The basic objective of resource management is to supply and support the field operations so that established time objectives can be met and costs can be kept within the construction budget.

The completion of a construction project at maximum efficiency of time and cost requires the judicious scheduling and allocation of available resources. Manpower, equipment, and materials are important project resources that require close management attention. The supply and availability of these resources seldom can be taken for granted because of seasonal shortages, labour disputes, equipment breakdowns, competing demands, delayed deliveries, and a host of associated uncertainties. Nevertheless, if time schedules and cost budgets are to be met, the work must be supplied with the necessary workers, equipment, and materials as they are needed on the job site.

**MANPOWER**

It is estimated that the labour costs constitute from 25 per cent of the production costs to 40 per cent of the selling costs in manufacturing enterprise. The advantages of proper and efficient manpower are as follows:

1. It helps in discovering talented and competent workers and developing them to move up the corporate ladder.
2. It ensures greater production by putting the right man in the right job.
3. It helps to avoid a sudden disruption of an enterprise's production run by indicating shortages of personnel, if any, in advance.
4. It helps to prevent under-utilisation of personnel through overmanning and the resultant high labour cost and low profit margins.
5. It provides information to management for the internal succession of managerial personnel in the event of an unanticipated turnover.
MANPOWER PLANNING

Manpower planning is the process by which a firm ensures that it has the right kind of people and the right number of people at the right places at the right time, doing work for which they are economically most useful.

From this definition it is clear that manpower planning is a vital tool in the hands of management to control labour costs by avoiding both shortages and surpluses of personnel in an organisation. In large organisations, this function is performed by the personnel department.

CLASS OF LABOUR

In India, traditionally the construction industry has been labour intensive as the labour is cheap and easily available. In general, there are three categories of manpower involved in this industry consisting of the skilled/semiskilled, unskilled and managerial/technical workers.

A construction activity is a very complex process, made up of many different systems, such as the structural system, exterior enclosure system, and HVAC system. These systems can be broken down into many more subsystems and sub subsystems. In this way, a construction project is divided into numerous work packages. These work packages can then be assigned to and completed by an individual worker or a crew. A crew is a team of workers, which can be of the same trade or a composite of many different trades. Due to the diverse nature of the different tasks associated with all the building systems, many types of craftsmen from many different trades are required in a construction project.

IS 10302: 1982, Indian Standards on 'Unified nomenclature of workmen for civil engineering, published by its Construction Management Section. Committee includes around 95 categories of labours. The trade categories and crew sizes used for determining construction output also varies with various agencies publishing output planning norms.
List of types of workers that can be involved in a construction project are as follows

**BUILDING TRADERS**

Carpentry Work

1. Shuttering carpenter
2. Furniture carpenter
3. Wood Polisher
4. Carpenter helper

Masonry Work

1. Concrete helper
2. Masonry Work
3. Concrete mason
4. Blockwork and plaster mason tiling mason
5. Marble mason
6. Mason helper

RCC Steel Work

1. Rebar fabricator
2. Rebar helper

Painting Works

1. Painter
2. Painter helper

Electrical works

1. Electrician
2. Cable jointer
3. Cable layer
4. Electrical helper
Plumbing and Sanitary Works

1. Plumber
2. Pipe fitter
3. Plumber helper
4. Unskilled Workers
5. General helpers

Mechanical Trades

1. Fitter
2. Machinist
3. Welder
4. AC mechanic
5. Sheet fabricator
6. Diesel mechanic
7. Auto electrician
8. Diesel mechanic
9. Petrol mechanic
10. Mechanic helper
11. Riggers

Drivers and Operators

1. Light vehicle drivers
2. Heavy vehicle drivers
3. Equipment operators
WAGES AND STATUTORY REQUIREMENT

Construction workers constitute one of the largest categories of workers in the unorganised sector. The workers are hired as and when required and are retrenched on completion of the work. Construction labour leads a migratory life working on different sites. The economic conditions of construction labour is the worst on account of their poor bargaining power, illiteracy and the temporary nature of their employment.

Construction workers have no job security and are last trained. Although industrial training institutes have been set up in our country, their contribution towards training of construction workers is not enough. Construction workers are paid very low wages.

There are two methods of making wage payment to labour, namely the time rate system and the piece rate system. In the time rate system, a suitable rate of payment is fixed per unit of time for which labour is engaged on the work. In the piece rate system, payment is based on output or production of the work. In this system, payment is made at the agreed rate for the actual quantum of work carried out by each labourer.

A number of trade unions are connected with the construction industry. These trade unions include the following:
1. All India Trade Union Congress (AITUC)
2. Indian National Trade Union Congress (INTUC)
3. Bhartiya Mazdoor Sangh (BMS)
4. United Trade Union Congress (UTUC)
5. Hind Mazdoor Sabha (HMS)
6. Centre of Indian Trade Unions (CITU)
The Trade Unions Act of 1926, as amended in 1987, conferred a legal and corporate status on registered trade unions and in certain respects defines the law relating to trade unions. This Act specifies certain activities as unfair practices on the part of recognised unions and certain other activities as unfair on the part of the employers.

The Labour Welfare Fund Act of 1965 was enacted to provide for the constitution of a fund to finance activities for promoting welfare of labour and for conducting such activities. The Labour Welfare Fund comprises of all fines realised from employees, unpaid wages of the workers including gratuity, bonus etc., grants and loans towards the fund and voluntary donations. The fund is used to carry on various activities conducive to the welfare of labour.

The Payment of Wages Act of 1936, as amended in 1982, provides the regulation for payment of wages to certain classes of persons employed in industry anywhere in India. Wages refer to the remuneration which is paid by the employer to the employee in lieu of the services provided by the latter engaged in a production or related process. The Payment of Wages Act, 1936 defines wages as all remuneration (whether by way of salary, allowances or other-wise) expressed -in terms of money or capable of being so expressed which would, if the terms of employment, expressed or implied, were fulfilled, be payable to a person employed in respect of his employment or of work done in such employment.

The Minimum Wages Act, 1948 provides for fixation/ periodic revision of minimum wages in employments where labour is vulnerable to exploitation. The minimum wages system serves a useful purpose in preventing worker’s exploitation in terms of payment of unduly low wage and helps in reducing inequalities in the standard of living of different social groups of workers by statutorily prescribing minimum wage rates.
The main provisions of the Minimum Wages Act 1948 are as follows:

- Different minimum rates of wages may be fixed for:
  a) different classes of work in the same scheduled employment,
  b) adults, children and apprentices,
  c) different states and different localities.
- In fixing minimum rates of wages, advisory committees are set up which collect detailed information such as the cost of living index on which the minimum wage is based.
- If an employee is employed on any day for a period less than the required number of hours constituting a normal working day by the employer, he shall be entitled to receive a full day's salary except when the employee is unwilling to work for the full period.
- The minimum wages under this Act shall be paid in cash to the employees with due notification.
- Every employer shall maintain a register indicating particulars of employees, wages paid to them and receipts given by them etc.
- The appropriate Government may employ suitable persons as Inspectors for the purposes of this Act.

The Workmen's Compensation Act of 1923, as amended in 1948, provides for payment of compensation to workmen for injury by accidents sustained during the course of employment. The Act covers workers employed in hazardous jobs but does not include clerical and administrative staff.

The Contract Labour (Regulations and Abolition) Act of 1970, as amended in 1986, was enacted with the object of regulating the employment of contract labour in certain establishments and providing for abolition of contract labour in certain circumstances. The Act incorporates provisions for improving the condition of contract labour. The Act is of special importance to the construction industry wherein works are generally executed on contract basis involving contract labour.
LABOUR PRODUCTION RATE OR PRODUCTIVITY

Productivity may be defined as the rate of transformation of inputs into outputs in a productive operation.

In order that we may produce a product or provide a service, we must have resources in the forms of men, machine, materials, money etc. In a broad sense, productivity means goods and services produced in relation to the resources utilised in producing the same.

Labour productivity may be defined as the ratio of output and labour input. In other words, it is the productivity of an industry measured in terms of labour input. For the purpose of productivity analysis, the average product, rather than marginal, is considered relevant because the latter fails to reveal the actual and potential level of productivity in their representative character.

The input of labour may be taken as number of workers or man-hours worked during the period. This ratio may be computed for one worker or group of workers in a unit of work or for the plant as a whole depending on the need.

There is another way of measuring labour productivity. For a given worker or group of workers doing a job, the enterprise fixes certain target volume of output in a given day or period. The actual volume of output produced by the workers during that period is compared with the target or standard volume of output for assessing labour productivity. This is a simple way to measure labour productivity, but it is not conforming with the definition of labour productivity as given above. In fact, this is a way to measure total productivity of the workers and not of the labour productivity alone.
FACTORS AFFECTING LABOUR OUTPUT OR PRODUCTIVITY

There are many factors that affect the productivity of labour in construction.

Here are some of the most recognized factors affecting labour productivity in the construction industry:

1) **Overtime:** Scheduling of extended work days or weeks exceeding a standard eight-hour work day or 40- hour work week lowers work output and efficiency through physical fatigue and poor mental attitude.

2) **Morale and Attitude:** Spirit of workers based on willingness, confidence, discipline, and cheerfulness to perform work or tasks can be lowered due to a variety of issues including increased conflicts, disputes, excessive hazards, overtime, over-inspection, multiple contract changes, disruption of work rhythm, poor site conditions, absenteeism, unkempt workspace, and so on.

3) **Work complexity:** A simple, familiar work, is easier to execute than an unfamiliar, complex one. The extra effort needed for the latter type of work, especially in the initial stages, may range from 10-100% of the normal expected productivity.

4) **Repetition of work:** While the first-time execution of an unfamiliar work needs extra effort and results in low output, the skill acquired in the process, when utilized over a period of time to execute similar works, improves productivity rate.

5) **Quality control:** Stringent quality control is sensitive projects, like in the construction of a nuclear reactor calls for frequent inspections, which involve elaborate documentation and is a time consuming task. They increase the non-productive time of workers and, in turn, reduces productivity by 10-25%.
6) *Equipment-intensive tasks:* The construction equipment executes works speedily, but it needs operators. The equipment-intensive tasks are less susceptible to productivity changes than the labour-intensive ones.

7) *Supervision:* An efficient and effective supervisor can get a higher productivity from labourers.

8) *Dilution of Supervision:* This occurs when supervision is diverted from productive, planned, and scheduled work to analyse and plan contract changes, expedite delayed material, manage added crews, or other changes not in the original work scope and schedule. Dilution is also caused by an increase in manpower, work areas, or project size without an increase in supervision.

9) *Labour availability:* The labour productivity also depends upon the employment opportunities available in the market. If jobs are plenty and labour is scarce, the labour productivity tends to become less. In scarce job situation, the overall productivity improves since the employers can then sort out labour with a light productivity.

10) *Mobilize/Demobilize:* This relates to moving resources on and moving off to projects as a result from changes or delays, causing work disruptions. Productivity may drop during these periods as time is lost when crews move from one area or work assignment to another.

11) *Errors and Omissions:* Increases in errors and omissions impact on labour productivity because changes are then usually performed on a crash basis, out of sequence, cause dilution of supervision, or any other negative impacts.

12) *Start/Stop:* This results from a work stoppage or suspension of work, which may cause a break in the schedule, usually triggering a start/stop of work activity. Stop-starts can have an impact on productivity and cost of a project.
Work scheduled or reassigned during holidays such as Festivals, New Year's, and so on are often impacted with stop-starts. Workers tend to discuss the time off and lose previous momentum with a drop in productivity before they get back in routine.

13) **Site Access:** This is a result of interferences to the convenient or planned access to work areas. This can be due to blocked stairways, roads, walkways, insufficient man-lifts, or congested work sites.

14) **Hazardous Work Area:** This is caused when working in an area that is classified as hazardous, requiring special safety equipment and clothing. Restrictions may limit time and exposure of workers to the area, resulting in less time on tools in the area.

15) **Climatic and weather conditions:** Performing work in a change of season, temperature zone, or climate change resulting in work performed in either very hot or very cold weather, rain or snow, or other changes in temperature or climate can impact workers beyond normal conditions. Since construction projects are spread over several months or even years, it is necessary to adjust the effect of weather changes month-by-month on worker’s productivity as well as work execution.

16) **Role of management:** The project management has a key role to play in planning and controlling productivity. It is responsible for specifying the weekly target of work to be accomplished by the workers as well as how the works are to be executed and using which resources.
CONSTRUCTION EQUIPMENTS

Construction equipment’s are one of the very important resources of modern construction, especially in infrastructure projects. Such projects utilize equipment’s for most of the works including earthmoving operations, aggregate production, concrete production and its placement, and so on. In fact, one cannot think of any major construction activity without the involvement of construction equipment. There are different types of construction equipment’s suitable for different activities in a construction project. The choice of construction equipment defines the construction method, which in a way leads to the determination of time and cost for the project. In order to select the right equipment to perform a specific task at the least cost, it is essential to know the features of a construction equipment including its rate of production and the associated cost to operate the equipment.

Plant, equipment, and tools used in construction operations are priced in the following three categories in the estimate:

a) *Small tools and consumables:* Hand tools up to a certain value together with blades, drill bits, and other consumables used in the project are priced as a percentage of the total labour price of the estimate.

b) *Equipment usually shared by a number of work activities:* These kinds of equipment items are kept at the site over a period of time and used in the work in progress.

c) Equipment used for specific tasks: These are capital items and used in projects such as digging trench or hoisting material into specified slots. This equipment is priced directly against the take-off quantities for the project it is to be used on. The equipment is not kept-on-site for extended periods like those in the previous classification, but the equipment is shipped to the site, used for its particular task, and then immediately shipped back to its original location.
CLASSIFICATION OF CONSTRUCTION EQUIPMENTS

Earthwork Equipment
a) Earth cutting and moving equipment: Bulldozers, Scrapers, Front-end loaders, Motor graders.
   b) Excavation and lifting equipment: Backhoes, Power Shovels, Draglines, Clamshells.
   c) Loading equipment: Loaders, Shovels, Excavators.
   d) Transportation equipment: Tippers, Dump Trucks, Scrapers, Conveyors.
   e) Compacting equipment: Tamping Foot Rollers, Smooth Wheel Rollers, Pneumatic Rollers, Vibratory Rollers, Plate Compactors.

Concrete Plant and Equipment
a) Production equipment: Batching Plants, Concrete Mixer
   b) Transportation equipment: Truck mixers, Concrete dumpers
   c) Placing equipment: Concrete pumps, Conveyors, Hoist, Grouting equipment.
   d) Concrete vibrating equipment: Needle vibrators, Plate compactors.

Material Hoisting Equipment
a) Hoists: Fixed, Mobile, Fork-lifts.
   b) Mobile Cranes: Crawler-mounted, self-propelled rubber-tired, truck mounted.
   c) Tower Cranes: Stationary, Travelling type.

Special Purpose Heavy Construction Plant and Equipment
a) Aggregate production equipment: Crushing plants, Rock blasting equipment, Screening plants.
   b) Concrete paving equipment: Concrete paver finishers.
   c) Pile driving equipment: Pile driving hammers.
   d) Asphalt mix production and Placement equipment: Asphalt plants, asphalt pavers.
   e) Tunnelling equipment: Drill jumbos, Muck-hauling equipment, Rock bolters, Tunnel boring machines.
2.12 EQUIPMENT PLANNING
Construction requires large quantities of materials handling, horizontally and vertically. In its simplest form, a construction operation is the moving of material from one location to another. The primary function of equipment is to handle and move varieties of materials around the construction site. For example, a construction site may need to be leveled, thus involving the excavation of soil material from one area and the transporting of the excavated material to fill in another location on-site. The complexity of an operation increases as the requirement for final placing or installation increases.

An example is the erection of structural steel members in a structural steel frame building. The members are hoisted from the hauling unit or storage location on-site and are moved and placed at the desired final location on the building structure. Structural steel workers then bolt and weld the members in place. These examples illustrate how the primary function of equipment is to handle and move materials on a construction site.

Equipment planning must identify the work to be done and establish:

i) Equipment lists and procurement schedules,

ii) Equipment productivity and a desired construction schedule, and

iii) Realistic cost estimates of equipment.

2.13 ESTIMATION OF PRODUCTIVITY FOR CONSTRUCTION EQUIPMENTS

2.13.1 Earthmoving Equipment
Earthmoving may include site preparation; excavation; embankment construction; backfilling; dredging; preparing base course, subbase, and subgrade; compaction; and road surfacing. The types of equipment used and the environmental conditions will affect the man- and machine-hours required to complete a given amount of work. Before preparing estimates, choose the best method of operation and the type of equipment to use.

Each piece of equipment is specifically designed to perform certain mechanical tasks. Therefore, base the equipment selection on efficient operation and availability.

The basic relationship for estimating the production of all earthmoving equipment is:

\[
\text{Production} = \text{Volume per cycle} \times \text{Cycles per hour}
\]

The term “volume per cycle” should represent the average volume of material moved per equipment cycle. Thus the nominal capacity of the excavator or haul unit must be modified by an appropriate fill factor based on the type of material and equipment involved. The term “cycles per hour” must include any appropriate efficiency factors, so that it represents the number of cycles actually achieved (or expected to be achieved) per hour. The cost per unit of production may be calculated as follows:
Cost per unit of production = \frac{\text{Equipment cost per hour}}{\text{Equipment production per hour}}

There are two principal approaches to estimating job efficiency in determining the number of cycles per hour. One method is to use the number of effective working minutes per hour to calculate the number of cycles achieved per hour.

This is equivalent to using an efficiency factor equal to the number of working minutes per hour divided by 60. The other approach is to multiply the number of theoretical cycles per 60-min hour by a numerical efficiency factor.

2.13.2 Excavating and Lifting Equipment

An excavator is defined as a power-driven digging machine. The major types of excavators used in earthmoving operations include hydraulic excavators and the members of the cable-operated crane-shovel family (shovels, draglines, hoes, and clamshells). Dozers, loaders, and scrapers can also serve as excavators.

These machines consist of the following components (Fig. 2.2):

- An undercarriage – this gives mobility to the excavator. This may be mounted with crawler track or wheel.
- A superstructure with operator’s cabin – this could traverse through 360° or fitted on a rigid frame.
- Hydraulically articulated booms and dipper arms with bucket.

![Excavator Diagram](image.png)
Excavators may be of mechanical (or cable operated) or hydraulic types. Hydraulic excavators have more advantages. They can be fitted with various multi-purpose attachments for various earth moving works. Most efficient action of the machine is that the hydraulic unit of action of the excavator which directs the bucket teeth at their most efficient angle during dipping operation.

Mechanical or cable operated excavators are of either hoe or shovel type. In hoe type the bucket opening fences towards the machine where as in shovel the bucket opening faces away from the machine.

Primary earth excavating equipment is the tractor-mounted excavator. Excavators operate in a stationary mode. They dump excavated materials on the sides, or directly into waiting tippers / dump trucks and they gradually, shift their position as the work progresses.

The excavating equipment is divided into four categories, viz., face shovels, backhoes, draglines and grab or clamshell. Further, excavators can be rope-operated or hydraulically operated. The type and size of the equipment depends upon the nature of the task, the type of soil, digging depth and the desired level of production.

**Face Shovel**

It operates from a flat surface, producing upward digging action, excavating and filling the bucket as it climbs. After the bucket is filled, its upper part swings to the dumping position where the bucket is empited in a waiting truck or on to a stockpile. Thereafter, it returns to its original position and starts the next cycle of excavation. It is capable of working in all types of dry soils. The struck-bucket capacity of the face shovel bucket varies from 1/2 $Yd^3$ (0.38M$^3$) to 4/1/2 $Yd^3$ (3.25M$^3$), and depending upon the size of the machine and bucket, its cutting length varies from 7M to 10.5M.

![Fig. 2.3: Face shovel](image_url)
Backhoe

It is primarily used for excavating materials below its track level, i.e., excavation of small and large pits, basements and large trenches. Backhoe are generally track-mounted but small capacity equipment do have wheel-mounting to add to their mobility.

The backhoes are fitted with buckets having struck capacity varying from $\frac{1}{2} \text{Yd}^3$ (0.38 M$^3$) to $4\frac{1}{2} \text{Yd}^3$ (3.25 M$^3$) and their corresponding digging depth capability is from 5M to a maximum of 9.5M.

Dragline

It is a rope-operated boom-fitted crane type machine. The bucket is thrown into the excavation area and the cable-controlled hook is rotated, so that, the bucket gets filled by scraping the surface to be excavated. It is used for digging below the ground level specially, in loose soils or marshy and underwater areas with soft beds.

The dragline can operate in a depth approximately up to $\frac{1}{3}$ of its boom length for broad sweeping type excavated work. Its boom length varies from 21M to 36M and the struck bucket capacity extends from $\frac{1}{2} \text{Yd}^3$ (0.38 M$^3$) to $4 \text{Yd}^3$ (3.06 M$^3$).
**Grab or Clamshell**

Like dragline, it is a rope-operated boom-fitted crane type machine having a grab or clamshell bucket. The grab bucket has interlocking teeth to penetrate loose soil whereas the clamshell bucket has no teeth. These buckets are dropped with their sides open like open jaws on the soil to be grabbed, and thereafter, these jaws are closed by rope machines prior to hauling. These machines are used primarily for deep confined excavations such as shafts, wells and spoil heaps removal. The depth of the excavation can be roughly taken as 1/3 of the boom length. The range of the size of the grab bucket and its length of boom are similar to those of the dragline.

![Clamshell](image)

**Excavator Production**

The output of an excavating equipment, for planning purposes, can be easily determined from the equipment output planning following table.

<table>
<thead>
<tr>
<th>Features Bucket struck capacity</th>
<th>Type of equipment-Earth excavation and lifting equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Face Shovel</td>
</tr>
<tr>
<td>Bucke t size M³</td>
<td>Engine HP</td>
</tr>
<tr>
<td>0.38</td>
<td>50</td>
</tr>
<tr>
<td>0.57</td>
<td>75</td>
</tr>
<tr>
<td>0.76</td>
<td>100</td>
</tr>
<tr>
<td>1.14</td>
<td>130</td>
</tr>
<tr>
<td>1.53</td>
<td>160</td>
</tr>
<tr>
<td>2.30</td>
<td>200</td>
</tr>
</tbody>
</table>

*Fig. 2.6: Clamshell*
Product output = Ideal output $\times$ Correction factor $\times$ Performance factor

Ideal output in Loose cubic meters (LCM)
Ideal output = Bucket output/cycle $\times$ Cycles / hour

(a) Bucket output/cycle - A cycle of a bucket starts from the point it strides the excavation place to its return to the next excavation point after unloading the excavated materials at the specified place in the transporter or on a heap of loose excavated materials. The maximum loose material in cubic meters (LCM) it can carry in its bucket per cycle is equal to its bucket struck capacity.

(b) Cycles/hour - the cycle time is the time taken by the cycle of bucket movements which includes load, swing, unload and return to start the cycle again.

Maximum number of cycles/hour = 60 minutes/cycle time in; minutes

**Correction Factors**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Nature of Secondary Tasks</th>
<th>Task Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shovel</td>
<td>Movement from excavating place to unloading place:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a. Within vicinity</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>b. Little movement</td>
<td>0.6 to 0.9</td>
</tr>
<tr>
<td></td>
<td>c. Appreciable, movement or delays</td>
<td>0.4 to 0.6</td>
</tr>
<tr>
<td>Backhoe</td>
<td>Trenching</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a. Equal on bucket width</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>b. More than bucket width</td>
<td>0.7 to 0.9</td>
</tr>
<tr>
<td>Dragline</td>
<td>a. Bulk excavation</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>b. Wide open ditches</td>
<td>0.7 to 0.9</td>
</tr>
<tr>
<td></td>
<td>c. Confined, restricted places</td>
<td>0.5 to 0.7</td>
</tr>
<tr>
<td>Clam shell</td>
<td>a. Dry soil Pits</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>b. Wet soil pits</td>
<td>0.5 to 0.9</td>
</tr>
</tbody>
</table>

(a) Equipment conversion factor: It relates to the type of equipment employed.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Factor multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face shovel</td>
<td>1.00</td>
</tr>
<tr>
<td>Backhoe</td>
<td>0.80</td>
</tr>
<tr>
<td>Dragline</td>
<td>0.75</td>
</tr>
<tr>
<td>Grab</td>
<td>0.40</td>
</tr>
</tbody>
</table>
(b) Soil digging factor: It depends upon the digging effort.

<table>
<thead>
<tr>
<th>Digging effort</th>
<th>Factor multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy digging</td>
<td>1.00</td>
</tr>
<tr>
<td>Medium digging</td>
<td>0.85</td>
</tr>
<tr>
<td>Hard digging</td>
<td>0.67</td>
</tr>
</tbody>
</table>

(c) Swing factor: The output varies with the angle of the swing of the bucket carrying arm, in the horizontal plan, enclosed by the arc connecting loaded bucket swing starting point and bucket unloading point on heap or transporter.

Typical swing factor

<table>
<thead>
<tr>
<th>Angle of swing</th>
<th>45°</th>
<th>60°</th>
<th>75°</th>
<th>90°</th>
<th>120°</th>
<th>150°</th>
<th>180°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor value</td>
<td>1.20</td>
<td>1.16</td>
<td>1.07</td>
<td>1.0</td>
<td>0.88</td>
<td>0.79</td>
<td>0.71</td>
</tr>
</tbody>
</table>

(d) Load casting factor: Output varies with the method of casting of load.

<table>
<thead>
<tr>
<th>Method of casting</th>
<th>Open area</th>
<th>Restricted area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side casting</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Loading in vehicle</td>
<td>0.8</td>
<td>0.6</td>
</tr>
</tbody>
</table>

(c) Task efficiency factor: Each equipment is designed for a primary task. There are occasions when equipment is employed on secondary tasks. For example, a backhoe excavating trenches using a bucket of width equal to the width of the trenches will yield more output than if the same bucket is used for excavating trenches of more than the bucket's width.

Example 2.1: Estimate the hourly production in bulk volume (LCM) of a backhoe with bucket capacity of 1.14M³ employed on excavation of a foundation 3M deep in hard digging soil. The excavated earth is to be loaded in waiting dump trucks, placed at a swing angle of 75°. The expected performance efficiency is 81%.

(a) Ideal output of loose soil in cubic meter (LCM) = 180 LCM

(b) Equipment conversion factor
operating at optimum depth

(c) Correction factors are

- Soil factor for hard digging
  \[ \text{Soil factor} = 0.67 \]
- Load factor for loading into vehicle
  \[ \text{Load factor} = 0.80 \]
- Swing factor for 75°

Solution:

Ideal output = 0.8 × 180 = 144 LCM
Correction factor = 0.67 × 0.8 × 1.05 = 0.56
Performance efficiency = 0.80

= 150 LCM (approximate)

= 0.80
Hence expected output/h

\[
= \text{Ideal output} \times \text{correction factor} \times \text{performance efficiency}
\]

\[
144 \times 0.56 \times 0.80 = 64.5 \text{ LCM/hour}
\]

2.13.3 Dozer

Dozers (track laying crawlers or wheel tractors equipped with a blade) are perhaps the most basic and versatile items of equipment in the construction industry. Dozers are designed to provide high drawbar pull and traction effort. They are the standard equipment for land clearing, dozing, and assisting in scraper loading. They can be equipped with rear mounted winches or rippers. Crawler tractors exert low ground-bearing pressure, which adds to their versatility. For long moves between projects or within a project, transport dozers on heavy trailers. Moving them under their own power, even at slow speeds, increases track wear and shortens the machine’s operational life.

![Diagram of a Dozer]

*Fig. 2.7: Dozer*

A dozer is a tractor unit that has a blade attached to its front. The blade is used to push, shear, cut, and roll material ahead of the dozer. Dozers are effective and versatile earthmoving machines. They are used both as support and as production machines on many construction projects.

They may be used for operations such as

i) Moving earth or rock for short haul (push) distances, up to 300 ft (91 m) in the case of large dozers.

ii) Spreading earth or rock fills.

iii) Backfilling trenches.

iv) Opening up pilot roads through mountains or rocky terrain.

v) Clearing the floors of borrow and quarry pits.

vi) Helping load tractor-pulled scrapers.

vii) Clearing land of timber, stumps, and root mat.
Dozers excavate and push earth with the help of a stiff welded steel blade fitted in front and controlled by two hydraulic cylinders. Blades are of four types. The straight S-blade is used for forward pushing of earth. U-blades have large capacity, and are used for pushing loose materials. Angle A-blades are used for pushing soil to one side rather than hauling it forward as is required in hill road formation cutting. Push P-blades are used for push loading a scraper. A dozer can also be fitted with a bucket attachment for ripping hard soil and rock and a winch for uprooting trees, skidding boulders and heavy materials.

Ideal output for dozing soft soil depend upon the engine power, straight-blade capacity and dozing distance.

Ideal output, measured in the bulk volume (loose soil), assumes forward dozing speed of 3 km/h, return speed of 6 km/h, manoeuvring time of 0.15 minutes, easy going on generally level ground and dozing of (bank) materials using a straight S-blade. This ideal production is corrected to conform to varying conditions as under

Dozer optimum output = Dozer ideal output $\times$ Correction factor

Output planning data = Dozer optimum output $\times$ performance factor

where, correction factor leads to the following effect.

(a) Blade factor - Multiply ideal output by the blade factor value.

<table>
<thead>
<tr>
<th>Type of blade</th>
<th>Blade factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>S blade</td>
<td>1.0</td>
</tr>
<tr>
<td>A blade</td>
<td>0.75</td>
</tr>
<tr>
<td>U blade</td>
<td>1.25 (used only for loose soil)</td>
</tr>
</tbody>
</table>

(b) Transmission system - For direct drive, take 80% of the ideal output which is based on the power shift system. Direct drive system output = 0.8 power shift system output.

(c) Grade factor - The manufacturer's manual provides the data for a change of output with varying slope, but for planning purposes it can be taken as under:

<table>
<thead>
<tr>
<th>Nature of slope</th>
<th>Effect on output (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downhill working</td>
<td>Increase $2.5 \times$ grade (%)</td>
</tr>
<tr>
<td>Uphill working</td>
<td>Decrease $2 \times$ grade (%)</td>
</tr>
</tbody>
</table>

(d) Soil factor - The ideal output is based on easy-dig and loose soil. This ideal output should be multiplied by the following soil factors where the nature of soil differs:

<table>
<thead>
<tr>
<th>Digging effort</th>
<th>Nature of soil</th>
<th>Soil factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy-dig</td>
<td>Loam, sand, gravel</td>
<td>1.0</td>
</tr>
<tr>
<td>Medium-dig</td>
<td>Common earth in natural state</td>
<td>0.85</td>
</tr>
<tr>
<td>Hard-dig</td>
<td>Hard stiff clay, soft rock</td>
<td>0.67</td>
</tr>
</tbody>
</table>

(e) Swing factor - The ideal output is stated in terms of bulk (or loose) volume excavated. This output can be converted into in-place (or bank) volume by dividing the bulk materials with the swell factor.

In-place (or bank) volume (BCM) = \( \frac{\text{Bulk (or loose) volume}}{\text{Swell factor}} \)
Example 2.2: Determine the output of a bulldozer having 215 HP engine, fitted with a blade rated capacity 4.40 M³. The dozer is employed for excavating a hard clayey area with average haulage of 50 meters, on a ground with up slope of 15%. It has direct drive transmission, and its expected performance is 50 minutes per hour.

(a) Ideal output/h for 50 meter haulage of
215 HP dozer with ‘A’ blade of capacity
4.40 M³ = 160 LCM (approximate)

(b) Correction factors:
Soil factor for hard digging = 0.67
Blade factor for A blade = 0.75
Transmission factor for direct drive = 0.8
Swell factor of clayey soil = 1.5

(c) Performance factor for 50 min/hour working = 0.83

Solution:

Grade factor 15% up grade = $1 - 2 \times \frac{15}{100} = 0.7$

Correction factor = $0.67 \times 0.75 \times 0.7 \times 0.8 \times \frac{1}{1.5} = 0.188$

Expected output in BCM

= Ideal output/h $\times$ corrector factor $\times$ performance factor

= $160 \times 0.188 \times 0.83$

= 24.96 BCM say 25 BCM

2.13. 4 Compactors

Types of Compaction Equipment

Principal types of compaction equipment include tamping foot rollers, grid or mesh rollers, vibratory compactors, smooth steel drum rollers, pneumatic rollers, segmented pad rollers, and tampers or rammers.

Smooth-Wheeled Rollers: These rollers may be provided with three wheels or two wheels of equal width called tandem type. These rollers are generally used for most of the works. But these rollers are not effective in uniformly graded sand, gravel or silt and on cohesive soil with high moisture content due to poor traction. These static rollers, also called as dead weight rollers, are diesel powered. These rollers rely on the weight only to compact the materials by passing over them. Units of 8–10 tonnes can impact a pressure of 20–40 kg per linear cm are generally in use. Rollers with weight up to 1 tonnes are used for light work.
Sheep's foot Rollers: Sheepfoot or Padfoot rollers are suitable for cohesive soils. These may be self-driven or tractor driven and are especially useful when the water content is on the higher side. The mass of the drum can be varied by adding ballast. For effective rolling, the lift thickness should be small and the contact pressure under the projection very high. These rollers are specially recommended for water-retaining earth works.

Pneumatic-tyred Rollers: In pneumatic-tyred rollers wheels are placed close together on two axles and placed such that the rear set of wheels overlap the lines of the front set to ensure complete coverage of the soil surface. In order to avoid the lateral displacement of soil, wide tyres with flat threads are provided. The compaction produced by these types is better than that of the smooth wheel rollers.

Tandem Compactors: Tandem compactors have two equal sized rollers and are centred in line-tandem. These rollers have smooth surface. Improvements have been made on these type of compactors as tandem vibratory compactors. Large size tandem vibratory compactors are generally preferred now-a-days as they can be used either as static compactor or as a vibratory compactor as per the requirement.

Vibratory compactors are available in a wide range of sizes and types. In size they range from small hand-operated compactors through towed rollers to large self-propelled rollers. By type they include plate compactors, smooth drum rollers, and tamping foot rollers. Small walk-behind vibratory plate compactors and vibratory rollers are used primarily for compacting around structures and in other confined areas.

Vibratory plate compactors are also available as attachments for hydraulic excavators. The towed and self-propelled units are utilized in general earthwork. Large self-propelled smooth drum vibratory rollers are often used for compacting bituminous bases and pavements.

While vibratory compactors are most effective in compacting noncohesive soils, they may also be effective in compacting cohesive soils when operated at low frequency and high amplitude. Many vibratory compactors can be adjusted to vary both the frequency and amplitude of vibration.

Rammers or tampers are small impact-type compactors which are primarily used for compaction in confined areas.

Estimating Compactor Production

Compactor production based on compactor speed, lift thickness, and effective width of compaction. The accuracy of the result obtained will depend on the accuracy in estimating speed and lift thickness. Trial operations will usually be necessary to obtain accurate estimates of these factors. Typical compactor operating speeds are given in Table. 2.7.

\[
\text{Production (CCM/h)} = \frac{10 \times W \times S \times L \times E}{P}
\]

where \(P\) = number of passes required
\(W\) = width compacted per pass (m)
\(S\) = compactor speed (km/h)
$L = $ compacted lift thickness (cm)

$E = $ job efficiency

The power required to tow rollers depends on the roller's total resistance (grade plus rolling resistance). The rolling resistance of tamping foot rollers has been found to be approximately 225–250 kg/t.

Table 2.7: Typical operating speed of compaction equipment

<table>
<thead>
<tr>
<th>Compactor</th>
<th>Speed km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tamping foot, crawler-towed</td>
<td>5 - 8</td>
</tr>
<tr>
<td>Tamping foot, wheel-tractor-towed</td>
<td>8 - 16</td>
</tr>
<tr>
<td>High-speed tamping foot</td>
<td></td>
</tr>
<tr>
<td>First two or three passes</td>
<td>5 - 8</td>
</tr>
<tr>
<td>Walking out</td>
<td>13 - 19</td>
</tr>
<tr>
<td>Final passes</td>
<td>16 - 23</td>
</tr>
<tr>
<td>Heavy pneumatic</td>
<td>5 - 8</td>
</tr>
<tr>
<td>Multitiered pneumatic</td>
<td>8 - 24</td>
</tr>
<tr>
<td>Grid roller</td>
<td></td>
</tr>
<tr>
<td>Crawler-towed</td>
<td>5 - 8</td>
</tr>
<tr>
<td>Wheel-tractor-towed</td>
<td>16 - 19</td>
</tr>
<tr>
<td>Segmented pad</td>
<td>8 - 24</td>
</tr>
<tr>
<td>Smooth wheel</td>
<td>3 - 6</td>
</tr>
<tr>
<td>Vibratory</td>
<td></td>
</tr>
<tr>
<td>Plate</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Roller</td>
<td>2 - 3</td>
</tr>
</tbody>
</table>

2.13. 5 Graders

Grading and Finishing

Grading is the process of bringing earthwork to the desired shape and elevation (or grade). Finish grading, or simply finishing, involves smoothing slopes, shaping ditches, and bringing the earthwork to the elevation required by the plans and specification. Finishing usually follows closely behind excavation, compaction, and grading. Finishing, in turn, is usually followed closely by seeding or sodding to control soil erosion. The piece of equipment most widely used for grading and finishing is the motor grader.

Grade trimmers and excavators are frequently used on large highway and airfield projects because their operating speed is greater than that of the motor grader. In highway construction, the process of cutting down high spots and filling in low spots of each roadway layer is called balancing. Trimming is the process of bringing each roadway layer to its final grade.
Motor Grader

The motor grader is one of the most versatile items of earthmoving equipment. It can be used for light stripping, grading, finishing, trimming, bank sloping, ditching, backfilling, and scarifying. It is also capable of mixing and spreading soil and asphaltic mixtures. It is used on building construction projects as well as in heavy and highway construction. It is frequently used for the maintenance of highways and haul roads.

The motor grader is the equipment mostly used for grading and finishing of large areas. Motor grades generally have engines up to 300 HP and the latest models are provided with hydraulically controlled attachments. These attachments include an excavation blade similar to the bulldozer, scarifier, ripper and backhoe. The blade of the motor grader has replaceable cutting edges. These blades come in flat, curved and serrated styles. Motor graders are fitted with articulated frames for increasing manoeuvrability. Motor graders are now available with automatic grade controls for achieving the desired grading. Grading distance of 500 meters and above give optimum output. For shorter distances, task efficiency gets reduced:

<table>
<thead>
<tr>
<th>Distance in meters</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task efficiency</td>
<td>0.4</td>
<td>0.6</td>
<td>0.8</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Grader’s optimum output for finishing is measured in M²/hour on an area basis or km/hour on an linear bases:

\[
\text{Output in M}^2/\text{hour} = \frac{W \cdot S \cdot E}{P}
\]

where,

- \( W \) = Width graded per pass
- \( S \) = Average speed in m/h
- \( E \) = Job efficiency factor
- \( P \) = Number of passes (generally 4 to 6)

### Table 2.8: Typical grader operating speed

<table>
<thead>
<tr>
<th>Operation</th>
<th>Speed km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank sloping</td>
<td>4.0</td>
</tr>
<tr>
<td>Ditching</td>
<td>4.0 - 6.4</td>
</tr>
<tr>
<td>Finishing</td>
<td>6.5 - 14.5</td>
</tr>
<tr>
<td>Grading and road maintenance</td>
<td>6.4 - 9.7</td>
</tr>
<tr>
<td>Mixing</td>
<td>14.5 - 32.2</td>
</tr>
<tr>
<td>Snow removal</td>
<td>19.3 - 32.3</td>
</tr>
<tr>
<td>Spreading</td>
<td>9.7 - 14.5</td>
</tr>
</tbody>
</table>
Example 2.3: Calculate the time required to grade and finish 50 km of road formation with width equal to thrice the width of the motor grader, using six passes of the motor grader with speed for each of the successive two passes as 6 km/h, 8 km/h and 10 km/h respectively. Assume machine efficiency based on operator’s skill, machine characteristics and working conditions as 80%.

Solution:

Given: \( E = 80\% = 0.80 \)

Average speed, \( S = \frac{2 \times 6 + 2 \times 8 \times 2 \times 10}{6} \) \hspace{1cm} \text{(No. of passes = 2 and total number of passes, } P = 2 \times 3 = 6) \)

\[ S = 8 \text{ km/h} = 8000 \text{ m/h} \]

Area to be graded per hour

\[
\frac{WSE}{P} = \frac{\text{Width graded per pass} \times \text{Average speed} \times \text{Machine efficiency}}{\text{Number of passes}}
\]

\[ = \frac{W \times 8000 \times 0.8}{6} = 1066.67W \]

Number of hours required to grade and finish 50 km long and 3 W wide area (width of road = 3 times width of motor grader given)

\[ = \frac{\text{Total area}}{\text{Area / hr}} \]

\[ = \frac{50000 \times 3W}{1066.67W} \]

\[ = 140.62 \text{ hours} \]

2.13.6 Hauling units

Hauling units transport the earth, aggregate, rock, ore, coal and other materials. Hauling units may be road vehicles or rail-road locomotives. Haulage mainly consists of trailers pulled by tractors or trucks. Trucks have been mobility and can haul various types of materials. But their performance and output is greatly hampered on rough roads and in bad weather. For better performance, greater road maintenance with lesser grade is required. Whereas rubber tyred tractors with separate wagons have better mobility and haulage speeds on less maintained rough roads and can carry heavier loads than that of trucks.

Crawler tractors with wagons are employed when roads are very rough and maintenance of roads is very costly.
Dump Trucks

Dump trucks are open vehicles which are capable of carrying and dumping earth, aggregate or other loose material to construction sites on various projects such as dams, highways, ports etc. Generally heavy-duty machines of more than 10 tonnes payload are intended for on-site haulage of construction or mine materials. Dump trucks in many sizes with pay loads ranging upto more than 300 tonnes are available.

![Diagram of a dump truck showing key components like Lift arm, Piston Rod, Hoist Cylinder, Tension Line, Body, Hinge, Tail Board, Gear Pump, and Power take off.]

Fig. 2.8: Dump trucks

For transportation of material by a dump truck, following operations are involved:

(i) Loading the dump truck.
(ii) Hauling.
(iii) Dumping the material at desired place.

Loading: The dump trucks are loaded by draglines, shovels, or by wheel loaders. The dump truck or dumper driver, for best efficiency and more production, should keep it in most efficient working area of the shovel or dragline or wheel loader.

Hauling: Drive the vehicle as per ground condition and the condition of the road, and use highest gear adjusting the road condition. Driver should ensure precautions for the safety of his own and for long life of the vehicle.

Dumping: Dumping operation depends upon the type of work where dumping is required to be done. For instance, for dumping at exact point, a second person, known as ‘spotter’ is required to control the dumping work, who directs the rear dump to its dumping area.
2.14 ESTIMATION OF OWNERSHIP COST

By investment made on the equipment the owner is losing an amount equal to the interest or return one would have otherwise received from bank or other sources of investment. For the purpose of calculating the total cost of investment, the interest, the taxes, insurance, etc., may be taken as the cost of equipment.

Ownership costs are fixed costs. Almost all of these costs are annual in nature and include:

i) Initial capital cost
ii) Depreciation
iii) Investment (or interest) cost
iv) Insurance cost, Taxes and Storage cost

i) Initial Cost

On an average, initial cost makes up about 25% of the total cost invested during the equipment’s useful life. This cost is incurred for getting equipment into the contractor’s yard, or construction site, and having the equipment ready for operation. Many kinds of ownership and operating costs are calculated using initial cost as a basis, and normally this cost can be calculated accurately.

Initial cost consists of the following items:

➢ Price at factory + extra equipment + sales tax
➢ Cost of shipping
➢ Cost of assembly and erection

ii) Depreciation

Depreciation represents the decline in market value of a piece of equipment due to age, wear, deterioration, and obsolescence. Depreciation can result from:

➢ Physical deterioration occurring from wear and tear of the machine.
➢ Economic decline or obsolescence occurring over the passage of time.

In the appraisal of depreciation, some factors are explicit while other factors have to be estimated.

Generally, the asset costs are known which include:

➢ Initial cost: The amount needed to acquire the equipment.
➢ Useful life: The number of years it is expected to be of utility value.
➢ Salvage value: The expected amount the asset will be sold at the end of its useful life.

However, there is always some uncertainty about the exact length of the useful life of the asset and about the precise amount of salvage value, which will be realized when the asset is disposed. Any assessment of depreciation, therefore, requires these values to be estimated.

Among many depreciation methods, the straight-line method, double-declining balance method, and sum-of-years’-digits method are the most commonly used in the construction equipment industry.
In calculating depreciation, the initial cost should include the costs of delivery and startup, including transportation, sales tax, and initial assembly. The equipment life used in calculating depreciation should correspond to the equipment’s expected economic or useful life.

**Methods of Depreciation**

There are several methods of accounting depreciation fund. These are as follows:

a) Straight line method of depreciation

b) Declining balance method of depreciation

c) Sum of the years—digits method of depreciation

d) Sinking-fund method of depreciation

**a) Straight-Line Depreciation**

Straight-line depreciation is the simplest to understand as it makes the basic assumption that the equipment will lose the same amount of value in every year of its useful life until it reaches its salvage value.

Let

- $P =$ first cost of the asset,
- $F =$ salvage value of the asset,
- $n =$ life of the asset,
- $B_t =$ book value of the asset at the end of the period $t$,
- $D_t =$ depreciation amount for the period $t$.

The depreciation in a given year can be expressed by the following equation:

\[
D_t = \frac{(P - F)}{n}
\]

\[
B_t = B_{t-1} - D_t
\]

**Example 2. 4 :** A company has purchased an equipment whose first cost is ₹ 2 lakh with an estimated life of 10 years. The estimated salvage value of the equipment at the end of its lifetime is ₹ 25,000. Determine the depreciation charge and book value at the end of various years using the straight line method of depreciation.

**Solution :**

\[
P = ₹ 2,00,000
\]
\[
F = ₹ 25,000
\]
\[
n = 10 \text{ years}
\]
\[
D_t = \frac{(P - F)}{n}
\]

\[
= \frac{2,00,000 - 25,000}{10} = ₹ 17,500
\]

In this method of depreciation, the value of $D_t$ is the same for all the years.
### Table 9.1: \( D_t \) and \( B_t \) Values under Straight line Method of Depreciation

<table>
<thead>
<tr>
<th>End of year ((t))</th>
<th>Depreciation ((D_t)) in ₹</th>
<th>Book value ((B_t = B_{t-1} - D_t)) in ₹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2,00,000</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>17,500</td>
<td>1,82,500</td>
</tr>
<tr>
<td>2</td>
<td>17,500</td>
<td>1,65,000</td>
</tr>
<tr>
<td>3</td>
<td>17,500</td>
<td>1,47,500</td>
</tr>
<tr>
<td>4</td>
<td>17,500</td>
<td>1,30,000</td>
</tr>
<tr>
<td>5</td>
<td>17,500</td>
<td>1,12,500</td>
</tr>
<tr>
<td>6</td>
<td>17,500</td>
<td>95,000</td>
</tr>
<tr>
<td>7</td>
<td>17,500</td>
<td>77,500</td>
</tr>
<tr>
<td>8</td>
<td>17,500</td>
<td>60,000</td>
</tr>
<tr>
<td>9</td>
<td>17,500</td>
<td>42,500</td>
</tr>
<tr>
<td>10</td>
<td>17,500</td>
<td>25,000</td>
</tr>
</tbody>
</table>

If we are interested in computing \( D_t \) and \( B_t \) for a specific period \((t)\), the formulae can be used. In this approach, it should be noted that the depreciation is the same for all the periods.

**Example 2.5:** A company has purchased an equipment whose first cost is ₹ 1,50,000 with an estimated life of eight years. The estimated salvage value of the equipment at the end of its lifetime is ₹ 25,000. Determine the depreciation and the book value for period 4 using the straight line method of depreciation.

**Solution:**

\[
P = ₹ 1,50,000
\]

\[
F = ₹ 25,000
\]

\[
n = 8 \text{ years}
\]

\[
D_4 = \frac{P - F}{n} = \frac{1,50,000 - 25,000}{8} = ₹ 15,625
\]

\[
B_4 = P - t \times \frac{(P - F)}{n} = 1,50,000 - 4 \times (15,625) = ₹ 87,500
\]
b) Declining Balance Method of Depreciation

In this method of depreciation, a constant percentage of the book value of the previous period of the asset will be charged as the depreciation amount for the current period. This approach is a more realistic approach, since the depreciation charge decreases with the life of the asset which matches with the earning potential of the asset. The book value at the end of the life of the asset may not be exactly equal to the salvage value of the asset. This is a major limitation of this approach.

Let

\[ P = \text{first cost of the asset,} \]
\[ F = \text{salvage value of the asset,} \]
\[ n = \text{life of the asset,} \]
\[ B_t = \text{book value of the asset at the end of the period } t, \]
\[ K = \text{a fixed percentage, and} \]
\[ D_t = \text{depreciation amount at the end of the period } t. \]

The formulae for depreciation and book value are as follows:

\[ D_t = K \times B_{t-1} \]
\[ B_t = B_{t-1} - D_t \]

While availing income-tax exception for the depreciation amount paid in each year, the rate \( K \) is limited to at the most \( 2/n \). If this rate is used, then the corresponding approach is called the double declining balance method of depreciation.

Example 2.6: A company has purchased an equipment for ₹ 1,50,000 with an estimated life of 10 years. The estimated salvage value of the equipment at the end of its lifetime is ₹ 25,000. Determine the depreciation charge and book value at the end of various years using the declining balance method of depreciation by assuming 0.2 for \( K \).

Solution:

\[ P = ₹ 1,50,000 \]
\[ F = ₹ 25,000 \]
\[ n = 10 \text{ years} \]
\[ K = 0.2 \]
\[ D_t = K \times B_{t-1} \]
\[ B_t = B_{t-1} - D_t \]
Table 2.10: Depreciation and Book value according to Declining Balance Method of Depreciation

<table>
<thead>
<tr>
<th>End of year (n)</th>
<th>Depreciation (D&lt;sub&gt;t&lt;/sub&gt;)</th>
<th>Book Value (B&lt;sub&gt;t&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>1,50,000.00</td>
</tr>
<tr>
<td>1</td>
<td>30,000.00</td>
<td>1,20,000.00</td>
</tr>
<tr>
<td>2</td>
<td>24,000.00</td>
<td>96,000.00</td>
</tr>
<tr>
<td>3</td>
<td>19,200.00</td>
<td>76,800.00</td>
</tr>
<tr>
<td>4</td>
<td>15,360.00</td>
<td>61,440.00</td>
</tr>
<tr>
<td>5</td>
<td>12,288.00</td>
<td>49,152.00</td>
</tr>
<tr>
<td>6</td>
<td>9830.40</td>
<td>39,321.60</td>
</tr>
<tr>
<td>7</td>
<td>7864.32</td>
<td>31,457.28</td>
</tr>
<tr>
<td>8</td>
<td>6291.45</td>
<td>25,165.83</td>
</tr>
<tr>
<td>9</td>
<td>5033.16</td>
<td>20,132.67</td>
</tr>
<tr>
<td>10</td>
<td>4026.53</td>
<td>16,106.14</td>
</tr>
</tbody>
</table>

c) Sum-of-the-Years-Digits Method of Depreciation

The sum-of-years'-digits depreciation method tries to model depreciation assuming that it is not a straight line. The actual market value of a piece of equipment after 1 year is less than the amount predicted by the straight-line method.

In this method of depreciation also, it is assumed that the book value of the asset decreases at a decreasing rate. If the asset has a life of 10 years, first the sum of the years is computed as

\[
\text{Sum of the years} = 1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10 = 55
\]

\[
\frac{n(n + 1)}{2} = 55
\]

The rate of depreciation charge for the first year is assumed as the highest and then it decreases. The rates of depreciation for the years 1 - 10, respectively are as follows: 10/55, 9/55, 8/55, 7/55, 6/55, 5/55, 4/55, 3/55, 2/55 and 1/55.

For any year, the depreciation is calculated by multiplying the corresponding rate of depreciation with \((P - F)\).

\[
D_t = \text{Rate} \times (P - F)
\]

\[
B_t = B_{t-1} - D_t
\]

The formulae for \(D_t\) and \(B_t\) for a specific year \(t\) are as follows:

\[
D_t = \frac{n-t+1}{n(n+1)/2} (P - F)
\]

\[
B_t = \frac{(P - F)(n-t)}{n} \cdot \frac{(n-t+1)}{(n+1)} + F
\]
Example 2.7: Purchase cost of equipment ₹1,50,000 and salvage value at the end of its life ₹25,000. Life of equipment 8 years. Determine Depreciation charge and Book value at the end of various years by sum of the years digit's method.

Solution:

\[ P = ₹1,50,000 \]
\[ F = ₹25,000 \]
\[ n = 8 \text{ years} \]
\[ \text{Sum} = n(n - 1)/2 = 8 \times 9/2 = 36 \]

The rates for years 1 - 8, are 8/36, 7/36, 6/36, 5/36, 4/36, 3/36, 2/36, and 1/36.

\[ D_i = \text{Rate} \times (P - F) \]
\[ B_i = B_{i-1} - D_i \]

Table 2.11: Depreciation and Book value under Sum-of-the-years-digits Method of Depreciation

<table>
<thead>
<tr>
<th>End of year (n)</th>
<th>Depreciation ( (D_i) )</th>
<th>Book value ( (B_i) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>1,50,000</td>
</tr>
<tr>
<td>1</td>
<td>27,778</td>
<td>1,22,222</td>
</tr>
<tr>
<td>2</td>
<td>24,306</td>
<td>97,916</td>
</tr>
<tr>
<td>3</td>
<td>20,833</td>
<td>77,083</td>
</tr>
<tr>
<td>4</td>
<td>17,361</td>
<td>59,722</td>
</tr>
<tr>
<td>5</td>
<td>13,889</td>
<td>45,833</td>
</tr>
<tr>
<td>6</td>
<td>10,417</td>
<td>35,416</td>
</tr>
<tr>
<td>7</td>
<td>6,944</td>
<td>28,472</td>
</tr>
<tr>
<td>8</td>
<td>3,472</td>
<td>25,000</td>
</tr>
</tbody>
</table>

In this method it is assumed that money is deposited in a sinking fund over the useful life that will enable to replace the asset at the end of its useful life. For this purpose, a fixed amount is set aside every year from the revenue generated and this fixed sum is considered to earn interest at an interest rate compounded annually over the useful life of the asset, so that the total amount accumulated at the end of useful life is equal to the total depreciation amount i.e., initial cost less salvage value of the asset. Thus the annual depreciation in any year has two components. The first component is the fixed sum that is deposited into the sinking fund and the second component is the interest earned on the amount accumulated in sinking fund till the beginning of that year.

For this purpose, first the uniform depreciation amount (i.e., fixed amount deposited in sinking fund) at the end of each year is calculated by multiplying the total depreciation amount (i.e., initial cost less salvage value) over the useful life by sinking fund factor. After that the interest earned on the accumulated amount is calculated. The calculations are shown below.
The first component of depreciation i.e., uniform depreciation amount ‘A’ at the end of each year is given by:

\[ A = (P - F) \times (A/F, i,n) = (P - F) \times \frac{i}{(1 + i)^{n-1}} \]

Where

- \( P \) = first cost of the asset.
- \( F \) = salvage value of the asset.
- \( n \) = life of the asset.
- \( i \) = rate of return compounded annually.

Depreciation amount for 1\(^{st}\) year is equal to only ‘A’ as this is the amount (set aside every year from the revenue generated) to be deposited in sinking fund at the end of 1\(^{st}\) year and hence there is no interest accumulated on this amount.

\[ D_1 = A = A \times (1 + i)^0 \]

Now book value at the end of 1\(^{st}\) year is given by:

\[ B_1 = P - D_1 = P - A \times (1 + i)^0 \]

Depreciation amount for 2\(^{nd}\) year is equal to uniform amount ‘A’ to be deposited at the end of 2\(^{nd}\) year plus the interest earned on the amount accumulated till beginning of 2\(^{nd}\) year i.e., on depreciation amount for 1\(^{st}\) year. Thus depreciation for amount for 2\(^{nd}\) year is given by:

\[ D_2 = A + D_1 \times i \]

Now putting ‘\( D_1 \)’ equal to ‘A’ in the above expression results in:

\[ D_2 = A + A \times i = A \times (1 + i) \]

Book value at the end of 2\(^{nd}\) year is given by:

\[ B_2 = B_1 - D_2 \]

\[ B = P - (P - F) \left( \frac{(1 + i)^{n-1}}{(1 + i)^{n-1}} \right) \]

Where \( B \) = Book value at the end of any year \( t \).

In this method, the depreciation during later years is more as compared to that in early years of the asset’s useful life.

**Example 2.7**: The initial cost of a piece of construction equipment is \( ₹35,000.00\). It has useful life of 10 years. The estimated salvage value of the equipment at the end of useful life is \( ₹50,000.00\). Calculate the annual depreciation and book value of the construction equipment using sinking fund method. The interest rate is 8% per year.

**Solution**:

\[ P = ₹35,000.00 \]
\[ F = ₹50,000 \]
\[ n = 10 \text{ years} \]
The interest rate per year = \( i = 8\% \)

Depreciation amount for 1\(^{st}\) year:

\[
D_1 = (35,000,00 - 50,000) \times \frac{0.08}{(1 + 0.08)^{10} - 1}(1 + 0.08)^{1-1} \\
= ₹ 207088.47
\]

Book value at the end of 1\(^{st}\) year

\[
B_1 = 35,000,00 - 207088.47 = ₹ 3292911.53
\]

Depreciation amount for 2\(^{nd}\) year

\[
D_2 = (35,000,00 - 50,000) \times \frac{0.08}{(1 + 0.08)^{10} - 1}(1 + 0.08)^{2-1} \\
= ₹ 223655.55
\]

Book value at the end of 2\(^{nd}\) year

\[
B_2 = 3292911.53 - 223655.55 = ₹ 3069255.98
\]

Similarly the annual depreciation and book value at the end of other years are calculated in the same manner and are given in Table 2.12.

The book value at the end of a given year can also be calculated by using equation (3.48). Using this equation, the book value at the end of 2\(^{nd}\) year is given by:

\[
B_2 = 3,50,000 - (3,50,5000 - 5,00,000) \left[ \frac{(1 + 0.08)^2 - 1}{(1 + 0.08)^{10} - 1} \right] \\
= ₹ 3069255.99
\]

Table 2.12 : Depreciation and book value of the construction equipment using sinking fund method

<table>
<thead>
<tr>
<th>Year</th>
<th>Sinking fund method</th>
<th>Book value (₹) ( B_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depreciation (₹) ( D_i )</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>3500000</td>
</tr>
<tr>
<td>1</td>
<td>207088.47</td>
<td>3293911.53</td>
</tr>
<tr>
<td>2</td>
<td>223655.55</td>
<td>3069255.98</td>
</tr>
<tr>
<td>3</td>
<td>241547.99</td>
<td>2827707.99</td>
</tr>
<tr>
<td>4</td>
<td>260871.83</td>
<td>2566836.16</td>
</tr>
<tr>
<td>5</td>
<td>281741.58</td>
<td>2285094.58</td>
</tr>
<tr>
<td>6</td>
<td>304280.90</td>
<td>1980813.68</td>
</tr>
<tr>
<td>7</td>
<td>328623.38</td>
<td>1652190.30</td>
</tr>
<tr>
<td>8</td>
<td>354913.25</td>
<td>1297277.06</td>
</tr>
<tr>
<td>9</td>
<td>384913.25</td>
<td>913970.75</td>
</tr>
<tr>
<td>10</td>
<td>413970.81</td>
<td>500000</td>
</tr>
</tbody>
</table>
iii) Investment (or Interest) Cost

Investment (or interest) cost represents the annual cost (converted into an hourly cost) of capital invested in a machine. If borrowed funds are utilized for purchasing a piece of equipment, the equipment cost is simply the interest charged on these funds. However, if the equipment is purchased with company assets, an interest rate that is equal to the rate of return on company investment should be charged. Therefore, investment cost is computed as the product of interest rate multiplied by the value of the equipment, which is then converted into cost per hour of operation.

The average annual cost of interest should be based on the average value of the equipment during its useful life. The average value of equipment may be determined from the following equation:

\[ C = \frac{P(n+1)}{2} \]

where \( P \) is the total initial cost, \( C \) the average value, and \( n \) the useful life (years).

This equation assumes that a unit of equipment will have no salvage value at the end of its useful life. If a unit of equipment has salvage value when it is disposed of, the average value during its life can be obtained from the following equation:

\[ C = \frac{P(n+1) + F(n-1)}{2n} \]

where \( P \) is the total initial cost, \( C \) the average value, \( F \) the salvage value, and \( n \) the useful life (years).

Example 2.8: Consider a unit of equipment costing ₹ 5,00,000 with an estimated salvage value of ₹ 50,000 after 5 years. The average value is

\[ C = \frac{5,00,000(5+1) + 50,000(5-1)}{2 \times 5} \]

\[ = ₹ 3,20,000 \]

iv) Insurance, Tax and Storage Costs

Insurance cost represents the cost incurred due to fire, theft, accident, and liability insurance for the equipment. Tax cost represents the cost of property tax and licenses for the equipment.

Storage cost includes the cost of rent and maintenance for equipment storage yards, the wages of guards and employees involved in moving equipment in and out of storage, and associated direct overhead.

The cost of insurance and tax for each item of equipment may be known on an annual basis. In this case, this cost is simply divided by the hours of operation during the year to yield the cost per hour for these items. Storage costs are usually obtained on an annual basis for the entire equipment fleet.

Insurance and tax costs may also be known on a fleet basis. It is then necessary to prorate these costs to each item. This is usually done by converting the total annual cost into a percentage rate, then dividing these costs by the total value of the equipment fleet. By doing so, the rate for
insurance, tax, and storage may simply be added to the investment cost rate for calculating the total annual cost of investment, insurance, tax, and storage.

**Total Ownership Cost**

Total equipment ownership cost is calculated as the sum of depreciation, investment cost, insurance cost, tax, and storage cost. As mentioned earlier, the elements of ownership cost are often known on an annual cost basis. However, while the individual elements of ownership cost are calculated on an annual cost basis or on an hourly basis, total ownership cost should be expressed as an hourly cost.

After all elements of ownership costs have been calculated, they can be summed up to yield total ownership cost per hour of operation. Although this cost may be used for estimating and for charging equipment cost to projects, it does not include job overhead or profit. Therefore, if the equipment is to be rented to others, overhead and profit should be included to obtain an hourly rental rate.

**2.15 OPERATIONAL AND MAINTENANCE COST OF CONSTRUCTION EQUIPMENTS**

**2.15.1 Cost of Operating Construction Equipment**

Operating costs of the construction equipment, which represent a significant cost category and should not be overlooked, are the costs associated with the operation of a piece of equipment. They are incurred only when the equipment is actually used. The operating costs of the equipment are also called "variable" costs because they depend on several factors, such as the number of operating hours, the types of equipment used, and the location and working condition of the operation.

Equipment operating costs are the direct costs associated with equipment operations. Unlike ownership cost, an operating cost is not a fixed cost but a variable one, directly proportional to the amount of work performed or operating hours. An operating cost is incurred only when the equipment is actually being used. The operating costs vary with the amount of equipment used and job-operating conditions.

The best basis for estimating the cost of operating construction equipment is the use of historical data from the experience of similar equipment under similar conditions. If such data is not available, recommendations from the equipment manufacturer could be used.

**2.15.2 Maintenance and Repair Cost**

The cost of maintenance and repairs usually constitutes the largest amount of operating expense for the construction equipment. Construction operations can subject equipment to considerable wear and tear, but the amount of wear varies enormously between the different items of the equipment used and between different job conditions. Generally, the maintenance and repair costs get higher as the equipment gets older. Equipment owners will agree that good maintenance, including periodic wear measurement, timely attention to recommended service and daily cleaning when conditions warrant it, can extend the life of the equipment and actually reduce the operating costs
by minimizing the effects of adverse conditions. All items of plant and equipment used by construction contractors will require maintenance and probably also require repairs during the course of their useful life. The contractor who owns the equipment usually sets up facilities for maintenance and engages the workers qualified to perform the necessary maintenance operations on the equipment.

The hourly cost of maintenance and repair can be obtained by dividing the annual cost by its operating hours per year. The hourly repair cost during a particular year can be estimated by using the following formula

\[
\text{Hourly repair cost} = \frac{\text{year digit}}{\text{sum - of - years'-digits}} \times \frac{\text{lifetime repair cost}}{\text{hours operated}}
\]

**Tire Cost**

The tire cost represents the cost of tire repair and replacement. Because the life expectancy of rubber tires is generally far less than the life of the equipment on which they are used on, the depreciation rate of tires will be quite different from the depreciation rate of the rest of the vehicle. The repair and maintenance cost of tires as a percentage of their depreciation will also be different from the percentage associated with the repair and maintenance of the vehicle.

The best source of information in estimating tire life is the historical data obtained under similar operating conditions.

Tire repair cost can add about 15% to tire replacement cost. So, the following equation may be used to estimate tire repair and replacement cost:

\[
\text{Tire repair and replacement costs} = 1.15 \times \frac{\text{cost of a set of tires}}{\text{expected tire life}}
\]

**2.15.3 Consumable Costs**

Consumables are the items required for the operation of a piece of equipment that literally gets consumed in the course of its operation. These include, but are not limited to, fuel, lubricants, and other petroleum products. They also include filters, hoses, strainers, and other small parts and items that are used during the operation of the equipment.

**a) Fuel Cost**

Fuel consumption is incurred when the equipment is operated. When operating under standard conditions, a gasoline engine will consume approximately 0.06 gal of fuel per flywheel horsepower hour (fwhp-h), while a diesel engine will consume approximately 0.04 gal/fwhp-h. A horsepower hour is a measure of the work performed by an engine.

The hourly cost of fuel is estimated by multiplying the hourly fuel consumption by the unit cost of fuel. The amount of fuel consumed by the equipment can be obtained from the historical data.

**b) Lubricating Oil Cost**

The quantity of oil required by an engine per change will include the amount added during the change plus the make-up oil between changes. It will vary with the engine size, the capacity of the engine, the condition of the piston rings, and the number of hours between oil changes.
**Mobilization and Demobilization Cost**

Equipment moving and setup costs or mobilization costs, and dismantling or demobilization costs can be substantial and must be considered. This is the cost of moving the equipment from one job site to another. It is often overlooked because of the assumption that the previous job would have already paid for it.Regardless of these calculations, the costs of equipment mobilization and demobilization can be large and are always important items in any job where substantial amounts of equipment are used.

These costs include freight charges (other than the initial purchase), unloading cost, assembly or erection cost (if required), highway permits, duties, and special freight costs (remote or emergency).

**Equipment Operator Cost**

Operator's wages are usually added as a separate item and added to other calculated operating costs. They should include overtime or premium charges, workmen's compensation insurance, social security taxes, bonus, and fringe benefits in the hourly wage figure. Care must be taken by the companies that operate in more than one state or that work for federal agencies, state agencies and private owners.

**SELECTION OF CONSTRUCTION EQUIPMENT**

The selection of the appropriate construction equipment is an important part of job planning. The contractor has many different options to choose from, which makes the selection even more complicated. A planner has to choose the alternative that provides the best value from a cost and schedule perspective.

(a) **Site condition:** Primary site condition (actors are: types of material to be handled, physical constraints onsite, and hauling distances.

(b) **The Nature of the Work:** Some factors relating to the nature of the work include payload, the total quantity of work, and the construction schedule. Payload has a direct relation to the capacity of the equipment selected.
(c) **Size of the Equipment**: Size of equipment should be such that it must be able to be used with other matching units. If the equipment selected is of larger size, that will remain idle for most of the time or shall work on part loads, which means production cost will be more. On other side, if the equipment is of smaller size than desired, the equipment will not be able to work with the matching equipment’s and hence other equipment’s will have to remain idle or to be allowed to work on part loads, which shall again be uneconomical.

(d) **Standardisation**: It is better to have same type and size of equipment’s in the project. It means lesser spare parts reserve, more interchangeability of parts if required, easy for the operators to understand it, mechanics will be able to maintain and repair better as they become expert by handling similar type of equipment.

(e) **Availability of Equipment**: The equipment which is easily available in the market should be purchased. It should also be ensured that the equipment is of repute and is likely to be continued to be manufactured in future also. This is necessary for future standardisation and ensuring spare parts supply. It is easy to dispose of such equipment after completion of projects.

(f) **Availability of Spare Parts**: While selecting a particular type or make of equipment, it should be ensured that the spare parts will be available at reasonable price throughout the working life of the equipment. It should also be ensured that the downtime of the equipment for want of spare parts may not be more. This is all the more necessary in case of imported equipment’s.

(g) **Multipurpose Equipment’s (Versatility)**: There are certain types of equipment’s which are not utilised fully. Therefore, if possible, they must be capable of performing more than one function for example, excavator with wheel loader bucket arrangement or with rock breaker attachment.

(h) **Client-and Project-specific**: The owner/client in a certain project may have certain preferences that are not in line with the construction company's preferred policies as far as equipment procurement is concerned. The schedule, quality and safety requirements demanded of a particular project may in some cases force the company to yield to the demands of the client.
(i) **Labour Consideration**: Shortage of manpower in some situations may lead to a decision in favour of procuring equipment that is highly automated.

(j) **Use in Future Projects**: When equipment completes only a part of their useful life in a project, it should be kept in view that the equipment can be used in future projects and may not become obsolete.

(k) **Economic Considerations**: The economic considerations such as owning costs, operating labour costs and operating fuel costs of equipment are most important in selection of equipment. Besides, the resale value, the replacement costs of existing equipment, and the salvage value associated with the equipment are also important.

(l) **Reliability of the Equipment**: Equipment selected for the project must be reliable one.

(m) **Service Support**: Service support should be available in the area of project where the equipment shall be used. Service after sales is a major criterion for selection of equipment.

(n) **Operating Requirements**: The equipment selected should be easy to operate and maintain, acceptable to the operator and should have lesser fuel consumption.

(o) **Past Performance**: If the equipment being purchased is of new make and model, it is desirable to enquire about its performance from other users, who are using this make and model.

Reputation of the manufacturer, Warranty or guarantee offered by the manufacturer, use of standard components in the equipment, etc. also considered while selecting equipment.


**BASIC CONCEPT ON EQUIPMENT MAINTENANCE**

Maintenance includes all labour (both direct and indirect), material, plant, and overhead required to sustain equipment in good serviceable condition; It includes periodic inspection, lubrication, servicing, repairs, and overhauls.

**Objectives of Maintenance**

1. To maximise availability of plant, equipment and machinery for productive purposes.
2. To extend the lifespan of plant, equipment and other facilities by minimising their wear and tear.
3. To ensure operational readiness of equipment at all times.
4. To reduce the cost of lost production due to breakdown.
5. To provide information to the management on the cost and effectiveness of maintenance.
6. To ensure safety through regular inspection and maintenance of plant, equipment and other facilities such as compressors, elevators, material-handling equipment etc.
Types of Maintenance

Generally, maintenance can be done in the following two types

1. **Breakdown maintenance**

Breakdown of a machine can occur due to the following two reasons:

(i) Due to unpredictable failure of components which cannot be prevented
(ii) Due to gradual wear and tear of the parts

which can be eliminated to a large extent by regular inspections, known as preventive maintenance. From experience it can be decided that, when a part should be replaced, so that breakdown can be avoided.

In breakdown maintenance, defects are rectified only when the machine cannot perform its function may longer, and the production department is compelled to call on the maintenance engineers for the repairs. After repairing the defect, the maintenance engineers do not attend the machine again until another failure occurs.

In this type of maintenance, repair shall have to be done on failure, thus it may disrupt the whole production, if it is performing an important work. This method is much expensive also due to increase of depreciation cost, payment to idle operators, overtime to the maintenance staff for doing the emergency repairs, and idling of matching equipment.

2. **Preventive maintenance**

Preventive maintenance is sometimes termed as "planned maintenance" or "scheduled maintenance" or "systematic plant maintenance" etc. It is an extremely important function for the reduction of maintenance cost and to keep the good operational condition of equipment and hence increases the reliability. Preventive maintenance aims to locate the sources of trouble and to remove them before the breakdown occurs. Thus it is based on the idea "prevention is better than cure". Scheduled maintenance is always economical than unscheduled maintenance.
Frequency of inspection should be decided on the basis of the importance of the machine; wear and tear of the machine and its delicacy. Thus, period of inspection or checking helps to find out the reasons leading to breakdown and to rectify them, when they are in minor stages. Thus, the repair can be done when one wants to do it, i.e., when it has least effect on the production schedule. Further this repair requires lesser time as compared to that of breakdown repair and thus down time is reduced by doing preventive maintenance.

Preventive maintenance has following main objects

- To obtain maximum availability of the equipment by avoiding breakdowns and by reducing the shutdown periods to a minimum.
- To keep the machine in proper condition so as to maintain the quality of the product.
- By minimising the wear and tear, preserve the value of the equipment.
- To ensure for the safety of the workers.
- To keep the plant at the maximum production efficiency.
- To achieve all the above objectives with most economical combination.

Following are some of the important functions of the preventive maintenance programme

I. Inspection or check-ups.
II. Servicing including cleaning, cooling and lubrication.
III. Planning and scheduling.
IV. Records and analysis.
V. Training to maintenance staff.
VI. Storage of spare parts.
INSPECTION AND MAINTENANCE PROGRAM

To ensure thorough inspection of all the vital components, detailed inspection and maintenance program should be prepared. Detailed inspection sheets should be used for each equipment listing specific points of inspection. Individual important parts such as track rollers, links, track shoes, etc. should be listed.

Maintenance instructions provided by the equipment manufacturer should be used as a reference in preparing the inspection report. A maintenance program should be prepared for implementation. Coordination between maintenance programs and construction operations is the most important responsibility. With cooperation between equipment operating personnel, servicing mechanics and the support of equipment dealer service personnel, the equipment manager can develop and implement a successful maintenance program.

The areas of responsibility of maintenance inspection personnel are as follows:

a) Regular inspecting and adjusting,

b) Scheduling machines for maintenance checks at most opportune times.

c) Advising the equipment manager of apparent service needs, and

d) Keeping records of their work on machines.
MATERIAL MANAGEMENT

Material management is the management system for planning and controlling all efforts necessary to ensure that the correct quality and quantity of materials are specified in a timely manner, obtained at a reasonable cost, and available at the point of use when required.

Materials management can also be defined as "the function responsible for the coordination of planning, sourcing, purchasing, moving, storing and controlling manner so as a pre-decided service can be provided at a minimum cost".

Objectives and Functions of Materials Management

- Efficient materials planning
- Buying or Purchasing
- Procuring and receiving
- Storing and inventory control
- Supply and distribution of materials
- Quality assurance

Secondary Objectives of Materials Management

- Efficient production scheduling
- To take make or buy decisions
- Prepare specifications and standardization of materials
- To assist in product design and development
- Forecasting demand and quantity of materials requirements
- Quality control of materials purchased
- Material handling
- Use of value analysis and value engineering
- Developing skills of workers in materials management
- Smooth flow of materials in and out of the organization
Importance of Materials Management

- Lower prices for material and equipment.
- Faster inventory turnover.
- Continuity of supply.
- Reduced lead time.
- Reduced transportation cost.
- Less duplication of efforts.
- Elimination of bulk-passing.
- Reduced materials obsolescence.
- Improved supplier relationship and better records and information.
- Better inter-department cooperation and Personnel development.

Advantages of Materials Management

- The better accountability part of the material, as well as other departments and no one can blame others.
- As materials management by a single authority, which can lead to better coordination, because it became the central point of any substance-related problems.
- Materials management departments· to ensure a better quality material. This can lead to a better performance of the organization.
- A materials management system is usually controlled through a system, therefore, can help decision-making related to the material in the organization.
- An indirect use of materials management is the development of good quality material, ethical and moral standards in an organization.
- Maximum company profit and Improvement of credibility.
- Improved customer service.
- Enhancement of communication.
- Improved quality of staff.
INVENTORY MANAGEMENT

Inventory is simply a stock, of physical assets having some economic value which can be either in the form of material, money or labour. Inventory is also known as an idle resource as long as it is not utilised. Inventory may be regarded as those goods which are procured, stored and used for day-to-day functioning of the organisation.

Inventory control is the technique of maintaining stock items at desired levels. In other words, inventory control is the means by which material of the correct quality and quantity is made available as and when it is required with due regard to economy in the-storage costs, ordering costs, set up costs, manufacturing costs, purchase prices and working capital.

There are following three main issues involved in inventory management and control:

- How and what to prioritize for procurement?
- How much to order?
- When to order?

Objectives of Inventory Control

As inventory is an essential part of any organisation, it consists of many items running into thousands. Systematic management and control of inventory for all the items is a challenging job.

- To maintain the overall investment in inventory at the lowest level, consistent with operating requirements,
- To supply the product,- raw material, sub-assemblies, semi-finished goods, etc.
- To its users as per their requirements at right time and at right price,
- To keep inactive, waste, surplus, scrap and obsolete items at the minimum level,
- To minimise holding, replacement and shmtage costs of inventories and maximise the efficiency in production and distribution, and
- To reduce the risk inherent in treating inventory as an investment which is risky. For some items, investment may lead to higher returns and for others less returns.
Factors affecting Inventory

Purchase Price or Production Cost
The cost of the item is the money paid to the supplier for the item received or the direct manufacturing cost, if produced. It is normally equal to purchase price. When the market prices go on fluctuating, planning for inventory is based on the average price mostly taken as a fixed price. The price factor is of special interest when price discounts can be secured or when large production runs may result in a decrease in the production cost.

(a) Selling Price
In some inventory situations, the demand may be affected by the quantity stocked. In such cases, the inventory model is based on a profit maximisation criterion which includes the revenue from selling the commodity. The unit selling price may be constant or variable, depending upon whether quantity discount is allowed or not.

(b) Procurement Costs
These costs are those incurred on a purchase (known as ordering costs) or incurred as set up costs related with the initial preparation of a production system if manufactured. These costs vary directly with each purchase order placed or with the set up made and are usually assumed independent of the quantity ordered or produced. Procurement costs include costs of administration (such as salaries of the persons concerned, telephone calls, computer costs, postage etc.), transportation of items ordered, expediting and follow up, receiving and inspection of goods, processing payments etc. This cost is expressed as the cost per order or per set up.
(c) *Shortage (or Stock out) Costs*

The demand pattern of commodity may be either deterministic or probabilistic. In the deterministic case, it is assumed that the quantities needed over subsequent periods of time are known with certainty. This may be expressed over equal periods of time in terms of known constant demands or in terms of known variable demands. The two cases are referred to as static and dynamic demands respectively.

(d) *Delivery Lag or Lead Time*

When the need of the material is felt and an order is placed, it may be delivered instantaneously or it may require sometime before delivery is affected. The time between the placement requisition for an item and its receipt for actual use is called delivery lag or lead time. In general, lead time has four components, viz. administrative lead time, supplier's lead time, transportation lead time and inspection lead time. While administrative lead time and inspection lead time can be fixed, the supplier's lead time and transportation lead time can never be fixed.
ix) Delivery Lag or Lead Time

When the need of the material is felt and an order is placed, it may be delivered instantaneously or it may require sometime before delivery is effected. The time between the placement of the requisition for an item and its receipt for actual use is called delivery lag or lead time. In general, lead time has four components, viz. administrative lead time, supplier's lead time, transportation lead time and inspection lead time. While administrative lead time and inspection lead time can be fixed, the supplier's lead time and transportation lead time can never be fixed. In general, the lead time may be deterministic or probabilistic.

2.25 ABC ANALYSIS

This is based on Pareto's Law, which says that in any large group there are 'significant few' and 'insignificant many'. For example, only 20 per cent of the items may be accounting for 80 per cent of the total material cost procured by a construction organization. Here, the 20 per cent constitute the 'significant few' that require utmost attention.

To prepare an ABC-type curve, we may follow a simple procedure:

1. Different materials required for the project are identified and their estimated quantities worked out. The quantity estimate could be on the basis of either annual consumption or the project's total requirement.

2. The unit rates of materials are estimated.

3. The usage values for each of the materials are obtained by multiplying the estimated quantities and their unit rates. These values are converted into percentage of total annual usage cost or total project cost, as the case may be.

4. The percentage usage cost for each of the materials is arranged in the descending order of their ranking, starting with the first rank, i.e., highest to lowest usage value. The cumulative percentage usage value is also calculated.

5. A curve as shown in Figure 2.10 is plotted, and points on the curve at which there are perceptible sudden changes of slopes are identified. In the absence of such sharp points, cut-off points corresponding to the top 10 per cent and the next 20 per cent or so are marked as a general indicator of A, B and C type of materials.

6. According to an empirical approach, 'A' class items account for about 70 per cent of the usage value, 'B' class items for about 20 per cent of the usage value, and 'C' class items for about 10 per cent of the usage value. In terms of numbers, 'A' class items constitute about 10 per cent of total items, 'B' class items about 20 per cent of total items, and 'C' class items about 70 per cent of total items. These percentages are indicative only and can vary depending on a number of factors.
Fig. 2.10: Illustration of ABC analysis

Upon classification of materials into A, B and C types, suitable inventory policies can be decided. Corresponding to each type of materials, the implications on inventory policy are mentioned below:

Item type ‘A’ - The salient features are:
- accurate forecast of quantities needed,
- involvement of senior level for purchasing,
- ordering is on requirement basis,
- enquiries for procurement need to be sent to a large number of suppliers,
- strict degree of control is required, preferably monitoring on a weekly basis,
- low safety stock is needed.

Item type ‘B’ - The salient features are:
- approximate forecast of quantities needed,
- requires involvement of middle level for purchasing,
- ordering is on EOQ basis,
- enquiries for procurement need to be sent to three to five reliable suppliers,
- moderate degree of control required, preferably monitoring on a monthly basis,
- moderate safety stock needed.
Item type ‘C’ The salient features are:
- no need of forecasting; even rough quantity estimate is sufficient,
- junior-level staff is authorized to order purchase,
- bulk ordering is preferred,
- quotations from even two to three reliable suppliers are sufficient,
- a relatively relaxed degree of control is sufficient, and monitoring can be done on a quarterly basis,
- adequate safety stock can be maintained.

2.26 VED ANALYSIS

This analysis attempts to classify items into three categories depending on the consequences of material stock-out when demanded.

In this type of analysis the items are classified into V (vital), E (essential) and D (desirable) categories. Vital items are the most critical having extremely high opportunity cost of shortage and must be available in stock when demanded. Essential items are quite critical with substantial cost associated with shortage and should be available in stock by and large. Desirable group of items do not have very serious consequences if not available when demanded, but these can be stocked items.

Obviously, the percentage risk of shortage with the vital group of items has to be kept quite small, thus calling for a high level of service. With ‘essential’ category we can take a relatively higher risk of shortage, and for ‘desirable’ category, even higher. Since even a C-class item may be vital or an A-class item may be desirable, we should carry out a two-way classification of items grouping them in nine distinct groups as A-V, A-E, A-D, B-V, B-E, B-D, C-V, C-E and C-D. We can then determine the aimed service level for each of these nine categories and plan for inventories accordingly.

Vital group comprises those items for the want of which the production will come to a stop—for example, power in the factory. Essential group features those items for whose non-availability the stock-out cost is very high. Desirable group contains items whose non-availability causes no immediate loss of production; the stock cost involved is very less and their absence may only cause minor disruption in the production for a short time.

The steps used for classifying materials as vital, essential and desirable are given below:

1. Factors such as stock-out case, lead time, nature of items, and sources of supply are identified and considered for VED analysis.
2. Assign points or weightages to the factors according to the importance they have to the company, as shown above.
3. Divide each factor into three degrees and allocate points to each degree.
4. Prepare categorization plan to provide basis for classification of items—for example, items scoring between 100 and 160 can be classified under desirable items; items between 161 and 230 can be classified under essential items; and items between 231 and 300 can be classified under vital items.
5. Specify the degree and allocate weightages to all the factors.
6. Evaluate and find the final score for every item, and specify the type of item.

2.27 FSN ANALYSIS

Not all items are required with the same frequency. Some materials are required quite regularly, some are required very occasionally, and yet some others may have become obsolete and might not have been demanded for years together. FSN analysis groups them as fast-moving, slow-moving and non-moving (dead stock), respectively. Inventory policies and models for the three categories have to be different. Most inventory models in literature are valid for the fast-moving items exhibiting a regular movement (consumption) pattern. Many spare parts come under the slow-moving category, which have to be managed on a different basis. For non-moving dead stock, we have to determine optimal stock disposal rules rather than inventory provisioning rules. Categorization of materials into these three types on value and critical usage enables us to adopt the right type of inventory policy to suit a particular situation.

‘F’ items are those items that are fast-moving—i.e., in a given period of time, say, a month or a year, they have been issued a number of times. However, ‘fast-moving’ does not necessarily mean that these items are consumed in large quantities.

‘S’ items are those items that are slow-moving—in the sense that in the given period of time they have been issued in a very limited number.

‘N’ or non-moving items are those that are not at all issued for a considerable period of time.

Thus, the stores department, which is concerned with the moving of items, would prefer to classify items in the categories F-S-N, so that they can manage, operate and plan stores activity accordingly. For example, for efficient operations it would be necessary that fast-moving items are stored as near as possible to the point of issue, for these to be issued with minimum of handling. Also, such items must be stored at the floor level, avoiding higher heights. Thus, if the items are slow-moving or issued once in a while in a given period of time, they can be stored in the interior of the stores and even at greater heights because handling of these items becomes rare. Further, it is necessary for the stores in-charge to know about non-moving items for various reasons mentioned below:

1. Non-moving items mean unnecessary blockage of money which affect the rate of returns of the company.
2. Non-moving items also occupy valuable space in the stores without any usefulness and, therefore, it becomes necessary to identify these items and find reasons for their non-moving status. If justified, recommendation may be made to top management for their speedy disposal so that company operations are performed efficiently.

To some extent, inventory control can be exercised on the basis of FSN analysis. For example, fast-moving items can be controlled more severely, particularly when their value is also high. Similarly, slow-moving items may not be controlled and reviewed very frequently since their consumption may not be frequent and their value may not be high.
2.28 INVENTORY MODELS

There are a number of computer-based analytical inventory models available (such as economic order quantity [EOQ] model), most of which are able to generate economic purchase orders, shipping orders, delivery notes and invoices. Most models claim to improve management control by reducing inventory-holding costs without loss of customer service. The basic philosophy behind these models is to use a trade-off analysis by comparing the cost of inventory holding versus the cost of ordering. We are discussing one of the most popular inventory models in the following section.

2.29 ECONOMIC ORDER QUANTITY (EOQ) MODEL

The EOQ model provides answers on how much to order. Figure 2.11 shows the behaviour of EOQ model. The reorder point R and the quantity to be ordered, Q, are shown in the figure 2.11 as is the lead time L. The ordered quantity derived from this model is known as economic order quantity, EOQ.

![Inventory behaviour under EOQ model](image)

It is usually less expensive to purchase (and transport) or produce a bunch of material at once than to order it in small quantities. If orders for large quantities are specified, there will be fewer orders placed. For purchasing, this means that quantity discounts and transportation efficiencies may be realized. The other side of the coin, however, is that larger lot sizes result in more inventory, and inventory is expensive to hold. EOQ model attempts to specify a balance between these opposing costs. This aspect is shown graphically in Figure 2.12, where it is clear that there is a decrease in cost associated with increase in order quantity, while there is increase in cost with increase of inventory.

![Total cost curve - EOQ model](image)
The total cost is given by the sum of inventory-carrying cost and ordering cost.

\[ Total\ cost\ TC = Ordering\ cost + Carrying\ cost \]

The following notations are used to develop the EOQ model:
D = Demand rate; unit/year
A = Ordering cost; ₹/order
C = Unit cost; ₹/unit of item
I = Inventory-carrying charges per year
H = Annual cost of carrying inventory/unit item
Q = Order quantity; number of units per lot

It is assumed that demand is at a uniform rate. Thus, the average inventory

\[ Required\ would\ be\ \frac{(0 + Q)}{2} = \frac{Q}{2} \] throughout the year.

The total number of orders placed would be \( \frac{D}{Q} \) per year.

Order cost per year = Number of orders placed per year \( \times \) Cost per order

Ordering cost per year = \( \frac{A \times D}{Q} \)

Carrying cost per year = \( \frac{Order\ quantity \times Unit\ cost\ of\ item \times Annual\ cost\ to\ carry}{2} \)

\[ Carrying\ cost\ per\ year = \frac{C \times I \times Q}{2} = \frac{H \times Q}{2} \]

where

\[ H = C \times I \]

Using the notations mentioned above, we can write the expression of TC as:

\[ TC = \frac{A \times D}{Q} + \frac{H \times Q}{2} \]

For optimum \( Q \), one needs to find the particular value of \( Q \) which will minimize total cost. This can be done by differentiation, and one gets:

\[ EOQ = \sqrt{\frac{2 \times Order\ cost \times Demand}{Inventory\ carrying\ cost}} \]

\[ EOQ = \sqrt{\frac{2 \times A \times D}{I \times C}} \]