{Sales}} \times 100 = \frac{\text{Increase in profit}}{\text{Increase in sales}} \times 100 \]

\[ = \frac{\text{Total Sales} - \text{Total VC}}{\text{Total sales}} \times 100 \]

\[ = \frac{\text{Fixed Cost} + \text{Profit}}{\text{Sales}} \times 100 \]

\[ = \frac{\text{Price/unit} - \text{Cost/unit}}{\text{Price/unit}} \times 100 \]
1.11.5. Limitations of Break-Even analysis

Some of the important limitations of break-even analysis are given below:

(i) Break-even analysis is a static picture as it assumes constant relationship of output to costs and revenue.

(ii) Practically, the selling price and variable cost per unit are not constant. So, the break-even analysis cannot be more realistic.

(iii) Break-even analysis is based on accounting data which may suffer from several limitations like neglect of imputed costs, arbitrary depreciation estimates, inappropriate allocation of overheads, etc.

(iv) The break-even chart is a tool for short run analysis. It cannot be used for long range analysis.
1.7 Break-even Analysis

Break-even analysis is carried out to find out the break-even point (BEP) which establishes the level of production at which the enterprise starts making profit. At break-even point, the revenue just covers the fixed overheads. Graphically, break-even point can be found out as shown in Figure 1.2.

Fig 1.2 Break-even analysis.

1. Total Cost of Production = Fixed costs + Variable costs.
2. Fixed Costs do not vary with the production level.
   Examples are:
   (i) Interest on long-term loan.
   (ii) Rent of factory or office.
   (iii) Depreciation on machinery and buildings.
3. Variable costs vary with the level of production and is directly related to the volume of production.
   Examples are:
   (i) Raw material cost.
   (ii) Direct labour cost.
4. Contribution is the difference of total sales revenue and total variable costs.
   Total contribution (CN) = Total sales revenue (SR) - Total variable cost (VC)
   Contribution (CN) = (Sales revenue per unit - variable cost per unit) × No. of units sold

Example:

No. of units produced = X
Total cost of X units = Fixed cost (FC) + Variable cost of X units (VC)
Contribution (CN) = Sales revenue (SR) - Variable cost (VC)

12. Break-even Point (BEP) can be determined graphically as shown in figure 1.2 or analytically as per following example.
Profit \( P \) for \( X \) units = Sales revenue for \( X \) units - Total cost

\[
P = SR - (VC + FC)
\]

or

\[
= SR - VC - FC
\]

\[
=(SR - VC) - FC
\]

\[
= CN - FC
\]

At break-even point,

Profit \( P = 0 \).

\[
CN = FC
\]

BEP can be expressed as no. of units or sales revenue.

6. BEP as Capacity Utilization Indicator: Break-even point can be expressed in terms of capacity utilization, i.e., at what percentage of installed capacity the plant should be operated to reach break point.

\[
BEP = \left( \frac{FC}{SR - VC} \right) \times 100
\]

\[
= \left( \frac{FC}{CN} \right) \times 100
\]

where \( BEP \) = Break-even production level (%age)

\( FC \) = Annual fixed cost (Rs).

\( VC \) = Annual variable cost (Rs).

\( SR \) = Annual sales revenue (Rs).

\( CN \) = Contribution (Rs).

Example:

If \( FC = Rs. 1,00,000 \)

\( VC = Rs. 2 \) per unit

\( SR = Rs. 4 \) per unit, and

Maximum production capacity = 1,00,000 units per year

\[
BEP = \frac{FC}{SR - VC} = \frac{1,00,000}{4 - 2} = 50,000 \text{ units}
\]

= 50% of the capacity

7. BEP as Sales Revenue Indicator: The %age of contribution to the volume of sales, or % age of sales revenue available to meet fixed cost to be followed by profit earning.

\[
P/V \text{ ratio} = \frac{\text{Contribution}}{\text{sales}}
\]

\[
= \frac{SR - VC}{SR}
\]

Break-even sales revenue = \[
= \frac{\text{Fixed cost}}{P/V \text{ ratio}}
\]

\[
= SR \left( \frac{FC}{SR - VC} \right)
\]
APPLICATIONS OF BREAK-EVEN ANALYSIS

(ii) GANTT CHART

8. Application of Break-even Analysis: The applications of break-even analysis are as follows:
(i) It helps to take investment decisions.
(ii) Production level to optimize profit.
(iii) It helps to make or buy decision.
(iv) It helps to fix product price.
(v) Profitability at various levels of production.

9. Conclusions: Break-even analysis is one of the most important tools for the entrepreneur at the stage of project planning as well as during managing the enterprise. BEP helps to decide production level, tendering, quantity discount, pricing, etc. BEP is an aid to arrive at final decision in complex situations.

1.8 GANTT CHART

Scheduling is crucial to successful production and is a critical component of production planning. Schedules can be developed by using many techniques. These techniques can be grouped into two categories:
1. Charts and Graphs

Many sorts of charts and graphs are used for scheduling. One of the best known and widely used chart is Gantt chart. It is a means of visualizing production planning. It makes plainly visible what has been done in relation to what was scheduled to have been done. In practice, there are many variations of the Gantt chart available for use in scheduling. Figure 1.3 is an example of Gantt chart. The activities are listed in vertical sequence and their durations are depicted horizontally on an appropriate time scale.

<table>
<thead>
<tr>
<th>Product No.</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4000</td>
<td>2</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>B</td>
<td>500</td>
<td>16</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>300</td>
<td>16</td>
<td>23</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1.3. Gantt chart.

SUMMARY

Production management is converting raw materials into finished goods by using resources like men, machines, money and materials. A long term production planning and management is very critical to earn profit, hence production planning and management is very critical to earn profit.