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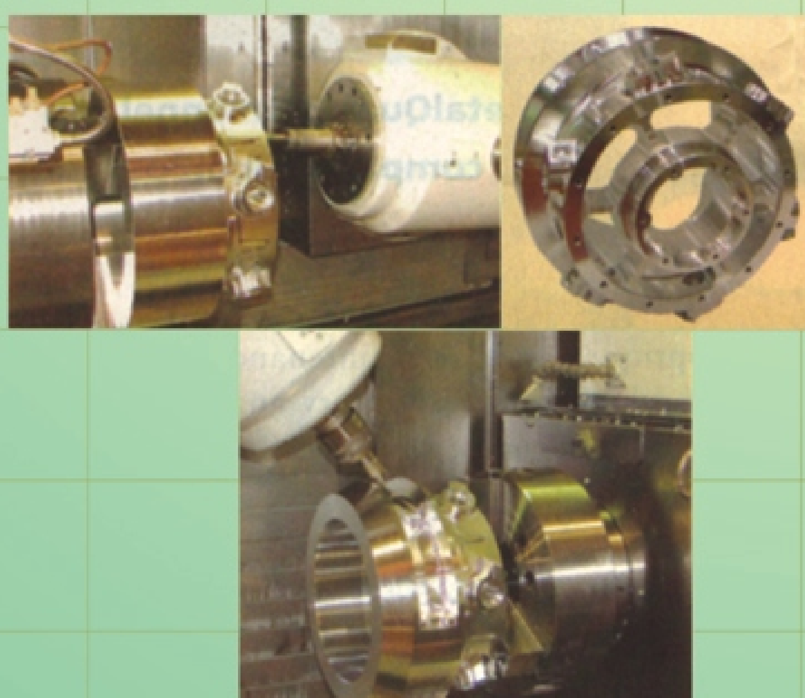
Process Planning and Cost Estimation

M. ADITHAN



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PREFACE

One purpose of this book is to introduce the subject "Process Planning and Cost Estimation" in an integrated manner to the students of Mechanical Engineering and Production Engineering Process Planning, Cost Estimation and Costing are the most critical factors for the continued success of a manufacturing enterprise. The world is an international market place. For a manufacturing company to be competitive in the international market place, process planning must be logical, rational, economical and costs of products, sub-assemblies and components must be accurately estimated, in order to secure business, its costing must also be accurate, to correctly determine the profitability of the various products manufactured.

This book provides an introduction to the Process Planning, Costing System and Cost Estimating relationships for manufacturing. This book gives the types of basic relationships used for costing and cost estimating and illustrates how they can be used.

It is essential that Mechanical Engineers and Production Engineers play a leading role in the determination of Cost estimates and that they work with professional Cost Accountants to obtain realistic cost estimates. This book is an attempt towards this direction.

The author fondly remembers Dr. Robert C. Creese, Professor in Industrial Engineering, West Virginia University (WVU), U.S.A., and Dr. B. S Pabla, Professor in Mechanical Engeering, National Institute of Technical Teachers Training and Research (NITTTR), Chandigarh for the association and the discussion he had with them when the concepts presented in this book are being evolved.

Vellore, Tamil Nadu

Dr. M. Adithan

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1 WORK STUDY AND ERGONOMICS

METHOD STUDY : Instructional Objectives

After studying this unit the student should be able to :

(i) Define work study and its uses.

(ii) Differentiate between method study and work measurement.

(iii) Decide which type of recording technique is used in a given situation.

(iv) Develop various type of charts and draw inference regarding unnecessary movements and delays.

(v) Suggest improvements in the existing processes and methods for improved productivity.

INTRODUCTION

An industrial undertaking, if it is to survive, must be aware of the latest developments brought about by continuous application of new technology and methods used in production. It must continuously strive for improvements in the efficiency of its production and must consistently aim at producing better quality goods at lower prices than its competitors. The performance of an undertaking can be improved by :

1. Improving the process of manufacture *i.e.*, by adopting new technology, by developing better machines and new equipment.
2. Improving the method of operation of existing facilities, equipment, plant and operating staff.

First of these approaches is called new technology development and is a long-term policy which deals with extensive improvements and involves heavy capital investment, research and development, new and improved processes, plant and machinery. The second approach, called Work Study, concentrates on raising effectiveness and efficiency of existing facilities through systematic analysis in a relatively short time and in general, with very little or no extra capital expenditure.

DEFINITION OF WORK STUDY

Work study is the study of human work with a view to increase the effectiveness with which the work is done. As per IS-6363, 1972 work study is defined as "a modern discipline which analyses and evaluates all aspects of a work system in order to enhance effectiveness and functional efficiency".

As per International Labour organization, (I.L.O., Geneva, Switzerland) work study is defined as "a generic term for those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts, and which leads systematically to the investigation of all the factors which affect the efficiency and economy of the situation being reviewed, in order to affect improvements".

In simple terms work study may be defined as the analytical investigation of methods, conditions and effectiveness of work and thereby the determination of the ways in which human effort may be applied most economically. It is a method used to increase productivity.

Work study embraces two distinct but interdependent techniques, *i.e.*, method study and work measurement.

Method study may be defined as the detailed analysis of existing or proposed method of doing the work for the purpose of effecting improvements. **Work measurement** may be defined as the determination of time allowed for the effective performance of a specified volume of work performed in a specified manner.

OBJECTIVES OF WORK STUDY

The main objectives of work study are :

(*i*) To find the most economical way of doing the work.

(*ii*) To standardise the methods, materials, tools and equipment.

(*iii*) To determine the time required to do a job by a qualified and properly trained person working at normal pace.

(*iv*) To assist in training the workers for new methods.

METHOD STUDY

Method study is that part of work study which deals with systematic analysis and improvement of work methods and systems through the application of innovative techniques to achieve better utilization of resources.

OBJECTIVES OF METHOD STUDY

The objectives of method study are :

(*i*) To bring improvement in processes and procedures.

(*ii*) To bring improvement in factory, shop and work-place layout.

(*iii*) To find the ways for optimum utilisation of resources *i.e.*, men, machines and materials.

(*iv*) To bring economy in human effort by reducing the unnecessary fatigue and thereby increase the efficiency.

(*v*) To develop suitable working conditions.

BASIC PROCEDURE FOR METHOD STUDY

In order to find an effective method for doing a job as well as for optimum utilization of resources, a systematic approach should be followed for method study. The basic procedure involves seven stages in the application of methods study. These stages are :

(*i*) Select the work to be studied.

(*ii*) Record all the relevant facts about the present method after observation.

(*iii*) **Examine** these facts critically in the order of sequence using the questioning techniques.

(*iv*) **Develop** the most practical, economic and effective method considering all circumstances.

(*v*) **Define the new method** (improved method) so that it can always be identified and specified.

(*vi*) **Install** the method as standard practice.

(*vii*) **Maintain** that standard practice by proper supervision, regular and routine checks.

All these seven steps are essential in the application of method study and none can be excluded. Also, strict adherence to their sequence as well as their contents is essential.

1. Select the Work to be Studied

One of the main difficulties in the programme of method study is to know where to start. One should start with a problem, section or area which is expected to give maximum benefit. The following defects and symptoms will indicate where the method study is likely to bring worthwhile savings :

(*i*) Poor use of men, materials and machine capacity.

(*ii*) Bad layout and poor planning resulting in unnecessary movements of materials.

(*iii*) Existence of bottlenecks (*i.e.*, problems obstructing smooth flow of work).

(*iv*) Inconsistencies in quality.

(*v*) Excess scrap and reworking cost.

(*vi*) Excessive overtime.

(*vii*) Highly fatiguing work.

(*viii*) Bad working conditions and high rates of accidents.

(*ix*) Frequent complaints by employees about a particular work.

The above indicators show the areas, where method study techniques can be applied for improvement of the work methods. A work study engineer should first tackle the jobs which are likely to have greatest overall effect on the productivity of the enterprise as a whole. It should also be remembered that work study should be readily acceptable to all the workers. For this purpose the jobs which are unpopular should be taken up first. The objectives of carrying out method study for a particular job should be clear to the work study/method study engineer at this stage.

2. Record

In order that the activities selected may be analysed fully, with a view to improve them, it is essential to have a record of all the facts about the existing method. The facts should be recorded systematically and nothing should be over looked or distorted.

The usual way of recording facts is to write them down but this method is not suitable for recording of the complicated procedures involved in the modern industry. The following are the most generally used **tools and techniques** for recording :

(*a*) Charts

(*i*) Outline process chart.

(*ii*) Flow process charts man type, material type and equipment type.

(*iii*) Two handed process chart.

(*iv*) Multiple activity chart.

(*v*) Simultaneous Motion (Simo) cycle chart.

(*b*) Diagrams and models

(*i*) Flow diagram.

(*ii*) String diagram.

(*iii*) Cyclegraph and chronocyclegraphs.

(*iv*) 2-dimensional and 3-dimensional models.

According to the nature of the job to be studied and purpose for which the record is required, one or more of the above techniques can be used and every type of normal activity can be recorded to the appropriate degree of details required. (Some of the above mentioned recording techniques will be discussed in the later part of this chapter).

3. Examine

Once all the facts relating to an existing method have been recorded, each of the recorded facts is subjected to critical examination.

Critical examination is the means by which each activity is subjected to a systematic and progressive series of questions. The objective of critical examination is to determine the true reasons underlying each event and to draw up a systematic list of all the improvements for later development into a new and improved method. This stage involves posing a series of questions in an impartial and objective manner. The stage "Examine" involves Questioning Techniques. The questions are divided into two categories :

(*a*) Primary questions : The primary questions indicate the facts and the reasons underlying them. This stage of questioning technique queries the fundamental need for the performance, place, sequence, person and means of every activity recorded and seeks a reason for each reply. The questioning sequence follows a well established pattern which examines :

the *purpose* for which
the *place* at which
the *sequence* in which
the *person* by whom
the *means* by which

} the activities are undertaken

with a view to : *eliminating*
combining
re-arranging
or
simplifying

} those activities with a view to bring out improvements.

(*b*) Secondary questions : The secondary questions cover the second stage of questioning technique, during which the answers to the primary questions are subjected to further query

CRITICAL EXAMINATION CHART

	Primary questions		Secondary questions	
	The present fact	**Challenging the facts**	**Possible alternative**	**Selected alternative**
Purpose	**What** is achieved ?	Is it necessary ? Yes, No (If yes - Why ?)	What else could be done ?	What should be done?
Place	**Where** is it done ?	Why there ?	Where else could it be done ?	Where should it be done ?
Sequence	**When** is it done ?	Why then ?	When else could it be done ?	When should it be done ?
Person	**Who** does it ?	Why that person ?	Who else could do it?	Who should do it ?
Means	**How** is it done ?	Why that way ?	How else could it be done ?	How should it be done ?

to determine whether possible alternatives of place, sequence, person and/or means are practicable and preferable as a means of improvement upon the existing method. Thus in this stage of questioning the method study engineer goes on to enquire : What else might be done ? and hence what should be done ? The following chart shows how, he (Method Study Engineer) should actually proceed :

The answers to these questions indicate the lines along which a new method for overall process should be developed. In obtaining the answers to secondary questions, which will be the pointers to improvement, the following considerations are the most important :

(*i*) When the purpose of an activity is challenged the main objective is to see whether it can be eliminated entirely.

(*ii*) If the activity proves to be essential, then the objective must be to see whether it can be modified by changing or combining it with some other activities. In some cases it is possible to obtain improvements by separating and redistributing the work contents of particular activities.

In this way the improvements are obtained by combining or changing the place where work is done, the sequence in which activities are performed or the persons performing the activities.

(*iii*) Finally when the means of doing job are being considered, attention is given to see how an activity can be simplified.

4. Develop New Method

The examination of the existing method provides a comprehensive statement of what is being done at present and shows in which direction improvements may be made. With the results of critical examination as a guide, the work study engineer can proceed further to develop an improved method.

The developed method should be :

(*i*) Practical and feasible,

(*ii*) Safe and effective,

(*iii*) Economical,

(*iv*) Acceptable to design, production control, quality control and sales department.

The development of new method is simplified with the co-operation from staff of other departments. Human aspect should also be considered carefully and everything reasonable should be done to ensure comfortable working conditions. Developing a new method, in some cases, may involve incurring some marginal expenditure, for which the management should agree.

5. Define the New Method

The work study engineer should prepare complete instruction sheets for the revised method or the new method to be introduced. The instruction sheet should cover all details of the new method and should be written out in straight forward terms, so that there is no confusion and no two different meanings can be taken from it. The instruction sheet serves the following purposes :

(*i*) It records the improved method for future reference in as much details as may be necessary.

(*ii*) It can be used to explain the new method to the management, foremen, supervisor and operating staff. It also advises all concerned of any new equipment required or new workplace design.

(*iii*) It is an aid to training of operating staff and can be used by them for reference until they are fully conversant with the new method.

(*iv*) It forms the basis on which time studies may be taken for setting standards etc.

New method arrived at is known as Written Standard Practice/Procedure which outlines the method to be used by the operator and a copy of it should be displayed or kept near the work spot.

6. Install the New Method

The process of installing a new (improved) method is very critical and requires co-operation and active support of everyone concerned. The new method should be introduced after adequate preparation has been made. Installation involves introduction of developed method as standard practice.

If the physical facilities are to be altered due to installation of the new method, these changes should generally be made outside the normal working hours so that it would not affect regular production. Provision should be made for training the workers on the new method. The workers will take some time to learn the new method, and this should be taken into consideration in estimating the output in initial stages. As a result of new method some workers may have to be displaced from old jobs, so alternative work should be found out for them before the installation of the new method in practice.

7. Maintain the New Method

It is important that when new method is installed it should be maintained in its specified form and the workers should not be allowed to slip back into old methods or introduce any further changes which are not allowed. Checking by work study department is necessary to maintain the application of new method, because if there is no check, the workers, foremen, supervisor and chargeman will tend to gradually fall back to the old method. It should be ensured that the new method is established as standard procedure and it is protected from unauthorised changes. Routine checks and verifications ensure the proper functioning of the installed method. Reasons for deviations, if any, should be explored and the necessary change may be made in the procedure being followed.

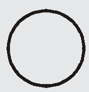
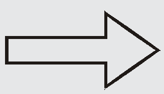
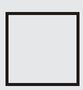
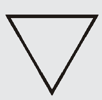
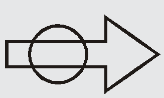
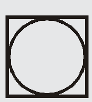
The views of operating staff, foreman, supervisor etc. may help in further improvement of the method.

RECORDING TECHNIQUES USED IN METHOD STUDY

A. Charts

Symbols used in charting : The following are the symbols used in the construction and interpretation of the charts.

Symbols Used in the Construction of Charts

Symbol	Activity	Example
	Operation	Produces, accomplished or enables the process to be carried out.
	Transport	Travel, movement of men equipment or materials etc.
	Inspection	Verifies quality and/or quantity.
	Delay	Delays, men, material, or machine in waiting.
	Storage	Holds, keeps or retains the material.
	Operation and transport (combined operation)	Painting or drying of parts on a conveyor.
	Operation and inspection (combined operation)	Operation (closing of caps) and inspection of quantity in bottles.

Depending upon the job being studied and the details required two or more of the above symbols may be used.

1. Process Charts

A process chart is a graphic representation of the sequence of events and related information that occur in the work method or procedure. The following are the various types of process charts :

(*i*) Outline process chart.
(*ii*) Flow process chart.
(*iii*) Two handed process chart.

(i) Outline Process Chart

The outline process chart gives an overall view of the process, from the beginning to the end. It is a graphic representation of the sequence of all the operations and inspections carried out in the entire process and the stage at which material is introduced. **In outline process chart only operation and inspection symbols are used**. In addition, a brief note of the nature of each operation or inspection is made along side the symbol and time allowed for it is also entered. An example of outline process chart is shown in Fig. 1.1.

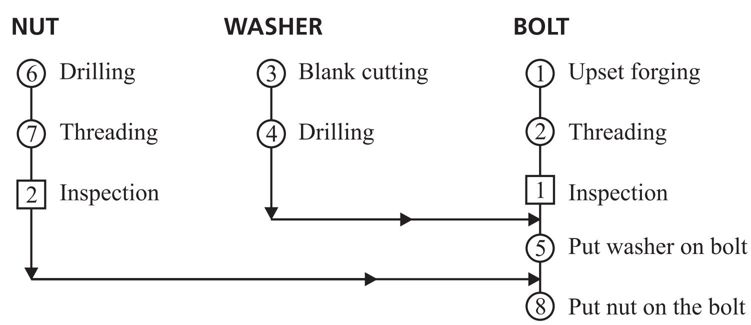


Fig. 1.1. Outline process chart for nut, bolt and washer assembly

If the final product is assembled from several subsidiary components or materials which join the major process during its progress, the major process is shown starting from the right hand side of the page and subsidiary processes are joined to the major process at the place of entry of the materials or subassemblies. All the operations are sequentially numbered; similarly all the inspections are sequentially numbered separately.

Summary				
Method	**Present**	**Proposed**	**Savings**	Company / No. of Page
				Plant
No. of storages ▽	1			
No. of transportations ⇨	5			Department / Date
No. of Operations ○	5			Job
No. of Inspections □	1			
No. of Delays D	0			✓ Man or ☐ Material
Distance travelled-meters				Chart Begins : Man in the work place.
Time per cycle-minutes				Chart Ends : Man places the welded plates in storage.
Total cost per month				Charted by :
Cost of change to proposed method				

Details of (Present) Method	**Storage**	**Transportation**	**Operation**	**Inspection**	**Delay**	**Distance in Metres**	**Time in Minutes**	**Notes**
1. Operator goes to collect individual plates								
2. Collects plates								
3. Goes to almirah to collect welding rods, bins etc.								
4. Collects welding material								
5. Goes to work place								
6. Keeps the plates and other material at work place								
7. Goes to switch on electric supply								
8. Makes the electric connection etc.								
9. Comes back to work place								
10. Does the welding								
11. Inspects the welded plates								
12. Keeps the welded plates in storage bin								
13.								
14.								
15.								

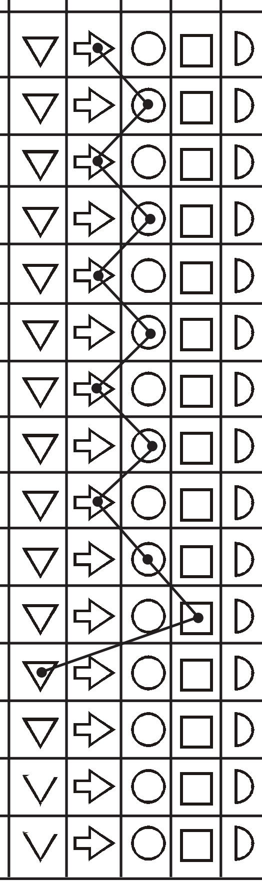


Fig. 1.2. Flow process chart (Man type)

Summary				Company	No. of Page
Method	Present	Proposed	Savings	Plant	Date
No. of storages ▽	1			Department	
No. of transportations ⇨	2			Job	
No. of Operations ○	5				
No. of Inspections □	1				
No. of Delays D	1			☐ Man or ☑ Material	
Distance travelled-meters				Chart Begins : Material in the bin.	
Time per cycle-minutes				Chart Ends : Finished job in storage bin.	
Total cost per month				Charted by :	
Cost of change to proposed method					

Details of (Present) Method	Storage	Transportation	Operation	Inspection	Delay	Distance in Metres	Time in Minutes	Notes
1. Pick-up job to be drilled	▽	⇨	**○**	□	D			
2. Take job to drilling machine	▽	**⇨**	○	□	D			
3. Place job in drilling jig	▽	⇨	**○**	□	D			
4. Clamp the job	▽	⇨	**○**	□	D			
5. Start drilling machine	▽	⇨	○	□	**D**			
6. Drill the hole in the job	▽	⇨	**○**	□	D			
7. Unclamp the job	▽	⇨	**○**	□	D			
8. Inspect	▽	⇨	○	**□**	D			
9. Take job to storage	▽	**⇨**	○	□	D			
10. Job kept in storage bin	**▽**	⇨	○	□	D			
11.	▽	⇨	○	□	D			
12.	▽	⇨	○	□	D			
13.	▽	⇨	○	□	D			
14.	▽	⇨	○	□	D			
15.	▽	⇨	○	□	D			

Fig. 1.3. Flow process chart (Material type)

(ii) Flow Process Chart

A flow process chart is a graphical representation of the sequence of all operations, transportations, inspections, delays and storages occurring during a process or procedure, and includes information considered desirable for analysis such as time required and distance moved.

As per IS-6363-1972, flow process chart is defined as a process chart setting out the sequence of the flow of a product or a procedure by recording all events under review using the appropriate process chart symbols.

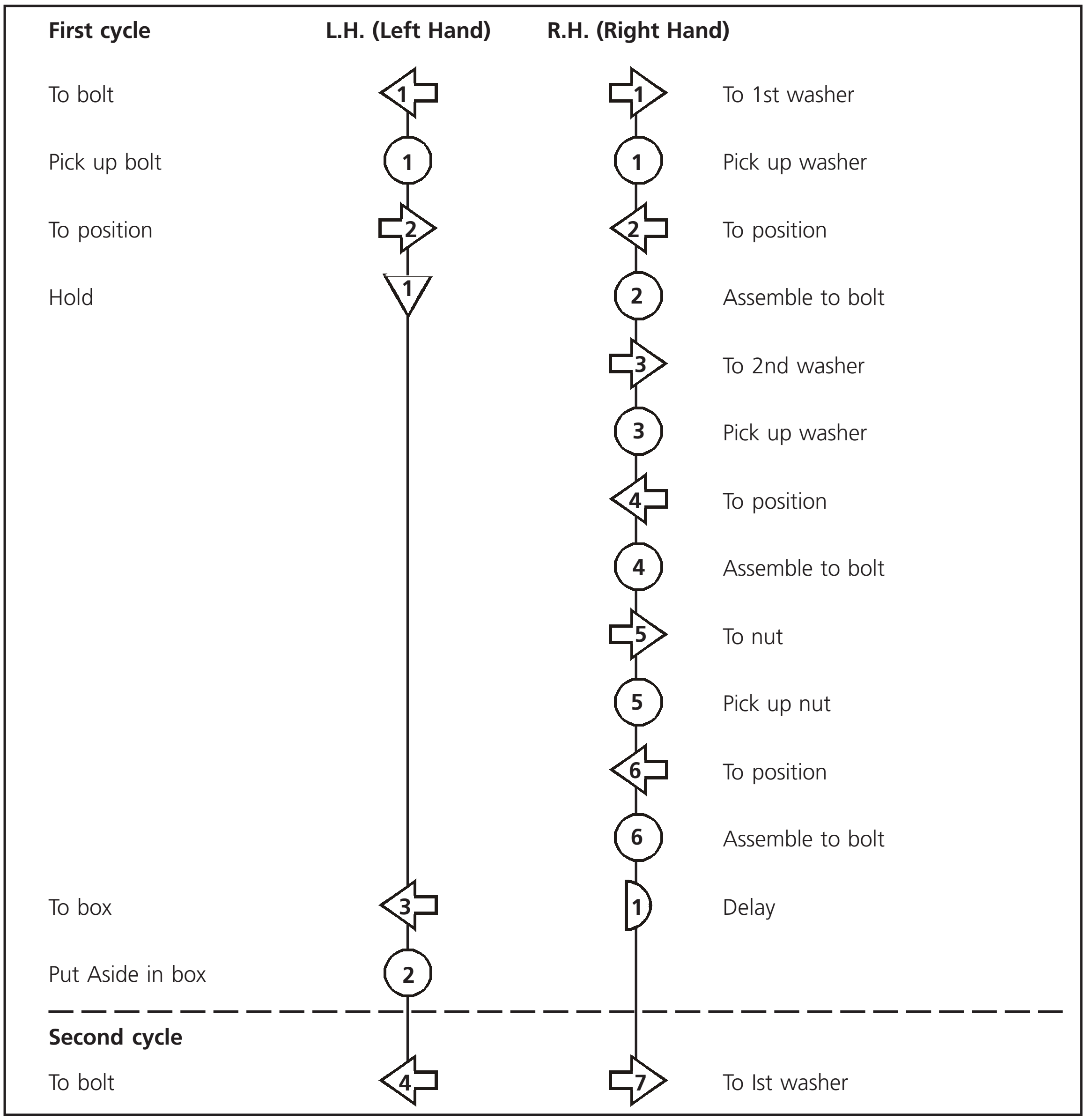


Fig. 1.4. Two-handed process chart. Job : Assemble two washers and a nut to bolt.

Types of flow process chart :

(*a*) **Man-type :** A flow process chart which records what the worker does and his movements.

(*b*) **Material type :** A flow process chart which records what happens to material and its movements.

(*c*) **Equipment type :** A flow process chart which records how the equipment is used and its movements.

It is essential that the activities of only a particular subject to which it refers, either man, material or equipment are recorded on any single chart *i.e.*, a chart should represent flow of either man, material or machine at a time. The flow process chart is constructed in the same way as outline process chart but it uses all the five symbols for charting. A man-type flow process chart for welding of two plates is shown in Fig. 1.2. The material type flow process chart is shown in Fig. 1.3.

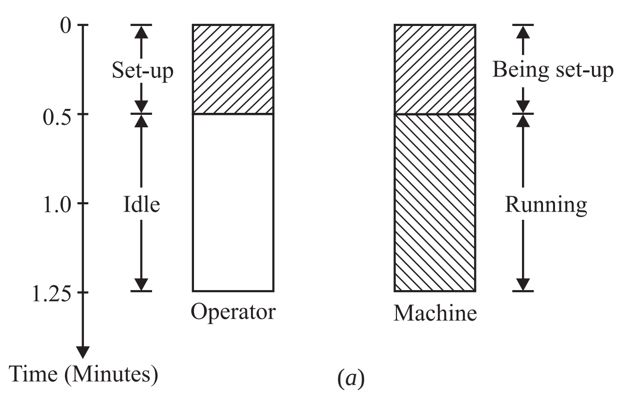
(iii) Two-handed Process Chart

Two-handed process chart is a specialised form of process chart and gives a graphical representation of work and movement of the operator's two hands in relationship to one-another. A two handed process chart is made up of two columns in which are recorded the symbols representing the activities of the left and the right hand respectively. Recording, in this case, is made with ordinary symbols with the omission of the inspection symbol since inspections will be shown as movement of hands. Also the triangle symbol used for storage implies "hold" in two handed process chart. An example of two handed process chart is shown in Fig. 1.4.

2. Charts Using Time Scale

(i) Multiple Activity Chart

A multiple activity chart is a chart on which the activities of more than one subject (such as a man and a machine, operator and machines, two or more workers) are recorded on a common time scale to study their interrelationship. It is a graphical representation of the co-ordinated activities of man and machine in terms of independent work, combined work or waiting. The chart is constructed by alloting separate bars to represent the activities of each worker or machine, against a common time scale. This type of chart is used when the work study analyst is interested in determining ineffective time within the process or procedure. The multiple activity chart clearly shows when a man or machine is idle during the process and action can be taken to utilise this time by rearranging the work. These charts are also constructed when one operator has to operate more than one machine. An example of multiple activity chart is shown in Fig. 1.5.



(*a*)

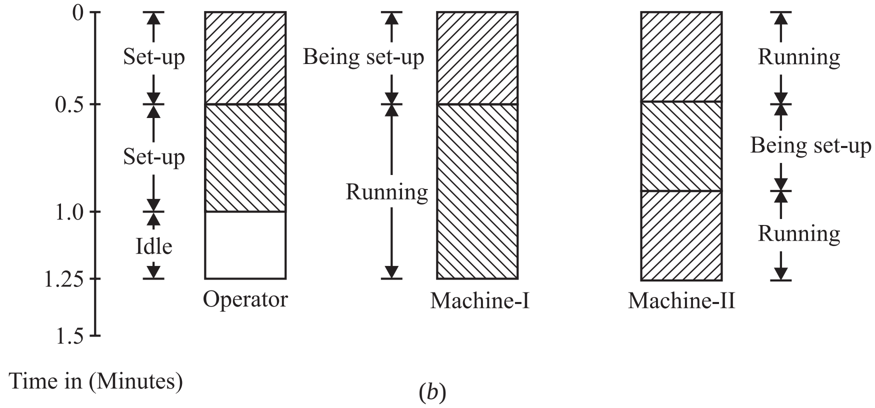


Fig. 1.5. Multiple activity chart

Consider a situation in which time to set up machine is 0.5 minute and machining time is 0.75 minute. As shown in the man-machine chart, when operator is working on one machine, he is idle for 0.75 minute per cycle. Whereas when he is operating two machines simultaneously, he is idle for 0.25 minutes only.

(ii) Gang Chart

When a group of men and equipment are involved in a combined activity, the chart plotted to show the individual activities of men or the equipment is known as gang chart. Gang chart are used in moulding (foundry) operations where a gang of 3 or 4 operators and equipment are employed.

(iii) Simultaneous Motion (Simo) Cycle Chart

Simo chart is used to record, simultaneously on a common time scale, the activities of two hands or other parts of worker's body during the performance of a single cycle of operation being investigated. The Simo chart is usually based on film analysis to record the Therbligs or groups of Therbligs performed by different part of the body of one or more workers. Therbligs are the symbols used to denote the various activities and movements done for different purposes. Fig. 1.6 shows the Therbligs used to represent the different movements of body such as eyes, hands etc.

B Diagrams and Models

Although the flow process chart shows the sequence and nature of movements in a process or procedure it does not provide any information about the path of movements. Sometimes it is of interest to the work study engineer to know the path of movement of men and materials. It is necessary to avoid undesirable features like bottle-necks, backtracking, congestion and unnecessary movements of men or machines through long distances. To investigate such situations, use of diagrams and models is made. These models and diagrams are widely used in plant layout and material handling studies because it is important to visualise the number of movements made by the workers or materials or equipment between facilities and different work stations and accordingly change the plant layout at design stage itself. So, their unnecessary movements and back tracking of materials can be avoided.

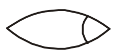
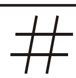
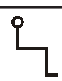
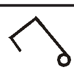
Symbol	Name of symbol	Description	Abbreviation
	Search	Locate an article	Sh
	Find	Mental reaction at end of search	F
	Select	Selection from a number	St
	Grasp	Taking hold	G
	Hold	Prolonged grasp	H
	Transport loaded	Moving an article	TL
	Position	Placing in a definite location	P
	Assemble	Putting parts together	A
	Use	Causing a device to perform its function	U
	Disassemble	Separating parts	DA
	Inspect	Examine or test	I
	Pre position	Placing an article ready for use	PP
	Release load	Release an article	RL
	Transport empty	Movement of a body member	TE
	Rest	Pause to overcome fatigue	R
	Unavoidable delay	Idle-outside person's control	UD
	Avoidable delay	Idle-within persons' control	AD
	Plan	Mental process before action	Pn

Fig. 1.6. Therbligs showing various movements of body members such as eyes, hands etc.

(i) Flow Diagram

Flow diagram is a drawing, made to a scale of the workplace showing the location of various equipment and machines, activities carried out and the routes followed by workers and materials. The routes followed in movement are shown by joining the points in a sequence, by a line which represents as nearly as possible the path of movement of men, material or equipment concerned and diagram is drawn to a scale. Numbered transport symbols on the flow line show the direction of movement.

Fig. 1.7 shows a flow diagram in which raw material moves from store to workstation A where an operation is performed. The semi-finished product is then sent to inspection room B for checking from where it goes to C and D where 2 more operations are performed. After operation at D it again goes to inspection room and after inspection goes to E which is a finished component store.

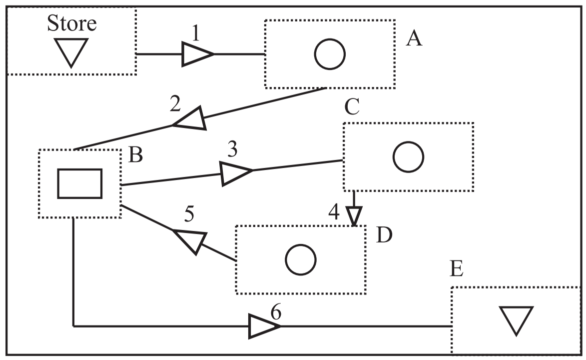


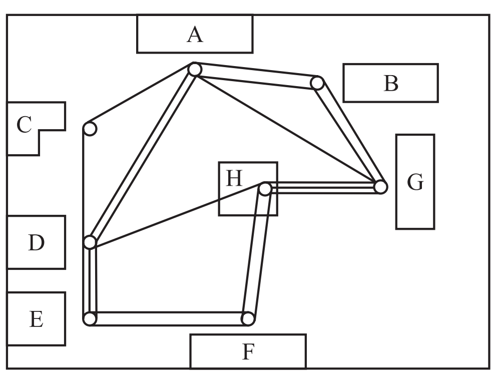
Fig. 1.7. Flow diagram (drawn to a scale)

(ii) String Diagram

String diagram is a scale layout drawing on which the length of string is used to record the extent as well as pattern of movement of a worker or material or equipment working within a limited area over a cycle of operations certain period of time. String diagram is used in such situations where the movements are congested and difficult to trace on flow diagram. To construct a string diagram the work area is shown as a plan to a scale. All the terminal points observed during the study are marked on the plan and pins or pegs are fixed at these points. Then a measured length of thread or string is taken and tied around the pin at the starting point. The string is then taken around the pins at other points in the order of the sequence of movements. The length of the left over string is measured and this is substracted from the total length of the string. This value gives the distance travelled by the material or equipment or man. Rearrange the layout, if required, to reduce the distance.

It is possible to record any number of journeys between any number of points for the purpose of analysis. It also helps in comparing the relative merits of different layouts.

String diagram is shown in Fig. 1.8.



A, B, C, D, E, F, G, H Work Stations; o Pegs / Pins; = String

Fig. 1.8. String diagram between different work stations (drawn to a scale)

(iii) Travel Chart

Travel chart is a tabular record for presenting quantitative data about the movement of workers, materials or equipment between any number of places over a given period of time. (Say in a shift or in one day). A travel chart is a table having number of small squares which represent different work stations. The squares from left to right along the top of the chart represent the stations from where the movement takes place and squares along vertical column represent the work-stations to which the movement is made as in Fig. 1.9.

Suppose the movement takes place from work station *c* to the work station *d*, two times, then tick two times as shown in Fig. 1.9. The travel chart is very useful in analysing the movements in a plant. The departments between which there is high frequency of movements can be situated nearer to each other to reduce the distance covered during the movements.

(iv) Templates and Models

To evaluate the feasibility of a new layout developed by the work study engineer 2-dimensional templates and 3-dimensional models are used. Templates and models supplement the flow chart and diagrams. 2-dimensional templates (corresponding to plan view of machine or equipment) are made to scale to represent the various facilities in a shop or plant and are placed on a flow diagram which is drawn to the same scale. On the scaled boundary of the shop floor, door-ways, pillars and other possible obstructions are also marked. These templates are moved to different positions on the floor plan and for every possible layout the feasibility of the flow is studied.

3-dimensional models of equipment are particularly useful when analysis involves the use of material handling devices in multistory buildings and for layout studies.

TO	MOVEMENT FROM				
	a	b	c	d	e
a					
b					
c					
d			✓✓		
e					

a, b, c, d, e are work stations

Fig. 1.9. Travel chart

WORK MEASUREMENTS : Instructional Objectives

After studying this unit the student should be able to :

(i) Define work measurement and state its objectives.
(ii) Decide which method of work measurement is to be used under given conditions.
(iii) Conduct time-study for a given manufacturing cycle and tabulate the results.
(iv) Rate the performance of an operator at work.
(v) Calculate the standard time for doing a job from the collected data.
(vi) Explain the relative advantages and disadvantages of various work-measurement techniques.

INTRODUCTION : WORK MEASUREMENT

Work measurement is the application of techniques used to determine the time taken by a qualified worker to carryout a specified job at a defined level of performance. Work measurement means measuring the work in terms of time content, (*i.e.,* minutes or hours) required for completion of job. Work measurement is concerned with investigating, reducing or eliminating all ineffective time.

OBJECTIVES OF WORK MEASUREMENT

The main objectives of work measurement are :

1. To determine the time required to do a job.
2. To estimate the man and machine requirements and to assess the plant capacity accurately.
3. To provide information for effective production planning and maintenance.
4. To assist in estimation of reliable delivery dates.
5. To provide a basis for fair and sound incentive schemes.
6. To standardise the rate of performance of workers.

TECHNIQUES OF WORK MEASUREMENT

Following methods are commonly used in work measurement. The selection of a particular method depends on the job situation.

1. Time study.
2. Work sampling.
3. Analytical estimating.
4. Synthesis.
5. Pre-determined Motion Time System (PMTS).

1. Time Study

Time study is concerned with the direct observation of work while it is actually being performed by the operator. Time study is defined as a work measurement technique, recording the time and rate or pace of working for the elements of a specified job carried out under specified conditions, and for analysing the data so as to determine the time necessary for carrying out the job at a defined level of performance.

Time study is the most satisfactory and accurate technique for determining the time taken for completing a manufacturing operation but due to its nature it is mainly used for repetitive work.

The steps involved (Procedure) in taking time study are :

(*i*) Select the job to be studied.

(*ii*) Note all the details about the operations and the operator being studied.

(*iii*) Split the work cycle into suitable elements. 'An element is a distinct part of a job, selected for convenience of observation, measurement and analysis'. Any non-repetitive and occasional element in the manufacturing cycle should be noted separately.

(*iv*) Determine the number of cycles required to be timed to get desired accuracy.

(*v*) Observe and record the actual time taken by the operator for each element of the job.

(*vi*) Simultaneously rate or judge the pace of the operator's performance.

(*vii*) Different time readings for each element are recorded on the record sheet.

(*viii*) Average time for each element is calculated after eliminating the abnormal values. (This is also called observed time.)

(*ix*) The observed time for every element multiplied by the corresponding rating factor (expressed in %) gives normal time or basic time.

$$\text{Normal Time} = \text{Observed Time} \times \text{Rating Factor (\%)}$$

(*x*) Determine the allowances to be made over and above the basic time for the operation.

(*xi*) Determine the standard time by adding all allowances to normal time. (Standard time is also called allowed time.)

Before conducting the time study it should be ensured that the method being followed is satisfactory and the operator is proficient. Wrong methods and untrained workmen should not be timed. Also all the constituents of the job such as materials, equipment, tools, working conditions and method should be standarised before conducting the time study.

DEFINITION OF NORMAL TIME AND STANDARD TIME

Normal Time : Normal time or basic time is the time for carrying out a work or an element of work at standard rating, *i.e.*,

$$\text{Normal Time} = \text{Observed time} \times \text{Rating factor \%}$$

Allowances : The normal time per cycle is the time that a qualified worker would take just to perform the job. There is no provision, in the normal time, for the interruptions that occur on every job each day, such as time required by the worker for personal needs and rest and for delays due to reasons beyond his control. To compensate for these delays, as standard practice, the normal time is increased by adding certain allowances.

The various allowances can be classified as follows :

(*i*) Relaxation allowance.

(*ii*) Fatigue allowance.

(*iii*) Personal needs allowance.

(*iv*) Process / unavoidable delay allowance.

(*v*) Special allowances such as interference and contingency allowance (for any unforeseen event).

The allowances to be provided are given as a percentage of normal time or basic time. The total of all allowances provided usually amount to 15 percent of basic time.

Standard Time : Standard time is the total time in which a job should be completed at standard level of performance.

$$\text{Standard Time} = \text{Normal Time} + \text{Allowances}$$
$$= (\text{Observed Time} \times \text{Rating Factor \%}) + \text{Allowances}$$

Fig. 1.10 shows the details of standard time.

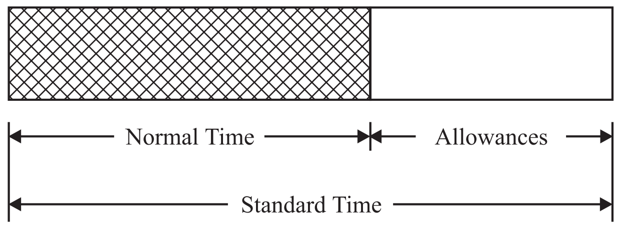


Fig. 1.10. Standard time

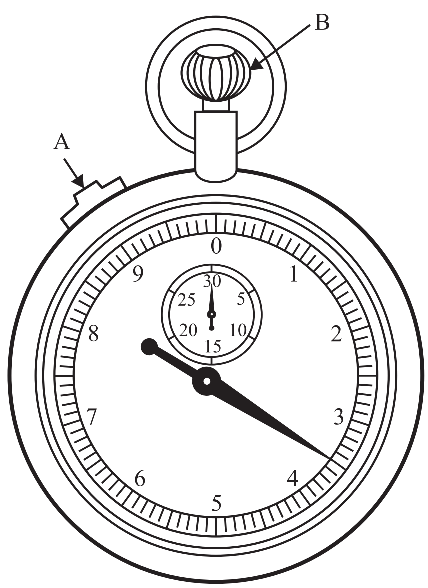
TIME STUDY EQUIPMENT

Stop Watch : The following are the two types of stop watches used :

(*a*) Decimal minute stop watch with a dial calibrated into 100 divisions, each division representing 0.01 minute. (1 full rotation of the needle corresponds to 1 minute).

(*b*) Decimal hour stop watch with a dial calibrated into 100 divisions and the needle completes 100 revolutions in one hour, *i.e.,* each division represents 0.0001 hour.

The decimal minute stop watch in industrial engineering work study practice is more common Fig. 1.11.



A = Slide for stopping and starting the stop watch.
B = Winding knob. Pressure on this knob returns both the hands to zero.
(i) Stop watch can be used for a maximum duration of 30 min. after which resetting required.
(ii) Div. in the outer dial = 0.01 min.

Fig. 1.11. Decimal minute stop watch

The stop watch used may be of flyback type or non-flyback type. In non-flyback stop watch, first pressing of the winding knob starts the watch and long hand begins moving. If winding knob is pressed second time, the long hand stops and with third pressing, hands return to zero position. In flyback system, the watch is started and stopped with the help of the slide. Pressing the winding knob brings the hands back to zero, but they do not stop, start immediately moving forward again. To stop the hands at any point, slide is used. Whatever type of watch is used, it should be checked for accuracy at regular intervals. For safety the stop watch should be clipped to the time study board. (After the study is over the watch should be allowed to run down to release the spring tension).

Time Study Board : Time study board is a flat board, usually of plywood or of suitable plastic sheet, on which forms for recording the time studies are placed using a clip. The size of the time study board should be larger than the largest of the forms likely to be used. Also it may have provision for fitting stop watch so that hands of the work study engineer are free. A time study board is shown in Fig. 1.12.

Observation sheet for time study

Observation sheet for time study	Sheet No..
Operation	Op. No.
Part name	Part No.
Machine name	Deptt.
Operator	Date
Experience on job	Years

Begin Finish Elapsed Time

Elements	Speed	Feed	Cycles 1	2	3	4	5	6	7	8	9	10	Average
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
												Total	

Average time for 1 cycle	
Rating factor %	
Normal time	
Personal allowance	
Fatigue allowance	
Other allowance	
Total allowances	
Standard time	

Tools, Jigs and fixtures used, if any

Observation taken by

Fig. 1.12. Time study board with stop watch and time study sheet

Time Study Forms : The time study data is recorded on forms of standard size called time study forms. The time study form can be easily held on the time study board. A time study form or sheet should be such that all essential information about the operation/process being studied can be recorded in it. A specimen of printed time study sheet is shown in the Fig. 1.12.

The time study sheet contains complete information about the operation being studied, the shop/ department, the material of part, part number/drawing number, operator's name, date, name of person who is taking time study and space for noting down the readings for individual elements The reverse side of the sheet can be used to note some other details about the process, sketch of the work place layout or part. When the time study for certain operation has to continue on more than one sheet, the continuation sheets may not have the top space for recording the common data. After completing the study, the various times for each element and then the operation as a whole are calculated as discussed earlier.

For measurement of time in time study, other sophisticated equipment such as motion picture cameras can also be used.

Motion Picture Camera : This is a camera which records or photographs the motions of an operator. The common speed of operation of these cameras is 1000 frames / minute. The time for each element is calculated by counting the number of frames which an element has taken for its completion. Thus the accuracy of timings obtained is 0.001 minute.

Number of Cycles to be Observed : The time required to perform an element of an operation varies slightly from cycle to cycle. The variation may be due to :

(*i*) Variation in the raw materials used for the operation.

(*ii*) Variation in reading the stop watch.

(*iii*) Possible difference in determining the exact end point at which watch readings are taken.

(*iv*) Variation in exact location of the parts and tools used by the operator.

Hence, the observed time should not be based on just 1 or 2 cycle of operations alone.

To obtain a reasonable representative time for any particular operation, a minimum of 10 cycles or readings should be taken. (The number of readings will depend on the precision and accuracy desired).

2. Work Sampling

Work sampling or activity sampling is a method of finding the percentage occurrence of certain activity by statistical sampling and random observations. Work sampling utilises the principle of drawing inferences from a random sample of the whole. It is an extremely useful work measurement technique as it is inexpensive, convenient, reliable and it can be done without using the stop watch or any subjective judgements of effort or rating (rate of performance).

Work sampling is particularly useful in the analysis of non-repetitive or irregularly occurring activities.

To determine the percentage of the working day that a worker or a machine is working or idle, the observer visits the workplace for predetermined number of times per day at random. The observations are recorded as follows : Fig. 1.13.

Observation as to working or idle	Tally (No. of observations)	%
Working	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 || (32)	80%
Idle	𝍸 ||| (8)	20%

Fig. 1.13. Work sampling observations

In the chart Fig. 1.13 the total number of observations made are 40, out of which 32 times the worker was found to be working and 8 times the worker was idle. The conclusion drawn is that 80 percent of the time $\left(\frac{32}{40} \times 100\right)$ the worker is working and 20 percent of the time $\left(\frac{8}{40} \times 100\right)$ the worker is idle.

Steps in Making Work Sampling Study

The following steps are involved in making work sampling study :

1. Define the problem
   (*a*) State the main objective or purpose of the study.
   (*b*) Describe the details of each element to be measured.
2. Obtain the approval of the incharge of the department/section in which the work sampling study is to be made. Make certain that the operators to be studied and other people in the department understand the purpose of the study and they should co-operate in the study.
3. Design the study
   (*a*) Determine the number of :
      (*i*) Observations to be made,
      (*ii*) Observers needed (if more than one observer is required). Select and instruct these people,
      (*iii*) Days or shifts needed for the study.

   There is a scientific procedure to determine the number of observations to be made, depending on the accuracy required. However, for practical purposes 40 to 50 observations spanning the entire period of activity of the concerned shop, office or plant are required. While determining the span or cycle of the period the peak periods and lean periods of the activity should be taken into consideration.

   (*b*) Make plans for taking the observations such as time and route to be followed by the observer. The visits to the shop for taking observations should be done randomly w.r.t. time of visit and route to be followed.
   (*c*) Design the observation form. Make the observations and record the data.
4. Summarize the data at the end of each day and at the end of the study period.
5. Make recommendations, if required.

Applications of Work Sampling

1. Work sampling is applied in the estimation of the percentage utilisation of machine tools and other equipment, workers etc.
2. It can be used to estimate the time consumed by various activities, *i.e.*, operation, supervision, repair, inspection etc.
3. Work sampling is also used to find out time standards, specially where job is not of repetitive nature and where time study by stop watch method is not applicable.

Time standards can also be calculated by the following formula :

$$\text{Standard time} = \text{Normal time} + \text{Allowances (expressed as a percentage of normal time)}$$

$$= \left[\frac{\begin{matrix}\text{Total time}\\ \text{in minutes}\end{matrix} \times \begin{matrix}\text{Working time}\\ \text{in percentage}\end{matrix} \times \begin{matrix}\text{Performance index}\\ \text{(rating) in percentage}\end{matrix}}{\text{Total number of items produced}}\right] + \text{Allowances}$$

Advantages and Disadvantages of Work Sampling Compared to Time Study

Advantages

1. It involves less cost as compared to stop watch study.
2. Many operations or activities which are difficult and costly to determine by time study can be readily estimated by work sampling.
3. It is possible to simultaneously study a group of operators and activities by a single work study engineer.
4. It does not involve any timing device like stop watch.
5. Observations may be taken over a period of days or weeks, thus decreasing the chance of day-to-day or week-to-week variations affecting the results.
6. If the study gets interrupted in between it does not introduce any error in the results.
7. Operator is not subjected to long periods of stop watch observations.
8. The random observations are taken thus avoiding prolonged observations.
9. This produces less fatigue and is less tedious to the work study engineer.

Disadvantages

1. It is not economical by this method to study a single operator or machine.
2. It is not economical by this method to study operators or machines located over wide areas.
3. This method does not break the job into elements and thus does not provide elemental details.
4. Workers may not be able to understand the principles of work sampling as easily as they do time study.
5. It normally does not account for the pace at which an operator is working.
6. No record of study of an individual operator is kept, therefore a new study must be made whenever a change occurs in any element in the method used.

3. Analytical Estimating

Analytical Estimating is defined as a work measurement technique whereby the time required to carryout the elements of a job, at a defined level of performance, is established from prior knowledge and practical experience of the elements and job concerned. Analytical estimating is used for non-repetitive work as in tool rooms and maintenance departments, where a standard time is to be estimated before the job is carried out. In analytical estimating the job is first broken down into elements and wherever possible the times for these elements are determined by adding individual elemental times. The records of individual elemental times are maintained by the industry based on the past data. The time for the remaining elements are estimated on the basis of experience. The elements are listed in the proper sequence. At the next stage an overall allowance is added to the total basic time for the job. The systematic procedure for conducting study by activity analysis (Analytical estimating) is shown in Fig. 1.14.

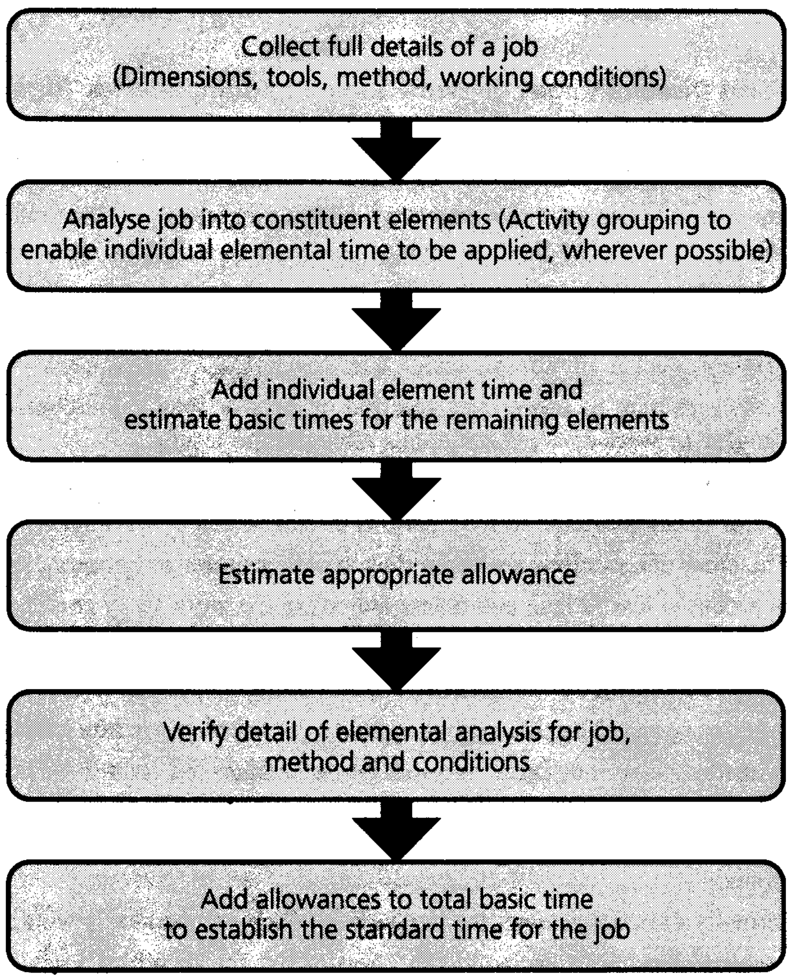


Fig. 1.14. Steps in Analytical estimating

The advantage of analytical estimating is that it extends the scope of work measurement to deal with jobs for which other techniques cannot be used. Standard times are available before the jobs are actually performed or undertaken. Possession of time standards by the industry for jobs like repair and service, plumbing, tool room work etc., will result in improved planning, scheduling, labour control and provide the means for designing and operating a sound financial incentive scheme.

4. Synthesis

Many operations can be conveniently synthesised (totalled up) from elemental times for which time study values have already been collected and are available. The time allowed for a job can, then, be quickly and economically determined by summing up the appropriate elemental times.

Elemental times are also called standard data, elemental data or synthetic time units or values. These should be compiled from very carefully chosen basic elements. All elemental times should be accompanied by the description of method, equipment used and end points of each element should also be defined.

5. Pre-determined Motion Time System (PMTS)

Pre-determined Motion Time System (PMTS) can be defined as a work measurement technique whereby times established for basic human motions (classified according to the nature of the motions and conditions under which they are made) are used to build up the time for a job at defined level of performance. PMTS is based on the assumption that any manual task done by the operators can be broken down into basic motions, based on elementary movements or therbligs. The Tables for times for elementary motions under varying conditions are available under PMTS standards from which the time required for the job is estimated.

Performance Rating

Performance rating is the process during which the time study engineer compares the performance of the operator under observation, with his own mental concept of normal performance. Mathematically,

$$\text{Performance rating or Rating factor \%} = \frac{\text{Observed performance}}{\text{Normal performance}} \times 100$$

The concept of normal performance or standard performance must be such that the time standards set from it must be within the capacity of majority of workers in the enterprise. Standard performance is the rate of output which qualified workers will naturally achieve without over exertion, as an average, over the working day or shift, provided they know and adhere to the specified method and that they are motivated to do their work and are under supervision. There are different methods used for performance rating :

1. Speed Rating.
2. Westinghouse System of Rating.
3. Synthetic Rating.
4. Objective Rating.
5. Physiological Evaluation of Performance.

1. Speed Rating

This method consists of judging the pace or speed of the operator's body/hand movements in relation to the normal pace and is taken as rating factor. This rating factor multiplied by observed time gives the normal time for that element or job.

2. Westinghouse System of Rating

This system of rating was developed by Westinghouse Company U.S.A.

In this system the time study engineer judges the performance rating of each element according to four factors *i.e.*,

(*i*) Skill,

(*ii*) Effort,

(*iii*) Conditions, and

(*iv*) Consistency.

A scale of numerical values for each factor is provided in the tabular form. The worker is observed while working and given a value from the tables. The time obtained from time study is then normalized by applying the sum of ratings of all the four factors. The numerical values for each factor are given in the Table 1.1.

Table 1.1. Westinghouse System of Rating

Skill			***Effort***		
+ 0.15	A1	Superskill	+ 0.13	A1	Excessive
+ 0.13	A2		+ 0.12	A2	
+ 0.11	B1	Excellent	+ 0.10	B1	Excellent
+ 0.08	B2		+ 0.08	B2	
+ 0.06	C1	Good	+ 0.05	C1	Good
+ 0.03	C2		+ 0.02	C2	
0.00	D	Average	0.00	D	Average
– 0.05	E1	Fair	– 0.04	E1	Fair
– 0.10	E2		– 0.08	E2	
– 0.16	F1	Poor	– 0.12	F1	Poor
– 0.22	F2		– 0.17	F2	
Conditions (i.e. working conditions)			***Consistency***		
+ 0.06	A	Ideal	+ 0.04	A	Perfect
+ 0.04	B	Excellent	+ 0.03	B	Excellent
+ 0.02	C	Good	+ 0.01	C	Good
0.00	D	Average	0.00	D	Average
– 0.03	E	Fair	– 0.02	E	Fair
– 0.07	F	Poor	– 0.04	F	Poor

For example, if the observed time for one operator is 5 minutes and if he is rated as follows :

	(From Table 1.1)
Skill B1	= 0.11
Effort B2	= 0.08
Conditions D	= 0.00
Consistency B	= 0.03
Total	**= 0.22**

This means 22 percent is added to the observed time to get normal time, so in this case.

$$\text{Normal time} = 5 \times \frac{122}{100} = 6.10 \text{ minutes.}$$

3. Synthetic Rating

It is a method of evaluating an operator's performance from values already known, called Pre-determined Motion Times (PMT) values. The procedure is to make a time study in usual manner, without rating operator's performance and then compare the actual time obtained for as many elements as possible with that of known standards. The rating for a particular element is given by

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

where R = Performance rating factor.

P = Pre-determined standard for an element.

A = Average of actual times obtained in the time study for that element.

4. Objective Rating

In this method, rating is done in two stages :

(*a*) In the first stage called pace rating, operator's speed of movement or pace of activity is rated and no attention is paid to job difficulty. This is called pace rating.

(*b*) In the second stage an allowance is added to the pace rating by considering the job difficulties For example, if the selected time or observed time for an element is 0.30 minutes, pace rating is 120 percent and factor for job difficulties is 25 percent, then the normal time for that element is $0.3 \times 1.20 \times 1.25 = 0.45$ minutes.

5. Physiological Evaluation of Performance Rating

There is a relationship between the physical work done by the operator and amount of oxygen consumed. Change in the rate of heart beat is a measure of physical activity. The changes in heart beats and oxygen consumption are used as a measure of performance rating.

ERGONOMICS : Instructional Objectives

After studying this unit, the student should be able to :

(i) Explain the meaning of the term "Ergonomics".

(ii) Explain how "Ergonomics" can be used to improve the productivity of workers.

(iii) Identify areas where ergonomics can be applied (such as design of machines, instruments and controls, design of work place and design of working environment).

(iv) Give some examples where ergonomics principles are applied to instrument design, machine design, design of work place and seating arrangements.

ERGONOMICS

Ergonomics is a scientific study that deals with the interactions between the human beings, the tools and the equipment (machinery) and the working environment. The subject has evolved out of two Greek words, "Ergon" and "Nomos". Ergon means work and Nomos means principles or laws; Ergonomics mean principles and laws concerning work.

The term "Ergonomics" was officially introduced by K.F.H. Murrell (in 1949) during the formation of Ergonomics Research Society in U.K. International Ergonomics Association (IEA) defines Ergonomics as "A scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance". Ergonomics is applicable to all the activities that a human body is performing, it is applicable in all the spheres of life of a human being.

Ergonomics professionals acquire specialization in making the products and workplaces more efficient, usable and safer. The knowledge and skill of ergonomics professionals covers wide areas of specialization such as occupational health and safety, product design, job design, equipment or machinery design, tool design, furniture design, work place design and working environment in factories and industries.

Ergonomics is also closely related to the topic "Human Factors Engineering".

Ergonomics is the link between the Engineering Sciences and the Human Sciences. (Fig. 1.15)

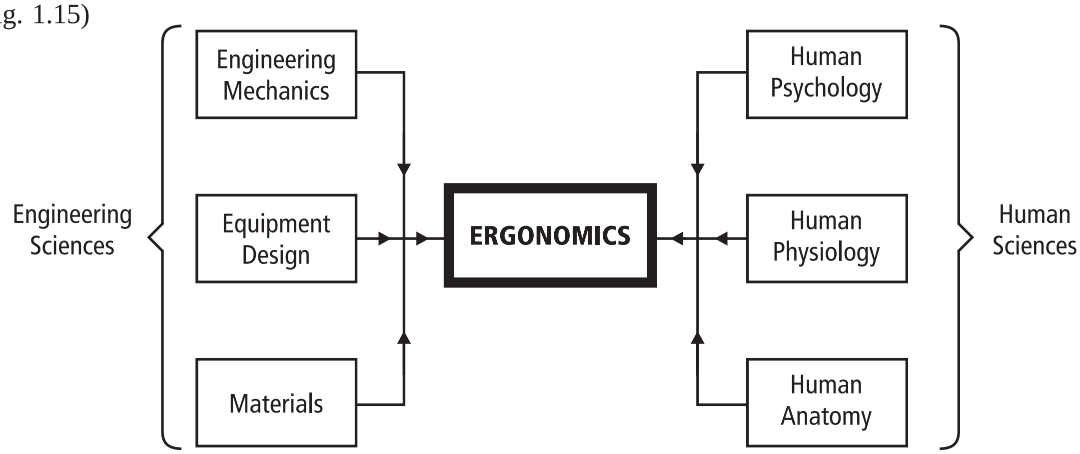


Fig. 1.15. Ergonomics linking the engineering sciences and the human sciences

Ergonomics is generally called as the science of fitting the job to the worker, and deals with the human operator and his working environment. It can be applied at the initial design stage when production lines and workplaces are being laid down, or it may be applied to improve the existing layout.

"Ergonomics" has developed from "work study" and the aim of Ergonomics and work study is to improve the work such that the operators fatigue and strain are reduced and the productivity and the efficiency of the manufacturing organization is increased.

Ergonomics is defined as the study of the relationship between man and his occupation, equipment and environment. Particularly the application of knowledge of anatomy, physiology and psychology to the problems arising therefrom. Ergonomics deals with applying knowledge of the human body and mind to industrial problems. Work study engineers have been doing this for years successfully, by using the medical science knowledge with intuition and practical common sense. In an ergonomics department / section more specialized knowledge and skills are available than could be possessed by the average work study practitioner.

Fig. 1.15 shows ergonomics as the link between the engineering sciences and the human sciences. Ergonomics is also known as "Human Factors Engineering.

The engineer studies the principles concerning the engineering sciences and technology. The activity of ergonomics brings together the two groups of specialists : those who know about machines and processes, and those who know about human capacities. If one observes the old machine in an old out of date factory, it may sometimes seem that the machine is clumsy, big and heavy to operate, the controls are out of easy reach, the lighting is poor, the instruments are difficult to read, and the environment is noisy and cold (or too hot). Ergonomics when applied, can show improvement in all the above features. The ergonomist studies the job with a view to keep it within human limitations, and makes the best use of human abilities. Ergonomics principles are applied to :

(*a*) Design of instruments and controls : This includes the design of the instruments which the operator must look at or listen to (called the **DISPLAY**), and the parts of the machine or equipment on which he exerts muscular force so as to change the state of the process or operation (called the **CONTROL**).

(*b*) Design of workplace : This includes the work space area around the operator, the working surface and seats.

(*c*) Design of working environment : This includes conditions of noise, lighting and other environmental factors.

1. Ergonomics Principles Applied to Instrument Design and Control

An instrument provides information, and the information should be displayed to the operator in the simplest manner. For example, a car engine temperature gauge need only display N for normal temperature, as against a fully calibrated scale which requires the motorist to know what is the normal working temperature for the engine. Display may be grouped into three types depending upon the type of information to be conveyed. These are :

(*a*) Qualitative display,

(*b*) Quantitative display, and

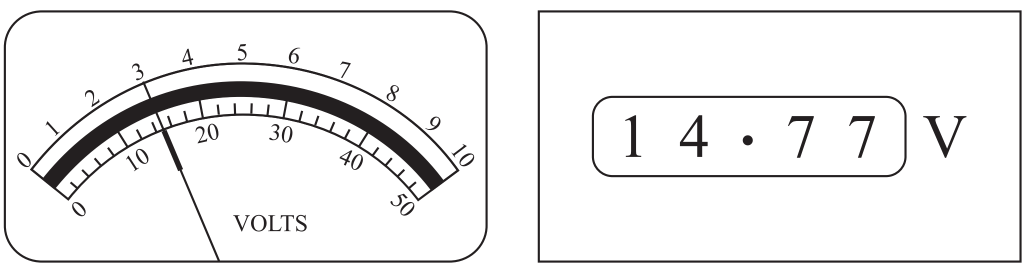
(*c*) Representational display.

(*a*) Qualitative display : These are used to indicate whether or not a particular function is being carried out, no numerical information being required from the display. They may be visual indicators, such as a red light which indicates that the main drive motor to a machine is running. Or, again a red light to indicate that a tool is broken on a transfer line. There is the problem of colour blindness here, and it should be remembered that visual indicators can not only have a different colour but also a different shape and size. A flashing light can be used for very important displays, this being shown to good effect on car direction indicators. There is a convention of colour codes. Red indicates danger to everyone. It may occur to the reader that the start button to switch on a machine tool might well be red (instead of green) in order to indicate that the machine is running when the button is pressed, and is therefore a source of potential danger to the operator.

Auditory or noise indicators, such as a buzzer or alarm, have the ability to attract immediate attention, this being a good feature for a warning display.

(*b*) Quantitative display : These are used where numerical information may be presented in *analogue* form or *digital* form.

Analogue indicators have a pointer which shows a reading on a scale analogous to the value it represents. A dial test indicator is an example, where one division on the scale may be analogous to 0.01 mm movement of the plunger. Fig. 1.16 (*a*) shows a typical analogue display.



(*a*) Analogue Display (*b*) Digital Display

Fig. 1.16

The disadvantage here is that a degree of estimation has to be used in order to decide on the position of the pointer between graduations. This type of display may also be qualitative. For example a rev/min. meter (revolutions counter) may have the scale coloured red beyond a certain value on the scale in order to indicate dangerously high revolutions per minute.

Digital indicators show the required information directly as a number. A kilometer in a car is an example where the number of kilometers covered can be read directly off the meter as a number. Fig. 1.16 (*b*) shows a digital version of a voltmeter.

The advantage here is that the precise reading to the desired accuracy can be read directly from the meter. However, for a quick approximate reading at a glance, the analogue version gives the best results.

The two types may be combined as shown in Fig. 1.17 when a rate indication is required for example (which might possibly be returned to zero as required), in addition to a cumulative quantity.

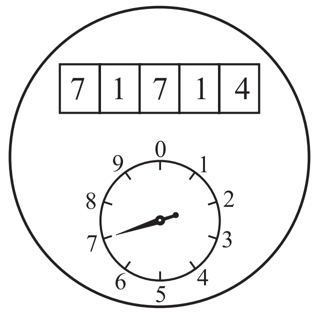


Fig. 1.17. Combined analogue and digital display

The important feature is that the scales are legible. White numerals on black background may in many instances prove to be clearer than vice versa. It is interesting to note the design and colour of the numerals on the motorway sign boards, compared to the older form used on most other roads. The type of scale used is important. Fig. 1.18 shows two analogue instruments displaying the same information.

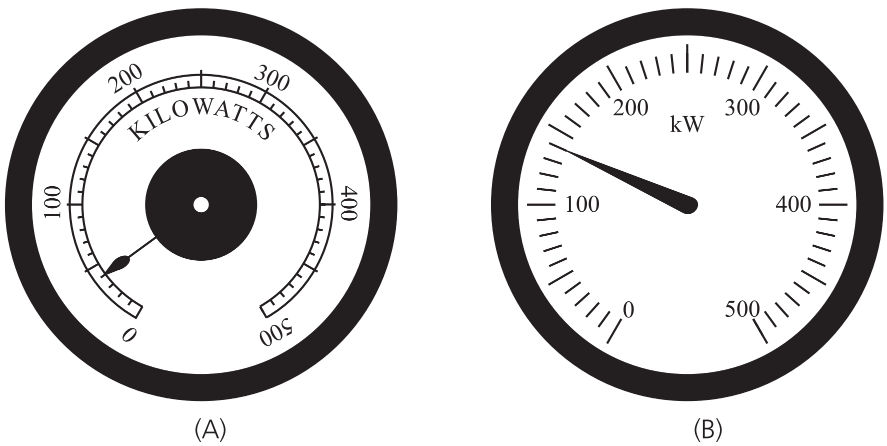


Fig. 1.18. Analogue Instruments

Instrument B is better than instrument A because :

1. Instrument scale B is simpler, bolder and hence more legible.
2. Instrument scale B is longer and divisions clearer because the numerals are inside the scale.
3. Numerals in scale B are upright, hence more legible.

There is a well known convention of scales which should be adhered to. These are shown in Fig. 1.19.

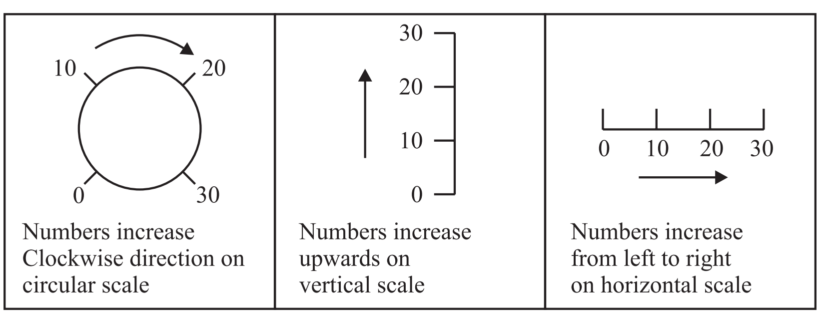


Fig. 1.19. Instrument scale convention

(*c*) **Representational display :** These are common in the chemical process industries (fertilizers, paint etc.). These are used to give a pictorial diagram or working model of a process. They are ideally suited to large processes because they give an overall display of the process. Examples can be found in modern railway signal boxes where a large display panel shows all the necessary information in a relatively simple manner. Simplicity must be the aim of the designer here, as shown in Fig. 1.20.

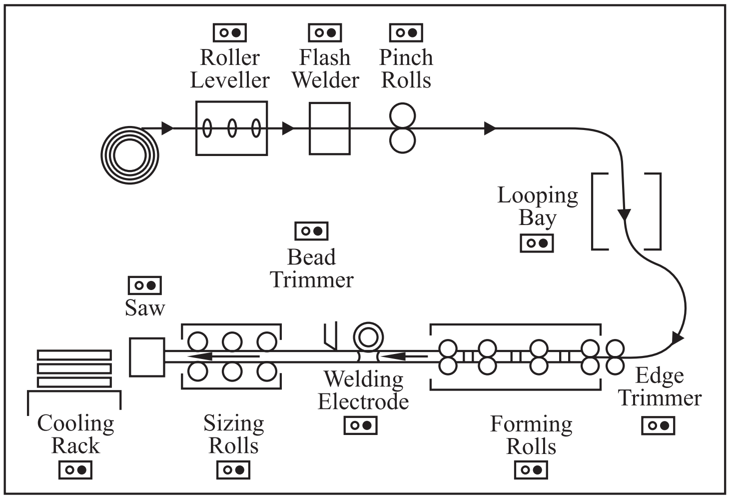


Fig. 1.20. Representational display showing a continuous tube welding process

The display shown would form part of a control panel and gives a visual indication of the state of the process. Light signals, as shown, by each operating point indicate which part of the process is active.

Multi-instrument display **:** In the case of a display having many instruments, a logical order or pattern of dials and pointers should be presented to the user. The pointers should all be set so that they are in the same position for the Normal reading of each instrument. (Fig. 1.21) where the clear contrast between dial and background should also be noted.

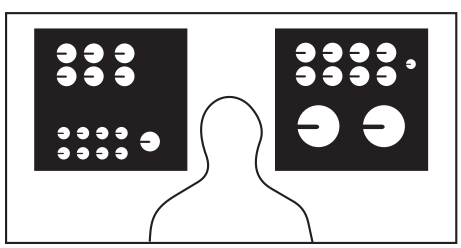


Fig. 1.21. Multi-instrument Display

The classic example of this principle is provided in the ergonomic design of the instrument display in the cockpit of a modern airliner.

2. Ergonomics Principles Applied to Machines and Controls

Levers, knobs, handwheels etc., should be positioned so that the operator can manipulate them with the least change in body position and with the greatest mechanical advantage. The operator is not expected to leave his normal working position (which may be sitting or standing) in order to reach a machine control. The controls should be placed comfortably close and in front such that the operator does not need to bend and twist to reach them. The ideal positions may be impossible to attain in the design of a machine because of difference in height and other anatomical dimensions, difference in sex and because majority of people being right handed. However, a machine for general use should be designed to suit the average human being, and statistics are available to help to do this. The function of a control should be considered when its position is determined. If fine, delicate adjustment is required then it should be located near the fingers. If heavy force is required then the legs through the medium of the feet can exert a large force. Foot operated controls relieve the hands for other tasks.

Ergonomists with their specialized knowledge have carried out extensive research on the force, speed and accuracy with which a man or woman can manipulate a control with any limb. Some general conclusions are :

Force : An operator can employ up to 15% of his maximum strength for an hour or so without rest, and up to 25% of his maximum strength for intermittent short periods all day. (Note — His maximum strength is usually measured over a period of 5 seconds).

'Jerk' forces which are used to displace tight controls are believed to be twice the magnitude of maximum steady forces. The maximum steady force which can be maintained on a control depends largely upon how the control is positioned relative to the operator.

Speed : This depends upon the shape of the control and again where it is positioned. Hand controls can be operated faster if they are located at, or just below, elbow height.

Accuracy : Depends not only on the design of the control but on the clear presentation of the information such as graduating marks/divisions to the operator.

Ergonomics principles applied to control design have resulted in certain types of controls being found to be most suitable for certain functions. The following table, along with Fig. 1.22 gives a summary of the suitability of different types of controls for different purposes.

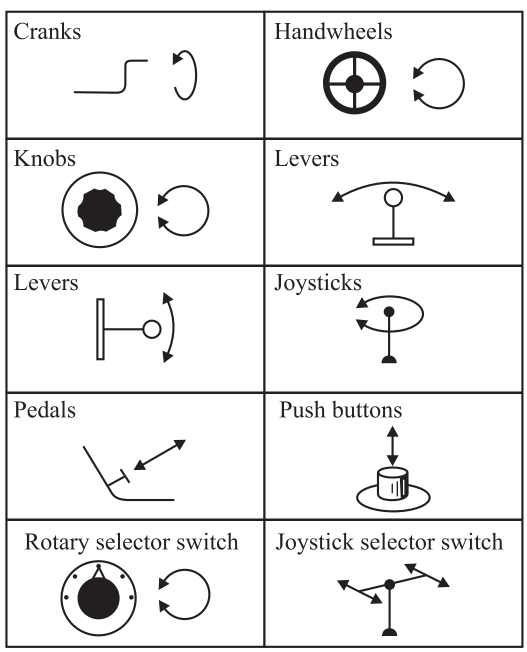


Fig. 1.22. Types of controls for different purposes

Suitability of Various Controls for Different Purposes

Type of control	Suitability for tasks involving				
	Speed	**Accuracy**	**Force**	**Range**	**Load (Newtons) or Torque (Newton metre)**
Cranks : Small Large	Good Poor	Poor Unsuitable	Unsuitable Good	Good Good	Up to 5 Nm Over 5 Nm
Handwheels	Poor	Good	Fair	Fair	Up to 20 Nm
Knobs	Unsuitable	Fair	Unsuitable	Fair	Up to 2 Nm
Levers : Horizontal	Good	Poor	Poor	Poor	Up to 110 N*
Vertical (to-from body)	Good	Fair	Short : Poor Long : Good	Poor	Up to 135 N*
Vertical (across body)	Fair	Fair	Fair	Unsuitable	One hand up to 90 N* Two hands up to 135 N*
Joysticks	Good	Fair	Poor	Poor	20 – 90 N
Pedals	Good	Poor	Good	Unsuitable	130 – 900 N depending on leg flexing and body support (ankle only up to 90 N)
Push buttons	Good	Unsuitable	Unsuitable	Unsuitable	10 N
Rotary Selector Switch	Good	Good	Unsuitable	Unsuitable	Up to 1 Nm
Joystick Selector Switch	Good	Good	Poor	Unsuitable	Up to 135 N

* When activated by an operator in standing position, depends on body weight.

In the case of the smaller hand controls, such as knobs or switches which are used for instrument control for example, it will be found that a larger diameter is most suitable for fine, sensitive control. Small diameter knobs can be used for coarse adjustment. Switches controlling power are best accompanied by a red indicating light which shows power on. Pointer shapes should be used on knobs which are designed to indicate some value, as shown in Fig. 1.23.

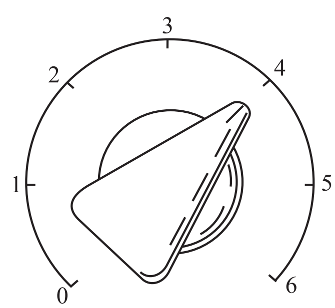


Fig. 1.23. Switch Knob

Knobs should be distinguishable by shape so that the control can be recognised by feel alone Fig. 1.24.

Where controls switch on or off, accepted conventions should be rigidly adhered to, with switches, pressing downwards is ON, or with rotary switches, turning clockwise is ON.

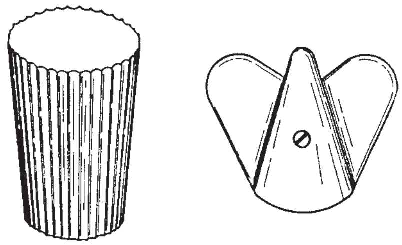


Fig. 1.24. Knobs

Again, where controls are combined with a display, accepted conventions should be rigidly adhered to. These are shown in Fig. 1.25. It should be remembered that in a moment of danger when the operator is under stress, he will almost certainly resort to actions which come to him naturally from a lifetime of experience.

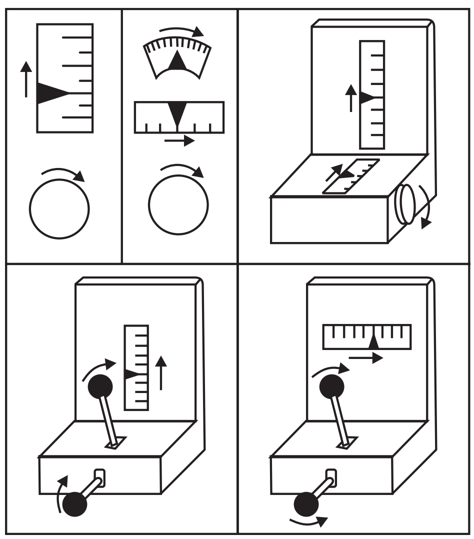


Fig. 1.25. Convention for controls

As is common using work study techniques, a 'mock up' *i.e.*, a model of a console, machine operating position or workplace layout should be made and tested before a design is finalised.

3. Ergonomics Principles Applied to the Layout of a Workplace

Many of the problems encountered in the ergonomic design of machines and controls will be applicable to the design of workplace layouts also. The workplace is a space in a factory, machine or vehicle which must accommodate an operator or operators, who may be sitting or standing. The efficiency of the operator will depend upon how the workplace is designed. Ideally, a workplace should be custom built for the use of one person whose dimensions are known. For general use, however, a compromise must be made to allow for the varying dimensions of humans. The ergonomist should be knowledgeable, not only in the science of anatomy but also anthropometry, *i.e.*, the measurements of people.

A general purpose machine should be designed for the average person. However, if one considers an operator who may be either sex, seated or standing at a work place, there are very few persons with average dimensions for *all* limbs. Therefore, a workplace should be so proportioned that it suits a chosen group of people. Adjustment may be provided (on seat heights for example) so that a group of people can use the workplace. If one considers the workplace (driving control area) in a modern motor car which will be required to suit one or two people from a large population, the benefits of adjustment should be provided. Ideally, the seat should be adjustable for height, inclination and position, the steering wheel for height, and the control levers and pedals for length.

Detailed anthropometric information is available for the different sexes, but simpler information could be obtained once the group of persons likely to use the workplace (or series of workplaces) is known. Fig. 1.26 shows suggested critical dimensions for a group of males using a seated workplace. These dimensions can be obtained quickly and easily and will be quite satisfactory for constructing a mock up of the proposed design.

Shaded area shows maximum work area. X shows approximate work position.

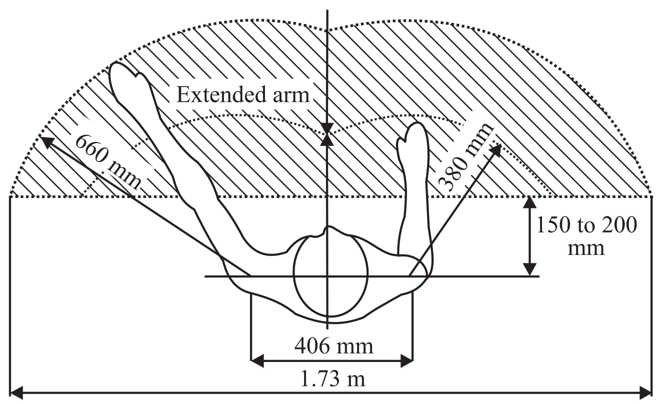


Fig. 1.26. Critical dimensions for seated male operator

Fig. 1.26 shows the left hand covering the maximum working area and the right hand covering the normal working area.

(*a*) Normal working area : The space within which a seated or standing worker can reach and use tools, materials and equipment when his elbows fall naturally by the side of the body.

(*b*) Maximum working area : The space over which a seated or standing worker has to make full length arm movements (*i.e.*, from the shoulder) in order to reach and use tools, materials and equipment.

Assuming the work is some operation requiring equipment, any tools, bins, etc. should be placed within the area shaded so that they can be seen and reached quickly and easily. The body dimensions given in the simple example shown in Fig. 1.26 must be the smallest in the group, not the average, in order that all can reach the equipment. If the equipment is numerous, then some tools might have to be placed outside the shaded area thus causing undue reaching for the minority of the people. The position of the seat must be adjustable.

Fig. 1.27 shows the situation with respect to bench (or work table) heights and seat heights.

In this view the seat should be adjustable for height and inclination. It is not usually convenient to have adjustable benches or work tops and the value of 712 mm to 762 mm is probably the best compromise dimension. With fixed bench heights, varying thickness footboards are a help for varying sized operators, particularly where the operator is standing. The design of seats is a specialist activity, and much data is available for dimensions and shapes. A seat should give good support for back, buttocks and thighs as it is a springboard for seated muscular activity. This criterion of support can be

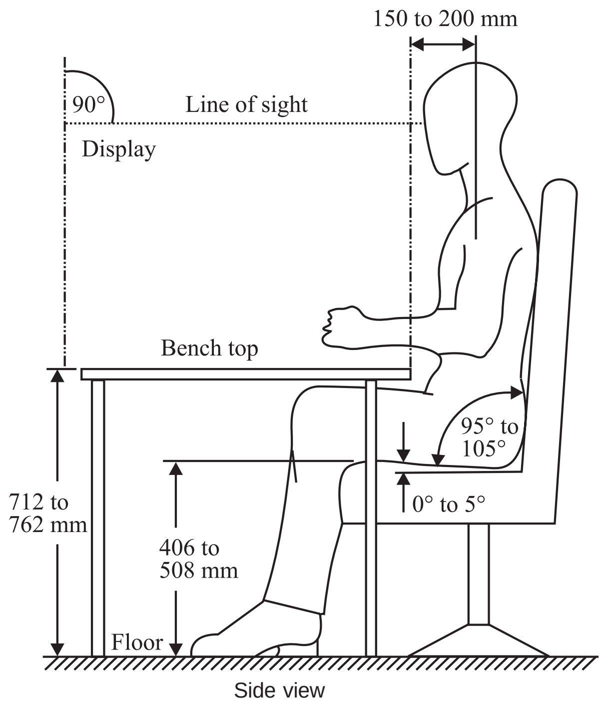


Fig. 1.27. Bench and seat heights

seen to conflict with that of comfort if a seat is required to meet both. Yet again, a good compromise usually gives best overall results. Ideally, with a seated workplace, the feet should be firmly on the floor or footboard, body and back well supported and comfortable and work top on or below elbow height when seated.

If an instrument display forms part of the workplace, then the size of the display should be such as to easily readable by all. Also the display panel should be at right angles to the line of sight of the operator.

In the case of tote (*i.e.*, collection) boxes, bins, loose or portable tools, etc., there should be a definite place for their location within the working area. Hence, the operator can develop habitual, confident movements when reaching for equipment often without any need for the eyes to direct the hands. The mental effort and strain are less. For the same reason, material and tools used at the

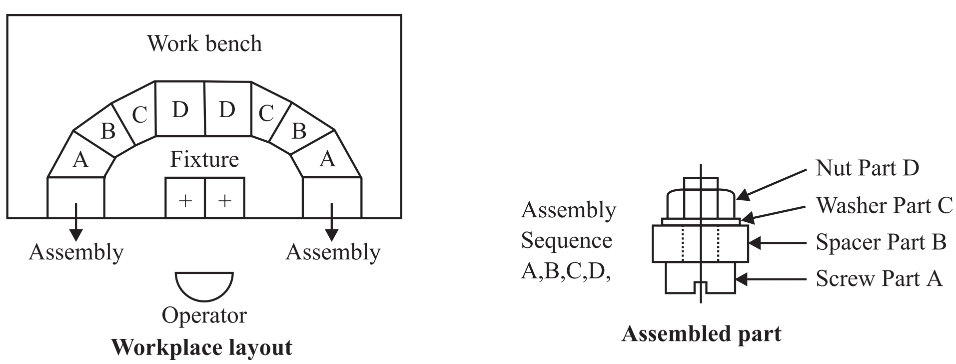


Fig. 1.28. Work place layout for assembled part.

workplace should always be located within the working area to permit the best sequence of operations. This is shown in Fig. 1.28.

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

Where possible clear access should be given around industrial workplaces to allow for adequate supervision and inspection. If workplaces are inside a conveyor system, access must be provided for the operator in case of fire or other emergency. If necessary, this must be done by bridging a conveyor. The Factories Acts stipulate certain regulations which must be observed in respect to 'safe means of access and place of work'. If sound ergonomic principles are observed in the design of workplaces, then the operator will be more efficient, less strained and tired and consequently less liable to have an accident. It is difficult to improve a poorly designed layout which has been established and used for some time. In the beginning itself, a good workplace layout should be used.

EVALUATIVE QUESTIONS ▶ METHOD STUDY

1. What do you understand by the term work study ? What are the objectives of work study ?
2. Explain what do you understand by method study ? Give the procedural steps employed in conducting method study.
3. What are the various symbols used in work study for making charts. Give two examples of use of each symbol.
4. What are the various recording techniques used in methods study ? Explain briefly.
5. The flow process chart for inspection, stencilling and filling of drums is shown in Fig. 1.29 and the floor plan is shown in Fig. 1.30. Draw the flow diagram for the same. Also suggest if any improvement can be made in the plant layout to improve the working method.

Job ________ Inspection, Stencilling and Filling of drum (5 cubic meters size) in stock.

Chart begins ___________ Empty drum in stock.

Chart ends ____________ Filled drum in stock.

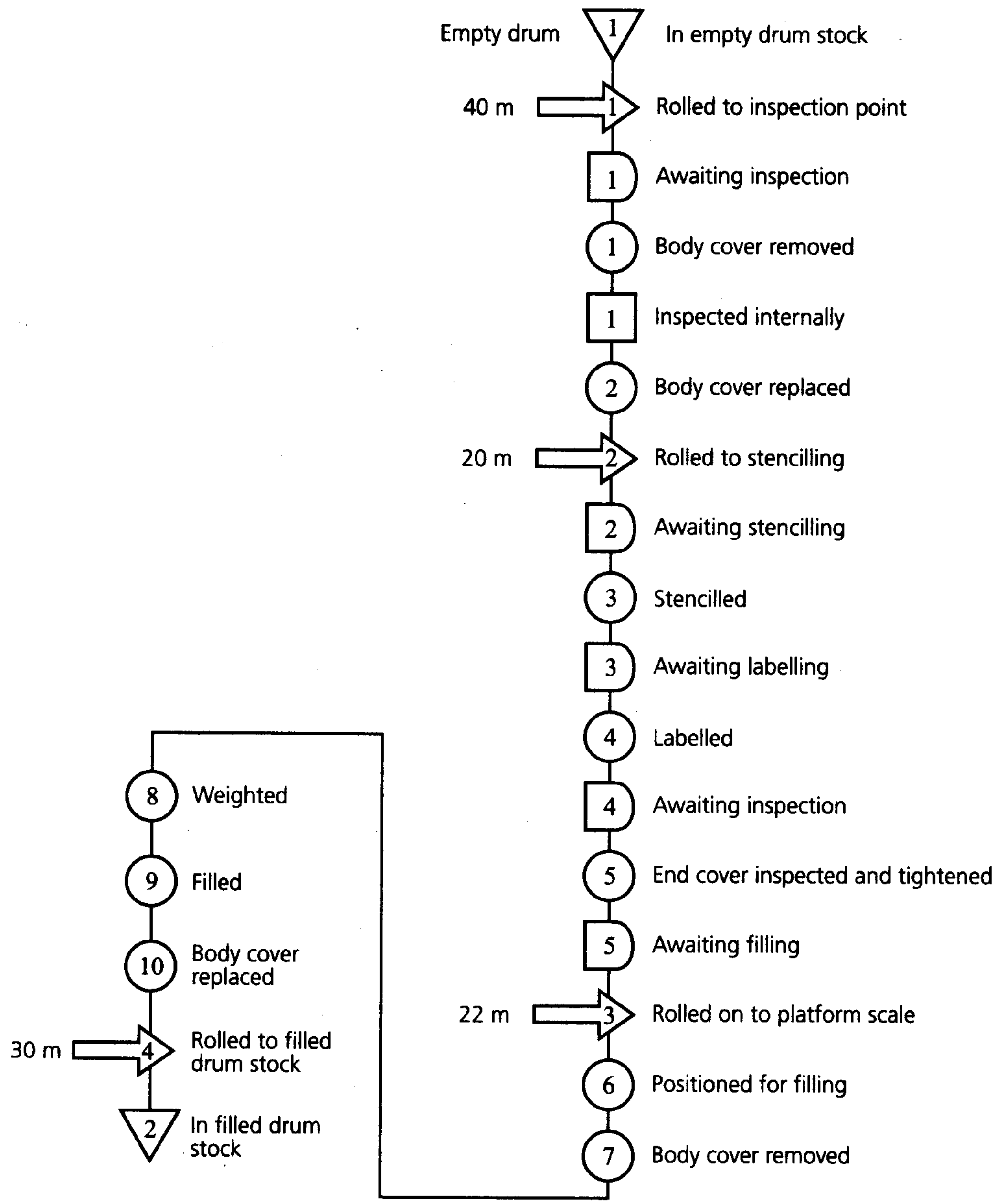


Fig. 1.29. Flow process chart – Material type

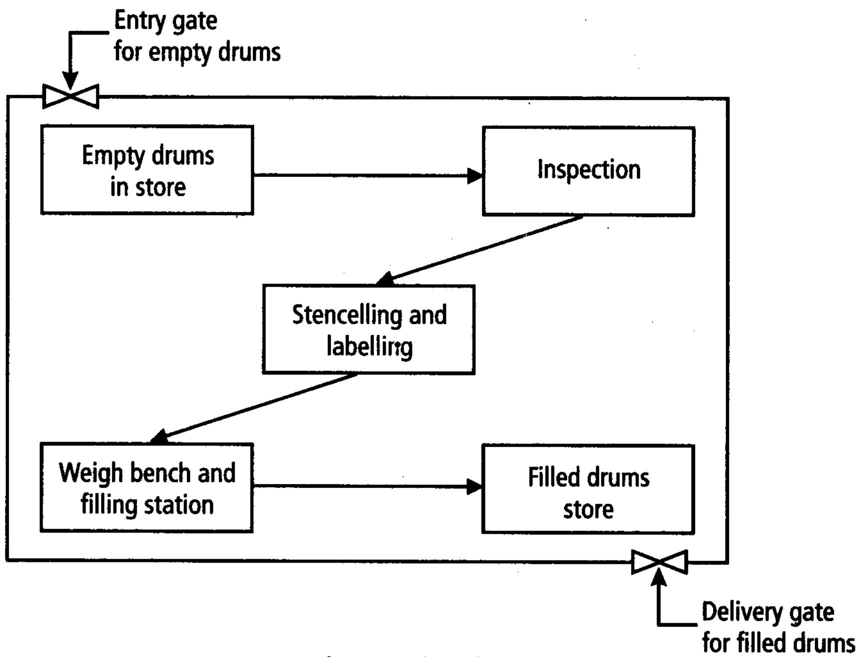


Fig. 1.30. Floor Plan

6. An induction hardening machine is being run by an operator to harden the surface of an automobile component. Following details are given :

Time for loading = 1 minute.
Time for unloading = 1.5 minute.
Hardening time = 3.5 minutes.
Cost for induction = Rs. 100 per hour.
Hardening machine operator cost = Rs. 10 per hour.

Draw a man-machine chart and calculate :

(*a*) Cycle time.
(*b*) Pieces hardened per hour.
(*c*) Hardening cost per piece.

7. Draw a two-handed process chart for rope and clip assembly.

8. Write short notes on :

(*i*) Use of diagrams and models in method study.
(*ii*) Flow diagram.
(*iii*) String diagram.
(*iv*) Travel charts.
(*v*) Symbols used in recording.

9. Tick the correct statements from the following :

(*a*) Work study increases the work content. ☐

(*b*) Work study increases production but decreases productivity. ☐

(*c*) Work study is used only in the manufacturing organisations. ☐

(*d*) Work study increases the cost of production. ☐

(*e*) Work study increases the idle time. ☐

(*f*) Work study helps in finding the correct sequence of operations. ☐

(*g*) Work study helps in identifying the unwanted operations. ☐

(*h*) Work study can be applied to all human activities. ☐

(*i*) Work study reduces fatigue of the operator. ☐

EVALUATIVE QUESTIONS ▶ WORK MEASUREMENTS

1. Explain what do you mean by work measurement and the various methods used for work measurement.

2. What is the equipment used in time study ? Explain the working of a decimal stop watch.

3. What do you understand by Analytical Estimating ? Give the procedure for conducting work measurement study by analytical estimating.

4. What do you understand by work sampling ? List the procedural steps in work sampling and give its areas of use.

5. Explain briefly the various methods used for rating the performance of an operator.

6. A worker takes 0.5 minute to do a job and his performance rating is 80 percent. What is normal time ? If the fatigue allowance is 10 percent of normal time and the worker spends one hour in one day (8 hour shift) on machine setting and personal work etc., what is standard time ?

7. A work sampling study was carried out in a machine shop having 10 machines over a period of ten working days. Number of rounds made per day on these machines are twenty and following observations are made :

(*a*) Number of times machine was under breakdown = 200 times.

(*b*) Worker not in place of work = 500 times.

(*c*) Worker waiting for material = 400 times.

Rest of the time the machine was found to be working. Calculate

(*i*) Percentage utilization of machine.

(*ii*) Percentage lost in waiting for material.

(*iii*) Which area should be tackled first to ensure better machine utilization.

8. Choose the correct answer(s) from the given alternatives :

(A) A decimal minute watch can read correctly up to :

(*a*) 0.1 minute

(*b*) 0.01 minute

(*c*) 0.001 minute

(*d*) $\frac{1}{60}$ minute

(B) Normal time is calculated by :

(*a*) Adding fatigue allowance to basic elemental time.

(*b*) Adding rating factor to basic elemental time.

(*c*) Multiplying observed elemental time by rating factor.

(*d*) Adding personal allowance to basic elemental time.

(C) Standard time is calculated by :

(*a*) Adding allowances to observed elemental time.

(*b*) Adding fatigue allowance to normal time.

(*c*) Adding allowances to normal time.

(*d*) Multiplying basic time by rating factor.

(D) Work sampling is used to :
- (*a*) Develop standard time for a job.
- (*b*) Find the rating factor.
- (*c*) Find the percentage of idle time.
- (*d*) Find the skill required in doing a job.

9. Tick the correct response : (Yes or No)
- (*a*) Analytical Estimating requires job knowledge. (Yes / No)
- (*b*) Stop watches are used for Analytical Estimating. (Yes / No)
- (*c*) Time study is taken before standardizing the method. (Yes / No)
- (*d*) Work sampling is carried out to find rating of a worker. (Yes / No)

10. Write short notes on :
- (*a*) PMTS
- (*b*) Westinghouse System of Rating
- (*c*) Standard time
- (*d*) Advantages and disadvantages of work sampling compared to time study.

11. Explain how you will proceed to rate :
- (*a*) The pace of a man walking on a level ground.
- (*b*) The pace of a man dealing a pack of playing cards.

12. The time study data for drilling three holes in a connecting link rod is given in Table 1.1. Calculate the standard time for drilling of one connecting rod.

The job description is :
- (*a*) Drilling machine pillar type, and drilling machine capacity 25 mm diametre.
- (*b*) Drill Jig is used for holding the hob on machine.
- (*c*) Pieces to be drilled are lying in a bin near the machine.
- (*d*) After drilling, the job is put in another bin lying near the machine.

Use the following information in calculating standard time. 10 connecting rods have been machined.

Rating factor 110 per cent.

Solution :

Average time for element (1)

$$x_1 = \frac{0.06 + 0.05 + 0.07 + 0.05 + 0.06 + 0.07 + 0.05 + 0.05 + 0.06 + 0.05}{10}$$

$$= \frac{0.57}{10} = 0.057 \text{ min.}$$

Average time for element (2)

$$x_2 = \frac{0.13 + 0.12 + 0.10 + 0.10 + 0.10 + 0.11 + 0.10 + 0.10}{8}$$

$$= \frac{0.86}{8} = 0.108 \text{ min.}$$

Average time for element (3)

$$x_3 = \frac{0.40 + 0.41 + 0.40 + 0.38 + 0.39 + 0.38 + 0.38 + 0.37}{8}$$

$$= \frac{3.11}{8} = 0.39 \text{ min.}$$

Average time for element (4)

$$x_4 = \frac{0.07 + 0.07 + 0.06 + 0.07 + 0.08 + 0.06 + 0.07 + 0.07 + 0.07}{9}$$

$$= \frac{0.62}{9} = 0.068 \text{ min.}$$

Average time for element (5)

$$x_5 = \frac{0.02 + 0.02 + 0.02 + 0.03 + 0.03 + 0.03 + 0.03 + 0.02 + 0.02 + 0.02}{10}$$

$$= \frac{0.24}{10} = 0.024 \text{ min.}$$

Total average cycle time = 0.057 + 0.108 + 0.390 + 0.068 + 0.024

= 0.647 min.

Rating factor = 110 percent

Normal time = 0.647 × 1.10

= 0.712 min.

Allowances = 25 percent of normal time

$$= 0.712 \times \frac{25}{100} = 0.178 \text{ min.}$$

Standard time for drilling of 1 connecting rod = Normal time + allowances

= 0.712 + 0.178

= 0.890 min.

Table 1.2 : Observation Sheet for Time Study (After recording the time for 10 cycles)

Sheet No. 1

Operation : Drilling	Op. No. 20
Part Name : Connecting Link Rod	Part No. W-020-25-110
Machine Name : Hand feed drilling machine	Deptt. Machine shop
Operator : Mr. XYZ	Date : 10 April, 2005
Experience on Job : 5	Years
Begin Finish Elapsed Time :	Unit Selected

Elements	**Speed**	**Feed**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
1. Pick-up job from bin			0.06	0.05	0.07	0.05	0.06	0.07	0.05	0.05	0.06	0.05	0.057 min
2. Tighten drill jig			0.13	0.12	0.10	0.10	0.18*	0.19*	0.10	0.11	0.10	0.10	0.108 min
3. Drilling three holes			0.40	0.41	0.40	0.38	0.39	0.38	0.59*	0.56*	0.38	0.37	0.390 min
4. Unclampling of job			0.07	0.07	0.06	0.07	0.08	0.16*	0.06	0.07	0.07	0.07	0.068 min
5. Remove from Jig and placed in a bin			0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.024 min
6.													
7.													
8.													
9.													
10.													
												Total	0.647 min

Average time for 1 cycle	0.647 min.
Rating	110%
Normal time	0.712 min.
Personal allowance	—
Fatigue allowance	—
Other allowance	—
Total allowance	25% of normal time
Standard time	0.89 min.

Tools, Jigs and Fixtures used, if any

(* indicates extreme value, not considered in the calculation of average)

Drilling Jig. No. ___________

Observation taken by Mr. ABC

EVALUATIVE QUESTIONS ▶ ERGONOMICS

1. What is Ergonomics ? Who is an Ergonomist ? What special skills does he require and how do you think these skills can be acquired ?

2. Define a

(*i*) Qualitative display

(*ii*) Quantitative display

(*iii*) A representational instrument display

Give one example of the application of each type.

3. Sketch the outline of a suggested dash board instrument display for a family car which should include the means of indicating

(*a*) Road speed in km/hr.

(*b*) Quantity of petrol contained in the tank.

(*c*) Engine running temperature.

(*d*) Oil pressure.

(*e*) Ignition working.

(*f*) Total distance covered.

(*g*) Battery discharge in Amps.

4. Examine the controls of a machine tool in your College workshop. Constructively criticize the layout of the controls from the point of view of accessibility for the students, safety, force required to operate them, colour, pictorial representation which indicates on a panel close to the control how it should be operated (if any), and the direction of operation of the control (check if the accepted conventions are observed). Suggest any alterations you think would improve the layout.

5. Assume you have to design a table and a chair on which a simple assembly operation is to be carried out by every student of your class. Obtain the appropriate limb dimensions for all the class, and hence arrive at the most suitable bench height, seat height and working areas for the table.

6. 15 Amp. electric plugs are to be assembled by hand. Simulate this process on a table fixing the position of the boxes holding the various component parts. Assume that the position and amount of light on the workplace can be varied suiting the operators. Draw the layout of the table showing the position of different boxes.

2 PROCESS PLANNING

PROCESS PLANNING : Instructional Objectives

After studying this unit, the student should be able to :

(i) Explain how a product is designed.
(ii) Explain the steps involved in process design.
(iii) Enumerate the factors affecting process design.
(iv) List the types of production and their characteristics.
(v) Distinguish between specialization, simplification and standardization.
(vi) Define process planning and list the steps involved in process planning.
(vii) State what is BOM (Bill of Materials) and its uses.
(viii) State the data that will be present in a process sheet, and the uses of process sheet.
(ix) Explain "Routing" and "Route Sheet" in the context of process planning.
(x) Calculate man-hrs. and machine-hrs. for a manufacturing situation.
(xi) Explain the use of computers in process planning and cost estimation.
(xii) State the two approaches adopted in CAPP (Computer Aided Process Planning).
(xiii) Explain what is Retrieval CAPP system and Generative CAPP system.
(xiv) Distinguish between Retrieval CAPP system and Generative CAPP system.
(xv) State the advantages of CAPP.
(xvi) State the factors involving in selecting a particular process.
(xvii) List the factors involved in machine selection.
(xviii) List the process selection parameters.
(xix) State the parameters involved in material selection.
(xx) List the documents required for process planning.
(xxi) Develop manufacturing logic involved in process planning by studying certain examples.
(xxii) Select cost optimal process using break-even chart.
(xxiii Draw a break-even chart given various cost elements.
(xiv) Work out certain problems involving break-even quantity.
(xv) Determine break-even quantity from various cost data given.

PRODUCT DESIGN

A product is designed to meet certain functional requirements, and to satisfy the customers needs. At the same time product must be aesthetically appealing to the customer or user. New technology and new materials currently available will also be explored during the product design stage. A product consists of assemblies, sub-assemblies and component parts. If the product is to be manufactured to customer's specifications, the design is provided by the customer. The manufacturer's product design department will not be involved.

If the product is proprietary, the manufacturing firm is responsible for the design and development of the product. The cycle of events that initiates a new product design often originates from the sales and marketing department. The departments of the firm that are organized to perform the product design function might include, Research and Development, Design engineering, Drafting, and perhaps a Prototype shop.

The product design is documented by means of *component drawings, specifications, and a bill of materials that defines how many of each component go into the product*. A prototype is often built for testing and demonstration purposes. The manufacturing engineering department is sometimes consulted for advice on matters of produceability or manufacturability. Questions like "What changes in design could be made to reduce production costs without sacrificing function" ? are raised and answers sought. Cost estimates are prepared to establish an anticipated price for the product.

Upon completion of the design and fabrication of the prototype, the top company management officials are invited for a presentation and discussion held. The design engineer gives a presentation and demonstration of the product so that management can decide whether to manufacture the item. The decision is often a two-step process. The first is a decision by engineering management that the design is approved. The second step is a decision by top corporate management as to the general suitability of the product. This second decision represents an authorization to produce the item.

MANUFACTURING PLANNING

The information and documentation that constitute the design of the product are considered in the *manufacturing planning*. The Departments in the organization that perform manufacturing planning include manufacturing engineering, industrial engineering, and production planning and process planning.

PROCESS DESIGN

Industry employs a set of procedures in the design of manufacturing processes. Generally speaking this activity starts with the receipt of the product specifications and ends with the final plans for the manufacture of the product. In a broad sense this pattern of activity is uniform, regardless of the kind of product or the type of manufacturing involved. The steps involved in process design are as follows.

(*i*) A careful review of the product design and specifications to make sure that economical manufacture is feasible.

(*ii*) Determination of the methods of manufacture that will result in the optimum manufacturing cost.

(*iii*) Selection or development and procurement of all machines, tools, and other equipment required for the manufacture of the product at the required quality and rate of production.

(*iv*) Layout of the production area and auxiliary spaces, and installation of the manufacturing facilities.

(*v*) Planning for and establishing the necessary control of materials, machines, and manpower to ensure the effective utilization of the manufacturing facility for the economical production of the product.

The above steps may be identified as functions of various activities, such as manufacturing engineering, process engineering, process planning methods engineering, or tool engineering. The scope of process-design activity can be identified as all work that is necessary to arrange for the manufacture of the product by the most economical means.

BASIC FACTORS AFFECTING PROCESS DESIGN

There are three basic factors that affect the design of a manufacturing process, namely:

(*i*) The volume or quantity of the product to be manufactured.

(*ii*) The required quality of the product.

(*iii*) The equipment that is available, or that can be procured, for the manufacture of the product.

The volume to be manufactured must always be considered as the volume to be produced within a given period — or as the rate of production. In this manner it can be related to the capacity of the manufacturing equipment under consideration and the best methods selected accordingly.

The anticipated volume should be based also upon a sales forecast. This is of particular importance in the introduction of a new product. Funds should be allocated for the improvement of processes only when the forecast indicates such a volume of sales that an appropriate return on the investment can be realized.

Generally speaking, the greater the volume of the product to be produced, the greater is the opportunity to incorporate advanced methods of manufacture into the design of the manufacturing process.

The number of identical units to be produced vitally affects the selection of manufacturing methods. The savings per unit of product or per component part, when multiplied by the total volume to be produced will give an idea of the money that can be allocated for the purchase of modern equipment. It may justify new and better machine tools, the use of numerically controlled machines, etc. It will also justify better auxiliary equipment such as jigs, fixtures, or dies, which will in turn increase the productive capacity of the existing equipment in the plant.

Methods of manufacture vary widely with the volume to be produced. The production of heavy industrial equipment and machinery involves very few units of product, requires skilled machinists or other craftsmen using general-purpose machines and tools, and assembly is by skilled labour. On the other hand, the mass production of washing machines, refrigerators, TVs, automobiles, and similar goods is accomplished with a large proportion of automatic machinery and on a planned assembly line that requires a minimum of skill.

TYPES OF PRODUCTION

Depending upon the type of industry and manufacturing situations, production can be divided into various types as follows:

(*i*) *From selling point of view*, products are manufactured either to customers' order or to stock. In manufacturing to customers' order, production of any product is taken up only when you have customers' orders on hand. In manufacturing to stock, the items are produced and stored and customers' requirements are met from the stock of the finished goods.

(*ii*) *From method of production point of view*, it can be divided into following two types:

(*a*) Intermittent production, and

(*b*) Continuous production.

These two types differ in the length of time the equipment set-ups is used without change. If a machine set-up is used for a very short period and then changed to make another product, it is called intermittent production. If a machine set-up is used for months without change it is called continuous production. It may be noted that difference in two types of production has nothing to do with regularity of industry's operation. Comparison of intermittent and continuous types of production is shown in a Tabular form. Table 2.1.

JOB, BATCH AND MASS PRODUCTION

1. Job Production

In this type of production the products are manufactured directly to customer's orders and the quantity produced is also small, in many cases it may be one piece only. The work is started only when the organization has orders on hand. The main characteristics of this type of production are:

(*i*) Each job is different from the previous one as regards specifications, quality and quantity.

Table 2.1. Comparison of Intermittent and Continuous Type of Production

Sr. No.	*Criteria for comparison*	*Intermittent production (job production or batch production)*	*Continuous production (mass production)*
1.	Quantity or volume produced	Small quantity	Large quantity
2.	Variety of product	Large variety	Small variety
3.	Machines used	General Purpose Machines (GPM)	Special Purpose Machines (SPM)
4.	Plant layout	Process controlled	Product controlled
5.	Machine capacities	Unbalanced	Balanced
6.	Raw material inventories	High	Low
7.	Inprocess inventories	High	Low
8.	Material flow	Intermittent	Continuous
9.	Material handling	Manual or trucks	Conveyors
10.	Operator's skill	Highly skilled	Unskilled or semi-skilled
11.	Job instructions	Detailed job instructions required	Less job instructions required
12.	Flexibility to product change	Flexible	Difficult and involves spending of lot of money
13.	Work stoppages	Less frequent	More frequent
14.	Output rate	Can be changed	Difficult to change

(*ii*) Flow of material is not continous *i.e*,. it is intermittent.

(*iii*) General purpose machinery is used, hence less initial investment in equipment.

(*iv*) Similar type of machines are grouped together.

(*v*) Highly skilled operators are needed.

(*vi*) Each work has to be planned and scheduled separately.

(*vii*) Raw material inventories are high.

(*viii*) Prior planning is not possible.

From the above characteristics it is clear that job order production is a case of intermittent production. The examples of job order production are manufacture of aircrafts large turbo-generators, ships, chemical plants, gates, doors and windows of houses etc.

2. Batch Production

In this type, the products are made in small batches and in large variety. The orders may be repeated with intervals of time. The characteristics of this type of production are:

(*i*) Products are manufactured in batches.

(*ii*) General purpose machines are used.

(*iii*) Flow of material is intermittent.

(*iv*) Plant layout is process type.

(*v*) In process inventory is high.

(*vi*) Process and product planning is done for each batch.

(*vii*) Work loads on various machines or sections are unbalanced.

(*viii*) Machine operators are highly skilled.

Batch production is also a form of intermittent production. This is a very common type of production. Drugs, chemicals, paints, sheet metal components, forgings and parts manufactured on turret/capstan lathes come under this type.

3. Mass Production

Mass production means the production of items in large quantity using very specialised machines and processes. Items like metal screws, nuts and bolts and plastic products are made in mass production. In this type of production there is a continuous and steady flow of materials. The various characteristics of mass production are:

(*i*) Small varieties and large volumes are manufactured.

(*ii*) Product type plant layout is used.

(*iii*) The flow of work is balanced *i.e.*, machine capacities are balanced.

(*iv*) Specialised machines and processes are used, hence high initial investment in equipment.

(*v*) Materials move by conveyors.

(*vi*) It results in lowest cost of production.

(*vii*) Easier production planning and control.

(*viii*) Inventory of work in progress is small.

Various characteristics of different types of production are given below:

There are four types of production:

(*a*) Job shop production.

(*b*) Batch production.

(*c*) Mass production of discrete products or components, and

(*d*) Production using Continuous—flow processes.

The characteristics and description of the four types of production are given in Table 2.2. The relationships among the four types in terms of product variety and production quantities can be conceptualized as shown in Fig. 2.1. There might be some overlapping of the categories as the figure indicates.

Table 2.2: Four Types of Production

S. No.	*Type of production*	*Characteristics, Description & Examples*
1.	Job shop production	Production of low quantities, often one of a kind of specialized products. The products are often customized and technologically complex. CNC machines are widely used in job shop production. (Examples: Prototypes, Aircraft and Machine tools)
2.	Batch production	Production of medium lot sizes of the same product or component. The lots may be produced at periodical intervals. CNC machines and Robots are widely used in batch production of industrial products and machinery. (Examples : Production of books in printing presses and cloth in textile mills).
3.	Mass production of discrete products	Dedicated production of large quantities of one product (with perhaps limited model variations). Mass production of discrete components involve the use of transfer machines, automated assembly lines, and automated materials handling systems, robots and extensive use of computers for monitoring the production. (Examples: Automobiles, Engine blocks and Home appliances)
4.	Production using Continuous-flow processes	Continuous dedicated production of large amounts of bulk product. (Examples: Production of chemicals and petroleum products in Continuous chemical plants, and Oil refineries)

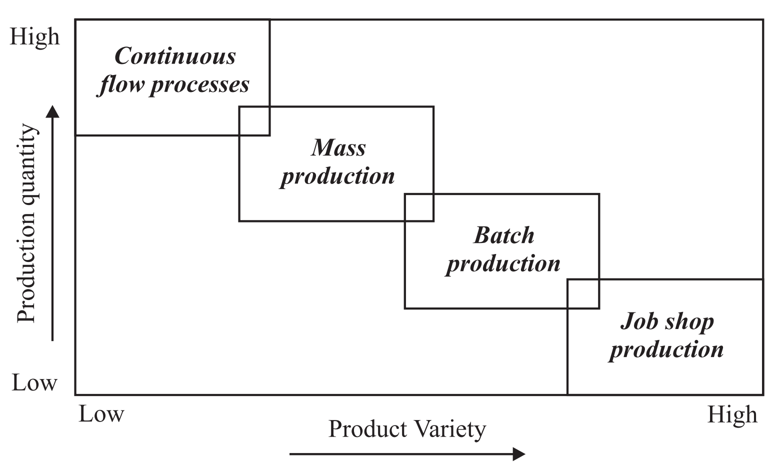


Fig. 2.1. Four types of production in relation to production quantity and product variety

SPECIALIZATION, SIMPLIFICATION AND STANDARDIZATION

Modern manufacturing has a number of characteristics that make for increasing success year after year. Some of the characteristics are Specialization, Simplification and Standardization.

1. Specialization : One of the important characteristics of manufacturing today is that of specialization. Some manufacturers concentrate on producing a single item, and others restrict production to a line of related products. The result of such specialization is usually lowered cost of production and improved quality.

Specialization also means the division of work or effort, and this occurs at the operator (worker) level and at the management level.

At the worker level there are those who work on jobs requiring a great skill, such as machinists, tool and die makers and welders, such craftsmen become high skilled specialists. Other workers do semi-skilled jobs. Both skilled and unskilled operators keep our mass-production and assembly lines running day after day. Although such specialization has elements of monotony and inflexibility, it results in high volume production at low cost.

Specialization of effort also operates at the management level. Management effort, generally, is divided into various special functions such as design, engineering, sales and finance and so on as the business grows in size and complexity. Within any one specialization there will be further specialization or sub-specialization. Engineering, for example will have its specialists in mechanical electrical and automobile work.

The efficiency of the engineer will probably increase as the scope of his assigned responsibility is narrowed.

Specialization as applied to different activities on the shop floor lead to the division of labour. This means that instead of one operater completing a whole product, he completes one small operation on the product hence becoming a specialist at that one activity. This principle is used in modern mass production and assembly lines.

Considering this machines are also designed for special purposes (SPM: Special Purpose Machines as opposed to GPM: General Purpose Machines) which will complete one specific operation as efficiently as possible on one type of component. This ensures a high degree of uniformity of work turned out. *i.e.*, consistency in the quality of work.

Companies/Industries concentrate their productive effort upon a limited number of products depending on their core competencies and manufacturing facilities available. Because of such specialization they will become more experts and specialists at producing a certain range of products and enjoy all the economic advantages which come as a result of such efforts.

2. Simplification : The concepts of specialization, standardization and simplification (known as three S's) are closely inter-related and lead to inter-changeability in manufacturing.

Simplification is the process of reducing the variety of products manufactured (also known as variety reduction).

3. Standardization : It is the broader concept of simplification and can be defined as the establishing of desirable criteria with respect to size, shape, material, quality etc. of product and if practical will lead to simplification of a company's products. This will inturn make mass production economically viable if the demand for the standardized product is sustained.

A product involves assemblies, sub-assemblies and component parts. If more than one product is manufactured in the industry, there is usually standardization of sub-assemblies or component parts among the different products.

Standardization : Results in overall cost reduction and economy in purchasing and manufacturing.

In this respect designs plays an important role in ensuring that there is standardization amongst all the assemblies and sub-assemblies and various components of the products manufactured.

Standardization promotes interchangeability **:** Interchangeability, or interchangeable manufacture, means that any standardized part produced can be interchanged such that any component will assemble equally well with any mating part without any fitting being necessary. The parts produced must be as near identical as possible, and standardization of all dimensions, tolerances fits and other part features ensure this.

Standardization : This is a process which leads to the establishment of desirable criteria with respect to material, size and other quality characteristics, to which every one can adhere. If they do, then they would expect that the standard would meet all their requirements and enable them to manufacture and stock the minimum variety of parts.

The greatest economic benefit can be obtained if every design makes use of standard parts, such as screws, nuts, fasteners, splines, shafts, bushes, gears etc. manufactured using standard materials, standard cutting tools, inspected using standard gauges, stored and despatched in standard containers.

Greatest economy can be effected if standard parts (screws, bushings, handles, clamps) can be incorporated into a new product. Standard parts, since they are made in large numbers, can be manufactured at a lower cost, than special jobs. Also, standard parts can be salvaged from old sub-assemblies and used again.

Every time the engineer calls for a special item (non-standard type), The work of preparation of specification becomes difficult and costs of processing such item also rise.

Standards are available to the engineer covering a wide variety of features such as

(*i*) Dimensions, tolerances, and fits,

(*ii*) Material specifications and properties; raw material sizes,

(*iii*) Machines, tools, gauges, instruments,

(*iv*) Methods of assessing and inspecting parts, sub-assemblies, assemblies and products; and

(*v*) Installation and commissioning of equipment and machinery,

Hand books and standard Data sheets contain the specifications and standards for the above. The application of standards enhances quality.

PROCESS PLANNING

When the design engineers have designed the product, the assembly drawings and working drawings of individual components are made. The process planners have to see how the product can best be made to meet the specifications mentioned in the part drawing.

Process plan : The detailed instructions for making a part or a component. It includes such information as the operations, their sequence, machines, tools, speeds and feeds, dimensions, tolerances, stock removed, inspection procedures and time standards (*i.e.*, cycle time).

Process planning : It may be defined as the determination of the processes and the sequence of operations required to make the product. It consists of devising, selecting and specifying processes, machine tools and other equipment to transform the raw material into finished product as per the specifications called for by the drawings.

The purpose of process planning is to determine and describe the best process for each job so that:

(*i*) Specific requirements are established for which machines, tools and other equipment can be designed or purchased.

(*ii*) The efforts of all engaged in manufacturing are co-ordinated.

(*iii*) A plan is made to show the best way to use the existing or proposed facilities.

STEPS INVOLVED (PROCEDURE) IN PROCESS PLANNING

The following are the steps involved in carrying out the process planning manually. Past experience of process planners are used in arriving at the economical manufacturing of the product.

The steps involved in process planning are :

(*i*) The finished product is analyzed so that its sub-assemblies and individual components are identified from manufacturing point of view.

(*ii*) Prepare a Bill Of Materials [BOM] for all components of the product which forms a basis for purchase of raw materials.

(*iii*) Decide which parts are to be manufactured in the plant and which parts are to be purchased from the market depending upon the facilities available in the plant, *i.e.*, decision with regard to "make" or "buy" to be taken.

(*iv*) Choose the appropriate blank size *i.e.*, raw material size and select the most economical process to be followed to manufacture components of the product. This is done by comparing the various possible methods of obtaining the final product. The basic factors of volume to be produced, *i.e.*, production quantity, required quality of the product and the capabilities of the equipment available are carefully considered in this step.

(*v*) Decide the sequence of operations to be performed on each component in the process selected.

(*vi*) Each operation is assigned to the type and size of machine or work station that will perform the job most economically.

(*vii*) Depending upon the accuracies called for by the drawings, determine the machine tools to do the operations

(*viii*) Determine the need for any special equipment like jigs, fixtures, cutting tools etc.,

(*ix*) Determine the inspection stages and instruments required and the need for designing any inspection devices (say gauges, etc.).

(*x*) Estimate the standard time for performing the job.

(*xi*) Determine the type of labour (skilled, semi-skilled or unskilled) required to do the job.

Process planning has been traditionally carried out by methods engineers, manufacturing engineers, industrial engineers or by process planners.

BILL OF MATERIALS (BOM)

Bill of materials is a tabular statement specifying all the components required for completing an assembly or sub-assembly. The items listed in a bill of materials are :

(*i*) Name of individual part, and No. required to complete an assembly and material of the part.

(*ii*) Whether the individual parts are to be manufactured from within or whether it is to be bought out. If the part is a standard item (*e.g.* bolts, nuts, bearings, washers, rubber/plastic moulded parts) it can be bought out economically than making it in the shop.

(*iii*) Name of engineer preparing the BOM, date of preparation and his signature. Bill of materials enables planning for items to be manufactured in house, raw material required and planning for procurement of bought out items and for making cost estimates. BOM is also known as parts list and is generally incorporated in the drawing of assembly or sub-assembly.

Uses of Bill Of Materials (BOM) :

Production Planning and Control Department uses BOM for deciding manufacturing and scheduling dates.

Process planners/Process engineers use it to know for what parts process planning is to be carried out.

Process planners and methods engineers (industrial engineering dept.) uses BOM in estimating standard time and time allowances (cycle time) for manufacturing and assembly operations.

Purchase and Stores Department compiles several BOM's and orders purchasing of all standard items so that these parts are made available at the time of assembly.

PROCESS PLANNING SHEET

The whole information determined by the process planning is recorded in a tabular form in a sheet called process planning sheet. This document is provided to the shop personnel for their use. The character of this sheet will very for different organisations depending upon the production conditions and degree of details required.

In general the following data is listed for each component of the product in the process sheet.

(*i*) Information regarding the main product, of which the component being manufactured is a part *i.e.*, name and part number of the main product.

(*ii*) Name, part number, drawing number of the component and number off *i.e.*, no. of components required per product.

(*iii*) Information concerning the blank *i.e.*, raw material used, size and weight of stock.

(*iv*) Operations are listed in proper sequence along with the shops in which these operations will be performed.

(*v*) Information regarding machines used for each operation.

(*vi*) Data on jigs, fixtures and other special tools required.

(*vii*) Inspection devices needed for inspection.

(*viii*) Cutting data *i.e.*, speeds, feeds & depth of cut for each machining operation.

(*ix*) Elements of standard time such as set-up time, handling time and machining time for the job.

A typical process sheet is shown in Table 2.3.

The process planning sheet is prepared by the process engineer in consultation with the tool engineer, industrial engineer, or methods engineer.

Table 2.3 : Process Sheet

Part Name.....................................

Material..

Blank size.....................................
(Raw material size required)

Number off......................................

Part No..

Drawing No.....................................

Standard time......................minutes

Operation No.	*Description of Operation*	*Deptt. or Shop*	*Machine used*	*Tool standard or special*	*Jig/Fixture/ Gauges used if any*	*Time analysis*				*Remarks*
						Machining Time (min)	*Handling Time (min)*	*Set-up Time (min)*	*Cycle Time (min)*	

USES OF PROCESS SHEET

A process sheet is a very important document which forms a basis for all planning, scheduling and despatching functions. Also it helps in advance planning and for purchase of raw materials design and manufacture of special tools, jigs, fixtures and inspection devices. It helps in estimating the cost of the product before it is a actually manufactured. It also helps in planning for man power required for doing the job.

Process Planning, Routing and Process Sheet (Route Sheet)

After findizing all the details of Product Design, manufacturing planning is to be carried out. Process planning is an integral part of manufacturing planning.

Process planning consists of determining the sequence of the individual processing and assembly operations needed to produce the part.

Routing

Routing may be defined as the planning of where and by whom work shall be done, the path or route to be followed by the work and necessary sequence of operations. Taking from raw material to the finished product, routing decides the path and sequence of operations to be performed on a job. Routing starts from the component drawings and aims at optimum utilization of resources. Routing forms the basis for the scheduling and dispatching functions of the production control department.

Routing Procedure : The following procedure is generally adopted for routing :

(*i*) From the drawings the final product is analysed from manufacturing point of view and broken into sub-assemblies and components.

(*ii*) A detailed bill of materials is prepared.

(*iii*) Based on the facilities and capacities available, a decision is taken regarding the components which can be manufactured in the plant and which can be bought from outside.

(*iv*) For each component to be manufactured in the plant, the operations which must be performed to transform the raw material into final shape are established and listed in proper sequence.

(*v*) A list of tooling required of each stage is also prepared. The information obtained in step (*iv*) and (*v*) is recorded in a sheet called **Route Sheet,** along with other information like component name, Part No., material, quantity to be produced, etc.,

Route Sheet

The Route Sheet is a listing of the sequence of operations which must be performed on the work part. It is called Route Sheet, because it lists the machines (machine tools) through which the part must be routed in order to accomplish the sequence of operations.

A sample proforma for route sheet is shown in Table 2.4.

The document used to specify the process sequence is called a Route Sheet. Process planning sheet and Route Sheet are one and the same. The term “process planning sheet” is more widely used in industries now a days.

The manufacturing engineering and industrial engineering departments and process planners are responsible for process planning and preparation of Route Sheets.

Table 2.4 : Route Sheet

Component No.. Drawing No.....................................

Name of component.................................... Quantity...

Material...

....

Operation No.	*Deptt./ Section*	*Operation Description*	*Machine*	*Tool required*	*Cutting data*	*Jigs/ Fixtures and other accessories*

Calculation of Man-Hours and Machine-Hours

A man-hour is defined as the availability of one man (operator) for one hour for doing a job. Availability of man-hours is calculated when the work is done by manual labour as in a scooter assembly shop, welding, making sand moulds and cores in a foundry shop, packing of soaps and detergents, etc. The requirement of man-hours is calculated to estimate the number of men (operators) required to complete the job.

A machine-hour is defined as the availability of one machine for one hour. Availability of machine-hours is calculated in production when work is done mainly with the help of machines as in the case of production with automatic machines, in gear shops manufacturing gears, or using lathe for machining turned components etc.

The requirement of machine hours is calculated to estimate the number of machines required to complete the job.

The number of man-hours or machine-hours available during a particular period is calculated as follows :

(*a*) Total number of days in the period under consideration = X

(*b*) Number of holidays in the period = A

(*c*) Number of shifts per day = B

(*d*) Number of hours per shift = C

Numbers of working hours available = $(X - A) \times B \times C$

This gives the total or gross man-hours or machine-hours available for working. But in actual practice allowances for absenteeism, power failures, repair and maintenance, rest and other factors have to be considered. The actual or net machine-hours or man-hours available is less than the gross man-hours or machine-hours available and it depends on the type of industry and type of labour available.

Example : Calculate the net machine-hours available in a factory from the following data for month of June :

(1) Number of milling machines = 8
(2) Number of working days = 25
(3) Number of shifts per day = 2
(4) Time lost due to maintenance and repairs, etc. = 3 hrs. per day
(5) Number of hours/shift = 8

Solution : For One Milling Machine :

Number of working days in June = 25

Net working hours available per day/machine = $(8 \times 2) - 3 = 13$ hrs.

Net machine-hours available per machine per month = $13 \times 25 = 325$ hrs.

Net machine-hours available for 8 machines/month = $325 \times 8 = 2600$ m/c hrs.

Use of Computers in Process Planning and Cost Estimation

There are different levels of involvement of the computer in the operations of any plant or industry.

The computer is used indirectly to support the production function but there is no direct connection between the computer and the process. The computer is used "off-line" to provide information for the effective planning and management of production activities.

Cost Estimating using Computers : The task of estimating the cost of a new product has been simplified in most industries by computerizing several of the key steps required to prepare the estimate. The computer is programmed to apply the appropriate labour and overhead rates to the sequence of planned operations for the components of new products. The programme then sums up the individual component costs from the engineering bill of materials to determine the overall product cost.

Computer Aided Process Planning (CAPP) : Process planning is concerned with the preparation of route sheets which list the sequence of operations and work centres required to produce the product and its components. CAPP systems are available today to prepare these route sheets.

Process planning involves the preparation and documentation of the plans for manufacturing the products. Computer-Aided Process Planning (CAPP) is a means of implementing this planning function by the use of computers

Computer Aided Process Planning represents the link between design and manufacturing in a CAD/CAM system. Process planning is concerned with determining the sequence of processing and assembly steps that must be accomplished to make the product. The processing sequence is documented on a sheet called a route sheet. The route sheet typically lists the production operations, machine tools, work centres or work stations where each operation is performed, jigs, fixtures and tooling required and standard time for each task.

In manufacturing enterprises, there has been an interest in automating the task of process planning by means of CAPP systems. The shop-trained engineers who are familiar with the details of machining and other processes will be retiring, and these experienced engineers will not be available in the future to do the process planning. An alternative way of accomplishing this function is needed and CAPP systems are providing this alternative.

Computer Aided Process Planning (CAPP) Systems are designed with two approaches in mind. These approaches are called :

(*a*) Retrieval CAPP Systems, and (*b*) Generative CAPP Systems,

Approaches to process planning : Details given earlier are the basic steps involved in process planning when it is carried out manually by an experienced process planner. CAPP (Computer Aided Process Planning) involves the use of an interactive computer system to automate the works involved in preparing a process plan. There are fundamentally **two different approaches** when computers are used in the process planning task.

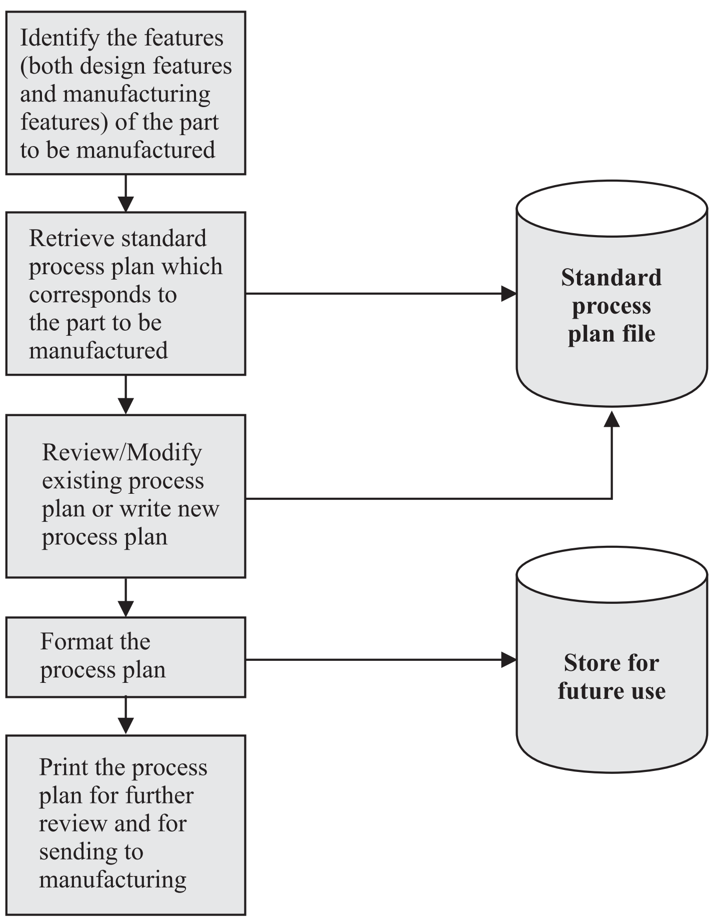
(1) Variant or Retrieval method of process planning.

(2) Generative method of process planning.

1. Variant or Retrieval Method of Process Planning (Retrieval CAPP System)

In this method, the computer makes a search of its storage or a data base or a no. of standard or completed process plans that have been previously developed by the company's process planners. The development of the data base of these process plans requires substantial knowledge of machining, time and efforts. Using the current design data supplied by the CAD system, (after a component has been designed and dimensioned), it searches for a process plan that was based on a part of similar design. (This search can make effective use of GT, Group Technology, design coding to simplify the search for similar part design).

The process plan **retrieved** is then modified or suitably **varied** (*i.e.*, altered) by the process planner, to suit the exact requirements of the current part design. The use of Computer and Group



Procedure for developing the Retrieval type Computer—Aided Process Planning (CAPP) system

Technology (GT) to search for the most appropriate or similar part design, and to retrieve the process plan for that design, significantly reduces the work required of the process planners. This also saves considerable amount of time required to develop a process plan for a new part. The task of process planner becomes one of modifying the existing plan to suit the particular dimensions of the current part. (*i.e.,* the selected process plan is provided to the user for modification and variation).

Process planners are required to perform the entire process planning method only in the case of a completely new part design.

This approach of process planning is also known as Retrieval CAPP system. This is based on the principles of Group Technology and parts classification and coding. One of the pre-requisites for implementation of this method is that the industries must develop and maintain a large computer data base of standard completed process plans. In addition, the part designs are to be developed using CAD systems.

2. Generative Method of Process Planning (Generative CAPP System)

The second method of computerized process planning is the generative method. In this method the computer uses the stored manufacturing and design data to generate a complete list of all possible process plans that could be used to manufacture the current part. It then exhaustively searches this list for the one which optimizes the cost function. This method always yields the optimum process plan for manufacturing a particular part.

However, it has a very high cost in terms of time and computer processing expenses. The computations required to provide even a single process plan for an arbitrary part design can be enormously complex. To repeat this for every feasible process plan or a part can become very costly.

This approach of process planning is also known as **Generative CAPP System.** Both the approaches viz. Variant (or retrieval) method of process planning and Generative method of process planning involves a systematic development of Code Numbers using Group Technology concepts and principles for the design and manufacture of the part. Both of these methods of computerized process planning can be enhanced through the application of AI (Artificial Intelligence) in the form of expert systems.

Benefits of CAPP

The benefits derived from computer aided process planning are the following

1. **Process rationalization and standardization :** Automated process planning leads to more logical and consistent process plans than when process planning is done completely manually.
2. **CAPP helps in arriving at standard and consistent process plans :** Standard plans tend to result in lower manufacturing costs and higher product quality.
3. **Increased productivity of process planners :** The systematic approach and the availability of standard process plans in the data files permit more work to be accomplished by the process planners.
4. **Reduced lead time for process planning :** Process planners working with the CAPP system can provide route sheets in a shorter lead time compared to manual preparation.
5. **Improved legibility and readability :** Computer prepared route sheets are legible and easier to read than manually prepared route sheets.
6. **Incorporation of other application programmes :** The CAPP programme can be integrated with other application programmes, such as estimation of standard time, cost estimating and formulation of work standards.

Practices of Process Planning

The practices of process planning vary widely in modern industry, depending on such factors as :

- Type of product
- The equipment available, and
- The volume of production (*i.e.,* production quantity)

The individual responsible for carrying out process planning / process analysis is the Process Engineer also known as process planner, process analyst or methods engineer. To be effective on his or her job, the process analyst must be familiar with material characteristics and manufacturing processes. Knowledge of the nature, types, and properties of standard materials and new materials will assist the process analyst in selecting the most appropriate process, equipment and methods for manufacturing a particular product. The process analyst must also be familiar with engineering drawings and product design. Drawings provide the part configuration and the dimensional tolerances and specifications that need to be met by the manufacturing process selected

In addition, the process planner must be familiar with the operating characteristics and costs of the production and tooling equipment, either available in the plant or to be purchased.

Process Planning starts with a careful examination of the drawing or design of the part. The process planner must be able to analyze the engineering drawing and visualize the three dimensional part configuration. The part configuration must then be analyzed to determine its basic geometric components. Identifying these basic geometric elements assists the process planner in selecting the most appropriate process to manufacture the product.

Process Selection

Consideration should be given to the following factors in selecting a particular process

1. Nature of part, including materials, tolerances, desired surface finish and operation required.
2. Method of fabrication including machining or assembling of similar parts or components.
3. Limitation of facilities including the plant and equipment available.
4. Possibility of likely product design changes to facilitate manufacturability or cost reduction.
5. In-plant and outside materials handling systems.
6. Inherent process to produce specified shape, surface, finish to give desired mechanical properties.
7. Available skill level of operators for the production.

Sometimes the following additional factors affect the selection of a particular process.

(*a*) Proposed or anticipated production requirements, including volume requirements, production rates and short- term or long- term production runs.

(*b*) Total end-product costs.

(*c*) Time available for tooling-up.

(*d*) Materials receipt, storage, handling and transportation.

Careful consideration of these factors will result in the selection of the most appropriate process for the manufacture of a particular product.

Selection of an appropriate manufacturing process depends on many factors and requires considerable knowledge, skill and competence of the process planner or process analyst.

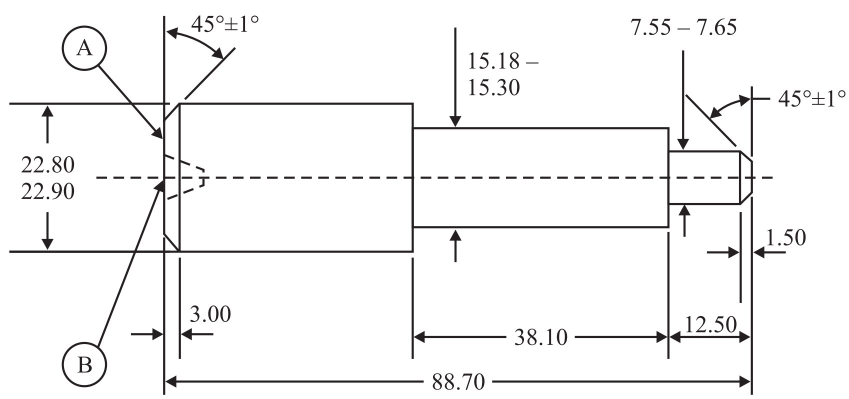
Process Sheet : Once the process (example : machining) has been selected, the next step is to list operations in a logical sequence. The processes are written in a sequential order in the process sheet or operation analysis sheet. The process sheets are used as instruction sheets, for the operator to process the part.

Process sheets format vary widely in industry depending on such factors as type of product, type of industry, type of equipment and type of manufacturing. However, most process sheets include such information as description and numerical order of operations, manufacturing equipment used jigs, fixtures, tools and gauges used, speeds, feeds and depths of cut, material specifications, drawing specifications and revisions, if any.

Process Planning Activities :

Example 1 : A part drawing is shown in Fig. 2.2 (Gear shaft for water pump). The following are the activities / decisions involved in process planning.

1. Study and read the drawing so that the part features are identified. The important feature of the part are:
   (*a*) Three concentric cylinders constitute the part.
   (*b*) There is one chamfer of 45° × 3 mm and one chamfer of 45° × 1.5 mm at the ends of the shaft.
   (*c*) The dimensional tolerances are ± 0.05 mm and the angular tolerance on the chamfer is ± 1°.
   (*d*) Material is SAE 1030 cold drawn steel.
2. Only 5 pieces are required. The most feasible process is machining on a standard centre lathe.
3. The parts can be machined from 25 mm diameter standard stock.
4. One lathe operator is required to complete the order.
5. The next step is to identify the operations. To produce the part the following operations are required:
   (*a*) Facing
   (*b*) Centre drilling
   (*c*) Cutting off (or) part off
   (*d*) Turning
   (*e*) Chamfering
   (*f*) Finishing (removing sharp edges)



Material: 25 mm diameter SAE 1030 cold drawn steel
All Tolerances : ± 0.05 unless otherwise specifield
All dimensions are in mm. Number of parts required : 5

Fig 2.2. Gear shaft for water pump.

6. In addition, the process planner must estimate the time for each of these operations : the set-up time, the cutting tools needed, jigs, fixtures and gauges required, the machining parameters such as: Cutting speed, feed, d.o.c. (deptt of cut).
7. Completing the process planning sheet. The operations listed are sequenced in numerical order and are listed in the process sheet along with other necessary information. Fig. 2.3

Process Planning Sheet

Oper. No.	*Description of Operation*	*Machine Name or No.*	*Cutting Tool*	*Cutting speed*		*Feed mm/rev*	*Depth of cut mm*	*Locating points on drawing*	*Fixtures, Tools, Gauges, etc.*	*Remarks*
				(m/min)	*rpm*					
10	Face end	Centre lathe 7071	Facing tool	30	300	Hand	—	A	Use 25 mm lathe chuck	Use 3-jawed universal chuck
20	Center drill end	Centre lathe 7071	Combina-tion center drill	—	650	Hand	—	B		Cutting fluid or oil may be used.
50	Cut off to 88.70 mm length	Centre lathe 7071	Parting cool	30	300	Hand	—	A	Support work with live center to avoid chatter	Use coolant
90										
100	Remove sharp edges	Centre lathe 7071	File or emery cloth		650	Hand	—	—		

No.	*Revisions Schedule*	*Date*	*Part Identification Details*	
1	Added Oper. No. 100	18-1-06	Drawing No. : 76-10 GM,	Stock No. : 48252
2			Part Name : Gear Shaft	Specification No. : 01-305GM
3			Material : SAE 1030 CRS	Process Engr.
4			APPROVED : Date : 16-1-06	Sheet No. 1 of 2 sheets

Fig 2.3. A typical sample of an operation (process) analysis sheet used in manufacturing.

Machine Selection

Product manufacturing requires tools and machines that can produce economically as well as accurately. Economy depends to a large extent on the proper selection of the machine or process for the job that will give a satisfactory finished product. The selection of the machine is influenced, in turn by the quantity of items to be produced. Usually there is one machine best suited for a certain output.

In small lot or jobbing type manufacture, general purpose machines such as the lathe, drill press, and milling machine may prove to be the best type since they are adoptable, have lower initial cost, require less maintenance, and possess the flexibility to meet changing conditions in the shop.

However, a special purpose machine should be considered when large quantities of a standard product are to be produced. A machine built for one type of work or operation, such as the grinding of a piston or the machining of a cylinder head, will do the job well, quickly and at a low cost requiring only the service of a semi-skilled operator.

Many of the special-purpose machines or tools differ from the usual standard type in that they have built into them some of the skill of the operator. A simple bolt may be produced on either a lathe or an automatic screw machine. The lathe operator must not only know how to make the bolt but must also be sufficiently skilled to operate the lathe. On the automatic machine the sequence of operations and movements of tools are controlled by cams and stops, and each item produced is identical with the previous one. This "transfer of skill" into the machine makes possible the use of less skillfull operators, but it does requires greater skill in supervision and maintenance. Often it is not economical to make a machine completely automatic, as the cost may become prohibitive.

The selection of the best machine or process for a given product requires a knowledge of all possible production methods. Factors that must be considered are:

(*a*) Volume of production (Quantity to be produced) *i.e.*, no. of components to be produced.

(*b*) Quality of finished product, and

(*c*) Advantages and disadvantages of the various types of equipment capable of doing the work.

Too much emphasis cannot be given to the fact that production can be by several methods, but usually there is one way that is most economical.

Factors Influencing Process Selection

After a product design is made process selection is to be carried out. There are several factors which influence the process selection, These are :

1. Shape requirements
2. Size or dimensional requirements
3. Tolerance requirements
4. Surface finish requirements
5. Annual volume requirements (*i.e.*, production quantity required per annum)
6. Material characteristics.

Process selection requires a broad and extensive knowledge of various materials and the associated manufacturing processes. A good understanding of the capabilities and limitations of the various processes available is an asset to any process planner. Evaluation of alternative processes can also be carried out simultaneously and a logical decision taken with respect to proper selection of the process.

It must be emphasized that the selection of a process is done and evaluated in the context of **product design - material - manufacturing process** in an integrated manner.

Process Selection Parameters

There are several factors which govern the selection of a manufacturing process:

1. **Shape requirements of the final product *i.e.*, Geometric Form :** Geometric parameters such as solid shape, hollow shape, flat shape, flanged shape, concave shape, convex shape, cylindrical shape, presence of any part feartures such as groove, threaded shape, hole, chamfer, etc. are considered in the selection of a manufacturing process. Each process has its own capabilities and limitations with respect to the production of the above shapes and part features.
2. **Size or Dimensional requirements :** Some processes are capable of handling parts of small sizes and some processes can handle large sized parts economically and effectively.

3. **Tolerance requirements :** Each manufacturing process has got its own capability with regard to tolerance or accuracy of parts that can be produced using that process *e.g.* grinding process always gives close tolerances when compared with turning process. Depending upon the tolerance specified on the part drawing, suitable machining process is to be selected.
4. **Surface finish requirements :** Each manufacturing process has got its own capability with regard to the surface finish which it can provide on the part machined, *e.g.* reaming process can provide a better surface finish in a hole when compared with drilling process. Similarly cylindrical grinding give a better surface finish, than a plain turning process. Depending on the finish requirements specified on the component drawing, appropriate machining process need to be selected.
5. **Production volume requirements :** The economics of any machining process depends on the production volume, *i.e.*, no. of components required on a weekly, monthly or annual basis as the case may be. Existing order quantity as well as any anticipated future orders and their quantity need to be considered in the process selection. Some of the processes and additional cost incurred in the specialized toolings, jigs and fixtures can be justified only when there is a large volume of production.
6. **Material requirements :** The hardness, and strength characteristics of the material influence the tooling required. To machine hard and tough materials, carbide and ceramic tools are required. If slender or thin materials are machined, proper work holding devices and specially designed jigs and fixtures are required is order to avoid distortion and bending of work pieces during machining. Thus material requirements of the part also influence the appropriate selection of machining process.

MATERIAL SELECTION

Material selection is done by the product designer considering the requirements of the parts designed and the hardness, strength properties and other mechanical characteristics of the material. Cost and availability of the material are also considered. Material should be strong enough and at the same time manufacturing or producibility of the part using the given material and the process are also equally important.

In the initial stages of design, the broad material groups such as ferrous or non-ferrous or other non-metallic materials can be considered. At a later stage specific material in the group can be identified.

In certain products or components specific properties of materials such as fatigue strength, thermal conductivity, electrical properties like conductivity, magnetic permeability and insulation resistance may have to be considered.

Material Selection parameters

(*i*) **Functional requirements :** The primary function of the part for which the material is selected is the foremost consideration. A good knowledge of the product application is important. The properties of materials which have a direct bearing on the functional requirement of the part are : fatigue characteristics, strength, hardness, electrical and thermal properties.

(*ii*) Reliability : Reliability of the materials refers to the consistency with which the material will meet all the products requirement throughout its service life. This is important for trouble-free maintenance of the product during its life time.

(*iii*) Service life durability : The length of service (years or hours of operation of the product) over which material is able to perform its function satisfactorily.

(*iv*) Aesthetics and appearance : Factors like colour, texture, lusture, smoothness and finish play an important role in the aesthetics or appearance of the final product.

(*v*) Environmental Factors : Environmental factors such as temperature, humidity, corrosive atmosphere affects the product and its performance. Hence proper materials which can with stand such environmental effects should be selected and they should be given suitable protective coatings.

(*vi*) Compatibility with other materials during service : When one type of material is used in combination with another type of material in a product or in an assembly the properties of both types of materials should be compatible and should suit each other. Otherwise deterioration in the performance of the product or assembly such as excessive wear & tear, and corrosion of parts in fitment are likely to take place.

(*vii*) Producibility or manufacturability : The extent to which the material can be processed effectively and easily using a particular machine tool or process should also be considered in the selection of the material. Machinability of materials for machined components is an important factor.

(*viii*) Cost : The cost of material is a significant factor in many situations. The availability of the material is equally important. Appropriate material for the product or component is to be selected taking into consideration all the above factors.

SET OF DOCUMENTS REQUIRED FOR PROCESS PLANNING

(*i*) Product design and the engineering drawings pertaining to all the components of the product. (*i.e.,* components drawings, specifications and a bill of materials that defines how many of each component go into the product).

(*ii*) Machining/Machinability Data Handbook (Tables of cutting speeds, depth of cut, feeds for different processes and for different work materials).

(*iii*) Catalogues of various cutting tools and tool inserts.

(*iv*) Specifications of various machine tools available in the shop/catalogues of machine tools in the shop (speeds, feeds, capacity/power rating of motors, spindle size, table sizes etc.).

(*v*) Sizes of standard materials commercially available in the market.

(*vi*) Machine Hr. cost of all equipment available in the shop.

(*vii*) Design Data Handbook.

(*viii*) Charts of Limits, Fits & Tolerances.

(*ix*) Tables showing tolerances and surface finish obtainable for different machining processes.

(*x*) Tables of standard cost.

(*xi*) Table of allowances (such as Personal Allowance, Fatigue Allowance etc. in % of standard time followed by the company).

(*xii*) Process plans of certain standard components such as shafts, bushings, flanges etc.

(*xiii*) Handbooks (such as Tool Engineers Handbook, Design Data Handbook).

DEVELOPING MANUFACTURING LOGIC AND KNOWLEDGE :

(*i*) Product : design, (*i.e.*, parts requirements) manufacturing process and materials characteristics all must be considered together in an integrated manner while developing a process plan.

(*ii*) Identify the datum surface on the component drawings which will form the basis for measurement and inspection of dimensions.

(*iii*) Adequate attention must be paid so that the component is properly located and clamped. The accuracy of the machined part and the time taken depend on these factors. This will also avoid any distortion that might occur on the machined component. Three point support (locating pins) are suitable for positioning large flat surfaces.

(*iv*) The no. of settings required to machine a part may be reduced to a minimum. Less no. of settings more is the accuracy of the part machined.

(*v*) Frequent tool changing can be reduced to a minimum.

(*vi*) Rough machining operations must be carried out first before finish machining operations.

(*vii*) Identify critical operations and provide for inspection immediately after critical operations.

(*viii*) Use appropriate cutting fluid depending on the severity of the operation, the work material and the tool material used.

(*ix*) Use of jigs and fixtures are justified when the production quantity is large.

STEPS IN PROCESS PLANNING

(*i*) Required operations must be determined by examining the design data and employing basic machining data such as :

(*a*) Holes can be made conveniently on drilling machines.

(*b*) Flat surfaces can be machined easily on milling machines.

(*c*) Cylindrical parts can be made using lathe.

Design data can be obtained from the part-drawing or from the finished part design file from the CAD system.

(*ii*) The machines required for each operation must be determined. This selection depends on knowledge of machine factors, such as availability of the machine, specifications of machine tools available in the shop, accuracy grade of the m/c, table size, spindle size, speed and feed ranges available, torque, power, machining rate and other size limitations.

(*iii*) The required tools for each identified machine or process must be determined. For selection of specialized tools knowledge and prior experience of process planner will be useful.

(*iv*) The optimum cutting parameters for each selected tool must be determined. These parameters include cutting speed, feed rate, depth of cut, and type of coolant/lubricant to be used. This determination depends on design data, such as work material, tool material, surface finish specifications and behaviour of cutting tool. Again expertise knowledge and prior experience of process planner and methods engineer will be useful in this regard. Machining data handbooks can also be referred.

(*v*) Finally an optimum combination of these machining processes must be determined. The best process plan is the one which minimizes manufacturing time and cost. This provides a detailed plan for the economical manufacturing of the part.

The results of each of these five basic steps can be seen in the final form of the process plan.

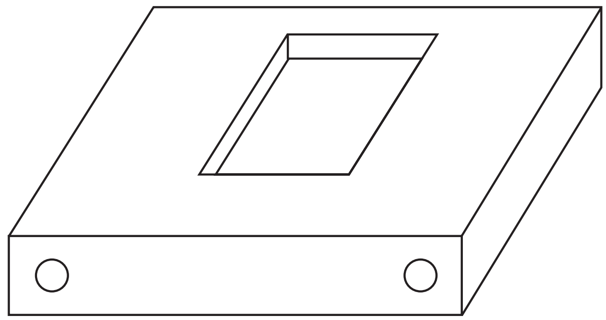


Fig. 2.4 (a) Part to be manufactured

Example 2 : Another example of a process plan for a part to be manufactured is shown below :

Machine : Vertical milling machine

Tool 1 : 150 mm dia. face mill

Operation 1 : Square to size 1000 mm × 1000 mm × 400 mm

Operation 2 : Finish mill to size : Tolerance + 0.03 mm

Tool 2 : 25 mm dia. Four-fluted end mill

Operation 1 : Mill pocket to 40.00 mm deep

Machine : Gun drilling machine

Tool 1 : 25 mm dia drill (850 mm long)

Operation 1 : Drill to 750 mm deep (2 holes)

Fig. 2.4 (*b*) Process plan

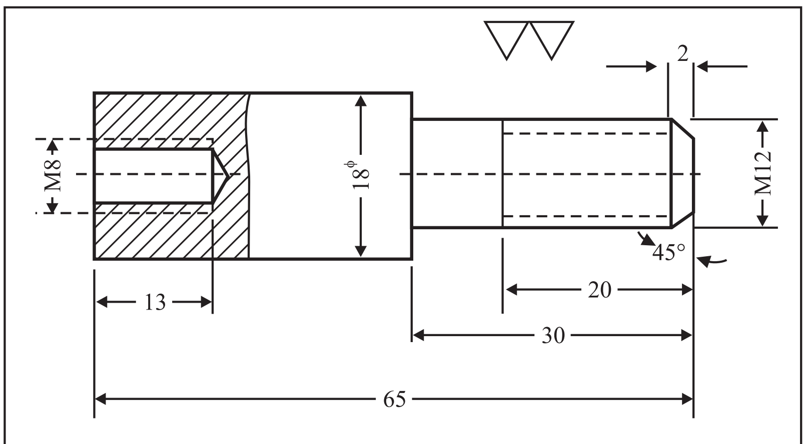
Computer Aided Process Planning (CAPP) involves the use of computers to automate this process.

Example 3 : This example refers to process planning for an "axle" (Fig. 2.5) involving Threading operations on the centre lathe using taps and dies. Axle part is shown as assembled in Fig. 2.6.

Operation Plan/Process Plan

No.	*Operations*	*Tools*
1.	Chucking (Holding) of workpiece and turning to length, 65 mm	3–jaw chuck, facing tool
2.	Rough and finish turning to 18 f	Pointed turning tool
3.	Drilling of corehole 6.7 f	Twist drill 6.75 N HSS
4.	Chamfering of corehole	Counter-sink 90°
5.	Tapping of M 8 (Internal thread)	M 8 taps (I, II, III), tap wrench
6.	Rechucking of workpiece, turning of part for M 12	Pointed turning tool and facing tool
7.	Cutting of external thread M 12	Die with die holder and collet
Measuring and checking instruments : Vernier caliper, depth gauge, thread plug gauge, ring thread gauge.		

The set up sketch for each operation is shown in Fig. 2.7.



1	*Axle*	*1*	*St. 42*	*20φ.1*
No. of pieces	*Nomenclature*	*Part No.*	*Material*	*Rough size*

Fig. 2.5. Component drawing of an "Axle".

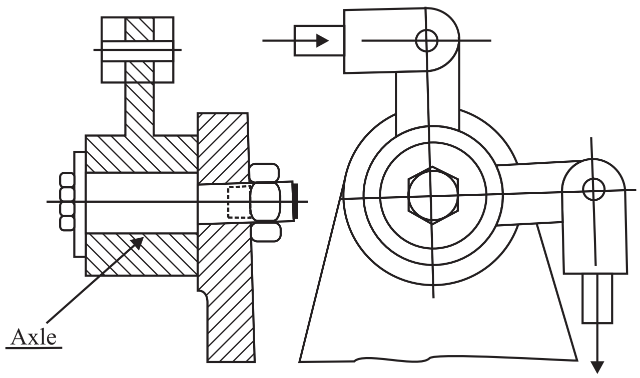


Fig. 2.6. Axle shown assembled.

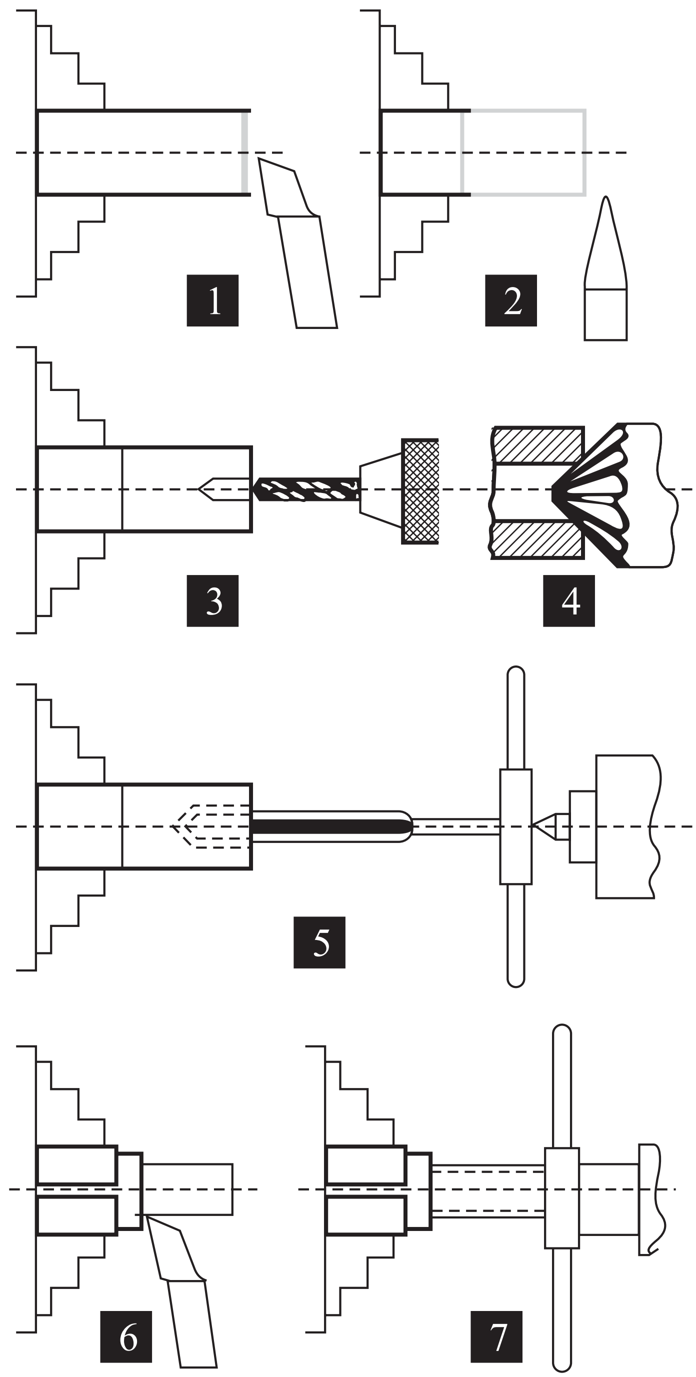


Fig. 2.7. Set up sketch for each operation for manufacturing of Axle.

The sequence of operations is explained below :

Operation No.	*Description of operations*
1.	Holding of workpiece in 3-jaw chuck and turning to length, 65 mm
2.	Rough turning and finish turning to 18 mm diameter.
3.	**Production of internal thread M 8 :** **Drilling of core hole :** For production of internal thread M 8 drilling of core hole is to be done. The core diameter amounts to 6.38 mm only. In the beginning of internal thread cutting burrs are likely to form. For this reason, it is necessary that core-hole must be drilled bigger than the core diameter of the thread.

Table : Tap Diameters for Thread Coreholes.

Metric thread (M.......)

Thread	M 3	M 3.5	M 4	M 5	M 6	M 8	M 10	M 12	M 14	M 16	M 18	M 20	M 22	M 24	M 27
Thread holes for steel	2.5	2.9	3.3	4.2	5.0	6.7	8.4	10.0	11.75	13.75	15.25	17.25	19.25	20.75	23.75
Cast iron, brass	2.4	2.8	3.2	4.1	4.8	6.5	8.2	9.9	11.5	13.5	15	17	19	20.5	23.5

(Fig. 2.8) As per Table given below the core hole must be drilled to 6.70 mm.

4.	**Counter sinking of core hole :** The core-hole is counter sunk with a 90° countersink bit, so that the tap cuts in easily and formation of burns is avoided.
5.	**Cutting of internal thread :** **Selection of Taps** for cutting of internal threads is to be done. In the selection of taps, the material of the workpiece, shape and length of thread have to be taken into account. The taps for triangular threads are standardized and are manufactured of tool steel or HSS. The threads on the tap are machined and ground. Since only one piece is required Hand Taps (M 8) in set of three (Rougher, Intermediate and Finisher) can be used for thread cutting in blind holes. (Fig. 2.9).

Table : Cutting Speeds (in m/min) for Thread Cutting.

Work material	*Thread cutting tool of*	
	Tool steel	*High-speed steel*
Unalloyed structural steel	5	12
Structural alloy steel	—	6
Cast iron	5	9
Brass	10	15
Aluminium alloy	16	25

Cutting of Internal Thread

Thread cutting will be done manually (by hand) with No. I tap and then the machine will be engaged. The sleeve will be adjusted regularly in conformity with the feed of the tap. The succeeding tap will be some what screwed in by hand and then the tap holder will be used.

During the cutting of internal thread it should be ensured that

(*a*) Taps must be sharp, otherwise the thread flanks become rough and cracks are developed.
(*b*) The work piece runs concentric to avoid formation of oblique threads.
(*c*) Hand taps are inserted in proper sequence of the set (*i.e.*, I, II and III) Fig. 2.9.
(*d*) Suitable lubricants are used to reduce friction and to get clean thread flanks.

Lubricants for thread cutting

Work Material	***Lubricant***
Unalloyed structural steel	Cutting oil
Alloy steel	Cutting oil, turpentine, kerosene
Cast iron	Dry or abundant oil
Brass and Bronze	Cutting oil
Aluminium alloy	Cooling oil (emulsion), kerosene

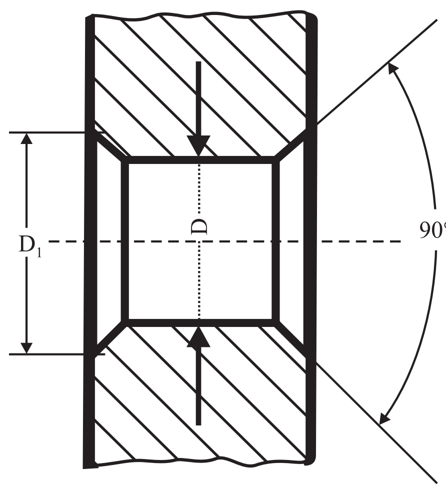


Fig 2.8. Preparation of the Core hole
D : Core Diameter of thread **D_1 :** External Diameter (*i.e.*, Maximum Dia.) of thread

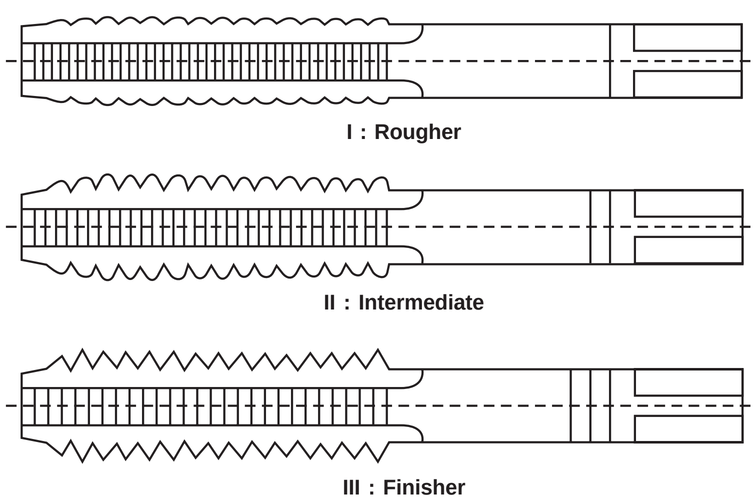


Fig 2.9. Hand taps in set of three.

6. Holding of workpiece, turning of part for M12.

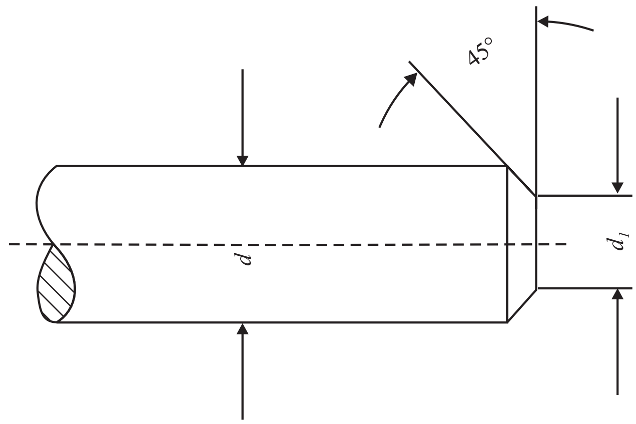


Fig. 2.10 : Preparing the bolt end
d : External diameter of the thread = 12 mm
d_1 : Core diameter of the thread = 11.85 mm

Preparing the bolt end : (Fig. 2.10). Since burrs are likely to form, the thread part of the bolt end is turned to 11.85 mm diameter, *i.e.*, external diameter reduced by 10% of the pitch (pitch = 1.5 mm; 12 mm – 0.15 mm = 11.85 mm). The chamfer enables an easy first cut Fig. 2.10.

7. **Production of male thread (External Thread) M12.**

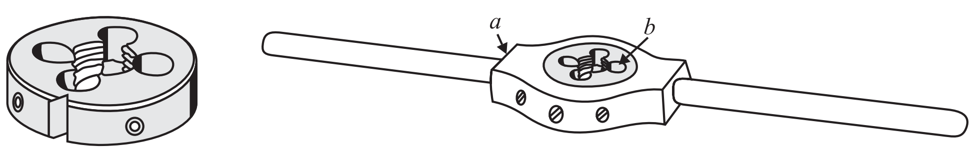
For this **selection of threading** die is to be done. A die of M12 is required. Threading dies are standardized and are generally made of tool steal or H.S.S Fig. 2.11.

Cutting of External Thread M12.

The first turns of the thread are cut by hand manually. After that, the machine will be engaged with proper no. of revolutions. The sleeve must be adjusted regularly. Use coolant/lubricant regularly.

During cutting or external thread it should be ensured that

(*a*) Face of the die must have good contact with the collet or die holder Fig. 2.11. The workpiece must run concentric, the threading die has to be applied in a straight way, otherwise the thread will become elliptical.



Threading die

Die with holder (a) Die holder, (b) die

Fig. 2.11

(*b*) Blunt threading dies create rough and irregular flanks. Hence ensure that the die is sharp.

(*c*) Chips in the chip hole damage the thread flanks. Withdraw the die now and then to ensure that the chips flow away.

(*d*) Lubrication has to be applied regularly.

SELECTION OF COST OPTIMAL PROCESS

Two different types of processes can be used for the same job. The processes can be compared and optimum process selected with the help of break-even charts.

Break-even charts : Break-even charts give the production engineer a powerful tool by which feasible alternative processes can be compared and the process which gives minimum cost can be selected. The fixed and variable costs for two alternative processes are plotted on a graph to a suitable scale as shown in Fig. 2.12.

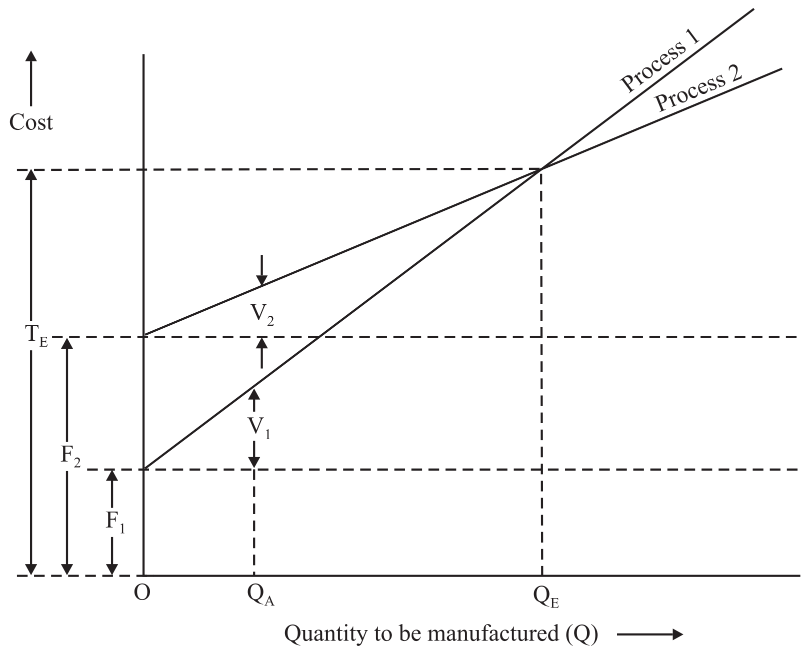


Fig. 2.12 Break-even chart for two processes

F_1 = Fixed costs for process (1)
F_2 = Fixed costs for process (2)
V_1 = Variable costs for process (1) } at quantity Q_A
V_2 = Variable costs for process (2) } at quantity Q_A
Q_E = Break-even quantity
T_E = Total costs of manufacture at quantity Q_E

For each process generally the variable cost is a linear function of the quantity manufactured. Therefore, once the fixed costs have been plotted, only one value for the variable costs is required at some value Q_A and the total cost lines can be drawn.

Where these lines intersect is known as the break-even point, *i.e.*, the point where the total cost of manufacture of quantity Q_E is same for both process (1) and process (2). The break-even chart tells us to :

Use process (1) if the quantity to be manufactured $\leq Q_E$

Use process (2) if the quantity to be manufactured $\geq Q_E$

The value of Q_E can be scaled directly from the chart with sufficient accuracy, although it can also easily be calculated.

Example 1 : A component can be produced with equal ease on either a capstan lathe or on a single spindle cam operated automatic lathe. Find the break-even quantity Q_E if the following information is known.

		Capstan Lathe	Automatic Lathe
(*a*)	Tooling cost	Rs. 30.00	Rs. 30.00
(*b*)	Cost of cams	—	Rs. 150.00
(*c*)	Material cost/Component	Rs. 0.25	Rs. 0.25
(*d*)	Operating labour cost	Rs. 2.50/hour	Rs. 1.00/hour
(*e*)	Cycle time/Component	5 minutes	1 minute
(*f*)	Setting up labour cost	Rs. 4.00/hour	Rs. 4.00/hour
(*g*)	Setting up time	1 hour	8 hours
(*h*)	Machine overheads (setting and operating)	300 % of (d)	1000 % of (d)

Solution

Capstan lathe : Overheads $= \frac{300}{100} \times 2.50 =$ Rs. 7.50/hour

Fixed Costs = tooling cost + setting-up cost

= 30.00 + 1(4.00 + 7.50)

= 30.00 + 11.50 = Rs. 41.50

≃ Rs. 42

Variable costs/Component $= \left(2.50 \times \frac{5}{60}\right) + 0.25 + \left(7.50 \times \frac{5}{60}\right)$

= 0.21 + 0.25 + 0.63 = Rs. 1.09

Variable costs/1000 components = Rs. 1090.00

Automatic lathe : Overheads $= \frac{1000}{100} \times 1.00 =$ Rs. 10.00/h

Fixed costs = tooling cost + cam cost + setting-up cost

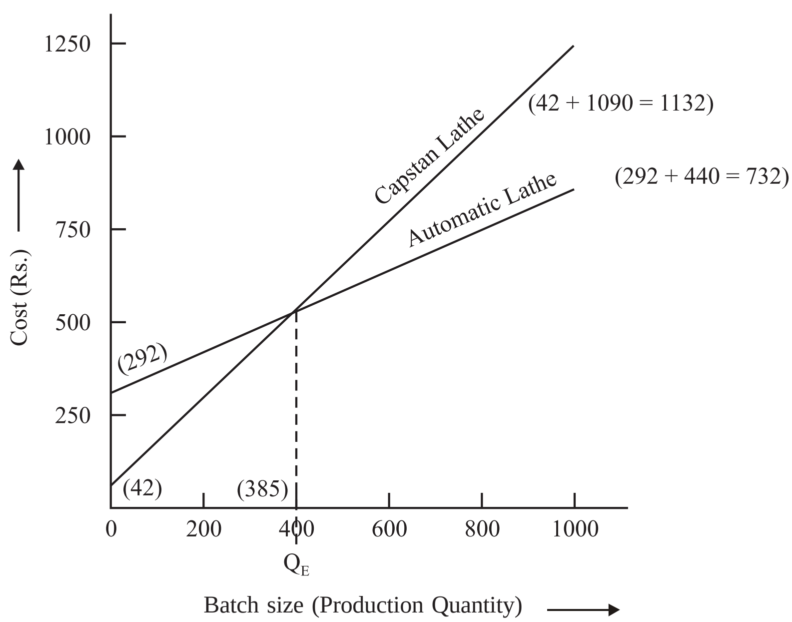


Fig. 2.13 : Break-even chart.

$$= 30.00 + 150.00 + 8\,(4.00 + 10.00\,)$$
$$= 180.00 + 112.00 \quad = \text{Rs. } 292.00$$
$$\text{Variable costs/Component} = \left(1.00 \times \frac{1}{60}\right) + 0.25 + \left(10.00 \times \frac{1}{60}\right)$$
$$= 0.02 + 0.25 + 0.17 \;=\; \text{Rs. } 0.44$$
$$\text{Variable costs/1000 components} = \text{Rs. } 440.00.$$

These costs can now be plotted on a break-even chat (Fig. 2.13) to find the value of Q_E.

Q_E is scaled from the break-even chart (Fig. 2.13) and found to be 385. If the batch size to be manufactured is equal to or less than 385 use the capstan lathe.

If the batch size to be manufactured is equal to or greater than 385 use the automatic lathe. The above is the graphical method of determining Break-even Quantity.

In this example no account was taken directly of the costs of depreciation and interest charges. The cost accountant's methods of dealing with these charges will be determined by circumstances.

If preferred, the break-even quantity Q_E can be calculated numerically thus :

Total cost of producing a quantity x on the capstan lathe

$$= 41.50 + 1.09\,x$$

Total cost of producing a quantity x on the automatic lathe

$$= 292.00 + 0.44\,x$$

When x is equal to Q_E the total costs for each machine must equal.

$$\therefore \quad 41.50 + 1.09\,x = 292.00 + 0.44\,x$$
$$1.09\,x - 0.44\,x = 292.00 - 41.50$$
$$\therefore \quad 0.65\,x = 250.50$$
$$x = \frac{250.50}{0.65} = 385 \text{ at the break-even point.}$$

Thus Break-even chart or break-even analysis can be made to select the cost optimal process.

Example 2 : A component can be produced will equal facility using either a numerically controlled milling machine, or an operator controlled milling machine (conventional machine).

(*a*) Which process should be chosen for minimum costs if two components only are required ? (Assume no special tooling for the conventional machine and hence no fixed costs, but that it is a toolroom universal milling machine with high overheads.)

(*b*) Which process should be chosen for minimum costs if a batch of 100 components is required ? (Assume special tooling such as fixture and gauges are required for the conventional machine, which is a plain milling machine on a production line).

The following cost information is known.

	Situation (a)		***Situation (b)***	
	N/c machine	***Conventional machine***	***N/c machine***	***Conventional machine***
Fixed cost	Rs. 80	—	Rs. 80	Rs. 300
Labour/part	Rs. 1.50	Rs. 12.50	Rs. 1.50	Rs. 0.35
Material/part	Rs. 1.00	Rs. 1.00	Rs. 1.00	Rs. 1.00
Overheads/part	Rs. 3.00	Rs. 30.00	Rs. 3.00	Rs. 2.25

Solution : Situation (*a*)

Variable costs/part for N/c machine = 1.50 + 1.00 + 3.00 = Rs. 5.50

Variable cost/part for conventional machine = 12.50 + 1.00 + 30.00 = Rs. 43.50

The costs can now be plotted on a break-even chart (Fig. 2.14)

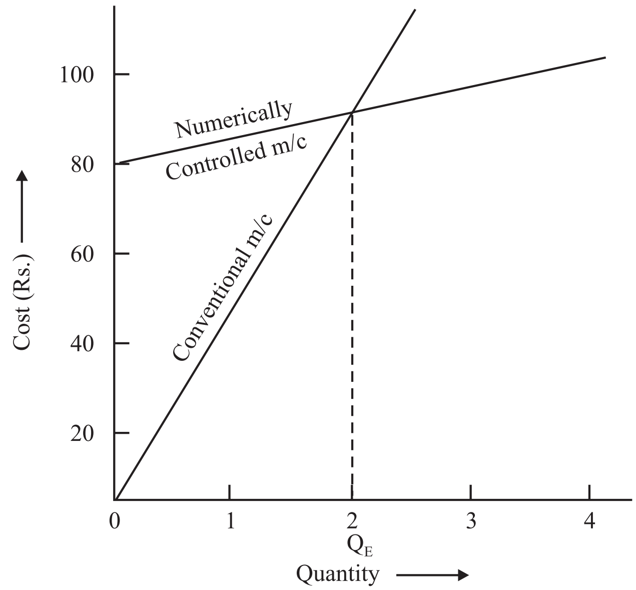


Fig. 2.14 : Break-even chart

Q_E is equal to approximately 2.2 components.

The conventional machine should be chosen if two components only are required.

Situation (*b*)

Variable costs/part for N/c machine = 1.50 + 1.00 + 3.00 = Rs. 5.50

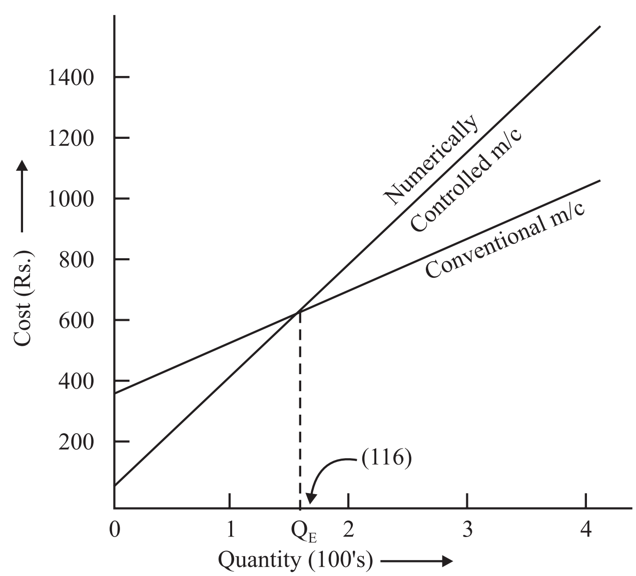


Fig. 2.15 : Break-even chart.

Variable costs/100 parts for N/c machine = Rs. 550.00

Variable costs/part for conventional machine = 0.35 + 1.00 + 2.25 = Rs. 3.60

Variable costs/100 parts for conventional machine = Rs. 360.00

The costs can now be plotted on a break-even chart (Fig. 2.15) to find the value of Q_E.

Q_E is equal to approximately 116 components.

The numerically controlled milling machine should be chosen if more than 100 components are required. The above problem can be solved analytically also.

BREAK EVEN POINT, BREAK EVEN CHART AND BREAK EVEN ANALYSIS : Instructional Objectives

After studying this unit the students will be able to :

(1) Distinguish between fixed costs and variable costs.
(2) Calculate hourly cost of running and maintenance of machines.
(3) Draw break-even chart from given data and select the best process.
(4) Select the most economical method for the manufacture of a component from the available alternatives.

The total cost of running and maintenance of machines can be divided into two parts–Fixed costs and Variable costs. The meaning of fixed costs and variable costs, in general is given below.

Fixed costs : The fixed costs are the items of expenditure which remain more or less constant irrespective of the volume of production. Some important items under fixed costs are depreciation of plant and machinery and building, interest on capital, supervisory charges, cost of lighting, heating and cleaning the works, operator charges, rent of building etc.

Variable costs : Variable costs are those items of expenditure which vary with the volume of production. Some important items under variable costs are direct material cost, cost of power/fuel consumed, cost of tools used, cost of consumable stores, repair and maintenance charges, storage charges, etc.

Calculation of hourly cost of running and maintenance of machines can be done on the basis of fixed costs and variable costs.

1. Fixed Costs

(*i*) **Depreciation :** Depreciation is defined as the reduction in the value of an asset, machinery, equipment or building with passage of time due to various reasons, such as wear and tear, and obsolescence. Whether we use the machine or not its value is decreasing with passage of time. Depreciation is computed and accounted for in calculating the hourly cost of running and maintenance of machines. There are different methods of calculating and apportioning depreciation charges.

(*ii*) **Interest on capital amount :** Interest on capital amount invested in the purchase of the machine is also considered in calculating hourly cost of running the machine. The rate of interest is that which the capital amount would have yielded if that amount is invested in a bank. The interest on capital is constant whether the machine is being used or not.

(*iii*) **Supervisory charges :** Supervisory charges include the wages of supervisors, foremen, inspectors etc., who supervise the production. These wages are calculated for a year for a particular department. The supervisory charges are distributed over the total number of machine-hours available in a year in that department.

(*iv*) **Operator charges :** If the operator of the machine is paid on monthly basis his wages are also included in the fixed costs and considered in calculating the hourly charges of running the machine. (However, if the operator is paid on piece rate basis, then the operator charges form a part of variable costs, since the operator charges are proportional to the number of pieces produced).

(*v*) **Rent of building :** The rent of space occupied by the machine is independent of the volume of production. The proportion of rent of building considered in hourly cost of running of machine is calculated by dividing the rent of building space by machine-hours available in one month.

2. Variable Costs

(*i*) **Power (or energy) or fuel consumed :** Cost of power or fuel consumed in running the machine varies with the volume of production. The total cost of power is calculated at the end of each month and is distributed over various departments according to the actual power consumed by each department. The power charges are then distributed on each machine in the department and hourly cost of power consumed is calculated. The total power cost includes the expenses made on salary of the power plant-incharge and other staff, expenses for repair and maintenance of power plant, depreciation of plant and machinery in power house and cost of coal and fuel (if used) or electricity bill.

(*ii*) **Repair and maintenance charges :** The repair and maintenance charges of a machine generally depend on the extent of the usage of the machine. Higher is the volume of production, higher will be the wear and tear and hence more expenses on repair and maintenance. If the repair of the machinery is got done from some outside parties, then the charges are taken from the repairers bill. But in all medium and large organisations, a separate maintenance department looks after the work of repair and maintenance. In such cases, a record of all the expenditure involved in the maintenance of equipment is made and the total cost of repair and maintenance over a year is computed. This cost divided by the number of machine-hours available in one year gives the hourly cost of repair and maintenance for that machine.

(*iii*) **Consumable stores and other charges :** The expenditure incurred on consumables like lubricants, coolants, oils, cotton waste and small tools depends on the volume of production. The cost of clerical work involved in the operation of stores, cost of storage space required and cost of labour required for handling the materials etc., are dependent on the volume of production and form a part of variable expenses.

Total cost of the consumables and services are added and apportioned to various departments, based on the consumable and services used up by various departments, or on the basis of direct labour cost or direct material cost. This is then distributed over various machines in the department.

HOURLY COST OF RUNNING AND MAINTENANCE OF A MACHINE

$$= \frac{\text{Fixed costs}}{\text{Machine life in hours}} + \text{Variable costs per hour}$$

The hourly cost of running and maintenance of a machine has to be calculated before we an calculate the total cost of any component requiring machining operations.

The cost of using a particular machine for one component is given by :

$$C = T \times R$$

where C = Cost of using a particular machine for making one component.

T = Machine hours required to make one component.

R = Hourly rate of running and maintenance of machine.

BREAK-EVEN POINT, BREAK-EVEN CHART AND BREAK-EVEN ANALYSIS

(1) Break-even point (BEP) represents the production quantity for which the total cost of producing the goods equals the total sales price. At break-even point there will be neither any profit nor any loss to the manufacturer.

If Q = Quantity at BEP

F = Fixed costs

V = Variable cost per unit produced

S = Selling price per unit

Then $F + (Q \times V) = S \times Q$

$$Q = \frac{F}{S - V}$$

(2) Break-even chart is a graphical representation of inter-relationship between quantity produced, cost of producing and sales return. The total cost of production (fixed cost + variable cost) and total sales return are plotted against quantity produced. The intersection of the total cost and total sales return lines gives the break-even point.

Uses of Break-even Chart

Break-even chart indicates the profit or loss at varying levels of production activity. From Fig. 2.16 we see that there will be loss to the organisation if the quantity produced is less than Q but if the quantity produced is more than Q, there will be profit.

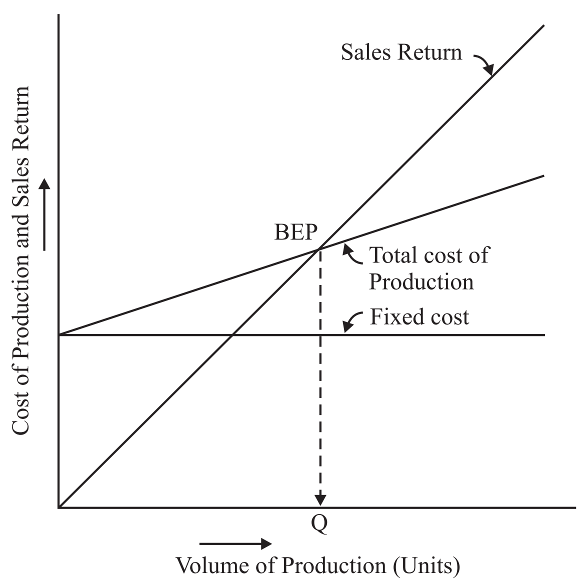


Fig. 2.16

3. Break-even Analysis

Break-even charts are also used for comparing the cost of producing a product by different manufacturing processes. The total costs for two alternative processes are plotted on a graph against quantity to be produced. The point where these two lines intersect is known as break-even point (Fig. 2.17). The break-even chart tells us :

(*i*) Use process A if the quantity to be manufactured is less than quantity at BEP.

(*ii*) Use process B if the quantity to be manufactured is more than quantity at BEP.

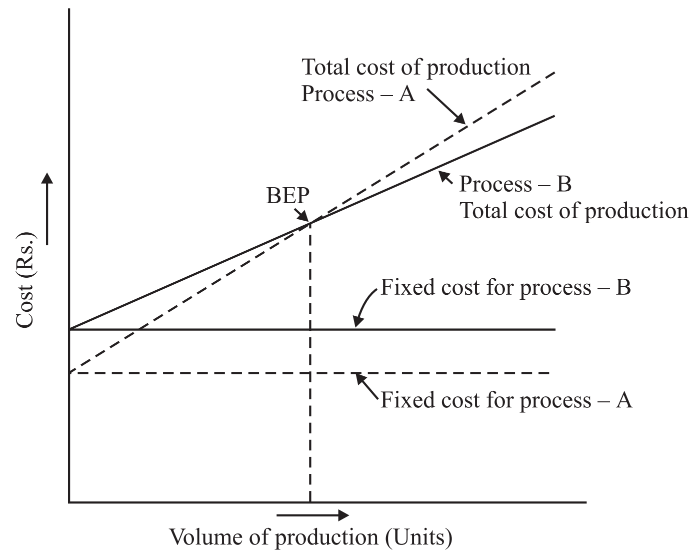


Fig. 2.17

ILLUSTRATIVE EXAMPLES ▶

Example 1 : In a small factory making toys, the fixed overhead costs are Rs. 5,000 per month and the variable cost is Rs. 4 per piece. The selling price is Rs. 6 per piece. Estimate the minimum monthly production so that the factory may not suffer any loss.

Solution :

Fixed cost = Rs. 5,000

Variable cost = Rs. 4 per piece

Selling price = Rs. 6 per piece

Let the required minimum production = P units

Total cost of producing P units = Fixed cost + Variable cost

$= 5,000 + (P \times 4)$

$= 5,000 + 4\,P$

Total selling price of P units = $6 \times P$

Now for no profit no loss conditions, the total cost of producing P units should be equal to total sales return

$$5,000 + 4\,P = 6\,P$$

$$P = 2,500$$

Therefore, to avoid any loss to the factory, minimum monthly production should be 2,500 pieces.

More than 2,500 pieces per month must be manufactured and sold so that the company can earn profit.

Example 2 : A factory has three sections in a machine shop. During one calender year the following details are available :

(*i*) Depreciation and rent of building Rs. 8,000

(*ii*) Supervisory charges Rs. 20,000
(*iii*) Indirect labour and indirect materials Rs. 7,000
(*iv*) Insurance charges Rs. 5,000
(*v*) Other charges (given below)

Item of expenditure	*Section I*	*Section II*	*Section III*
Depreciation of machines	Rs. 5,000	Rs. 7,000	Rs. 4,000
Cost of power consumed	Rs. 3,000	Rs. 5,000	Rs. 2,000
Area occupied as percentage of total area	40%	20%	40%
M/C hours worked	8,000	25,000	10,000
Maintenance charges	Rs. 2,000	Rs. 3,000	Rs. 1,000

Find out the machine-hour rate for each section if the common fixed expenses are to be apportioned on the basis of floor space occupied by each section.

Solution : The total expenses for Section I are as follows :

(*i*) Common fixed expenses such as depreciation and rent of building, supervisory charges, indirect labour and indirect materials and insurance charges are charged on the basis of floor area occupied.

$$= (8{,}000 + 20{,}000 + 7{,}000 + 5{,}000) \times \frac{40}{100}$$

$$= \text{Rs. } 16{,}000 \text{ per year}$$

(*ii*) Depreciation of machines = Rs. 5,000

Power charges = Rs. 3,000

Maintenance charges = Rs. 2,000

Total expenses = 16,000 + 5,000 + 3,000 + 2,000

= Rs. 26,000 per year.

Machine-hours worked during one year = 8,000

$$\text{Machine-hour rate for Section I} = \frac{26{,}000}{8{,}000} = \text{Rs. } 3.25$$

For Section II :

$$\text{Total cost} = (8{,}000 + 20{,}000 + 7{,}000 + 5{,}000) \times \frac{20}{100} + (7{,}000 + 5{,}000 + 3{,}000)$$

$$= \text{Rs. } 23{,}000 \text{ per year}$$

Machine-hours worked during one year = 25,000

$$\text{Machine-hour rate for Section II} = \frac{23{,}000}{25{,}000} = \text{Rs. } 0.92$$

Similarly calculate the machine-hour rate for Section III = Rs. 2.30

Example 3 : A manufacturing concern purchased two identical machines each for Rs. 15,000. If depreciation of the machines is on the basis of machine-hours and if the two machines are to share the rent, lighting, water charges etc., proportional to floor area occupied by the machine, workout the machine-hour rate from the given data :

Scrap value of each machine after 10 years	=	Rs. 2,500
Machine-hours/year/machine	=	2,200
Power consumption per hour per machine	=	10 Units
Rate per Unit of power consumed	=	Rs. 3
Maintenance and repair charges/year/machine	=	Rs. 150
Overhead charges per machine per year	=	Rs. 160
Workshop rent per year	=	Rs. 12,000
Lighting, water charges per year	=	Rs. 600
Floor space occupied by each machine	=	20 per cent of floor space of works

Solution : We will make the calculations for one machine.

The fixed costs are :

(*i*) Depreciation,

(*ii*) Maintenance and repair charges,

(*iii*) Overhead charges,

(*iv*) Workshop rent,

(*v*) Lighting, water charges etc.

The variable costs are :

(*i*) Power consumed

Fixed costs :

(*i*) Depreciation :

Initial cost = Rs. 15,000

Scrap value = Rs. 2,500

Life of m/c = 10 years

$$\text{Depreciation per year} = \frac{15{,}000 - 2{,}500}{10} = \frac{12{,}500}{10} = \text{Rs. } 1{,}250$$

(*ii*) Maintenance and repair charges/year	=	Rs. 150
(*iii*) Overhead charges/year	=	Rs. 600
(*iv*) Workshop rent/year	=	Rs. 12,000
(*v*) Water and lighting charges/year	=	Rs. 600

Now the machine occupies 20 percent of floor space of works. Share of rent and lighting charges for one machine

$$= \frac{20}{100} \times (12{,}000 + 600) = \text{Rs. } 2520 \text{ per year}$$

Fixed costs per year = 1,250 + 150 + 600 + 2520 = Rs. 4520

No. of machine-hours per year = 2,200

$$\text{Fixed costs per machine-hour} = \frac{4520}{2{,}200} = \text{Rs. } 2.10$$

Variable costs

Power consumed per hour = 10 Units

Rate per Unit of power = Rs. 3

Cost of power consumed per hour = 10 × 3 = Rs. 30

Variable costs per machine-hour = Rs. 30

Now machine-hour rate = Fixed cost per m/c hour + Variable costs per m/s hour

= 2.10 + 30.00 = Rs. 32.10

Example 4 : In a factory fixed overhead charges are Rs. 45,000 and the variable overhead charges are Rs. 2.50 per article. The factory is producing 45,000 articles per month under normal conditions. Find :

(*i*) Overhead cost per article under normal conditions.

(*ii*) If the production drops to 80 percent, calculate the charges that remain uncovered.

(*iii*) If the production increases to 125 percent, by what amount these charges will be over-recovered.

Take the overhead rate per article the same as during normal production, in both the cases.

Solution : (*i*) Under normal conditions :

Rate of overheads per article = Fixed overheads per article + Variable overheads per article

$$= \frac{45{,}000}{45{,}000} + 2.50 = \text{Rs. } 3.50 \text{ per article.}$$

(*ii*) If the production drops to 80 percent of normal production

$$\text{No. of articles produced} = \frac{45{,}000 \times 80}{100} = 36{,}000$$

The total amount spent on producing 36,000 articles

= Fixed cost + Variable costs

= 45,000 + (36,000 × 2.5)

= Rs. 1,35,000

Amount recovered as overheads @ Rs. 3.50 per article

= 36,000 × 3.50 = Rs. 1,26,000

So, the amount that remains uncovered = 1,35,000 – 1,26,000 = Rs. 9,000

(*iii*) If the production increases to 125 percent of normal production

$$\text{Number of articles produced} = 45{,}000 \times \frac{125}{100} = 56{,}250$$

Amount spent on producing 56,250 articles = 45,000 + (56,250 × 2.50) = Rs. 1,85,625

Amount recovered @ Rs. 3.50 per article = 56,250 × 3.50 = Rs. 1,96,875

Amount that is over-recovered = 1,96,875 – 1,85,625 = Rs. 11,250

Example 5 : The fixed costs for a factory for the year 2003–04 are Rs. 1,50,000 and the variable cost is Rs. 10 per unit produced. The selling price per unit is Rs. 25, calculate the break-even quantity.

Solution : Fixed costs = Rs. 1,50,000 per year

Variable cost = Rs. 10 per unit

Selling price = Rs. 15 per unit

The break-even quantity can be calculated analytically as well as by plotting a graph.

(*i*) Analytical method :

Let the break-even quantity = X units

Total cost of producing X units = 1,50,000 + 10 X

Return from sale of X units = 15 X

At break-even point

$$1{,}50{,}000 + 10\text{ X} = 15\text{ X}$$

$$\text{X} = 30{,}000 \text{ units.}$$

(*ii*) Graphical method :

The total cost of producing and sales return is plotted against the quantity produced Fig. 2.18. The quantity at which the two lines intersect gives the break-even point. From graph we see that the lines intersect at 30,000 units which gives break-even quantity.

Example 6 : The following information is available for two machines in a manufacturing unit :

	Item of expenditure	*Machine I (Capstan lathe)*	*Machine II (Automatic lathe)*
(*i*)	Tooling cost	Rs. 300	Rs. 1,800
(*ii*)	Operating labour cost per hour	Rs. 5	Re. 1
(*iii*)	Cycle time per piece	5 min.	1 min.
(*iv*)	Setting up cost	Rs. 20	Rs. 150
(*v*)	Overheads	Rs. 30	Rs. 250
(*vi*)	Maintenance cost per hour	Rs. 6	Rs. 25
(*vii*)	Power charges per hour	Rs. 2	Rs. 4

Draw the break-even chart for the two machines and find out break-even quantity. Also find out which process is suitable for producing 4,000 items.

Solution : This is a problem on comparision of cost of manufacturing the components on two different machines or processes.

(*i*) Machine I : (Capstan lathe)

Fixed cost = Tooling cost + Set-up cost + Overheads

= 300 + 20 + 30 = Rs. 350

Variable cost = Operating labour cost + Maintenance charges + Power charges

$$= \frac{5 \times 5}{60} + \frac{5 \times 6}{60} + \frac{5 \times 2}{60} = \text{Rs. } 1.08$$

(*ii*) Machine II :

Fixed costs = Tooling cost + Set-up cost + Overheads

= 1,800 +150 + 250 = Rs. 2,200

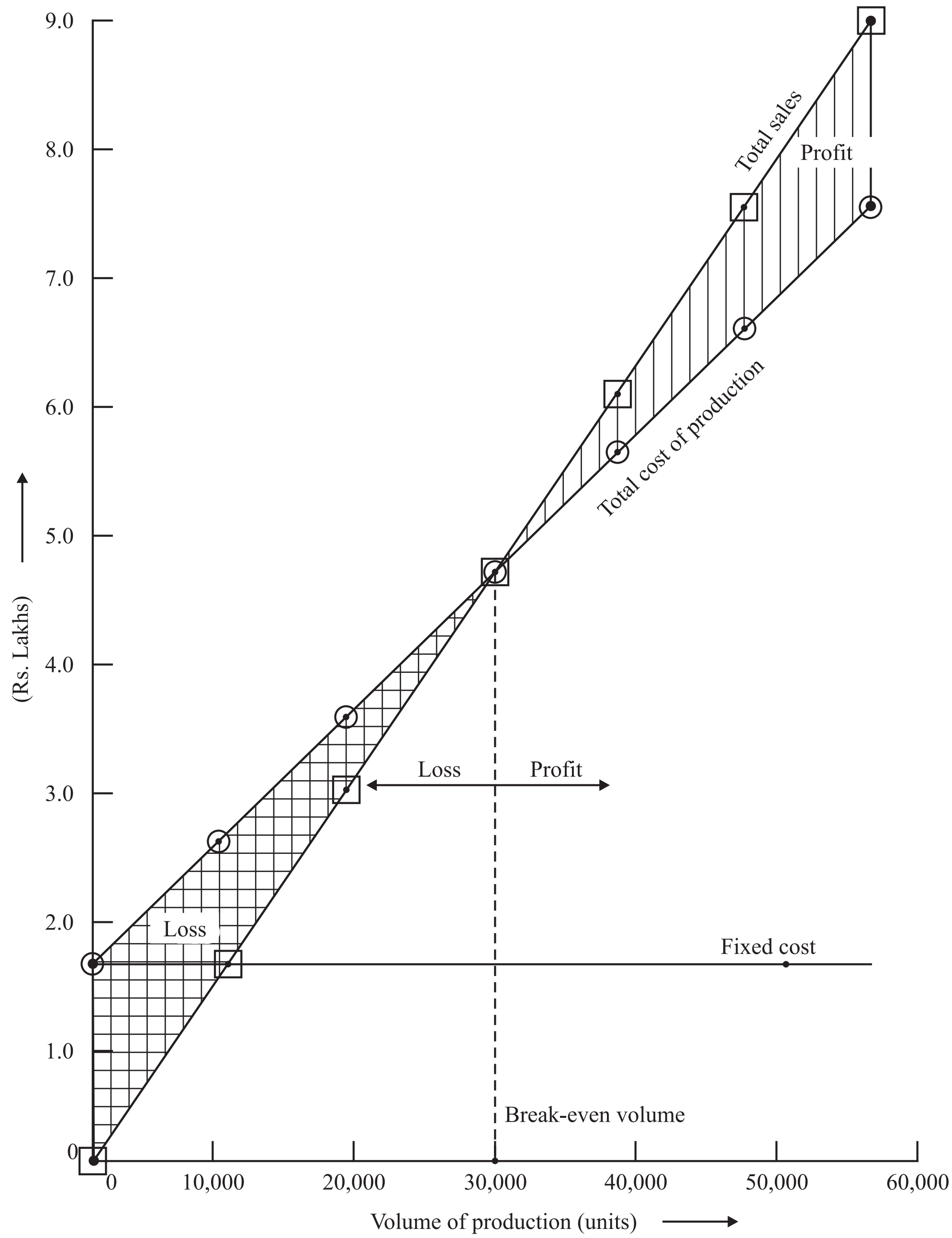


Fig. 2.18 Break-even chart

$$\text{Variable cost} = \frac{1 \times 1}{60} + \frac{1 \times 25}{60} + \frac{1 \times 4}{60} = \text{Rs. } 0.50$$

The break-even chart is shown in Fig. 2.19.

$$\text{Break-even quantity } Q_E = 3,190$$

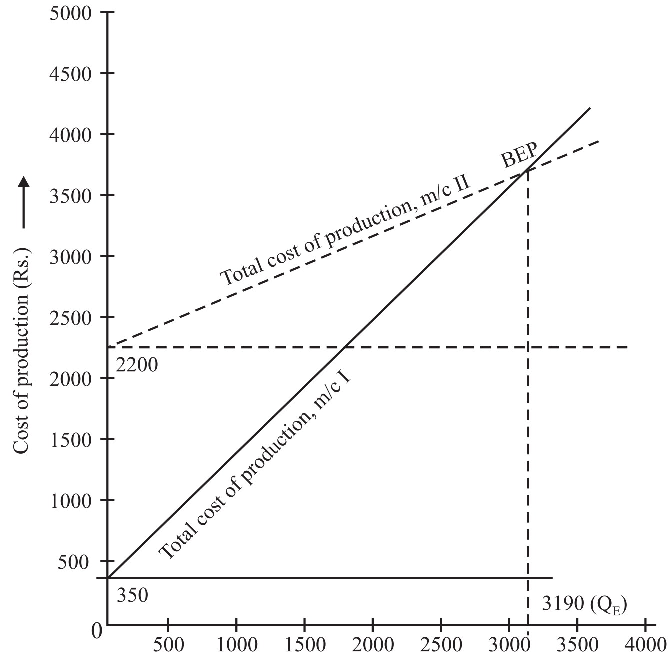


Fig. 2.19. Volume of production (units)

Now from the chart we see that machine I is economical if quantity to be produced is less than Q_E and machine II is economical if quantity to be produced is more than Q_E.

To produce 4,000 units, machine II is economical.

EVALUATIVE QUESTIONS ▶ PROCESS PLANNING

1. Give the main characteristics of job, batch and mass production.

2. What do you understand by Process Planning ?

3. Give a procedure for process planning for the manufacture of a component in machine shop.

4. Write short notes on :

(*a*) Batch production

(*b*) Calculation of material quantity required

(*c*) Uses of a process sheet.

5. Explain the steps involved in calculation of man-hours and machine-hours availability.

6. Name the type of production activity (Job, batch or mass production) for the following :

(*a*) Press tools

(*b*) Nuts and Bolts

(*c*) Fertilizers

(*d*) Bricks

(*e*) Readymade shirts

(*f*) Pencils

(*g*) Tractors

(*h*) Cars

(*i*) Cloth

(*j*) Watches

(*k*) Furniture

7. The following data is available for a machine shop :

(*a*)	No. of machines	6
(*b*)	No. of working days/month	25
(*c*)	Working hours per day	8 (one shift only)
(*d*)	Overtime allowed per day	1.5 hours
(*e*)	Absenteeism	10%
(*f*)	Repair and maintenance allowance	5%

Calculate the net available machine-hours in one month.

8. What factors are taken into consideration in product design ?

9. What are the steps involved in process design ?

10. What is process design and what are the factors affecting process design ?

11. Draw a graph connecting “product variety” and “production quantity” for different types of production.

12. What are the advantages of ‘Standardization” ?

13. What are the steps involved in “Process Planning ?

14. What is a “Route Sheet” ?

15. What are the two approaches to Process Planning in the context of CAPP (Computer Aided Process Planning) ? Explain them clearly.

16. What factors are taken into consideration in Process Selection ?

17. What factors are taken into consideration in Machine Selection ?

18. What are the process selection parameters ?

19. What are the various parameters considered in the material selection ?

20. What are the documents required for Process Planning ?

21. What are the different factors considered in developing a manufacturing logic ?

22. What are the basic steps in Process Planning ?

EVALUATIVE QUESTIONS ▶ BREAK-EVEN POINT AND BREAK-EVEN CHART

1. (*a*) What do you understand by hourly cost of running a machine ?

(*b*) What are the various cost elements considered in calculating the hourly cost of running a machine ?

2. Define break-even point and how to calculate break-even quantity ?

3. What is a break-even chart ? What are the uses of break-even chart ?

4. Explain the following :

(*a*) Fixed costs

(*b*) Variable costs

(*c*) Break-even point

5. A component can be made either on an ordinary lathe or on an automatic lathe. The time taken in first case is $1\frac{1}{2}$ hours per piece and overheads are 30 percent of labour cost. In the second case, the time taken is 30 minutes per item and overheads are 200 per cent of labour cost. If the material cost is Rs. 20 per piece and labour charges are Rs. 5 per hour, compare the total cost in both the cases.

6. A factory has 15 lathes of same make and 15 shapers of same make and capacity. Lathes occupy 30 m^2 floor area while shapers occupy 15 m^2 floor area. During one calender year, factory expenses are as follows :

		Rs.
(*i*)	Building rent and depreciation	5,000
(*ii*)	Indirect labour and material costs	15,000
(*iii*)	Insurance charges	2,000
(*iv*)	Depreciation charges of lathes	5,000
(*v*)	Depreciation charges of shapers	3,000
(*vi*)	Power consumption for the lathes	2,000
(*vii*)	Power consumption for the shapers	1,000

Find out the machine-hour rate of on-cost allocation for lathes and shapers, if all the lathes and shapers work for 2,500 hours and 8,000 hours respectively.

7. A component can be conveniently manufactured either on an ordinary centre lathe or on an automatic lathe machine. Each machine has a working life of 20,000 hours. The following data is available :

	Item of expenditure	***Ordinary Centre Lathe***	***Automatic m/c***
(*i*)	Initial cost	Rs. 75,000	Rs. 1,40,000
(*ii*)	Tooling cost	Rs. 600	Rs. 7,500
(*iii*)	Material cost/piece	Rs. 2.00	Rs. 2.00
(*iv*)	Labour cost/hour	Rs. 10.00	Rs. 18.00
(*v*)	Cycle time/piece	6 min.	1 min.
(*vi*)	Setting up labour cost	Rs. 40	Rs. 70
(*vii*)	Machine overheads/hours	Rs. 40	Rs. 60
(*viii*)	Salvage value after 20,000 hours	Rs. 15,000	Rs. 20,000

Calculate the quantity at break-even point.

8. In a manufacturing concern the variable overhead charges are Rs. 2 per article and the fixed overheads are Rs. 2,40,000 per annum. The factory is producting 15,000 articles per month. Calculate :

(*i*) Normal overhead cost per product.

(*ii*) If the production drops to 70 percent of normal production, the overheads charges that remain uncovered.

(*iii*) If the production increases to 125 percent, by what amount the charges will be over-recovered.

Take the overhead rate per article the same as that during normal conditions.

3 INTRODUCTION TO COST ESTIMATION

COST ESTIMATION : Instructional Objectives

After studying this unit, the student will be able to :

(i) Differentiate between costing and cost estimation.

(ii) Understand the importance of preparing realistic cost estimates and concept of over estimating and underestimating.

(iii) Identify the various components of a cost estimate.

(iv) Understand the procedure for preparing the cost estimate.

Estimating, in general, implies indication of a carefully considered computation of some quantity, the exact magnitude of which can not be determined at that stage.

COST ESTIMATING

Cost estimating is the estimation of the expected cost of producing a job or executing a manufacturing order before the actual production is taken up or predicting what new products will cost, before they are made. The expected expenditure on all the items used to make a product is added to give the estimated cost of final product.

An ideal estimate will give lowest cost of production in actual practice but an estimate will never guarantee that the actual cost of production will be equal to the estimated cost. The accuracy of cost estimate depends on the order of details of estimate, basis of calculation and the reliability of the data used. In general the accuracy of an estimate increases, *i.e.*, the estimated cost approximates more closely to the actual production cost, as more and more detailed calculations are made in estimating.

COST ACCOUNTING

Costing or cost accounting means classifying, recording and allocating the appropriate expenditure for determining the cost of production and achieved by keeping a continuous record of all the costs involved in manufacturing.

DIFFERENCE BETWEEN COSTING OR COST ACCOUNTING AND COST ESTIMATION

Costing or cost accounting gives the actual expenditure incurred on the production of the component based on the records of expenditure on various activities involved, when the product has already been manufactured whereas estimating is a type of forecasting and gives the expected expenditure to be incurred on the manufacture of the product before the actual manufacturing is taken up. Also, cost estimating is done by qualified engineers, whereas costing is done by accountants or cost accountants.

OBJECTIVES OF COST ESTIMATION

The objectives of cost estimation are given below :

(*i*) It gives an indication to the manufacturer whether the project to be undertaken will be economical or not.

(*ii*) It enables the manufacturer to choose from various methods of production the one which is likely to be most economical, as all possible methods of production for particular product are analysed and evaluated.

(*iii*) It enables the manufacturer to fix the selling price (sales price) of the product in advance of actual production. This is required to ensure that the product will be competitive and also to provide a reasonable profit on the investment of the company.

(*iv*) it helps in taking decisions to make or to buy.

(*v*) Cost estimation gives detailed information of all the operations and their costs, thus setting a standard to be achieved in actual practice.

(*vi*) It gives an estimate of the total expenditure expected to be made on a project enabling the management to arrange the necessary finance or capital.

(*vii*) It helps a contractor to submit accurate tenders for entering into contract to manufacture certain products.

(*viii*) Cost estimation enables the management to plan for procurement of raw materials/tools etc., as it gives detailed requirements.

The value of an estimate lies in its accuracy, which depends on the care with which it is prepared. Carelessly prepared estimates may prove to be harmful to the organisation or may even result in the closure of the firm.

If a job is overestimated, *i.e.*, the estimated cost is much above the actual cost of the product, the shop or firm will not be able to compete with its competitors who have estimated the price correctly and loses the order to its competitors. On the other hand, to underestimate *i.e.*, estimated cost is below the actual cost of product, means a financial loss to the firm and too many losses mean failure or closure of the shop. (But when the cost estimate is to be used as a goal, *i.e.*, target cost to be achieved in production, it should be set on lower side than the actual estimated cost. The factory is more likely to try to meet a low cost target than to try to get costs down very far below an overestimated target cost).

COMPONENTS OF A COST ESTIMATE OR JOB ESTIMATE

The total estimated cost of a product consists of the following cost components :

1. Cost of design.
2. Cost of drafting.
3. Cost of research and development.
4. Cost of raw materials.
5. Cost of labour.
6. Cost of inspection.
7. Cost of tools, jigs and fixtures.
8. Overhead cost.

1. Cost of Design

The cost of design of a component or product is estimated by ascertaining the expected time for the design of that component. This may be done on the basis of similar job previously manufactured but for new and complicated jobs the estimator has to consult the designer who gives the estimated time of design. The estimate design time multiplied by the salary of designer per unit time gives the estimated cost of design. If the design of the component is done by some outside agency, the total amount paid to outside agency gives the cost of design.

2. Cost of Drafting

Once the design of the component is complete, its drawings have to be prepared by draftsman. The expected time to be spent in drawing or drafting is estimated and is then multiplied by the standard drafting rate or by the salary of the draftsman per unit time to get estimated cost of drafting.

3. Cost of Research and Development Work

Before taking up the manufacturing of actual components/parts considerable time and money has to be spent on research and development. The research may be theoretical, experimental or developmental research. The cost of R and D can be estimated by considering various items of expenditure incurred during R and D work which include :

(*i*) Cost of labour involved.

(*ii*) Cost of material used.

(*iii*) Cost of special equipment used or fabricated for the prototype.

(*iv*) Depreciation, repair and maintenance cost of experimental set-up.

(*v*) Cost of services of highly qualified and trained personnel needed for experimentation.

(*vi*) Cost of preparing Test Reports, if any.

In some cases the cost of R and D may be estimated on the basis of research involved in similar products produced in the past.

4. Cost of Raw Material

The estimation of cost of materials used in production of a component/product consists of following steps :

(*i*) A list of all the materials used in the manufacture of the product is made which includes the direct as well as indirect materials.

(*ii*) The quantity (weight or volume) of all the material expected to be used in the manufacture of the product is estimated. The allowance for material wastage, spoilage and scarp are also added for each component/part.

(*iii*) Cost of each material is estimated by multiplying the estimated quantity of each material with its estimated future price. The estimate of future price of a material is made keeping in view of present prices and general trends and variations.

(*iv*) Estimated cost of all the materials is added to get the overall estimated material cost.

5. Cost of Labour

The cost of labour involved in the manufacture of a product is estimated by estimating the labour time needed to manufacture the product and multiplying it by cost of labour per hour. In order to estimate the labour time expected to be spent on a job, one must have thorough knowledge of the various operations to be performed, machines to be used, sequence of operations, tools to be used and labour rates. For this purpose, the estimator may consult engineers, supervisors or foremen from production or industrial engineering departments.

6. Cost of Inspection

A product being manufactured is inspected at various stages during its manufacture. It may be inspection of raw material or in-process inspection or inspection of finished goods. The cost of inspection equipment, gauges and consumable involved in the inspection and testing are taken into account while estimating the cost of the product.

7. Cost and Maintenance Charges of Tools, Jigs and Fixtures

Estimated cost of a product includes the estimated cost and maintenance charges for the tools, jigs, fixtures and dies required in the production. The cost of tools, jigs, fixtures etc., is estimated considering their present prices, market trend and the number of times a particular tool can be used during its life-time. The estimated cost divided by the number of jobs, it can make, gives the tool cost per unit produced.

8. Overhead Costs

Overhead or indirect costs are those which are not incurred specifically for any one order or product and these can not be charged directly to a specific order or product. The overhead costs may be estimated by referring to the records of overhead costs in similar items produced in past. The overhead cost per unit varies considerably with the volume of production *i.e.* number of components produced.

COST ESTIMATION PROCEDURE

For estimating the cost of a product, the various items of expenditure discussed earlier are grouped as follows :

1. **Direct material costs :** It is the cost of those materials which become a part of final product.
2. **Direct labour costs :** It is the expenditure made on the wages and salaries of workers who are directly engaged in the manufacturing processes *e.g.* turner, milling machine operator, painter, etc.
3. **Direct other expenses :** These are the expenses, except direct materials cost and direct labour cost, which can be identified and allocated to a particular product, *e.g.* cost of machine hours and cost of tools, jigs and fixtures etc.
4. **Overhead costs :** Overhead expenses include all other expenditure made on the product except direct materials cost, direct labour charges and direct other expenses. Administrative expenses, sales and advertisement costs etc., form a part of overhead expenses.

BASIC STEPS IN COST ESTIMATION

The basic steps in the cost estimation of any product are given below :

1. Make thorough study of cost estimation request to understand it fully.
2. Make an analysis of the product and prepare a bill of materials.
3. Make separate lists of parts to be purchased from the market and parts to be manufactured in plant.

4. Determine the cost of parts to be purchased from outside.
5. Estimate the material cost for the parts/components to be manufactured in plant.
6. Make manufacturing process plan for the parts to be manufactured in plant.
7. Estimate the machining time for each operation listed in the manufacturing process plan.
8. Multiply each operation time by the labour wage rate and add them up to find direct labour cost.
9. Add the estimate of step 4, 5, and 8 to get prime cost of component.
10. Apply overhead costs to get the total cost of the component.

The selling price of the component is estimated by adding profit to the total cost obtained in step 10.

After estimating all the elements of cost, these are entered in a cost estimate form as in Table 3.1.

Table 3.1. Cost Estimate Form (Specimen)

Description .... *Date* ....
Drawing No. .... *Enquiry No.* ....
Lot size .... *Components* *Customer* ....
Estimated by ....

Sr. No.	Item of Expenditure	Total cost for the Entire lot	Cost/Component
1.	Direct material cost per component. (i) .... (ii) .... (iii) .... (iv) .... **Total :**		
2.	Labour Cost per component *Operation* *Labour cost* *Overhead* (i) (ii) (iii) (iv)		
3.	Other Direct Expenses		
4.	Office and Administrative expenses		
5.	Selling expenses (i) Packing and transport (ii) Advertising and publicity (iii) Other allied expenses		
6.	Total cost/component		
7.	Profit (usually as a percent of total cost per component)		
8.	Total (selling price per component)		

CLASSIFICATION OF COSTING

Methods of costing can be classified as follows :

1. Job Costing

It is essentially a method of costing applicable to industrial manufacture in which the cost figures are determined for each job or a batch of jobs. This method proves valuable in jobbing work (job shop production *i.e.*, or production of low quantities, often one of a kind of specialized products) or batch production.

2. Output Costing

In many cases cost figures for a job or a batch may not be easy to isolate (*e.g.* in the case of foundry operations, chemical plants, collieries, etc.) and in such cases the cost figures are usually expressed in terms of overall output, viz. Rs. per ton, or Rs. per kg, or Rs. per litre etc.

3. Operating Cost

This method usually applies to utilities or service undertakings viz. transport, gas, electricity etc. and is same as servicing cost (Rs. per km, Rs. per kWHr/unit).

4. Process Costing

Process costing refers to accumulation of cost by process (Dept./section) rather than by jobs. Cost of a process such as filtering or of a Dept. is distributed to units of products processed through by simple division of total cost by number of units or products processed.

There are **other methods of classification of costs** also :

(a) Fixed Costs and Variable Costs

The **Fixed Costs** are the items of expenditure which remain more or less constant irrespective of the quantity or volume of production. Examples of fixed costs are : Supervisory charges, cost of lighting, cost of cleaning the works, operator charges, rent of building, interest on capital, depreciation of plant and building.

The **Variable Costs** are those items of expenditure which vary with quantity or volume of production. Examples are : direct material cost, cost of energy or fuel consumed, cost of tools used, cost of consumables, repair and maintenance charges and storage charges.

(b) Direct Costs and Indirect Costs

Direct costs are costs of those factors which directly contribute to the final product and hence can be directly charged or allocated to the manufacture of a specific product. Examples : cost of raw materials, cost of labour processing the materials, cost of equipment and special toolings, jigs and fixtures used in the manufacturing of the product.

Indirect costs are costs which cannot be directly allocated to the manufacture of a particular product. Examples : Wages of inspection and supervisory staff, selling and distribution expenses, administrative expenses, overhead charges, and cost of indirect materials like lubricants, coolants, grease, repair and maintenance cost.

(c) Direct Cost System and Standard Cost System

In **direct cost system,** costs are classified as fixed cost and variable cost. With these classifications, management can determine which of its products contributes the most and which the least to cover fixed costs and providing a profit. Direct costing provides information for decisions to expand, reduce or continue production of given product lines.

In a **standard cost system,** product costs for materials, labour and overhead are budgeted or planned before the actual production takes place. The pre-established costs then provide a point of reference for analyzing the costs of actual production. By analyzing the variances from these standards, the manufacturer can identify the sources of excessive cost and investigate the causes. The identification of a problem area and the discover of its cause can point the way to actions that will reduce costs and improve profits.

ELEMENTS OF COST : Instructional Objectives

After studying this unit, the student should be able to :

(i) Explain what is costing and the purpose of costing.

(ii) Identify the various elements which constitute the ultimate cost of product.

(iii) Differentiate between various elements of cost.

(iv) Understand how cost-build up occurs in manufacturing organisations.

COSTING

Costing is the process of recording the expenses incurred in producing a product and computing the cost of the produced article by keeping a record of the cost of each item involved in the manufacture of a product. Similarly the cost of a service is calculated by adding all the expenses incurred in providing the service.

UTILITY OF COSTING

Important functions of costing are :

1. To determine the actual cost of each component and cost of the final product.
2. To form a basis for fixing the selling price.
3. To analyse the expenses incurred in production, so that control can be kept over them.
4. To check the accuracy of estimates.
5. To decide which of the components to manufacture and which ones to buy from outside.
6. To ascertain which product/products are profitable to manufacture.
7. Manufacturer may compare the cost of manufacturing an article by different processes and thus arrive at the most efficient and economical process.

The cost of an engineering product consists of a large number of expenses incurred by the manufacturer in purchasing the raw materials, bought out parts, processing and selling the finished product. The total cost of the product can be divided into following two major groups :

1. Direct Costs

Direct costs are costs of those factors which directly contribute to the final product and can be directly allocated to the manufacture of a specific product. Direct costs include the cost of raw materials, cost of labour processing the materials and cost of equipment (machine tools) and special toolings (jigs and fixtures) etc., used in the manufacturing of the product.

2. Indirect Costs

Indirect costs are the costs which can not be directly allocated to the manufacture of a particular product. These costs are usually combined together and allocated to a number of products manufactured in the plant in a specific period, usually in the form of overhead charges. Indirect costs include the wages of supervisory and inspection staff, selling and distribution expenses, administrative expenses and costs of indirect materials like grease, lubricants, coolants and repair and maintenance cost etc.

Elements of Cost : For the purpose of calculations, the total cost of the product is divided into the following :

(A) Material cost, (B) Labour cost, (C) Other expenses.

(A) Material Cost

Material cost consists of the cost of materials which are used in the manufacture of product. It is divided into the following

(*a*) **Direct material cost :** It is the cost of those materials which are directly used for the manufacture of the product and become a part of the finished product. This expenditure can be directly allocated and charged to the manufacture of a specific product or job and includes the scrap and waste that has been cut away from original bar or casting.

The procedure for calculating the direct material cost is as follows :

(*i*) From the product drawing, make a list of all the components required to make the final product.

(*ii*) Calculate the volume of each component from the drawing dimensions after adding machining allowances, whereever necessary.

(*iii*) The volume of component multiplied by the density of material used gives the weight of the material per component.

(*iv*) Add process rejection and other allowances like cutting allowance to get the gross weight per component.

(*v*) Multiply the gross weight by the cost of material per unit weight to get the cost of raw material per component.

(*vi*) The cost of raw material for all the components is, similarly, calculated and added up which gives the cost of direct material for the product.

(*b*) **Indirect material cost :** In addition to direct materials a number of other materials are necessary to help in the conversion of direct materials into final shape. Though these materials are consumed in the production, they don't become a part of the finished product and their cost cannot be directly booked to the manufacture of a specific product. Such materials are called indirect materials. The indirect materials include oils, general tools, grease, sand papers, coolants, cotton waste etc. The cost associated with indirect materials is called indirect material cost.

In some cases certain direct materials like nails, screws, glue, putty etc., are used in such small quantity that it is not considered worthwhile to identify and charge them as direct materials. In such cases these materials are also charged as indirect materiels.

Depending upon the product manufactured, the same may be direct materials for one concern and indirect materials for others.

(B) Labour Cost

It is the expenditure made on the salaries, wages, overtime, bonuses, etc. of the employees of the enterprise. It can be classified as :

(*a*) **Direct labour cost :** Direct labourer is one who actually works and processes the materials to convert it into the final shape. The cost associated with direct labour is called direct labour cost. The direct labour cost can be identified and allocated to the manufacture of a specific product. Examples of the direct labour are the workers operating lathes, milling machines or welders, or assemblers in assembly shop. The direct labour cost may be allocated to a product or job on the basis of time spent by a worker on a job.

(*b*) **Indirect labour cost :** Indirect labourer is one who is not directly employed in the manufacturing of the product but his services are used in some indirect manner.

The indirect labour includes supervisors, inspectors, foreman, storekeeper, gatekeeper, maintenance staff, crane driver etc. The cost associated with indirect labour is called indirect labour cost. The indirect labour costs cannot be identified with a particular job or product but are charged on the total number of products made during a particular period in a plant.

To make the concept of direct and indirect labour cost clear, consider an operator working on a drilling machine. The operator in this case is direct labour whereas the man supervising the job, inspector and storeman supplying the material are indirect labour.

(c) Other Expenses

In addition to the material cost and labour cost, several other expenses such as rent of building, depreciation of plant and machinery, cost of packing materials, transport and distribution expenses, wages and salaries of administrative staff and executives are also incurred by the manufacturer. All this expenditure including the indirect material cost and indirect labour cost is called other expenses. We can say that except direct material and direct labour costs all other expenditure incurred by the manufacturer is known as "Other Expenses".

Expenses are further classified as :

(*a*) Direct expenses : Direct expenses include all that expenditure which can be directly allocated and charged to a particular job. The direct expenses include cost of special jigs or fixtures, patterns, toolings made for job, or cost of research and development work done for that specific job.

(*b*) Indirect expenses : Except direct expenses, all other indirect expenditure incurred by the manufacturer is called indirect expenses. The indirect expenses are also called overhead expenses or on-cost.

The indirect expenses are further classified as :

(*i*) Factory expenses.

(*ii*) Administrative expenses.

(*iii*) Selling and distribution expenses.

(*i*) Factory expenses : Factory expenses comprise of the indirect expenses incurred from the receipt of the order to the completion of production. In addition to indirect material and indirect labour cost it includes rent of factory building, licence fee, electricity and telephone bills of factory, insurance charges etc.

Factory expenses are also called "Works expenses", or "Factory or Works overhead".

(*ii*) Administrative expenses : Administrative expenses or office expenses include the expenditure incurred on control and administration of the factory. It includes the salaries of office and administrative staff, rent of office building, postage and telephone charges, water and electricity charges for office, Director's fee, legal and audit charges etc. Administrative expenses are also known as 'Administrative overheads'.

(*c*) Selling and distribution expenses : This is the expenditure incurred on Sales Department for selling the product, *i.e.*, wages, salaries, commission and travelling allowances of salesmen and officers in Sales Department, cost of advertisement, packing, delivery and distribution expenses, rent of warehouses etc.

Various cost elements are shown in Fig. 3.1.

COST OF PRODUCT (LADDER OF COSTS)

The components of cost discussed above can be grouped as follows :

1. Prime cost = Direct material cost + Direct labour cost + Direct expenses
2. Factory cost = Prime cost + Factory expenses
3. Production cost = Factory cost + Administrative expenses
4. Total or Ultimate cost = Production cost + Selling and distribution expenses.
5. Selling price = Ultimate cost + Profit

The above relations can be illustrated on a chart (Ladder of costs) Fig. 3.2

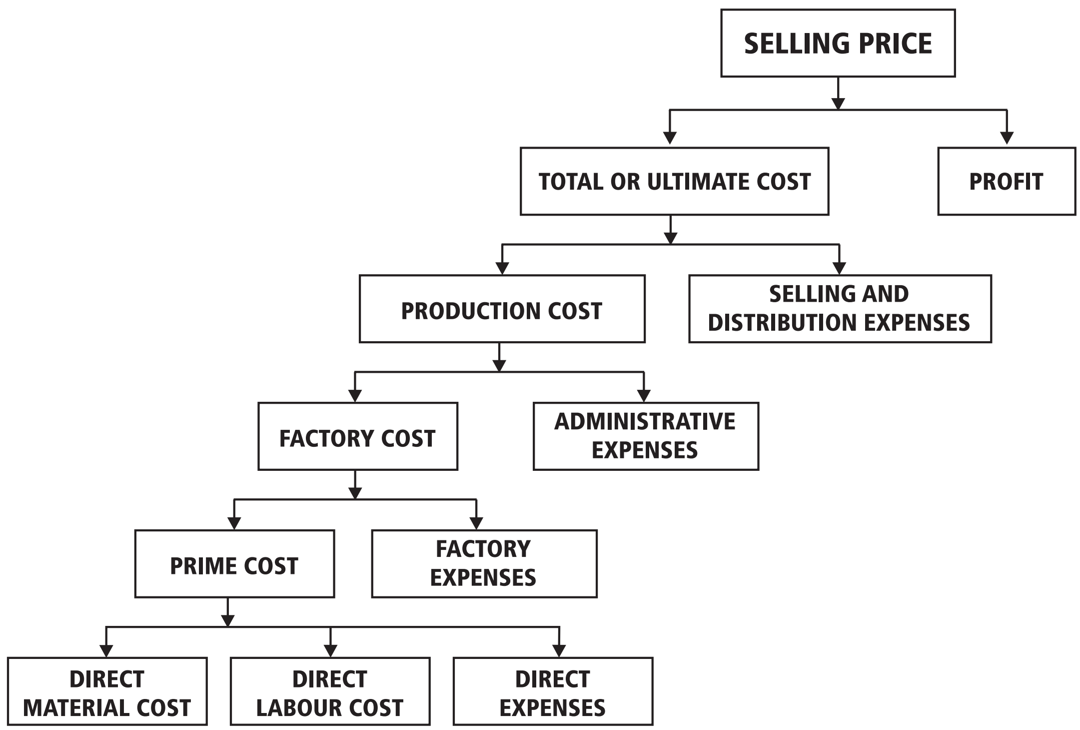


Fig. 3.1. A block diagram showing the build-up of total cost and selling price of a component.

ILLUSTRATIVE EXAMPLES

Example 1 : Calculate prime cost, factory cost, production cost, total cost and selling price per item from the data given below for the year 2003-04.

	Rs.
Cost of raw material in stock as on 1-04-2003	25,000
Raw material purchased	40,000
Direct labour cost	14,000
Direct expenses	1,000
Factory/Works overhead	9,750

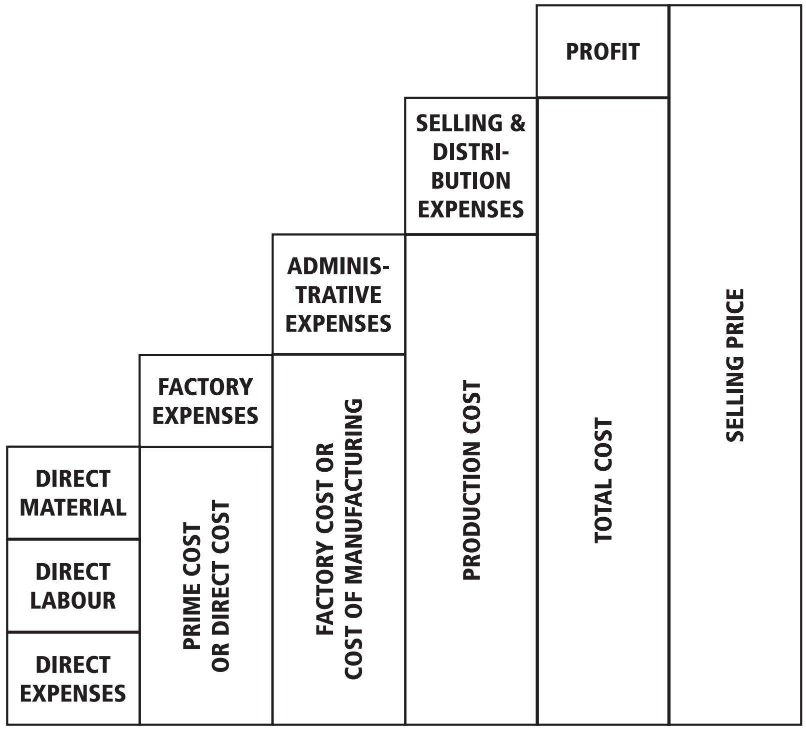


Fig. 3.2. Ladder of costs

	Rs.
Administrative expenditure	6,500
Selling and distribution expenses	3,250
No. of items produced	650
Cost of raw material in stock as on 31-03-2004	15,000

Net profit/item is 10 percent of total cost of the product.

Solution : For 650 units produced during 2003-04

(*i*) Direct material used = Stock of raw material on 1-04-2003 + raw material purchased – stock of raw material on 31-03-2004

= 25,000 + 40,000 – 15,000

= Rs. 50,000

(*ii*) Direct labour = Rs. 14,000

(*iii*) Direct expenses = Rs. 1,000

Prime cost = 50,000 + 14,000 + 1,000

= Rs. 65,000

Factory cost = Prime cost + Factory expenses

= 65,000 + 9,750

= Rs. 74,750

Production cost = Factory cost + Administrative expenses

= 74,750 + 6,500

= Rs. 81,250

Total cost = Production cost + Selling expenses
= 81,250 + 3,250
= Rs. 84,500

Selling price = 84,500 + 10 percent of 84,500
= 84,500 × 1.10 = Rs. 92,950

$$\text{Prime cost/item} = \frac{65,000}{650} = \text{Rs. } 100$$

$$\text{Factory cost/item} = \frac{74,750}{650} = \text{Rs. } 115$$

$$\text{Production cost/item} = \frac{81,250}{650} = \text{Rs. } 125$$

$$\text{Total cost/item} = \frac{84,500}{650} = \text{Rs. } 130$$

$$\text{Selling price/item} = \frac{92,950}{650} = \text{Rs. } 143$$

Example 2 : From the following data for a sewing machine manufacturer, prepare a statement showing prime cost, Works/factory cost, production cost, total cost and profit.

	Rs.
Value of stock of material as on 1-04-2003	26,000
Material purchased	2,74,000
Wages to labour	1,20,000
Depreciation of plant and machinery	8,000
Depreciation of office equipment	2,000
Rent, taxes and insurance of factory	16,000
General administrative expenses	3,400
Water, power and telephone bills of factory	9,600
Water, lighting and telephone bills of office	2,500
Material transportation in factory	2,000
Insurance and rent of office building	2,000
Direct expenses	5,000
Commission and pay of salesman	10,500
Repair and maintenance of plant	1,000
Works Manager salary	30,000
Salary of office staff	60,000
Value of stock of material as on 31-03-2004	36,000
Sale of products	6,36,000

Solution :

(*i*) Material cost = Opening stock value + Material purchases – Closing balance
= 26,000 + 2,74,000 – 36,000
= Rs. 2,64,000

Prime cost = Direct material cost + Direct labour cost + Direct expenses
= 2,64,000 + 1,20,000 + 5,000
= Rs. 3,89,000

(*ii*) Factory overheads are :

	Rs.
Rent, taxes and insurance of factory	16,000
Depreciation of plant and machinery	8,000
Water, power and telephone bill of factory	9,600
Material transportation in factory	2,000
Repair and maintenance of plant	1,000
Work Manager salary	30,000
Factory overheads or Factory cost	66,600

Factory cost = Prime cost + Factory expenses
= 3,89,000 + 66,600
= Rs. 4,55,600

(*iii*) Administrative/office expenses are :

	Rs.
Depreciation of office equipment	2,000
General administrative expenses	3,400
Water, lighting and telephone bills of office	2,500
Rent, insurance and taxes on office building	2,000
Salary of office staff	60,000
Total	**69,900**

Production cost = Factory cost + Office expenses
= Rs. 4,55,600 + Rs. 69,900
= Rs. 5,25,500

(*iv*) Selling overheads are :

Commission and pay to salesmen = Rs. 10,500

Total cost = Production cost + Selling expenses
= 5,25,500 + 10,500
= Rs. 5,36,000

(*v*) Profit = Sales – Total cost
= 6,36,000 – 5,36,000
= Rs. 1,00,000

Example 3 : Calculate the selling price per unit from the following data :

Direct material cost	=	Rs. 8,000
Direct labour cost	=	60 percent of direct material cost
Direct expenses	=	5 percent of direct labour cost
Factory expenses	=	120 percent of direct labour cost
Administrative expenses	=	80 percent direct labour cost
Sales and distribution expenses	=	10 percent of direct labour cost
Profit	=	8 percent of total cost
No. of pieces produced	=	200

Solution :

Direct material cost = Rs. 8,000

Direct labour cost = 60 percent of direct material cost

$$= \frac{60 \times 8,000}{100} = \text{Rs. } 4,800$$

Direct expenses = 5 percent of direct labour cost

$$= \frac{4,800 \times 5}{100} = \text{Rs. } 240$$

Prime cost = 8,000 + 4,800 + 240

= Rs. 13,040

Factory expenses = 120 percent of direct labour cost

$$= \frac{4,800 \times 120}{100} = \text{Rs. } 5,760$$

Administration Expenses = 80 percent of direct labour cost

$$= \frac{4,800 \times 80}{100} = \text{Rs. } 3,840$$

Sales and distribution expenses = 10 percent of direct labour cost

$$= \frac{10 \times 4,800}{100} = \text{Rs. } 480$$

Total cost = Prime cost + Factory expenses + Office expenses + Sales and distribution expenses

= 13,040 + 5,760 + 3,840 + 480

= Rs. 23,120

Profit = 8 percent of Total cost

$$= \frac{23,120 \times 8}{100} = \text{Rs. } 1,849.60$$

= Rs. 1,850 (say)

Selling price = Total cost + Profit

= 23,120 + 1,850

= Rs. 24,970

$$\text{Selling price 1 unit} = \frac{24{,}970}{200} = \text{Rs. } 124.85$$

$$= \text{Rs. } 125$$

Example 4 : A factory is producing 1000 high tensile fasteners per hour on a machine. The material cost is Rs. 375, labour cost is Rs. 245 and direct expense is Rs. 80. The factory oncost is 150 percent of the total labour cost and office oncost is 30 percent of the factory cost. If the selling price of each fastener is Rs. 1.30, calculate whether there is loss or gain and by what amount ?

Solution : For 1000 fasteners

Material cost = Rs. 375.00

Labour cost = Rs. 245.00

Direct expenses = Rs. 80.00

Factory oncost = 150 percent of labour cost

$= 245 \times 1.5$

= Rs. 367.50

Factory cost = 375 + 245 + 80 + 367.50

= Rs. 1,067.50

Office oncost = 30 percent of factory cost

$$= \frac{1{,}067.50 \times 30}{100}$$

= Rs. 320.25

Total cost for 1000 fasteners = 1,067.50 + 320.25

= Rs. 1387.75

$$\text{Cost per fastener} = \frac{1387.75}{1000} = \text{Rs. } 1.387 = \text{Rs. } 1.39$$

Selling price = Rs. 1.30

As selling price is lower than total cost per fastener, the management will suffer a loss.

Loss per fastener = (1.39 – 1.30) = Rs. 0.09

Loss per 1000 fastener = 0.09×1000 = Rs. 90

Example 5 : A certain product is manufactured in batches of 100. The direct material cost is Rs. 50, direct labour cost in Rs. 80 and factory overhead charges are Rs. 65. If the selling expenses are 45 percent of factory cost, what should be selling price of each product so that the profit is 10 percent of the total cost ?

Solution : Batch size = 100

Direct material cost = Rs. 50

Direct labour cost = Rs. 80

Factory overheads = Rs. 65

Factory cost = 50 + 80 + 65

= Rs. 195

Selling expenses = 45 percent of factory cost

$$= \frac{45 \times 195}{100} = \text{Rs. } 87.75$$

Total cost = 195 + 87.75

= Rs. 282.75

Profit = 10 percent of total cost

$$= \frac{282.75 \times 10}{100} = \text{Rs. } 28.28$$

Selling price of 100 components = 282.75 + 28.28

= Rs. 311

$$\text{Selling price per component} = \frac{311}{100} = \text{Rs. } 3.11 = \text{Rs. } 3.15$$

Example 6 : A factory owner employed 50 workers during the month of November 2004, whose detailed expenditure is given below :

(*i*) Material cost = Rs. 30,000

(*ii*) Rate of wage for each worker = Rs. 6 per hour

(*iii*) Duration of work = 8 hours per day

(*iv*) No. of holidays in the month = 5

(*v*) Total overhead expenses = Rs. 15,000

If the workers were paid over time of 400 hours at the rate of Rs. 12 per hour, calculate

(*a*) Total cost, and

(*b*) Man hour rate of overheads.

Solution : (*a*) Material cost = Rs. 30,000

No. of workers = 50

Duration of work = 8 hrs/day

No. of working days = 30 – 5 = 25

Total no. of work hours for the month of November 2004

= 25 × 8 × 50 = 10,000 hrs

Wage rate = Rs. 6 per hour

Labour cost = 10,000 × 6 = Rs. 60,000

Overtime paid = No. of overtime hours × hourly rate

= 400 × 12

= Rs. 4800

Total labour cost = 60,000 + 4800

= Rs. 64,800

Overhead expenses = Rs 15,000

Total cost = 30,000 + 64,800 + 15,000

= Rs. 1,09,800

(*b*) Total no. of man hours = 10,000 + 400 = 10,400

$$\text{Man hour rate of overheads} = \frac{\text{Total overheads}}{\text{Total no. of man hours}}$$

$$= \frac{15{,}000}{10{,}400} = \text{Rs. } 1.44$$

Example 7 : The catalogue price of a certain gadget is Rs. 1,050, the discount allowed to distributors being 20 percent. Data collected for a certain period shows that the selling price and factory cost are equal. The relation between material cost, labour cost and factory oncost (overhead expenses) are in the ratio 1 : 2 : 3. If the labour cost is Rs. 200, what profit is being made on the gadget ?

Solution : Catalogue Price = Rs. 1,050

$$\text{Distributors discount} = 20\% = \frac{1{,}050 \times 20}{100} = \text{Rs. } 210$$

Selling price = 1,050 – 210

= Rs. 840

Labour cost = Rs. 200

$$\text{Material cost} = 200 \times \frac{1}{2} = \text{Rs. } 100$$

$$\text{Factory oncost} = 200 \times \frac{3}{2} = \text{Rs. } 300$$

Factory cost = 200 + 100 + 300 = Rs. 600

It is given that selling price = Factory cost

= Rs. 600

Selling price = Total cost + Profit

840 = 600 + Profit

Profit = 840 – 600

= Rs. 240

Profit = Rs. 240 per gadget.

Example 8 : An electric fan is available in the market at a catalogue price of Rs. 1500. The discount allowed to the distributor is 12 percent. Administrative and sales overheads are 80 percent of factory cost. The direct material cost, direct labour cost and factory overheads are in the ratio of 1 : 3 : 2 respectively. If the direct labour cost is Rs. 300 and the central excise duty 10 percent of the selling price, determine the company's profit on each item.

Solution : Catalogue Price = Rs. 1500

Discount to distributor = 1500 × 0.12 = Rs. 180

Catalogue price = Factory cost + Administrative and selling expenses + Profit + Central excise + Discount to distributors

= Sales price + Central excise + Discount to distributor

Direct labour cost = Rs. 300

$$\text{Direct material cost} = \text{Rs. } 300 \times \frac{1}{3} = \text{Rs. } 100$$

$$\text{Factory oncost} = \text{Rs. } 300 \times \frac{2}{3} = \text{Rs. } 200$$

$$\text{Factory cost} = 300 + 100 + 200 = \text{Rs. } 600$$

Administrative and sales overheads = 80 percent of factory cost

$$= \frac{600 \times 80}{100} = \text{Rs. } 480$$

Let the profit = Rs. P per item

Then selling price = 600 + 480 + P

= Rs. (1080 + P)

Excise duty = 10 percent of selling price

$$= (1080 + P) \times \frac{10}{100}$$

$$= \frac{1}{10}(1080 + P)$$

Catalogue Price = Sales Price + Central Excise + Discount to dsitributors

$$1500 = (1080 + P) + \frac{1}{10}(1080 + P) + 180$$

Profit P = Rs. 120 per item

Example 9 : Find out the production cost per crank shaft for a 4 stroke oil engine from the following data :

Charges for forging per kg	=	Rs. 2.5
Wrought iron used/week @ Rs. 10 per kg	=	3 tonnes
Wages of operators	=	Rs. 50/day
No. of operators employed	=	4
Cartage/day	=	Rs. 250
Depreciation of machines and tools	=	Rs. 500 per month
Wages of helpers	=	Rs. 30 per day each
No. of helpers employed	=	4
Salary of supervisor	=	Rs. 5000 p.m.
Packing charges for 12 shafts	=	40
Electric charges	=	Rs. 1300 p.m.
Salary of manager and maintenance staff	=	Rs. 14,000 per month

If 1,500 crank shafts are produced per month and factory runs 26 days a month, what should be the selling price of each shaft so as to earn a profit of 20 percent of the factory cost ?

Solution : Assuming 6 working days per week, for 26 working days in a month, the various expenses for 1,500 crank shafts are calculated as follows :

$$\text{Wrought iron used} = \frac{3{,}000 \times 26}{6} = 13{,}000 \text{ kgs}$$

$$\text{Cost of wrought iron used} = 13{,}000 \times 10 = \text{Rs. } 1{,}30{,}000$$

$$\text{Forging charges} = 13{,}000 \times 2.5 = \text{Rs. } 32{,}500$$

Cartage = 250 × 26 = Rs. 6500

Wages of 4 operators = 26 × 50 × 4 = Rs. 5200

Depreciation of machine tools = Rs. 500/month

Wages of 4 helpers = 30 × 4 × 26 = Rs. 3120

Salary of supervisor = Rs. 5000

Packing charges for 1,500 shafts = $\frac{40}{12} \times 1,500$ = Rs. 5,000

Electricity charges = Rs. 1300 p.m.

Pay of manager and maintenance staff = Rs. 14,000

Factory cost = 1,30,000 + 32,500 + 6,500 + 5,200 + 500 + 3,120 + 5,000 + 1,300 + 14,000

= Rs. 1,98,120

Packing charges = Rs. 5000

Total cost = 1,98,120 + 5000

= Rs. 2,03,120

Profit = 20 percent of factory cost

= $1,98,120 \times \frac{20}{100}$ = Rs. 39,624

Selling price = 2,03,120 + 39,624

= Rs. 2,42,744

Selling price per crank shaft = $\frac{2,42,744}{1,500}$

= Rs. 162

Example 10 : Segregate the fixed cost and the variable cost of running a motor car for one year :

Solution :

Fixed cost (Independent of distance or mileage covered in the year)

(*i*) Depreciation per year : This is the amount by which the car depreciates in value each year.

(*ii*) Interest costs/year : This is the amount of interest the capital spent on the car would have earned if the capital had been invested.

(*iii*) Road tax and insurance charges per year.

(*iv*) Rent for garage (if applicable)

(*v*) Maintenance costs : That portion of total maintenance costs which would have been incurred even if the car has not been used.

Variable cost (Varies proportionally to the distance covered in the year)

(*i*) Cost of petrol

(*ii*) Cost of oil

(*iii*) Maintenance costs : That proportion of total maintenance costs which would have been incurred due to the driving of the car, *i.e.*, a greater proportion of the total maintenance costs.

EVALUATIVE QUESTIONS ▶ COST ESTIMATION

1. Define cost estimating and explain its objectives ?

2. What are the various expenses to be considered while estimating the cost of a product ? Discuss.

3. Explain the procedure followed for estimating the cost of an industrial product.

4. Define the following
   (*a*) Under-estimating.
   (*b*) Over-estimating
   (*c*) Overhead expenses.

5. Differentiate between estimating and costing.

6. Cost estimation is done by ...., whereas costing is done by ....

7. What are the functions or purposes served by cost estimation ?

8. What is meant by target cost ?

9. What is a “Bill of Materials” ?

10. Give an example of indirect material cost.

11. What do you understand by the term “Costing” ? What is the utility of calculating the cost of a product ?

12. What are the usual three elements of cost ? Explain.

13. Write short notes on :
   (*a*) Direct labour cost
   (*b*) Direct material cost
   (*c*) Overheads.

14. (*a*) Explain the terms prime cost, factory cost, total cost and selling price. Show the relationship between various components of cost with the help of a block diagram.
   (*b*) What do you understand by the term ‘Overhead Expenses’. Give 10 items of overhead expenses in a factory.

15. Which of the following are charged as direct labour ?
   (*i*) Turner, (*ii*) Foreman,
   (*iii*) Supervisor, (*iv*) Painter,
   (*v*) Cleaner/Sweeper, (*vi*) Fitter,
   (*vii*) Storekeeper/Clerk, (*viii*) Inspector,
   (*ix*) Crane driver, (*x*) Maintenance crew.

16. Which of the following can be charged as overhead charges ?
   (*i*) Supervisor, (*ii*) Turner,
   (*iii*) Air conditioning charges, (*iv*) Special tools,
   (*v*) Sweeper, (*vi*) Cost of emery paper,
   (*vii*) Cost of job material.

17. Cancel out which is not applicable :

(*i*) Prime cost is the sum of direct/indirect expenditure.

(*ii*) Factory cost is the sum of prime cost and factory expenses/office expenses.

(*iii*) Grease is a direct/indirect material.

(*iv*) Turner is a direct/indirect labour.

(*v*) Foreman is a direct/indirect labour.

(*vi*) Prime cost is less/more than factory cost.

(*vii*) Overhead expenses are direct/indirect expenses.

(*viii*) Service charges are part of direct/indirect expenses.

(*ix*) Nails used in large quantity in a product are direct/indirect material.

18. The following particulars relate to M/s XYZ engaged in the manufacture of electronic components for the year 2004. Prepare a cost statement showing prime cost, works cost, production cost and selling price per component :

	Rs.
Value of material in stock as on 1-01-2004	35,000
Raw material purchased during 2004	50,500
Value of material in stock as on 31-12-2004	25,000
Manufacturing wages	21,000
Direct expenses	3,000
Works indirect material expenditure	400
Works indirect labour expenditure	5,000
Works indirect expenses	600
Office indirect expenses	1,000
Office indirect labour expenditure	6,000
Office indirect material expenditure	1,000
Expenditure on distribution	6,000
Profit	20% on selling cost
No. of components manufactured during the year	500

19. From the following particulars of yearly expenditure of a sewing machine manufacturer, calculate the production cost and selling price per sewing machine :

	Rs.
Raw material used	1,50,000
Wages to manufacturing labour	50,000
Direct expenses	4,000
Wages of works supervisory staff	60,000
Cost of electric power, fuel, oil etc.	2,000
Repair and depreciation of building	30,000
Repair and depreciation of plant	10,000
Storage expenses	10,000

	Rs.
Office stationery	5,000
Office telephone, postage, insurance, charges and legal expenses	6,000
Cost of electricity for office, factory and sales department	2,000
Wages and salaries of office staff	40,000
Salary of sales and packing department	5,000
Cost of packing material	16,000
Profit	20% on selling cost
Number of machines produced	2,000

80 Percent of the building space is occupied by the factory and office and remaining 20 percent space is occupied by sales and packing department.

20. A factory producing 150 electric items a day involves direct material cost of Rs. 250, direct labour cost of Rs. 200 and factory overheads of Rs 225. Assuming a profit of 10 percent on selling cost and selling on cost (overheads) as 30 percent of factory cost, calculate the selling price of one item.

21. Certain product is manufactured in batches of 100. The different cost constituents are :

Direct material cost = Rs. 150
Direct labour cost = Rs. 200
Factory expenses = Rs. 100
Overhead expenses = 20% of factory cost

Make calculations of factory cost, total cost and the selling price of each product, if a profit of 10 percent is to be ensured on total cost.

22. The catalogue price of a motor driven sewing machine is Rs. 1,200 and allowable discount to distributor is 15 percent. Manufacturer's data at a certain time, shows that sum of administrative and selling expenses, and factory cost are in the ratio 1 : 1 and the materiel cost, labour cost and factory overheads are in the ratio 1 : 3 : 2. If the cost of labour on the manufacture of the machine is Rs. 240, determine the profit realised on each sewing machine.

23. A cast iron foundry employs 30 persons. It consumes material worth Rs. 25,000, pays workers @ Rs. 10 per hour and total overheads are Rs. 10,000. In a particular month (25 days) workers had overtime of 150 hrs and were paid at double their normal rate. Find

(*i*) Total cost

(*ii*) Man hour rate of overheads.

Assume an 8 hours working day.

4 COST ESTIMATION

COST ESTIMATION : Instructional Objectives

After studying this unit, the student will be able to :

(i) List the different types of cost estimates.
(ii) State the different levels of design.
(iii) State the different methods of cost estimation used in the conceptual design stage.
(iv) Explain factor method of cost estimation with an example.
(v) Explain the material cost method of estimation giving an example.
(vi) State the function method of cost estimation giving an example.
(vii) State what is mean by Parametric Cost Estimating.
(viii) Explain what is meant by "Cost Data Base".
(ix) Define conceptual cost estimating.
(x) Mention different conceptual cost estimating methods.
(xi) Explain the method of cost estimating based on cost size relationships.
(xii) Enumerate the data required and sources of information for cost estimation.
(xiii) List the various allowances used in the estimation of standard time.
(xiv) State the two important constituents of Relaxation allowance.
(xv) Explain the meaning of different allowances such as relaxation allowance, process allowance, interference allowance, contingency allowance and special allowance.
(xvi) Solve problems related to cost estimating and estimation of standard time/cycle time.

TYPES OF COST ESTIMATES

One classification system for cost estimates is based on design level when the product is designed. The three levels of design considered are :

(*i*) Conceptual design,
(*ii*) Preliminary design, and
(*iii*) Detailed design.

The conceptual design stage is that stage at which only the functional requirements are considered by the designer using techniques such as feature-based design and/or solid modelling and a rough magnitude of estimate can be obtained. Geometry of parts and materials are not known at this stage.

The accuracy of conceptual cost estimates are approximately – 30% to + 50%. The cost estimation methods used at this level are

(*a*) Factor method,
(*b*) Material cost method, and
(*c*) Function method.

(a) Factor Method of Cost Estimation

According to this method :

Estimated cost of an item = Factor for total cost estimate × Amount of major cost item

Some examples of factor are :

(*i*) Cost of construction per km of highway.

(*ii*) Cost of fabricated component per kg of casting.

(*iii*) Cost of house construction per SQ.M. of livable space.

Example 1 : If a casting weighed 15 kg, and the factor of the cost of casting per kg of casting is Rs. 75, what is the estimated cost of the casting ?

Estimated cost of the casting = Rs. 75 per kg of casting × wt. of the casting (= 15 kg)

= Rs. 1125 per casting

(b) Material Cost Method of Estimation

Material cost method predicts the total cost of the product based on the ratio of the material cost of the product to the material cost share of the total cost.

According to this method :

$$\text{Estimated cost of an item} = \frac{\text{Material cost of the item being estimated}}{\text{Material cost share of item being estimated (in \%)}}$$

This method is used for complex assemblies :

Examples of material cost share :

Product	***Material cost share (%)***
Passenger car	65%
Diesel engine	50%
Clocks, watches	25%
Glass product	10%

Example 2 : If the material cost of an automobile was Rs. 2.50 Lakhs, what would be the total cost of the automobile ? Use the table above.

$$\text{Estimated total cost of automobile} = \text{Rs. } \frac{2.50 \text{ Lakhs}}{0.65}$$

= Rs. 3.85 Lakhs

(c) Function Method of Cost Estimation

This method is also referred to as **Parametric cost estimating.**

This method is similar to the factor method, but more variables are used. Function method uses a mathematical expression with constants and parameters derived for specific process, such as casting or machining or for specific classes of parts based on material, size, weight or other cost parameters.

According to this method :

Estimated cost of an item = $G \times (a + b) + (R \times c) + (N \times d)$

where G = Weight of the item, kg

a = Material cost per kg

b = Tolerance cost per, kg

R = Weight of material Removed, kg

c = Cost per kg of material removed

N = No. of dimensions of a product surface

d = Cost per dimension

(The above is an example of function method for a machined component).

Other types of cost estimates are based on the following :

(*i*) Product comparison : The new product is compared with existing products (of similar function, design etc.) and adjustments/modifications are made for the differences.

(*ii*) Data base calculations : The product cost estimate is determined from cost data bases which a company is expected to maintain over a period of time (Historical Cost Data Base).

(*iii*) Detailed cost runctions and/or parametric cost estimation : The product cost estimate is determined using parametric cost estimation technique. All variables or parameters of process, part features and other cost parameters are considered in cost estimation.

METHODS OF COST ESTIMATES

There are different methods of estimates of cost. These are in addition to conventional method of estimating of cost such as calculating material cost, labour cost, factory expenses and overhead expenses and adding all these cost elements.

The methods of estimates are :

1. Conceptual Cost Estimating

It is estimating during the conceptual design stage. In the conceptual design stage, the geometry of parts and materials have not been specified, unless they dictate essential product functions. In the conceptual design stage, the costs associated with a change in the design are low. In the conceptual design stage, the incurred costs are only 5 to 7% of the total cost whereas the committed costs are 75 to 85% of the total cost.

The accuracy of the conceptual cost estimate depends on the accuracy of the data base. The accuracy of conceptual cost estimating is approximately – 30% to + 50%. Accuracy in conceptual cost estimating is important since at the conceptual design stage only significant cost savings can occur.

Conceptual cost estimating methods include :

(*a*) Expert opinion,

(*b*) Analogy methods, and

(*c*) Formula based methods.

(a) Conceptual Method Based on Expert Opinion

If back-up and/or historical cost data are not available, getting expert opinion is the only way for estimating cost.

The disadvantages of this method are

(*i*) The estimate is subjected to bias.

(*ii*) The estimate can't be quantified accurately.

(*iii*) The estimate may not reflect the complexity of the product or project.

(*iv*) Reliable data base for future estimates are not possible.

In spite of these disadvantages, the expert opinion is useful when historical data base is not available. It is also useful to verify cost estimate arrived at using other methods of conceptual estimating (like analogy methods and formula based methods).

(b) Conceptual Method Based on Analogy

Analogy estimating derives the cost of a new product based on past cost data of similar products. Cost adjustments are made depending on the differences between the new and previous product/system. Analogy estimating requires that the products be analogous or similar and products manufactured using similar facilities or technology. If the technology changes, the analogy estimating relationship has to changed to reflect the changes in technology. Another limitation of this method is that analogy estimates often omit important details that makes cost considerably higher than the original cost estimates.

(c) Conceptual Method Based on Formula

There are formula based methods that are primarily used in the conceptual cost estimating. These are :

(*i*) Factor method,

(*ii*) Material cost method,

(*iii*) Function method, and

(*iv*) Cost-size relationship.

These methods are known as **Global cost estimation methods** and they generally use one of the above methods only.

(i) Factor method

This is the simplest method, but it can give reliable estimates if the data are kept up-to-date, taking into consideration factors such as inflation, and environmental issues which tend to increase the cost.

Example : In respect of different categories of equipment, material cost per kg is given below. The equipment in each category costs about the same on a weight basis and the cost between categories increases by a factor of approximately 10.

Type of equipment	Examples of equipment	Material cost
Functional	Automobile, earth moving equipment, pipe laying machinery	Rs. 500 per kg
Mechanical and electrical equipment	Kitchen appliances, mixer, small mechanical and electrical equipment, washing machines, home drilling machine, portable telephone.	Rs. 5,000 per kg
Precision equipment	Automatic focussing cameras, electronic testing equipment	Rs. 50,000 per kg

A precision piece of equipment is approximately 10 times the cost of a mechanical/electrical piece of equipment which is about 10 times the cost of a functional piece of equipment. Material cost figures given are rough values. They can be refined.

Example 1 :

What is the expected cost of

(*i*) an automobile if the weight is 900 kg.

(*ii*) a camera if its weight is 0.75 kg

Use the material cost information given above.

Cost of an automobile = Rs 500/kg × 900 kg
= Rs. 4,50,000
= Rs. 4.5 Lakhs

Cost of a camera = Rs. 50,000/kg × 0.75 kg
= Rs. 37,500

(ii) Material cost method

Material cost method is justified since the material cost is the largest cost item in the prime cost of many manufacturing companies.

According to this method :

$$\text{Estimated cost of an item} = \frac{\text{Material cost of the item being estimated}}{\text{Material cost share of item being estimated (in \%)}}$$

Examples of material cost share :

Product	***Material cost share (%)***
Automobile/Passenger car	65%
Diesel engines	50%
Machine tools	48%
Amplifiers	45%
Clocks and watches and electrical instruments	25%
Measuring tools	20%
Glass products	10%
Cups and saucers (vitrified)	7%

Example 2 : What is the total cost of a measuring tool if the material cost is Rs. 100 ? Use the table above.

$$\text{Total cost of measuring tool} = \frac{\text{Material cost of the item}}{\text{Material cost share of the item being estimated (in \%)}}$$

$$= \frac{100}{0.2} = \text{Rs. } 500$$

Another approach to the material cost method is the 1 : 3 : 9 rule for product cost estimation.

1 represents material cost, 3 represents manufacturing cost, and 9 represents the selling price.

(Generally material cost include a 10% scrap factor as well as 10% tooling cost, so the material cost is actually the raw material value of the part with a 20% addition for scrap and tooling costs).

Example 3 : If a part is made from aluminium which costs Rs. 150 per kg and weighs 2 kg, what is the estimated material cost, part cost and selling price ?

Use 1 : 3 : 9 Rule, and 10% allowances for scrap and 10% allowances for tooling.

The material cost would be = 1.2 × Material cost (Rs. 150 per kg) × Part weight (2 kg)
= 1.2 × 150 × 2
= Rs. 360

Part cost = 3 × Rs. 360
= Rs. 1080

Selling price = 3 × Rs. 1080
= Rs. 3240

The material cost share method should be used only for complex objects which include many parts and many operations. This method should not be used for estimating operation costs. This method accounts for inflation as the material costs are subject to inflation.

(iii) Function method

In function method more variables are used and the expressions are non-linear. The function is basically a mathematical expression with constants and variables that provides a mathematical function for the cost estimate. One expression is given below :

Cost of turbo fan engine development, (in Rs. Lakhs)

$$= 41.2 \times a^{0.74} \times b^{0.08}$$

where a = Maximum engine thrust, in kg

and b = No. of engines produced

Example 4 : If the engine thrust is 7,500 kg, and the no. of engines to be produced is 100, what is the development cost ?

$$\text{Development cost} = 41.2 \times 7500^{0.74} \times 100^{0.08}$$

= Rs. 1270 crores.

The disadvantage with such formula is that the range limitations of the expression are not given in the formula, *i.e.*, there is a range of thrust for which the expression is applicable (*e.g.* 50,000 kg. thrust may be outside the range of data used to develop the formula. Such a thrust may call for a new technology and development of a new formula).

Cost equation models have also been developed for turned components involving several parameters such as : Materials, shape of component (component complexity factor), machining factors (surface finish and tolerance), size of component, number of machine set-ups, machine capability, machine tooling capacity (maximum no. of tools that can be mounted).

The accuracy of such cost equations or models is about $\pm 10\%$.

(iv) Method based on cost-size relationships

Another approach to the determination of conceptual costing is by considering the cost-size relationships. In this approach, one can compare the cost of different designs on a relative basis or on an actual cost basis. Expression have been developed from data on investment castings and for machined parts.

The cost-size relationship in respect of investment casting is given below as an example :

Relative cost of an investment casting of volume V cm^3 = 5.0 $V^{0.6}$

where 5.0 represents cost of 1 cm^3 investment casting

V, Volume of investment costing, cm^3

0.6, size cost exponent for investment casting (the relationship is less than linear).

Example 5 :

(*a*) If one wanted to double the volume of an investment casting turbine blade from 4 to 8 cubic centimeters, what would be the increase in cost ?

(*b*) What would be the cost of an 8 cubic centimetre turbine blade compared to the cost of a one cubic centimeter turbine blade ?

Solution :

(*a*) Increase in the cost $= \left(\frac{8}{4}\right)^{0.6} = 1.5$ (times)

The cost of 8 cm^3 investment casting is 1.5 times the cost of 4 cm^3 investment casting. *i.e.*, the cost would increase by 50% when the volume of investment casting is doubled. (This relationship was developed for a volume range of 1.5 to 160 cm^3).

(*b*) The cost of an 8 cm^3 investment casting turbine blade compared to the cost of 1 cm^3 turbine blade

$$= \left(\frac{8}{1}\right)^{0.6} = 3.5 \text{ (times)}$$

i.e., cost of an 8 cm^3 investment casting is 3.5 times the cost of 1 cm^3 investment casting *i.e.*, the cost increased by 250%.

Such relationships have been developed for other casting processes. The exponent of 0.6 is the value commonly used in such equations and is frequently called the "six-tenths rule". Similar expressions for cost estimates have been developed for machined components also.

When applying conceptual formulae, care must be exercised since the cost data needs to be updated and also they should be documented as to the range applicable. These formulae are generally for the factory cost and do not represent the total cost or selling price. The development of cost-size relationships for conceptual cost estimating in manufacturing is an important advancement in the area of cost estimating.

Data requirements and sources of information for cost estimation

1. Man-hour cost (Labour rate) *i.e.*, hourly cost of skilled, semi-skilled and unskilled labourers of the company.
2. Machine-hour cost for different types of equipment and machinery available in the company.
3. Material cost in respect of commercially available materials in the market :
   - Cost in Rs. per kg for different categories of materials like ferrous, non-ferrous, special steel etc., for rods of different diameters and for different thicknesses in respect of flats/sheet metals.
4. Scarp rates *i.e.*, scarp values of different materials in Rs. per kg.
5. In respect of welding operations, information such as electrode cost, gas cost, flux cost, power cost, etc.

6. Set-up time for different processes.
7. % allowances to be added for computing standard time, relaxation allowance, process allowance, special allowance as % of normal time as per the policy of the management.
8. Standard time for different types of jobs, if available.
9. Overhead charges in terms of % direct labour cost or overhead rate in Rs. per hr.
10. Life in years permitted for various types of equipment and machines available in the plant for calculation of depreciation, for cost recovery and for calculation of machine—hour rate.
11. Data base of cost calculations carried out by the company in respect of earlier products or jobs (Historical cost data).
12. Cost data of products available in the market similar to the ones manufactured by the company.
13. Budget estimates prepared by the company for new projects/products.
14. Journals or Data sheets of Professional Associations dealing with Costs and Accounting.

ALLOWANCES IN ESTIMATION

Normal Time = Observed time × Rating factor

Observed time and rating factor are obtained during the time study of an operation or a job.

Various allowances are considered in estimating the standard time for a job. These allowances are always expressed as % of Normal Time and are added to Normal Time to compute the Standard Time.

Standard Time = Normal Time + Allowances

Standard Time is time required to complete one cycle of operation (usually expressed in minutes). Standard Time for a job is the basis for determining the standard output of the operator in one day or shift.

Need for Allowances

Any operator will not be able to carry out his work throughout the day without any interruptions. The operator requires some time for his personal needs and rest, and hence such time should be included in standard time. There are different types of allowances, and they can be classified as follows :

1. **Relaxation Allowance :** This is also known as **Rest Allowance**. This allowance is given to enable the operator to recover from the physiological and psychological effects (Fatigue) of carrying out the specified work and to attend to personal needs.

   Relaxation allowance consists of :

   (*i*) Fatigue allowance, and

   (*ii*) Personal needs allowance.

   (*i*) Fatigue allowance is intended to cater for the physiological and psychological effects of carrying out the work.

   This time allowance is provided to enable to operator to overcome the effect of fatigue which occurs due to continuous doing of the work (monotony etc.).

Relaxation allowance (Fatigue allowance and Personal needs allowance put together) is commonly 5% to 10% (of normal time).

(*ii*) Personal needs allowance : This allowance is provided to enable the operator to attend to his personal needs (*e.g.* going to toilet, rest room, etc.).

2. **Process Allowance :** It is an allowance to compensate for enforced idleness of the worker. During the process, it may be likely that the operator is forced to be idle due to certain reasons, such as :

   (*i*) When the process is carried out on automatic machines, (the operator is idle after loading the job on the machine).

   (*ii*) When the operator is running more than one machine (as in the case of cellular manufacturing).

   Process allowance varies from one manufacturing situation to another depending on factors such as hazardous working conditions, handling of heavy loads, strain involved, mental alertness required etc. Generally 5% of the normal time is provided towards process allowance.

3. **Interference Allowance :** This allowance is provided where in a cycle of operation, there are certain elements which are machine controlled. The operator cannot speed up those elemental operations.

   This allowance is also provided when one worker is working on several machines.

4. **Contingency Allowance :** This is a small allowance of time which may be included in the standard time to meet unforeseen items of work, or delays (*e.g.* waiting for raw materials, tools). Contingency allowance is 5% (maximum) or Normal Time.

5. **Special Allowances :** These allowances are a policy matter of the management, *e.g.* when the job is newly introduced or when a new machine or new method is introduced, because worker takes some time to learn the new method or job; Special allowance is also provided depending on the working conditions such as noise, dust, etc.

   Once the normal time is obtained, the standard time can be estimated or obtained by adding all the allowances to normal time.

$$\text{Standard time} = \text{Normal time} + \text{Allowances}$$

Example 1 : In a manual operation, observed time for a cycle of operation is 0.5 minute and the rating factor as observed by the time study engineer is 125%. All allowances put together is 15% of N.T. (Normal Time). Estimate the Standard Time.

Solution :

$$
\begin{aligned}
\text{Observed time for a cycle} &= 0.5 \text{ min.} \\
\text{Rating factor} &= 125\% \\
\text{Normal time} &= \text{Observed time} \times \text{Rating factor} \\
&= 0.5 \times 1.25 \\
&= 0.625 \text{ min.} \\
\text{Allowances} &= 15\% \text{ of Normal Time} \\
\text{Standard Time} &= \text{Normal Time} + \text{Allowances} \\
&= 0.625 \text{ min.} + (0.15 \times 0.625) \text{ min.}
\end{aligned}
$$

$$= 0.625 \text{ min.} + 0.094 \text{ min.}$$
$$= 0.719 \text{ min.}$$
$$= 0.72 \text{ min.}$$

Example 2 : In a manufacturing process, the observed time for 1 cycle of operation is 0.75 min. The rating factor is 110%. The following are the various allowances as % of normal time :

Personal allowance = 3%

Relaxation allowance = 10%

Delay allowance = 2%

Estimate the standard time.

Solution :

$$\text{Basic time or normal time} = \text{Observed time} \times \text{Rating factor}$$
$$= 0.75 \text{ min} \times 110\%$$
$$= 0.75 \times 1.1$$
$$= 0.825 \text{ min.}$$
$$\text{Standard time} = \text{Normal time} + \text{All allowances}$$
$$= \text{Normal time} + [3\% + 10\% + 2\%] \text{ of normal time}$$
$$= 0.825 \text{ min.} + (0.15 \times 0.825) \text{ min.}$$
$$= 0.825 \text{ min.} + 0.124 \text{ min.}$$
$$= 0.949 \text{ min.}$$
$$\simeq 0.95 \text{ min.}$$

Standard time is the basis for calculation of standard output (*i.e.*, no. of components produced) in 1 day or in 1 shift (of 8 hours). Incentive schemes are based on the standard output.

EVALUATIVE QUESTIONS ▶ COST ESTIMATION

1. What are the three levels of design considered in new product development ?

2. What is meant by "conceptual cost estimating" ?

3. What is the order of accuracy expected in conceptual cost estimates ?

4. What are the three methods used in conceptual cost estimation ?

5. If the material cost for a lathe is Rs. 1,75,000, what is the expected factory cost using material cost share method ? Use the information given in the table below :

Product	*Material cost share (%)*
Machine tools	48%
Measuring tools	20%

6. What is meant by "Parametric Cost Estimating" ?

7. What are "Global Cost Estimation" methods ?

8. In the 1 : 3 : 9 Rule for Product Cost Estimation, what does the 'three' represent ?

9. Estimate the development cost of a lot of 50 turbofan engines with 2,500 kg, thrust. What is the cost, if only 10 engines are in the lot ? Use the formula given below :

$$\text{Cost (Rs. Lakhs) of turbofan engine development} = 40 \times a^{0.75} \times b^{0.10}$$

where a = Maximum engine thrust, kg

b = No. of engines produced

10. What is meant by "Cost-size Relationships" in conceptual cost estimating ? Give an example and explain.

11. What are the various data requirements and sources of information for cost estimation ?

12. What is "normal time" and how is it computed ?

13. What is "standard time" and how is it estimated ?

14. What are the different types of allowances that are considered in the estimation of standard time ?

15. What is meant by Relaxation Allowance ? What are the two constituents of Relaxation Allowance ?

16. What is meant by Fatigue Allowance ?

17. What is meant by Process Allowance ? Under what circumstances it is provided ?

18. What is meant by Interference Allowance and under what circumstances this allowance is provided ?

19. What is meant by Contingency Allowance ?

20. What is meant by Special Allowance and under what circumstances this allowance is provided ?

21. What is the importance of standard time ?

22. What are the different uses of standard time ?

5 PRODUCTION COST ESTIMATION

PRODUCTION COST ESTIMATION : Instructional Objectives

After studying this unit, the student should be able to :

(i) Know how cost costimation is done in respect of a casting.

(ii) List the various sections that will be normally found in a foundry shop.

(iii) List the various elements of cost involved in the total cost of manufacturing a casting.

(iv) Explain what are overhead expenses.

(v) Calculate the total cost of a cast component.

(vi) Explain how cost estimation is done in respect of a welded component or welding job.

(vii) List the various elements of cost involved in weldment or a welded component.

(viii) Solve problems in the calculation of cost of welded joints.

(ix) Explain how cost estimation is carried out in respect of a forging or a forged component.

(x) List the various losses that occur in the material during a forging process.

(xi) What are the various costs involved in the calculation of total cost of forged components.

(xii) Calculate the cost of forging of typical forged components such as forged crankshaft, etc.

(xiii) Explain how machining time is estimated in respect of machined components.

(xiv) State the various components of total time required to perform a machining operation.

(xv) Calculate the time required for various machining operations such as Turning, Facing, External relief, Undercutting, Chamfering, Knurling, Boring, Drilling, Threading, Tapping, shaping, Planing and slotting, Milling and Grinding.

(xvi) Calculate the total time required to machine a component given all the machining parameters and part drawing.

(xvii) Estimate the cost of machining a given component given all the elemental costs.

COST ESTIMATION IN FOUNDRY SHOP

Foundry is a metal casting process in which the metal is melted and poured into the moulds to get the components in desired shape and size. Castings are obtained from a foundry shop.

Generally a foundry shop has the following sections :

1. Pattern Making Section

In this section the patterns for making the moulds are manufactured. The machines involved in making the patterns are very costly and small foundries may not be able to afford these machines. In such cases the pattern are got made for outside parties who are specialists in pattern making. Patterns are made either from wood or from a metal.

2. Sand-mixing Section

In this section raw sand is washed to remove clay etc., and various ingredients are added in the sand for making the cores and moulds.

3. Core-making Section

Cores are made in this section and used in moulds to provide holes or cavities in the castings.

4. Mould Making Section

This is the section where moulds are made with the help of patterns. The moulds may be made manually or with moulding machines.

5. Melting Section

Metal is melted in the furnace and desired composition of metal is attained by adding various constituents. Metal may be melted in a cupola or in an induction or in an arc furnace. In some cases pit furnace is also used for melting the metals.

6. Fettling Section

The molten metal after pouring in the moulds is allowed to cool and the casting is then taken out of mould. The casting is then cleaned to remove sand and extra material and is shot blasted in fettling section. In fettling operation risers, runners and gates are cut off and removed.

7. Inspection Section

The castings are inspected in the inspection section before being sent out of the factory.

ESTIMATION OF COST OF CASTINGS

The total cost of manufacturing a component consists of following elements :

1. Material cost.
2. Labour cost.
3. Direct other expenses.
4. Overhead expenses.

1. Material Cost

(*a*) Cost of material required for casting is calculated as follows :

(*i*) From the component drawing, calculate the volume of material required for casting. This volume multiplied by density of material gives the net weight of the casting.

(*ii*) Add the weight of process scrap *i.e.* weight of runners, gates and risers and other material consumed as a part of process in getting the casting.

(*iii*) Add the allowance for metal loss in oxidation in furnace, in cutting the gates and runners and over runs etc.

(*iv*) Multiply the total weight by cost per unit weight of the material used.

(*v*) Subtract the value of scarp return from the amount obtained in step (*iv*), to get the direct material cost.

Note : The casting drawing is made by adding various allowances like-shrinkage, draft and machining allowance, etc., to the dimensions of finished component.

(*b*) In addition to the direct material, various other materials are used in the process of manufacture of a casting. Some of the materials are :

(*i*) Materials required in melting the metal, *i.e.*, coal, limestone and other fluxes etc. The cost of these materials is calculated by tabulating the value of material used on per tonne basis and then apportioned on each item.

(*ii*) Material used in core shop for making the cores, *i.e.*, oils, binders and refractories etc. The cost of core materials is calculated depending upon the core size and method of making the core. Similarly the cost of moulding sand ingredients is also calculated.

The expenditure made on these materials is generally expressed as per kg of casting weight and is covered under overhead costs.

2. Labour Cost

Labour is involved at various stages in a foundry shop. Broadly it is divided into two categories :

(*i*) The cost of labour involved in making the cores, baking of cores and moulds is based on the time taken for making various moulds and cores.

(*ii*) The cost of labour involved in firing the furnace, melting and pouring of the metal. Cleaning of castings, fettling, painting of castings etc., is generally calculated on the basis of per kg of cast weight.

3. Direct Other Expenses

Direct expenses include the expenditure incurred on patterns, core boxes, cost of using machines and other items which can be directly identified with a particular product. The cost of patterns, core boxes etc., is distributed on per item basis.

4. Overhead Expenses

The overheads consist of the salary and wages of supervisory staff, pattern shop staff and inspection staff, administrative expenses, water and electricity charges etc. The overheads are generally expressed as percentage of labour charges.

The cost of a cast component is calculated by adding the above constituents.

Example 1 : Calculate the total cost of CI (Cast Iron) cap shown in Fig. 5.1, from the following data :

Cost of molten iron at cupola spout	=	Rs. 30 per kg
Process scrap	=	17 percent of net wt. of casting
Process scrap return value	=	Rs. 5 per kg
Administrative overhead charges	=	Rs. 2 per kg of metal poured.
Density of material used	=	7.2 gms/cc

The other expenditure details are :

Process	***Time per piece***	***Labour charges per hr***	***Shop overheads per hr***
Moulding and pouring	10 min	Rs. 30	Rs. 30
Casting removal, gate cutting etc.	4 min	Rs. 10	Rs. 30
Fettling and inspection	6 min	Rs. 10	Rs. 30

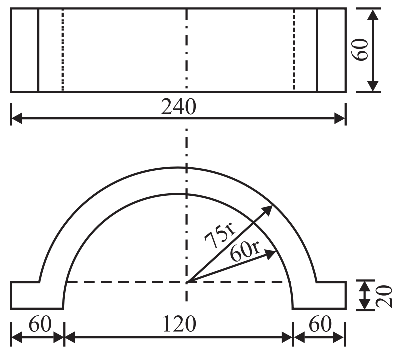


Fig. 5.1. All dimensions are in mm.

Solution : To calculate material cost :

$$\text{Volume of the component} = (2 \times 6 \times 2 \times 6) + \frac{1}{2} \times p\,[(7.5)^2 - (6)^2]\,6$$

$$= 335 \text{ cc}$$

$$\text{Net weight of the casting} = 335 \times 7.2$$

$$= 2{,}412 \text{ gms}$$

$$= 2.4 \text{ kgs}$$

$$\text{Process scrap} = 2.4 \times 0.17 = 0.4 \text{ kg}$$

$$\text{Metal required per piece} = 2.4 + 0.4 = 2.8 \text{ kgs}$$

$$\text{Material cost/piece} = 2.8 \times 30 = \text{Rs. } 84$$

$$\text{Process return} = 0.4 \times 5 = \text{Rs. } 2$$

$$\text{Net material cost per piece} = 84 - 2 = \text{Rs. } 82$$

(*ii*) Calculate Labour Cost and Overheads

Process	***Time per piece***	***Labour charges per piece (Rs.)***	***Shop overheads per piece (Rs.)***
Moulding and pouring	10 min	$\frac{10}{60} \times 30 = 5$	$\frac{30 \times 10}{60} = 5$
Casting removal, gate cutting etc.	4 min	$\frac{4}{60} \times 10 = 0.67$	$\frac{30 \times 4}{60} = 2$
Fettling and inspection	6 min	$\frac{6}{60} \times 10 = 1$	$\frac{30 \times 6}{60} = 3$
Total		**Rs. 6.67**	**Rs. 10**

$$\text{Labour charges} = \text{Rs. } 6.67 \text{ per piece}$$

$$\text{Shop overheads} = \text{Rs. } 10 \text{ per piece}$$

$$\text{Administrative overheads} = 2 \times 2.8 = \text{Rs. } 5.6$$

$$\text{Total cost per piece} = 82 + 6.67 + 10 + 5.6$$

$$= \text{Rs. } 104.27$$

Example 2 : A cast iron component is to be manufactured as per Fig. 5.2. Estimate the selling price per piece from the following data :

Density of material	=	7.2 gms/cc
Cost of molten metal at cupola spout	=	Rs. 20 per kg
Process scrap	=	20 percent of net weight
Scrap return value	=	Rs. 6 per kg
Administrative overheads	=	Rs. 30 per hour
Sales overheads	=	20 percent of factory cost
Profit	=	20 percent of factory cost

Other expenditures are :

Operation	*Time (min)*	*Labour cost/hr (Rs.)*	*Shop overheads/hr (Rs.)*
Moulding and pouring	15	20	60
Shot blasting	5	10	40
Fettling	6	10	40

The component shown is obtained after machining the casting. The pattern which costs Rs. 5,000 can produce 1,000 pieces before being scrapped. The machining allowance is to be taken as 2 mm on each side.

Solution : Fig. 5.2 (*b*) shows the component in finished condition. Fig. 5.2 (*a*) has been drawn by adding the machining allowance of 2 mm on each side.

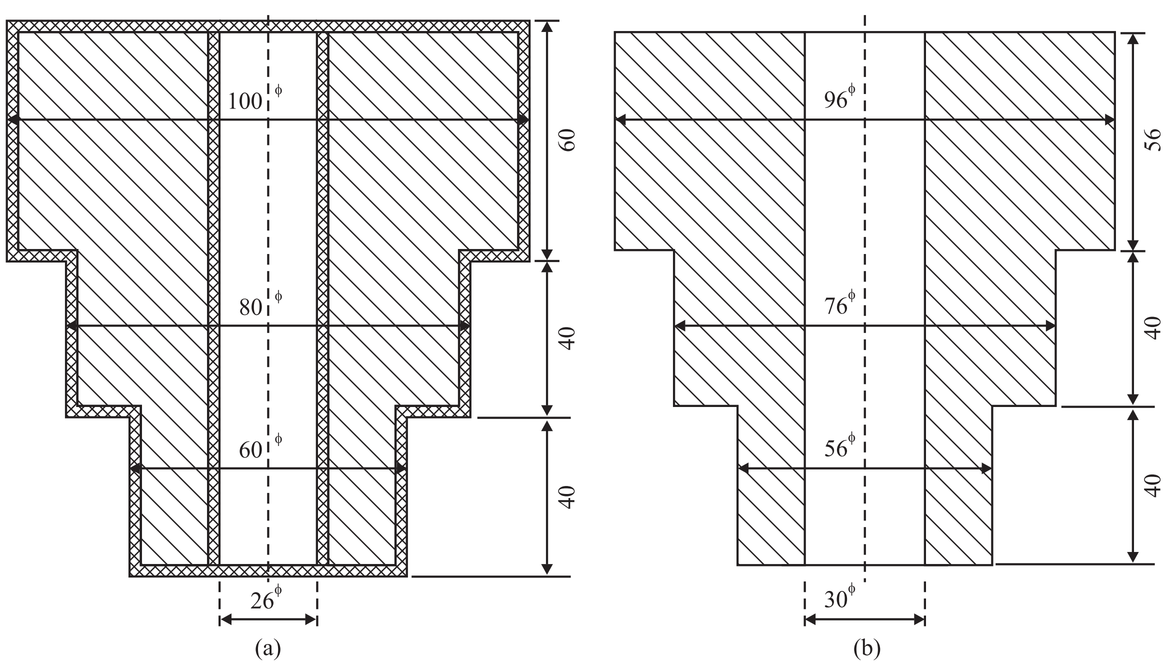


Fig. 5.2 (*a*) Component as cast, (*b*) Finished component (All dimensions are in mm).

(*i*) *Material cost :*

Net volume of cast component $= \frac{\pi}{4}(10^2 \times 6 + 8^2 \times 4 + 6^2 \times 4 - 2.6^2 \times 14)$

= 711 cc

Net weight of cast component = 711 × 7.2 = 5117 gms

= 5.117 kg

Process scrap = 20 percent of 5.117 kg

= 0.2 × 5.117 = 1.02 kg

Total metal required per component = 5.12 + 1.02 = 6.14 kg

Cost of metal poured = 6.14 × 20 = Rs. 122.8

Process return value = 1.02 × 6 = Rs. 6.12

Material cost per component = 122.8 – 6.1 = Rs. 116.7

(*ii*) *Labour cost and factory overheads :*

Labour cost = Rs. 6.83

Shop overheads = Rs. 22.33

Process	***Time per piece (Minutes)***	***Labour cost per piece (Rs.)***	***Shop overheads per piece (Rs.)***
Melting and pouring	15	5.00	15.00
Shot blast	5	0.83	3.33
Fettling	6	1.00	4.00
Total	**26 min**	**6.83**	**22.33**

(*iii*) Factory cost per component = 116.70 + 6.83 + 22.33 = Rs. 145.86

(*iv*) Administrative overheads $= \frac{30 \times 26}{60}$ = Rs. 13

(*v*) Sales overheads = 0.2 × 145.86 = Rs. 29.17

(*vi*) Profit = 0.2 × 145.86 = Rs. 29.17

Selling price per component = Factory cost + Administrative overheads + Sales overheads + profit

= 145.86 + 13 + 29.17 + 29.17

= Rs. 217.2

COST ESTIMATION IN WELDING SHOP

Gas welding :

The most commonly used gas welding is oxy-acetylene welding. The high temperature required for welding is obtained by the application of a flame from mixture of oxygen and acetylene gas.

The filler material is used to fill the gap between the parts to be welded.

The welding technique used may be leftward welding or rightward welding.

Leftward welding : In this method, welding is started from right hand side of the joint and proceeds towards left. This method is used for welding plates upto 5 mm thick. No edge preparation is required in case of the plates of thickness upto 3 mm.

Rightward welding : This method is adopted for welding thicker plates. Welding proceeds from left to right. The flame is directed towards the deposited metal and rate of cooling is very slow.

The cost of welding depends on the welding process used, the type of joint, materials, and labour employed in making and inspecting the joint. Various types of welded joints are shown in Fig. 5.3.

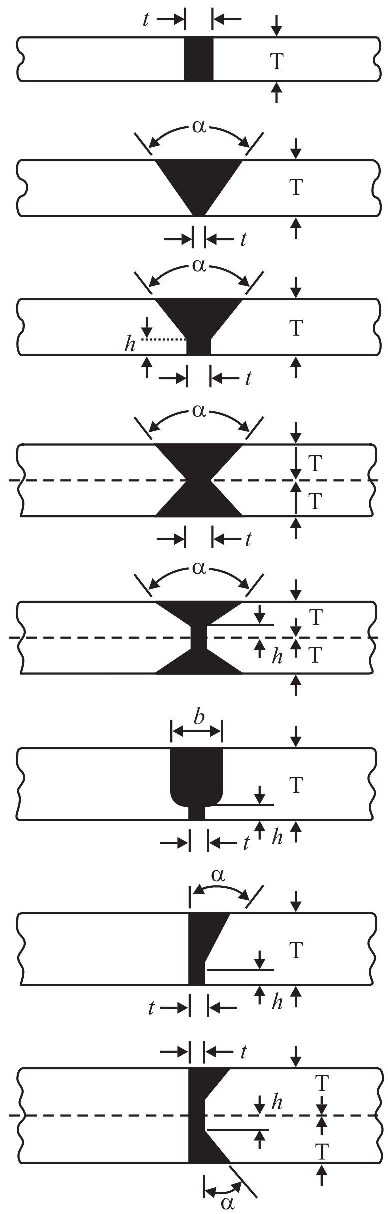


Fig. 5.3. Types of Welded Joints.

Estimation of Cost in Welding

The total cost of welding consists of the following elements :

1. Direct material cost.
2. Direct labour cost.
3. Direct other expenses.
4. Overheads.

1. Direct Material Cost

The direct material cost in a welded component consists of the following :

(*i*) Cost of base materials to be welded *i.e.*, sheet, plate, rolled section, casting or forging. This cost is calculated separately.

(*ii*) Cost of electrodes/filler material used. The electrode consumption can be estimated by using the charts supplied by the suppliers. Another way to find the actual weight of weld metal deposited is to weigh the component before and after the welding and making allowance for stub end and other losses during welding.

Also the weight of weld metal = Volume of weld × Density of weld material

2. Direct Labour Cost

The direct labour cost is the cost of labour for preparation, welding and finishing operations.

Preparation or pre-welding labour cost is the cost associated with preparation of job for welding, *i.e.*, the edge preparation, machining the sections to be welded etc. If gas is used in cutting/preparation of edges, its cost is also taken care of.

Cost of labour in actual welding operation is calculated considering the time in which arc is actually in operation.

The cost of labour for finishing operation is the cost of labour involved in grinding, machining, sand or shot blasting, heat treatment or painting of welded joints.

3. Direct Other Expenses

The direct other expenses include the cost of power consumed, cost of fixtures used for a particular job etc.

Cost of power : The cost of power consumed in arc welding can be calculated from the following formula :

$$\text{Power cost} = \frac{V \times A}{1{,}000} \times \frac{t}{60} \times \frac{1}{E} \times \frac{1}{r} \times C$$

Where V = Voltage

A = Current in Amperes

t = Welding time in minutes

E = Efficiency of the welding machine

= 0.6 for welding transformer

= 0.25 for welding generator

r = Ratio of operating time to connecting time taken by the operator

C = Cost of electricity per kWh *i.e.*, Unit.

In case of gas welding, the cost of gas consumed is calculated by taking the values from Tables 5.1 and 5.2. Cost of welding fixtures is apportioned on the total number of components that can be manufactured using that fixture.

4. Overheads

The overheads include the expenses due to office and supervisory staff, lighting charges of office and plant, inspection, transport, cost of consumables and other charges. The cost of equipment is also apportioned to the individual components in the form of depreciation.

Table 5.1. Data for Oxy-Acetylene Welding.

1. Leftward Welding

Thickness of plate (mm)	*Consumption of Oxygen and Acetylene (m^3/hr)*	*Diameter of filled rod used (mm)*	*Rate of welding (meters/hrs)*	*Filler rod used per meter of weld (meters)*
1.0	0.035 – 0.072	1.0	6.0 – 8.0	1.00
1.5	0.06 – 0.09	1.5	7.5 – 9.0	1.75
2.0	0.075 – 0.125	2.0	6.0 – 7.5	2.50
2.5	0.093 – 0.155	2.5	6.0 – 8.0	2.75
3.0	0.14 – 0.19	2.5	5.5 – 6.0	1.65
4.0	0.20 – 0.30	3.0	4.5 – 5.5	2.10
5.0	0.30 – 0.37	3.0	3.5 – 4.5	4.80

2. Rightward Welding

Thickness of plate (mm)	*Consumption of O_2 and C_2H_2 (m^3/hr)*	*Diameter of filler rod used (mm)*	*Rate of welding (meters/hr)*	*Filler rod used per meter of weld (meters)*
5	0.37 – 0.52	2.5	3.6 – 4.5	3.40
6	0.50 – 0.70	3.0	3.0 – 3.6	3.40
7	0.65 – 0.80	3.5	2.5 – 3.1	3.40
8	0.71 – 0.86	4.0	2.1 – 2.4	3.40
9	0.95 – 1.20	4.5	1.9 – 2.2	4.00
10	1.00 – 1.30	5.0	1.7 – 2.0	4.50
12	1.25 – 1.40	6.0	1.3 – 1.5	4.75
15	1.55 – 1.65	6.0	1.2 – 1.3	6.75
20	1.70 – 2.00	6.0	0.9 – 1.0	9.75
25	2.00 – 2.5	6.0	0.6 – 0.7	16.5

Table 5.2. Data for Oxyacetylene Cutting by Hand and by Machine.

Plate thickness (mm)	*Cutting speed in meters/hr*		*Gas consumption in m^3/h*			
			Oxygen		*Acetylene*	
	Hand cutting	*Machine cutting*	*Hand cutting*	*Machine cutting*	*Hand cutting*	*Machine cutting*
5	20 – 30	18 – 30	0.85 – 2.2	0.82 – 2.2	0.15 – 0.20	0.13 – 0.20
10	15 – 25	15 – 30	1.25 – 2.4	1.1 – 2.4	0.19 – 0.25	0.15 – 0.25
15	18 – 27	18 – 25	3.3 – 4.0	3.3 – 4.5	0.33 – 0.42	0.33 – 0.42
25	9 – 18	15 – 27	3.5 – 4.5	3.6 – 4.8	0.36 – 0.45	0.36 – 0.45
50	10 – 13	12 – 20	5.6 – 6.5	5.2 – 7.3	0.45 – 0.56	0.45 – 0.50
75	9 – 12	12 – 17	6.3 – 8.2	5.9 – 8.6	0.46 – 0.71	0.46 – 0.66

Example 3 : A lap welded joint is to be made as shown in Fig. 5.4.

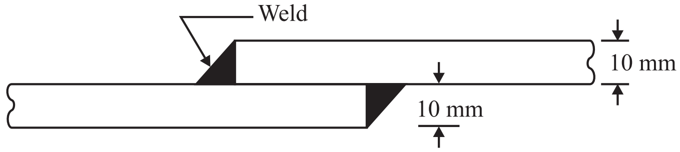


Fig. 5.4. Lap joint

Estimate the cost of weld from the following data :

Thickness of plate	=	10 mm
Electrode diameter	=	6 mm
Minimum arc voltage	=	30 Volts
Current used	=	250 Amperes
Welding speed	=	10 meters/hour
Electrode used per meter of weld	=	0.350 kgs
Labour rate	=	Rs. 40 per hour
Power rate	=	Rs. 3 per kWh
Electrode rate	=	Rs. 8.00 per kg
Efficiency of welding m/c	=	50 percent
Connecting ratio	=	0.4
Overhead charges	=	80 percent of direct charges
Labour accomplishment factor	=	60 percent

Solution :

$$\text{Time per meter run of weld} = \frac{1}{10} \text{ hrs} = 6 \text{ minutes.}$$

$$\text{Cost of power consumed per meter run of weld} = \text{Rs. } \frac{V \times A}{1,000} \times \frac{t}{60} \times \frac{1}{E} \times C \times \frac{1}{r}$$

$$= \text{Rs. } \frac{30 \times 250}{1{,}000} \times \frac{6}{60} \times \frac{1}{0.5} \times 3 \times \frac{1}{0.4}$$

= Rs. 11.25

$$\text{Cost of labour per meter of weld length} = \frac{\text{Cost of labour per hour}}{\text{Welding speed in m/hr}} \times \frac{1}{\text{Labour accomplishment factor}}$$

$$\text{Cost of labour} = \frac{40}{10} \times \frac{100}{60}$$

= Rs. 6.66/meter of weld length

Cost of electrodes per meter of weld = 0.350 × 8

= Rs. 2.80

Total direct cost per meter of weld = Rs. 11.25 + 6.66 + 2.80

= Rs. 20.71

$$\text{Overhead charges per meter of weld} = \text{Rs. } \frac{20.71 \times 80}{100}$$

= Rs. 16.60

Total charges for welding one meter length of joint = Rs. 20.71 + 16.60

= Rs. 37.31

As this is a double fillet weld, lap joint length of weld = 1.5 × 2 = 3 meters

Total charges of making the welded joint = Rs. 37.31 × 3

= Rs. 112

Example 4 : Calculate the welding cost from the following data :

Plate thickness	=	12 mm
Form of joint	=	60°V
Root gap	=	2 mm
Length of joint	=	2 meters
Electrode diameters	=	3.5 mm and 4.0 mm
Electrode length	=	350 mm
Electrodes required per meter weld for 100 per cent efficiency and 50 mm stub length	=	10 nos. of 3.5 mm dia and 24 nos. of 4 mm dia
Average deposition η	=	80 percent
Melting time per electrode	=	1.3 minutes for 3.5 mm dia and 1.50 minutes for 4 mm dia electrode
Connecting ratio	=	2
Hourly welding rate	=	Rs. 40
Overhead charges	=	40 percent of welding cost.

Solution : (*i*) No. of 3.5 mm dia electrodes required per meter length of weld with 100 percent deposition efficiency and 50 mm stub length

$$= 10 \text{ nos.}$$

Electrodes required for 2 meter length of weld with 80 percent deposition efficiency and 50 mm stub length

$$= \frac{2 \times 10 \times 100}{80} = 25 \text{ nos.}$$

(*ii*) No. of 4 mm dia electrodes required for 2 meter weld length with 80 percent deposition efficiency and 50 mm stub length

$$= \frac{2 \times 24 \times 100}{80} = 60 \text{ nos.}$$

(*iii*) Time required to melt 25 electrodes of 3.5 mm dia and 60 electrodes of 4 mm dia and with connecting ratio of 2

$$= 2 \times (25 \times 1.3 + 1.5 \times 60)$$
$$= 245 \text{ minutes}$$

(*iv*) Welding cost @ Rs. 40 per hour

$$= \frac{245}{60} \times 40$$
$$= \text{Rs. } 163$$

Overhead charges = 40 percent of direct charges
= Rs. 163 × 0.4
= Rs. 65

Total cost of welding = 163 + 65
= Rs. 228

Example 5 : Work out the welding cost for a cylindrical boiler drum $2\frac{1}{2}$ m × 1 m diameter which is to be made from 15 mm thick m.s plates. Both the ends are closed by arc welding of circular plates to the drum. Cylindrical portion is welded along the longitudinal seam and welding is done both in inner and outer sides. Assume the following data :

(*i*)	Rate of welding	=	2 meters per hour on inner side and 2.5 meters per hour on outer side
(*ii*)	Length of electrodes required	=	1.5 m/meter of weld length
(*iii*)	Cost of electrode	=	Rs. 0.60 per meter
(*iv*)	Power consumption	=	4 kWh/meter of weld
(*v*)	Power charges	=	Rs. 3/kWh
(*vi*)	Labour charges	=	Rs. 40/hour
(*vii*)	Other overheads	=	200 percent of prime cost
(*viii*)	Discarded electrodes	=	5 percent
(*ix*)	Fatigue and setting up time	=	6 percent of welding time.

Solution :

Diameter of drum = 1 meter

Length of drum = 2.5 meter

As the cylindrical portion is welded on both sides and both the ends are closed by welding circular plates, the welding on circular plates being on one side only.

Length of weld = $2 \times \pi \times$ dia of drum + (2 × length of drum)

= $2 \times \pi \times 1 + (2 \times 2.5)$

= 11.28 meters

≃ 11.3 meters.

(*i*) **To calculate direct material cost :** In this example the cost of electrodes is the direct materiel cost.

Length of electrode required = 1.5 m/m of weld

Net electrode length required for 11.3 meters weld length = 1.5×11.3

= 16.95 meters

Discarded electrode = 5 percent

Total length of electrodes required = $16.95 + \dfrac{5 \times 16.95}{100}$

= 17.8 meters

Cost of electrodes = 0.6×17.8

= Rs. 10.68.

(*ii*) **To calculate direct labour cost :** To calculate the labour charges, first we have to calculate the time required for making the weld (assuming that side plates have single side welding and longitudinal seam is welded on both sides).

Length of weld on inside of drum = 2.5 meter

Length of weld on outside of drum = $2 \times \pi \times 1 + (2.5)$

= 8.8 meters

Time taken for inside weld = $\dfrac{2.5 \times 1}{2}$

= 1.25 hrs

Time taken for outside weld = $\dfrac{8.8 \times 1}{2.5}$

= 3.5 hrs

Net time required for welding = 1.25 + 3.5

= 4.75 hrs

Fatigue and setting up allowances = 4.75×0.06

= 0.28 hrs

Total time required = 4.75 + 0.28

= 5 hrs

Direct labour cost = 40×5

= Rs. 200

(*iii*) To calculate cost of power consumed

Power consumption = 4 × 11.3
= 45.2 kWh
Cost of power consumed = 45.2 × 3
= Rs. 135.6

(*iv*) To calculate the overhead charges :

Prime cost = Direct material cost + Direct labour cost + Direct other expenses
Prime cost = 10.68 + 200 + 135.60
= Rs. 346

$$\text{Overheads} = \frac{200}{100} \times 346$$

= Rs. 692

(*v*) Total cost of making boiler drum = 10.68 + 200 + 135.6 + 692
= Rs. 1038

Example 6 : A container open on one side of size 0.5 m × 0.5 m × 1 m is to be fabricated from 6 mm thick plates Fig. 5.5. The plate metal weighs 8 gms/cc. If the joints are to be welded, make calculations for the cost of container. The relevant data is :

Cost of plate	=	Rs. 10 per kg
Sheet metal scarp (wastage)	=	5 percent of material
Cost of labour	=	10 percent of sheet metal cost
Cost of welding material	=	Rs. 20 per meter of weld.

Solution :

(*i*) To calculate material cost :

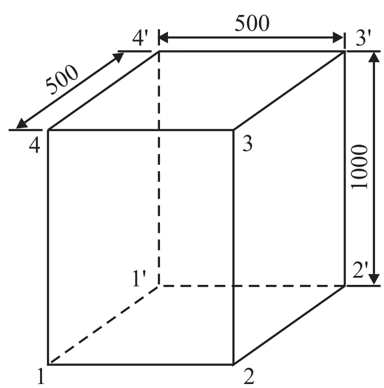


Fig. 5.5. Welded water tank

Net volume of material used = (4 × 50 × 100 × 0.6) + (50 × 50 × 0.6)
= 13,500 cc
Net weight of container = Volume × density of material
= 13,500 × 8
= 1,08,000 gm
= 108 kgs

Sheet metal scrap = 5 percent of net weight

$$= \frac{108 \times 5}{100} = 5.40 \text{ kgs}$$

Total weight of sheet metal required for fabrication of one container

= 108 + 5.4

= 113.4 kgs

Cost of sheet metal per container = 113.4 × 10

= Rs. 1134

(*ii*) To calculate labour charges :

Cost of labour = 10 percent of sheet metal cost

$$= \frac{1134 \times 10}{100} = \text{Rs. } 113$$

(*iii*) To calculate cost of welding material :

Length to be welded = (4 × 50) + (4 × 100)

= 600 cm = 6 meters

Cost of welding material = 6 × 20

= Rs. 120

(*iv*) Cost of container = Cost of sheet metal material + Cost of labour + Cost of welding material

= 1134 + 113 + 120

= Rs. 1367

Example 7 : Calculate the cost of welding two pieces of mild steel sheets 1 meter long and 7 mm thick. A 60° V is prepared by means of gas cutting before welding is to the commenced. The cost of Oxygen is Rs. 7/cu meter and of acetylene is Rs. 4/cu meter. The filler metal costs Rs. 20 per kg. The following data is also available :

For gas cutting (For 10 mm thick plate)

Cutting speed	=	20 m/hr
Consumption of Oxygen	=	2 cu meter/hr
Consumption of acetylene	=	0.2 cu meter/hr

Data for Rightward Welding (For 7 mm thick plate)

Consumption of Oxygen	=	0.8 cu meter/hr
Consumption of acetylene	=	0.8 cu meter/hr
Dia of filler rod used	=	3.5 mm
Filler rod used per meter of weld	=	3.4 meters
Rate of welding	=	3 meters/hr
Density of filler metal	=	8 gm/cc

Solution : Cost of V preparation :

Time taken to cut two plates of one meter length each for edge preparation

$$= \frac{2 \times 1}{20} = 0.1 \text{ hr}$$

Consumption of oxygen for cutting = 2 × 0.1
= 0.2 cu meters
Cost of oxygen for cutting = 0.2 × 7
= Rs. 1.4
Consumption of acetylene for cutting = 0.2 × 0.1
= 0.02 cu meter
Cost of acetylene for cutting = 4 × 0.02
= Re. 0.08
Total cost of gases for cutting = 1.40 + 0.08
= Rs. 1.48

Cost of welding

(*i*) Cost of filler rod :

Length of weld = 1 meter
Length of filler rod used = 3.4 × 1
= 3.4 meters = 340 cms

$$\text{Weight of filler rod used} = \frac{\pi}{4}\left(\frac{3.5}{10}\right)^2 \times 340 \times 8$$

= 261.8 gms = 0.262 kgs
Cost of filler rod used = 0.262 × 20
= Rs. 5.24

(*ii*) Cost of gases :

$$\text{Time taken for welding} = \frac{1}{3} \times 1 = \frac{1}{3} \text{ hr}$$

$$\text{Volume of oxygen consumed for welding} = \frac{1}{3} \times 0.8 = 0.26 \text{ cu meter}$$

Cost of oxygen consumed for welding = 0.26 × 7 = Re. 1.82

$$\text{Volume of acetylene consumed for welding} = \frac{1}{3} \times 0.8 = 0.26 \text{ cu meters}$$

Cost of acetylene consumed for welding = 0.26 × 4 = Rs. 1.04
Cost of gases for welding = 1.82 + 1.04 = Rs. 2.86
Total cost of making the weld = 1.48 + 5.24 + 2.86
= Rs. 9.58

Example 8 : Calculate the cost of welding two plates 200 mm × 100 mm × 8 mm thick to obtain a piece 200 mm × 200 mm × 8 mm approximately using rightward welding technique Fig. 5.6. The following data is available :

Cost of filler material	=	Rs. 60 per kg
Cost of oxygen	=	Rs. 700 per 100 cu meters
Cost of acetylene	=	Rs. 700 per 100 cu meters

Consumption of oxygen = 0.70 cu m/hr
Consumption of acetylene = 0.70 cu m/hr
Diameter of filler rod = 4 mm
Density of filler material = 7.2 gms/cc
Filler rod used per meter of weld = 340 cms
Speed of welding = 2.4 meter/hr

Labour is paid Rs. 20 per hour and overheads may be taken as 100 percent of labour cost.

Solution :

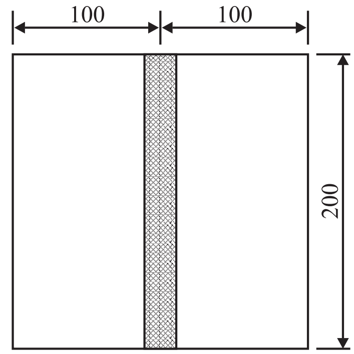


Fig. 5.6

Total length of weld = 200 mm

$$\text{Filler rod used} = 340 \times \frac{200}{1,000}$$

$$= 68 \text{ cms}$$

Volume of filler rod used = X-sectional area of rod × length of rod

$$= \frac{\pi}{4}(0.4)^2 \times 68$$

$$= 8.5 \text{ cm}^3$$

Weight of filler rod = 8.5 × 7.2 = 61.2 gms

$$\text{Cost of filler material} = 61.2 \times \frac{60}{1,000}$$

$$= \text{Rs. } 3.67$$

$$\text{Time to weld 200 mm length} = \frac{200}{1,000 \times 2.4} = 0.08 \text{ hrs}$$

Oxygen consumed = 0.08 × 0.7 = 0.056 cu m

Acetylene consumed = 0.08 × 0.7 = 0.056 cu m

$$\text{Cost of oxygen consumed} = 0.056 \times \frac{700}{100} = \text{Rs. } 0.40$$

$$\text{Cost of acetylene consumed} = 0.056 \times \frac{700}{100} = \text{Rs. } 0.40$$

Labour cost

Time to weld = 0.08 hours

Add 80 percent of time to weld for edge preparation, finishing and handling time.

Total labour time = 0.08×1.8 hrs
= 0.144 hrs

Labour cost = 0.144×20 = Rs. 3

Overheads = 100 percent of labour cost
= Rs. 3

Cost of making the joint = 3.67 + 0.40 + 0.40 + 3.00 + 3.00
= Rs. 10.50

COST ESTIMATION IN FORGING SHOP

Forging is the process of forming a metal into desired shape and size by the application of localised compressive forces. The component may be forged in cold or hot condition. In case of hot forging the metal is heated to a high temperature below its melting point and is pressed into shape by the application of compressive forces by manual or power hammers, presses or special forging machines.

Forging Processes

Forging processes can be divided into following categories :

1. **Smith forging :** In smith forging, also known as hand forging, the component is made by hammering the heated material on an anvil. The hammering may be done by hand or machine.
2. **Drop forging :** The forging is done by using the impressions machined on a pair of die blocks. The upper half of the die is raised and allowed to drop on the heated metal placed over the lower half of the die. The metal is thus squeezed into required shape.
3. **Press forging :** In this method the metal is squeezed into desired shape in dies using presses. Instead of rapid impact blows of hammer, pressure is applied slowly. This method is used for producing accurate forgings.
4. **Machine forging or Upset forging :** In machine forging or upset forging the metal is shaped by making it to flow at right angles to the normal axis. The heated bar stock is held between two dies and the protruding end is hammered using another die. In upset forging the cross-section of the metal is increased with a corresponding reduction in its length.
5. **Roll forging :** Roll forging is used to draw out sections of bar stock, *i.e.*, reducing the cross-section and increasing the length. Special roll forging machines, with dies of decreasing cross-section are used for roll forging.

Material Losses in Forging

While calculating the volume of material to be used for a component an allowance is made for wastage of metal due to various factors. Various allowances to be taken into account are discussed below :

(*i*) **Shear loss :** The blank required for forging a component is cut from billets or long bars. The material equal to the product of thickness of sawing blade and cross-section of bar is lost for each cut. Similarly, if the small pieces left at the end are not of full length, these also go as waste. Shear loss is generally taken as 5 percent of net weight.

(*ii*) **Tonghold loss :** Drop forging operations are performed by holding the stock at one end with the help of tongs. A small length, about 2.0 – 2.5 cm and equal to diameter of stock is added to the stock for holding.

$$\text{Tonghold loss} = \text{Area of X-section of bar} \times \text{Length of tonghold}$$

(*iii*) **Scale loss :** As the forging process is performed at very high temperature, the Oxygen from air forms iron oxide by reacting with hot surface. This iron oxide forms a thin film called scale, and falls off from surface at each stroke of hammer. Scale loss is taken as 6 percent of net weight.

(*iv*) **Flash loss :** When dies are used for forging, some metal comes out of the die at the parting line of the top and bottom halves of the die. This extra metal is called flash. Flash is generally taken as 20 mm wide and 3 mm thick. The circumference of component at parting line multiplied by cross-sectional area of flash gives the volume of flash. The flash loss in weight is then calculated by multiplying the volume of flash by density of the material.

(*v*) **Sprue loss :** When the component is forged by holding the stock with tongs, the tonghold and metal in the die are connected by a portion of metal called the sprue or runner. This is cut off when product is completed. Sprue loss is taken as 7 percent of net weight.

Estimation of Cost of Forgings

The cost of a forged component consists of following elements :

1. Cost of direct materials.
2. Cost of direct labour.
3. Direct expenses such as cost of dies and cost of press.
4. Overheads.

1. Cost of Direct Material

Cost of direct material used in the manufacture of a forged component is calculated as follows :

(*i*) **Calculate the net weight of forging :** Net weight of the forged component is calculated from the drawings by first calculating the volume and then multiplying it by the density of material used.

$$\text{Net weight} = \text{Volume of forging} \times \text{Density of material}$$

(*ii*) **Calculate the gross weight :** Gross weight is the weight of forging stock required to make the forged component. Gross weight is calculated by adding material lost due to various factors discussed above, to the net weight.

$$\text{Gross weight} = \text{Net weight} + \text{Material loss in the process}$$

In case of smith or hand forging, only scale loss and shear loss are to be added to net weight but in case of die forging all the losses are taken into account and added to net weight.

(*iii*) **Diameter and length of stock :** The greatest section of forging gives the diameter of stock to be used, and

$$\text{Length of stock} = \frac{\text{Gross weight}}{\text{X-sectional area of stock} \times \text{Density of material}}$$

(*iv*) The cost of direct material is calculated by multiplying the gross weight by price of the raw material

Direct material cost = Gross weight × Price per kg

2. Cost of Direct Labour

Direct labour cost is estimated as follows :

$$\text{Direct labour cost} = t \times l$$

where t = time for forging per piece (in hours)

l = labour rate per hour.

It is very difficult to estimate the exact time to forge a component. In practice the forging time per component is estimated based on the total production of eight hours or a day.

3. Direct Expenses

Direct expenses include the expenditure incurred on dies and other equipment, cost of using machines and any other item, which can be directly identified with a particular product. The method of apportioning die cost and machine cost is illustrated below :

Apportioning of Die Cost

Let cost of Die = Rs. X

No. of components that can be produced using this die (*i.e.*, die life) = Y components

Cost of die/component = Rs. X/Y

Apportioning of Machine (Press) Cost

Let cost of press = Rs. A

Life of press = n years

$= n \times 12 \times 4 \times 5 \times 8 = 1920n$ hours

(Assuming 8 hours of working per day, 5 days a week and 4 weeks a month in 12 months of year).

$$\text{Hourly cost of press} = \frac{A}{1920\,n}$$

No. of components produced per hour = N

$$\text{Cost of using press per component} = \text{Rs. } \frac{A}{1920\,n\ N}$$

This excludes cost of power consumed and cost of consumables, if any.

4. Overheads

The overheads include supervisory charges, depreciation of plant and machinery, consumables, power and lighting charges, office expenses etc. The overheads are generally expressed as percentage of direct labour cost.

The total cost of forging is calculated by adding the direct material cost, direct labour cost, direct expenses and overheads.

Example 9 : Calculate the net weight and gross weight for the component shown in Fig. 5.7. Density of material used is 7.86 gm/cc. Also calculate :

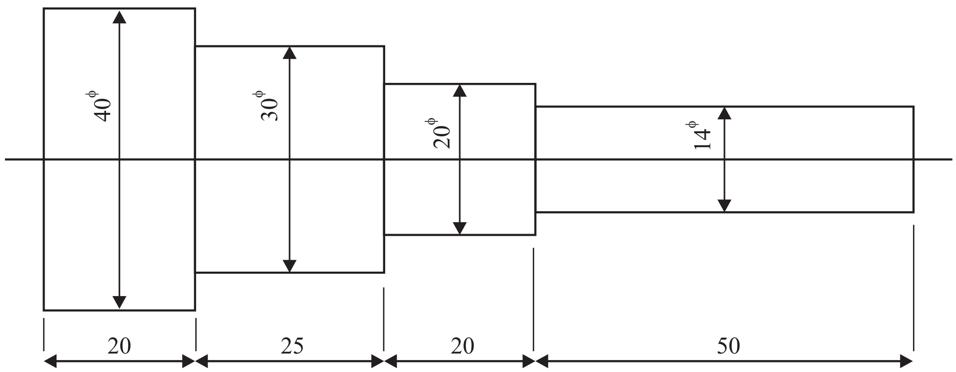


Fig. 5.7

(*i*) Length of 14 mm dia bar required to forge one component.

(*ii*) Cost of forging/piece if :

Material cost = Rs. 80 per kg

Labour cost = Rs. 5 per piece

Overheads = 150 percent of labour cost.

Solution :

$$\text{Net volume of forged component} = \frac{\pi}{4}\left[(4)^2 \times 2 + (3)^2 \times 2.5 + (2)^2 \times 2 + (1.4)^2 \times 5\right]$$

$$= \frac{\pi}{4}(72.3) = 56.76 \text{ cc}$$

Net weight = 56.76 × 7.86 = 446 gms

***Losses* :**

Shear loss = 5 percent of net weight

$$= \frac{5}{100} \times 446 = 22.30 \text{ gms}$$

Scale loss = 6 percent of net weight

$$= \frac{6}{100} \times 446 = 26.76 \text{ gms}$$

Taking flash width = 20 mm

Flash thickness = 3 mm

Flash loss = (periphery of parting line) × 2 × 0.3 × 7.86

= [2 (2 + 2.5 + 2 + 5) + 1.4 + (2 – 1.4) + (3 – 2) + (4 – 3) + 4] × 2 × 0.3 × 7.86

= 31.0 × 2 × 0.3 × 7.86 = 146 gms

Tonghold loss = 2 × Area of cross-section of bar × 7.86

$$= 2 \times \frac{\pi}{4}(1.4)^2 \times 7.86 = 24.22 \text{ gms}$$

Sprue loss = 7 percent of net weight

$$= \frac{7}{100} \times 446 \text{ gms}$$

$= 31.22$ gms

Total material loss $= 22.3 + 26.8 + 146 + 24.22 + 31.22$

$= 250$ gms

Gross weight = Net weight + Losses

$= 446 + 250 = 696$ gms

(*i*) New length of 14 mm f bar required per piece

$$= \frac{\text{Volume of forging}}{\text{Area of X – Section of bar}}$$

$$= \frac{56.76}{\frac{\pi}{4}(1.4)^2} = 36.86 \text{ cm}$$

Direct material cost $= \dfrac{696}{1,000} \times 8$

= Rs. 5.57

Direct labour cost = Rs. 5 per piece

Overheads = 150 percent f labour cost

$= 1.5 \times 5 =$ Rs. 7.5

Cost per piece $= 5.57 + 5 + 7.5$

= Rs. 18

Example 10 : 150 components, as shown in Fig. 5.8 are to be made by upsetting a f 20 mm bar. Calculate the net weight, gross weight and length of f 20 mm bar required. The density of material may be taken as 7.86 gms/cc.

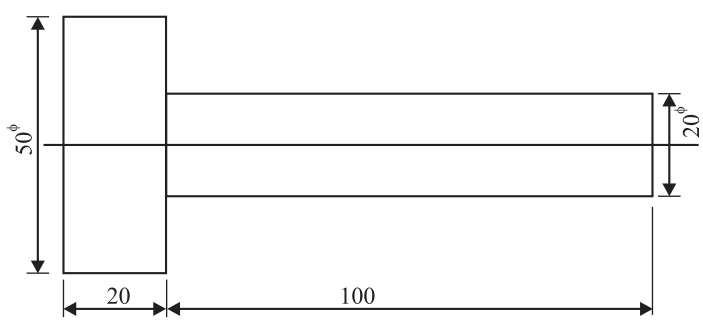


Fig. 5.8

Solution :

Net volume of material $= \dfrac{\pi}{4} [(5)^2 \times 2 + (2)^2 \times 10]$

$$= \frac{\pi}{4} (50 + 40) = 70.72 \text{ cm}^3$$

Net weight per component = 70.72 × 7.86 = 556 gms

Net weight for 150 components = 556 × 150 = 83,400 gms

= 83.4 kgs

Losses :

Shear loss = 5 percent of net weight

$$= \frac{5}{100} \times 556 = 27.8 \text{ gms}$$

Scale loss = 6% of net weight

$$= \frac{6}{100} \times 556 = 33.4 \text{ gms}$$

Gross weight/component = 556 + 27.8 + 33.4

= 617 gms

Gross weight for 150 components = 617 × 150 = 92,550 gms

= 92.550 kgs

$$\text{Length of 20 mm } \phi \text{ bar required} = \frac{92550}{\frac{\pi}{4}(2)^2 \times 7.86}$$

= 3744 cms = 37.44 meters.

Example 11 : Calculate the cost of forging a crank shaft as shown in Fig. 5.9. The forging is to be made out of a bar stock of 50 mm ϕ and following data is available :

(*i*)	Material price	=	Rs. 80 per kg
(*ii*)	Direct labour charges	=	Rs. 23 per piece
(*iii*)	Overhead charges	=	150 percent of material cost
(*iv*)	Density of material	=	7.5 gms/cc
(*v*)	Losses	=	28 percent of net weight

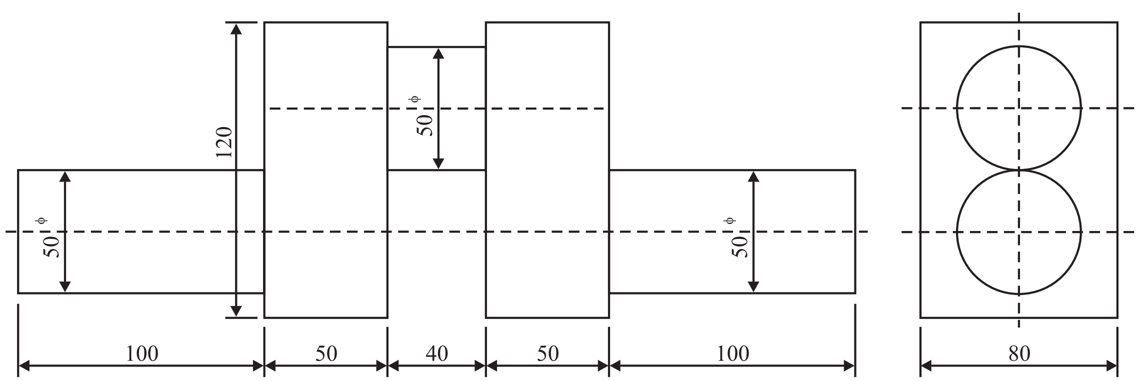


Fig. 5.9. Crank shaft.

Solution : From the drawing of the forged component

$$\text{Volume of forging} = \left[2 \times \frac{\pi}{4}(5)^2 \times 10\right] + [2 \times 12 \times 5 \times 8] + \left[\frac{\pi}{4}(5)^2 \times 4\right]$$

$$= 1430 \text{ cm}^3$$

Net weight of component = 1,430 × 7.5 = 10,725 gms

= 10.725 kgs

Losses = 28 percent of net weight

$$= \frac{28 \times 10.725}{100} = 3 \text{ kg}$$

Gross weight = 10.725 + 3 = 13.725 kgs

Material cost per piece = 13.725 × 80 = Rs. 1100

Labour cost = Rs. 23 per piece

Overheads = 150 percent of material cost

$$= \frac{150 \times 1100}{100} = \text{Rs. } 1650$$

Cost of component = 1100 + 23 + 1650 = Rs. 2773

ESTIMATION OF MACHINING TIME : Instructional Objectives

After studying this unit, the student will be able to :

(i) Distinguish between the various elements of total time required to manufacture a component.

(ii) Select proper cutting speeds and feeds for machining operations.

(iii) Estimate the time taken for various machining operations.

(iv) Select the best method of manufacture a component.

(v) Balance the plant facilities against the work load.

(vi) Fix reliable delivery schedules based on machining time.

To estimate the cost of any product involving machining operations, the machining time is required to be estimated before the total cost of the product/component can be computed. In addition to actual time taken for operation to be carried out, time is spent on certain other elements of work. The total time required to perform a machining operation consists of following elements :

(*i*) Set-up time,

(*ii*) Handling time,

(*iii*) Machining time,

(*iv*) Tear down time,

(*v*) Down time, and

(*vi*) Allowances.

1. Set-up Time

This is the time taken to prepare the machine for operation. The set-up time includes the time taken to :

(*i*) Study the component drawing.

(*ii*) Draw tools from tool crib, and

(*iii*) Install and adjust the tools, jigs and fixtures on the machine.

The time over and above the unit standard time to produce first few pieces is also considered in set-up time. We can say that set-up time is the overall preparation time less the standard time for the units produced during the process of preparation.

The set-up time occurs only once for a batch or lot being taken up for production. Standard data are available for set-up time for various machine tools.

2. Handling Time

It is the time taken by the operator in preparing a part for machining and for disposing the part after operation has been completed. The handling time includes the time for loading and unloading the component on the machine, making measurements on parts during machining, etc.

3. Machining Time

It is the time for which the machine works on the component, *i.e.* from the time when the tool touches the work piece to when the tool leaves the component after completion of operation. The machining time depends on the type and extent of machining required, material being machined, speed, feed, depth of cut and number of cuts required.

4. Unit Operation Time

The sum of handling time and machining time for a job is called operation time. It is the duration of time that elapses between output of two consecutive units of production. It is also called cycle time.

5. Tear Down Time

It is the time taken to remove the tools, jigs and fixtures from the machine and to clean the machine and tools after the operation has been done on the last component of batch. The tear down time is usually small. The tear down time occurs only once for a complete lot or batch taken for machinging. Standard data are available for tear down time for various machines.

6. Down Time

It is the time wasted by the operator due to breakdowns, non-availability or delay in supply of tools and materials etc.

7. Allowances

In additions to the elements of time described above, the total time to perform an operation includes a number of allowances like time for personal needs of the operator, time for checking, time for tool sharpening etc. The various allowances are follows :

(*a*) **Personal allowance :** This is the time taken by the operator in attending to his personal needs and includes the time spent in going to toilet and cafeteria. It is usually taken as 5 percent of total time, *i.e.*, 24 minutes $\left(\frac{1}{2}\text{ hr}\right)$ in 8 hrs shift.

(*b*) **Fatigue :** The long working hours and working conditions such as poor lighting, poor ventilation etc., cause fatigue and affects the efficiency of worker *i.e.*, fatigue decreases the workers capacity to work. The allowance for fatigue is taken depending upon the type of work.

Table 5.3

Instrument	***Standards time to check one dimension (Min).***
Scale	0.10
Outside micrometer	0.15
Depth micrometer	0.20
Dial micrometer	0.30
Outside callipers	0.05
Inside callipers	0.10
Plug gauge	0.20
Snap gauge	0.10
Surface gauge	0.20
Thread snap gauge (Male/Female)	0.30
Thread micrometer	0.25
Vernier callipers	0.50

(*c*) **Tool sharpening/Tool change allowance:** This allowance is provided for the time taken by the operator to get the tool changed or to resharpen the tool when it becomes dull. This time varies from machine to machine and depends upon the type of tool being used.

(*d*) **Inspection or Checking allowance :** Inspection is a vital part of the total process of production. Inspection is necessary to ensure that parts are manufactured according to laid down standards. The time taken in checking the part for its dimension, process and fitness is reckoned as inspection time. The inspection time depends on the dimensional tolerances and the instrument being used for checking. The standard times for inspection with various types of instruments are given in Table. 5.3.

(*e*) **Other allowances :** Some allowance is provided to compensate for the activities, in which the operator is engaged, but are not included in normal operation cycle. The activities include periodic cleaning of machines, getting stocks, filling coolant reservoirs and disposal of scrap etc. These miscellaneous activities vary from shop to shop and in a well organised shop, these may be reduced to a minimum by proper planning.

The total time required to make a component is the sum of unit operation time and proportion of set-up time, tear-down time, down time and allowances for one work piece.

$$\text{Total time per component} = \frac{\begin{array}{c}\text{Handling time + Machining time + Set-up time}\\ \text{+ Tear-down time + Down time + Allowances}\end{array}}{\text{N}}$$

where N = Number of components produced in one lot.

In the process of drilling a hole in a batch of 50 components, the following elements of work are performed :

(*i*) Study the component drawing
(*ii*) Draw tool/jig from store
(*iii*) Install the jig on drilling machine
} Set-up elements

(*iv*) Pick-up the part from bin
(*v*) Place the part in jig and tighten
(*vi*) Advance the drill to work
} Handling elements

(*vii*) Drill one hole through the part — Machining element

(*viii*) Clear drill from work
(*ix*) Release part from jig
(*x*) Remove part from jig
(*xi*) Place the part in bin
} Handling elements

(*xii*) Remove jig from the machine
(*xiii*) Remove the drill bit from machine
(*xiv*) Clear the machine and jig
} Tear-down elements

ESTIMATION OF MACHINING TIME

Estimation of machining time means calculating the time required to complete the operations to make the components as per drawing.

Machining time is the time for which the machine works on the component. The basic formula used for determining the machining time is :

$$T = \frac{L}{F}$$

where T = Machining time, minutes

L = Length of cut or total tool travel, mm

F = Feed rate of tool, mm/minute

= Feed per revolution × r.p.m.

Before we take up the estimation of machining time for various operations, the terms used in cutting time formula are defined, in general, as follows :

Length of cut : It is the distance travelled by the tool to machine the work piece and is calculated as follows :

Length of cut = L

= Approach length + Length of work piece to be machined + Over travel

Approach is the distance a tool travels, from the time it touches the work piece until it is cutting to full depth. Over travel is the distance the tool is fed while it is not cutting. It is the distance over which the tool idles before it enters and after it leaves the cut. These terms are explained in the Fig. 5.10 for a cutting operation on lathe.

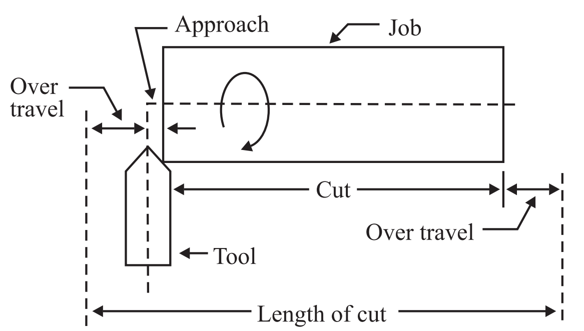


Fig. 5.10

Feed : Feed is the distance that a tool travels along the work or the work travels w.r.t. the tool for each revolution of the work-piece or cutter.

Depth of cut : (Fig. 5.11) It is the difference between unfinished dimension and finished dimension of the job. For example, in case of turning, depth of cut is the difference between radius of the bar before and after taking the cut. The feed and depth of cut for a particular operation depend on the material to be machined, surface finish required and tool used.

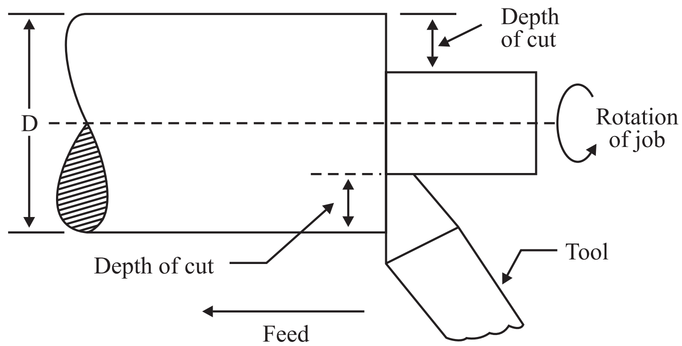


Fig. 5.11

Cutting speed : Cutting speed is the speed at which the cutting edge of tool passes over the job and it is usually expressed in meters per minute. The cutting speed depends on the cutting tool material, the work piece material and the operation. Once the cutting speed has been selected, the revolution per minute of job/machine are calculated as follows :

$$S = \frac{\pi DN}{1000}$$

or

$$N = \frac{1000\,S}{\pi D}$$

where S = Surface cutting speed in meters per minute

D = Diameter of the job in mm

N = r.p.m. of machine/job.

CALCULATION OF MACHINING TIME FOR LATHE OPERATIONS

The calculation of machining time for various lathe operations is discussed here.

Turning : Turning, on a lathe, is the removal of excess material form the workpiece by means of a pointed tool, to produce a cylindrical or cone shaped surface. From cutting speed, r.p.m. of job are calculated by using the formula.

$$N = \frac{1000\,S}{\pi D}$$

where N = r.p.m. of job

S = Surface cutting speed in meters/minute

D = Diameter of the stock to be turned (in mm)

if f = Feed per revolution (in mm)

L = Length of stock to be turned (in mm)

T = Time required for turning (in minutes)

Then

$$T = \frac{L}{f \times N}$$

In case it is not possible to obtain the required dimensions in single cut, more than one cut may be required. In such cases the r.p.m. is determined by using the mean diameter of the job.

$$N = \frac{1000\,S}{\pi \times D\ (\text{average})}$$

Table 5.4. Cutting Speeds and Feed Rates for Lathe Operations

Work material	**Cutting speed metres/min**								**Feed rate *f* in mm/rev**	
	HSS Tool				***Carbide Tool***		***Stellite Tool***			
	Turning		***Reaming and Threading***	***Drilling***	***Turning***		***Turning***			
	Rough	***Finish***			***Rough***	***Finish***	***Rough***	***Finish***	***Rough***	***Finish***
Mild Steel	40	60	7.5 to 15	30	90	180	50	75	0.65 to 2.0	0.12 to 0.75
Cast Steel	15	24	3.5	12	45	100	24	33	0.5 to 1.25	0.12 to 0.5
Stainless Steel	15	18	3	12	27	45	22	25	0.5 to 1.0	0.07 to 0.17
Grey C.I.	18	27	3.5	13	60	100	33	45	0.4 to 2.5	0.2 to 1.0
Aluminium	90	150	15	72	240	360	120	180	0.1 to 0.5	0.07 to 0.25
Brass	75	100	18	60	180	270	90	150	0.37 to 2.0	0.2 to 1.25
Phosphor Bronze	18	36	4.5	13	120	180	30	50	0.37 to 0.75	0.12 to 0.5

where D (average) = Average Diameter of job

$$= \frac{D + d}{2}$$

where D = Diameter of stock before turning

d = Diameter of job after turning

and $$T = \frac{L}{f \times N} \times P$$

where P = Number of cuts (passes) required.

If over travel and approach are also to be taken into account

$$T = \frac{A + L + O}{f \times N} \times P$$

where A = Approach length

O = Over travel

The cutting speeds and feeds for various tool and work material combinations for lathe operations are given in Table 5.4. The depth of cut should not exceed 3 mm in roughing operation and 0.75 mm in finishing operation.

Facing : Facing is the process of removing material from the ends of the job by moving the tool perpendicular to the axis of the job Fig. 5.12 (*a*) and (*b*). Time taken for facing is calculated in the same way as for turning but here

$$\text{Length of job} = \frac{1}{2} \times \text{dia. of job (in case of solid job)}$$

$$= \frac{1}{2}\,(D - d) \text{ in case of hollow jobs}$$

D = Outer diameter of job

d = Inner diameter of job

f = Feed/revolution,

is the movement of tool per revolution perpendicular to the axis of the job.

Table 5.5. Cutting Speeds and Feeds for Drilling Operation (Tool Material : HSS)

Work material	S mpm	Drill size, mm	*f* mm per revolution
Stainless steels	9 – 12	0 – 3.2	0.02 – 0.05
C-steels (0.4 – 0.5% C)	21 – 24	3.2 – 6.35	0.05 – 0.10
C-steels (0.2 – 0.3 % C)	24 – 33	6.35 – 12.7	0.10 – 0.17
Soft grey C.I.	30 – 45	12.7 – 25.4	0.17 – 0.37
Brass and Bronze	60 – 90	> 25.4	0.37 – 0.62
Aluminium alloys	60 – 90		
Magnesium alloys	75 – 120		

Time taken,

$$T = \frac{\text{Length of cut}}{f \times N}$$

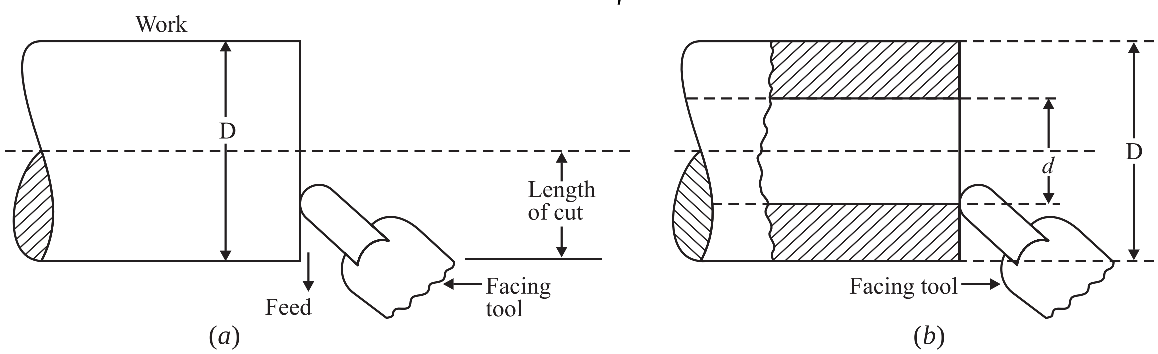


Fig. 5.12. (*a*) and (*b*). (a) Facing operation (Solid shaft) (b) Facing (hollow shaft)

External relief : The external relief is the removal of material from a previously turned surface along the same axis and within the limits of turned area. The method of calculating the time for external relief is same as for turning.

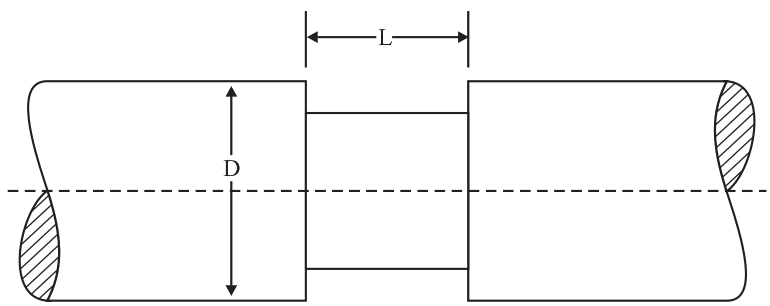


Fig. 5.13. External relief.

$$T = \frac{L}{f \times N} \times P$$

P = Number of cuts (passes)

In external relief process, there is no approach length and over travel. The term, L is the length to be machined.

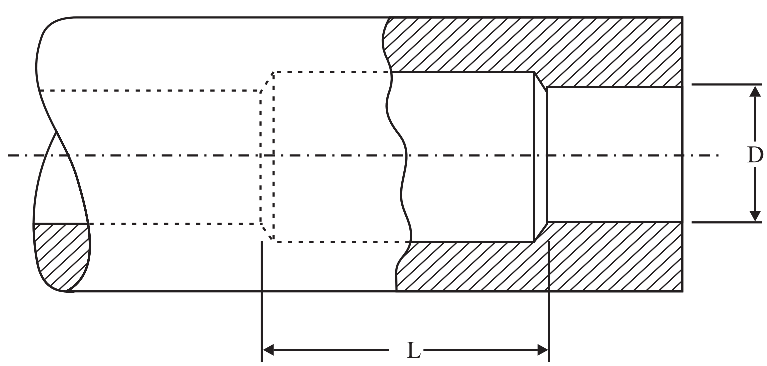


Fig. 5.14. Internal relief.

Undercutting : In undercutting, also called internal relief, a previously bored hole is made larger along the same axis and is within the longitudinal limits of the main bore. Internal relieving time is calculated by the same formula as for turning, *i.e.*,

$$\text{Time required} = \frac{\text{Length of cut}}{\text{Feed pre rev.} \times \text{r.p.m.}} \times \text{No. of cuts}$$

Chamfering : Chamfering is the process of removal of material from the edges of external or internal diameters to facilitate the entering of mating parts or to form a seat.

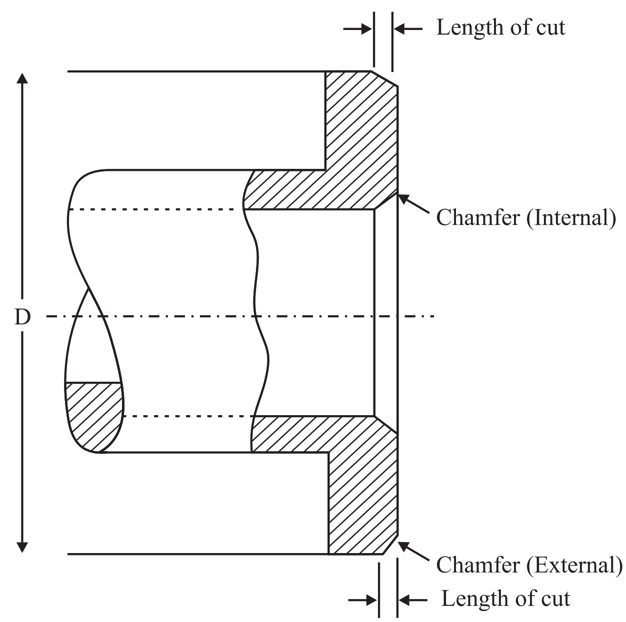


Fig. 5.15. Chamfer (External and Internal)

Formula for calculating the time for chamfering is the same as for turning operation

$$T = \frac{L}{f \times N}$$

Knurling : The purpose of knurling operation is to provide a rough surface on a part so that it will not easily slip when grasped by the fingers or hand. The material on surface is upset (deformed) in such a way that straight lined or diamond shaped patterns are formed on the surface. The formula for calculation of time is the same as for turning.

$$\text{Time,} \quad T = \frac{\text{Length of cut}}{\text{Feed} \times \text{r.p.m.}}$$

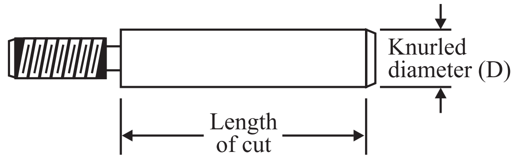


Fig. 5.16. Knurling

Boring : It is the operation of enlarging or finishing an hole which has been previously drilled or bored. The cutting time formula is similar to that used for simple turning.

Drilling : Drilling is the removal of material to produce holes in the material. Sometimes the drilling operation is done on the lathe by holding the drill in tailstock and forcing it into the rotating workpiece. As in case of turning the time taken to drill a hole is affected by material of job, size of drill, material of drill, the feed and depth of the drilled hole. Generally the drilling speeds are lower than the turning speeds for the same type of tool material. The speeds and feeds for drilling in various materials are given in Table 5.5.

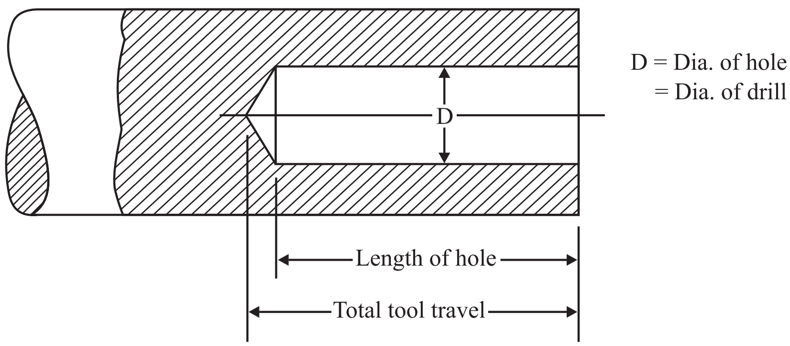


Fig. 5.17. Drilling operation

If length of cut = L

f = feed/revolution

N = r.p.m.

$$\text{Time T} = \frac{L}{f \times N}$$

Threading : Threads can be cut on lathe with the help of a single point cutting tool or on a turret lathe with the help of a die head. The time for cutting threads is calculated as follows :

$$\text{Time T} = \frac{\text{Length of cut}}{\text{Feed per revolution} \times \text{r.p.m.}}$$

where Feed/rev. = lead of thread

Full depth of the thread cannot be obtained in a single cut when cutting threads by single point cutting tool on a lathe. A number of cuts have to be taken to get the full depth.

The number of cuts may be calculated with the help of following relations :

$$\text{Number of cuts} = \frac{25}{\text{Thread per cm}} \text{ for external threads}$$

$$= \frac{32}{\text{Thread per cm}} \text{ for internal threads}$$

If threads are cut with the help of die nuts, then full depth of the threads is obtained in single cut upto 3 mm pitch threads, otherwise two cuts may have to be taken.

$$\therefore \quad \text{Time for threading} = \frac{\text{Length of cut}}{\text{Feed/rev.} \times \text{r.p.m.}} \times \text{No. of cuts}$$

Tapping : Tapping is the operation of cutting internal threads with the help of a tool called tap. The time required is calculated as follows :

$$\therefore \quad \text{Time taken T} = \frac{\text{Length of cut}}{\text{Feed per revolution} \times \text{N}}$$

where $\text{N} = \dfrac{1{,}000\ \text{S}}{\pi \times \text{D}}$

and feed/rev. = pitch of thread

$$\text{Length of cut} = \text{Length to be threaded} + \frac{\text{D}}{2}$$

where D = Major dia of thread.

ESTIMATION OF DRILLING TIME ON DRILLING MACHINE

Drilling is the process of making holes in workpiece by means of a revolving tool called drill. The drilling machine can also be used for some other operations like counter-sinking, counter-boring and threading. The machining time for drilling operation is calculated as follows :

$$\text{Time,} \quad \text{T} = \frac{\text{L}}{f \times \text{N}}$$

L = Length of drill travel
= Length of hole + Allowance
f = Feed per revolution
N = r.p.m. of drill
Allowance = 0.3 d for 118° drill point angle
where d = Dia of drill in mm.
If S = Surface cutting speed of drill in meters/min
N = r.p.m. of the drill
d = dia of the drill

$$\text{S} = \frac{\pi d \text{N}}{1000}$$

or

$$\text{N} = \frac{1000\ \text{S}}{\pi d}$$

Data on drilling speeds and feeds in given in Table 5.5.

ESTIMATION OF TIME FOR SHAPING, PLANING AND SLOTTING

In all the above operations the relative motion between the tool and the work-piece is reciprocating. The cutting action takes place only in the forward stroke and the return stroke is idle. So the return stroke should be completed in minimum time.

$$\text{Effective cutting speed} = \frac{\text{L}}{1{,}000} \times \text{N meters/minute}$$

where L = Length of forward stroke in mm (including clearance on both sides)
N = No. of forward strokes/minute

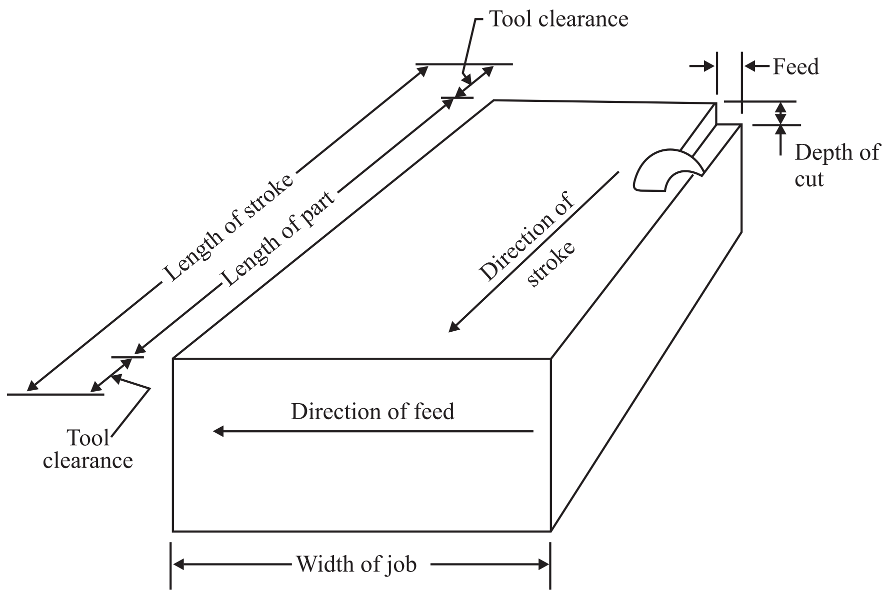


Fig. 5.18. Shaper operation terms.

If
$$K = \frac{\text{Time for return stroke}}{\text{Time forward stroke}}$$

Then cutting speed is given by

$$S = \frac{L\,(1 + K)}{1{,}000} \times N \text{ m/min}$$

$$\text{Now time taken by cutting stroke} = \frac{L}{S \times 1{,}000}$$

$$\text{Now time taken by return stroke} = \frac{L}{S \times 1{,}000} \times K$$

The total time for one cut (one cutting stroke and one return stroke)

$$T = \frac{L}{S \times 1{,}000} + \frac{LK}{S \times 1{,}000} = \frac{L\,(1 + K)}{1{,}000 \times S}$$

Now if W = Width of job in mm

f = feed per stroke

$$\text{Then number of strokes required to complete one pass on full width} = \frac{W}{f}$$

$$\text{Total time for completing one cut} = \frac{L\,(1 + K)}{1{,}000\ S} \times \frac{W}{f}$$

Table 5.6. Cutting Speed and Feeds for Shaping, Planing and Slotting

Work material	*Type of tool*					
	HSS		*Cast alloys*		*Carbides*	
	S mpm	***f* mm/rev.**	**S mpm**	***f* mm/rev.**	**S mpm**	***f* mm/rev.**
Steel (hard)	6 – 10.5	0.75 – 1.25	—	—	30 – 54	0.9
Steel (medium)	18 – 21	0.75	—	—	54 – 75	1.25
Steel (soft)	21 – 30	0.75 – 3.0	—	—	54 – 90	1.25
Cast steel	7.5 – 18	1.25	18 – 24	1.0	30 – 54	1.00
C.I. (hard)	9 – 15	1.50	15 – 24	1.25	30 – 60	1.25
C.I. (soft)	15 – 24	3.0	27 – 36	1.25	33 – 67.5	1.25
Malleable iron	15 – 27	2.25	14 – 36	1.25	45 – 75	1.0
Brass	45 – 75	1.25 – 1.50	—	—	—	—
Bronze	9 – 18	2.0	—	—	45 – 90	1.25
Aluminium	60 – 90	0.75 – 1.25	—	—	—	—

If it is not possible to cut the material in one pass, more than one pass may be required

If $\qquad P = \text{No. of passes required}$

$$\text{Time,} \quad T = \frac{L\,(1 + K)}{1{,}000\ S} \times \frac{W \times P}{f}$$

The cutting speeds and feeds for shaping, planing and slotting are given in Table 5.6.

ESTIMATION OF MILLING TIME

Milling machine is a very versatile machine. The milling machine employs a multipoint tool, called milling cutter, for machining. The various operations done on a milling machine include facing, forming or profile machining, slotting, key way cutting, etc.

In milling machine, the formula to calculate machining time is :

$$\text{Time} = \frac{\text{Length of cut}}{(\text{Feed per rev.}) \times (\text{r.p.m.})}$$

where $\quad \text{r.p.m. (N)} = \dfrac{1000 \times S}{\pi \times D}$ (D is cutter dia)

In case of milling cutters :

$$\text{Feed per revolution} = \text{Feed per tooth} \times \text{number of teeth on cutter}$$

Average cutting speeds and feeds per tooth for various materials are given in Table 5.7.

$$\text{Time taken per cut} = \frac{\text{Length of cut (Total table travel)}}{\text{Feed per rev.} \times \text{r.p.m. of cutter}}$$

$$\text{Total table travel} = \text{Length of job + added table travel}$$

$$\text{The added table travel} = \text{Cutter approach + over travel}$$

Table 5.7 (*a*) Cutting Speeds (For Carbide Cutter for a Feed Rate of 0.2 mm per Tooth)

	S in meters per minute							
	Brazed cutters				*Indexable inserts*			
	I.S.O. Carbide grade				*I.S.O. Carbide grade*			
Work material	***P.10***	***P.30***	***P.40***	***K.20***	***P.10***	***P.30***	***P.40***	***K.20***
Aluminium	150	130	100	—	200	170	130	—
C-Steel, 0.7% C	120	90	75	—	150	90	75	—
Steel Castings	60	45	50	—	80	75	50	—
Stainless steel	100	100	100	—	125	125	115	—
Grey C.I.	150	130	110	—	150	130	110	—
Aluminium Alloy	—	—	—	600	—	—	—	600

Table 5.7 (*b*) Feed per Tooth (HSS Cutter)

Type of cutter	***Slab Mill (Helix angle up to 30°)***	***Slab Mill (Helix angle 30° to 60°)***	***Face Mill***	***End Mill***	***Slot Mill***	***Form relieved cutter***
Feed per tooth (mm)	0.10 to 0.25	0.07 to 0.20	0.12 – 0.50	0.02 – 0.25	0.07 – 0.12	0.07 – 0.20

Table 5.7 (*c*) Cutting Speed (HSS Cutter)

Material being cut	***Brass***	***C.I.***	***Bronze***	***Mild Steel***	***Hard C Steel***	***Hard alloy Steel***	***Alluminium***
S, mpm	45 – 60	21 – 30	24 – 45	21 – 30	15 – 18	9 – 18	15 – 30

$$\text{Time taken/cut} = \frac{\text{Length of job + added table travel}}{\text{Feed per rev.} \times \text{r.p.m.}}$$

The added table travel will depend upon the type of milling operation.

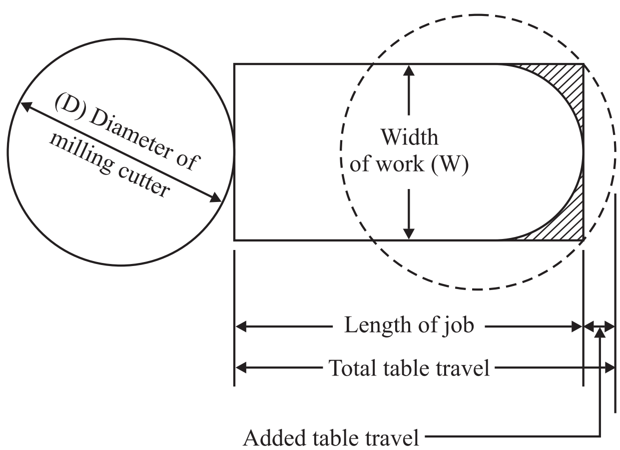


Fig. 5.19. Face milling

(*i*) For face milling : In a face milling operation, refer Fig. 5.19, when the milling cutter has traversed the length of face, some portion of the face is yet to be milled as shown by shaded area.

In order to complete milling an additional distance must be travelled by the table, which is given by :

$$\text{Added table travel} = \frac{1}{2}\left(D - \sqrt{D^2 - W^2}\right)$$

where D = cutter dia

W = Width of work piece

If D = W, then approach = $\frac{D}{2}$

If D > W, then approach = $\frac{D}{2}$

but we will have to take more than one transverse cut to complete one cut on the face width.

(*ii*) For slab or spot milling :

$$\text{Added table travel} = \sqrt{Dd - d^2}$$

where D = Dia of cutter

d = Depth of cut.

This formula is valid when depth of cut is less than radius of cutter *i.e.*, $d < \frac{D}{2}$. If $d = \frac{D}{2}$ the added table travel is equal to radius of cutter.

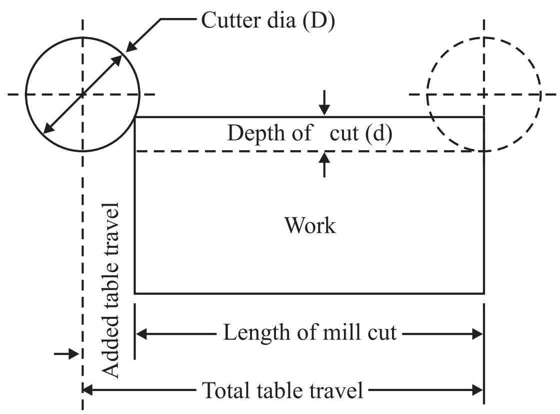


Fig. 5.20. Slab milling.

ESTIMATION OF TIME FOR GRINDING

Grinding is the process of machining in which material is removed by means of multipoint cutting tool called grinding wheel. Mostly grinding is a finishing operation and the volume of material removed is very small.

The time for grinding operation can be calculated as below :

$$\text{Time} = \frac{\text{Length of cut}}{\text{Feed per revolution} \times \text{r.p.m.}}$$

(*i*) In case of surface grinding the workpiece reciprocates under the rotating wheel. The time required is calculated as follows :

$$\text{Time} = \frac{L \times b}{S \times 1000\, f} \times \text{No. of passes}$$

where l = length of work piece to be ground, mm.

b = width of work piece, mm.

S = velocity of table in meters/min.

f = Feed mm/stroke.

L = length of workpiece + allowances

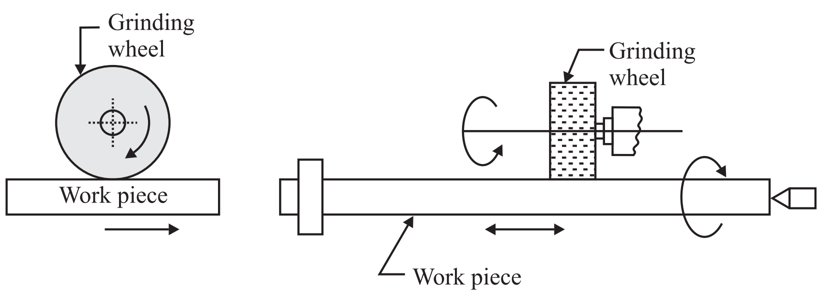


Fig. 5.21

(*ii*) In case of cylindrical grinding the revolving grinding wheel moves along the axis of the work and removes the metal to the required depth of cut.

If S = Surface speed of work in meters/min.

D = dia of work piece in mm.

N = r.p.m. of work piece.

$$N = \frac{1{,}000\, S}{\pi D}$$

$$\text{Length of cut} = L - W + 5 \text{ mm.}$$

where L = length of work piece to be machined.

W = width of grinding wheel.

5 mm = approach length.

The longitudinal feed of the grinding wheel is taken as :

$\frac{W}{2}$ = for rough grinding (per revolution)

$\frac{W}{4}$ = for finish grinding (per revolution)

$$\text{Time} = \frac{L - W + 5}{\left(\frac{W}{2} \text{ or } \frac{W}{4}\right) \times N}$$

The grinding process requires more than one pass for finishing a component.

If d = depth of stock to be removed

t = depth/cut

$$\text{No. of passes} = \frac{d}{t}$$

$$\text{Total time required} = \frac{L - W + 5}{\left(\frac{W}{2} \text{ or } \frac{W}{4}\right) \times N} \times \frac{d}{t}$$

$$= \frac{\text{Length of cut}}{\text{Feed per rev.} \times (\text{r.p.m. of workpiece})} \times \text{No. of passes}$$

ILLUSTRATIVE EXAMPLES

Example 1 : Calculate the machining time to turn the dimensions shown in Fig. 5.22. Starting from a m.s. bar of f 80 mm. The cutting speed with HSS tool is 60 meters per minute and feed is 0.70 mm/rev., depth of cut is 2.5 mm per pass.

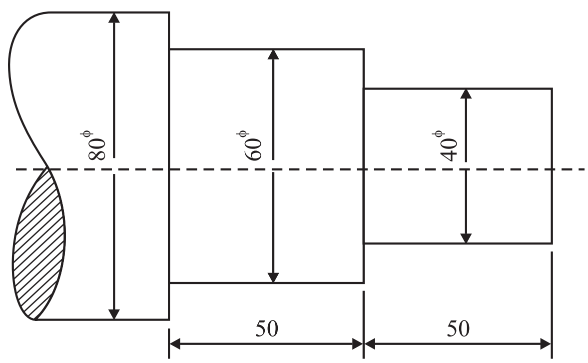


Fig. 5.22

Solution :

$$S = 60 \text{ m/min}$$

$$f = 0.70 \text{ mm/rev.}$$

The turning will be done in 2 steps. In first step a length of (50 + 50) = 100 mm will be reduced from 80 f to 60 f and in second step a length of 50 mm will be reduced from 60 f to 40 f.

***Step I* :** For turning from 80 f to 60 f and 100 mm long.

$$N = \frac{1{,}000\ S}{\pi D} = \frac{1{,}000 \times 60}{\pi \times 80}$$

$$= 238.8 \simeq 240 \text{ r.p.m.}$$

$$\text{No. of passes} = \frac{\text{Depth of material to be removed}}{\text{Depth of cut}}$$

$$= \frac{(80 - 60)}{2 \times 2.5} = 4$$

$$\text{Time required : } \frac{100}{0.7 \times 240} \times 4 = 2.38 \text{ min.}$$

Step II : To turn f 40 from f 60 and 50 mm long.

$$N = \frac{1{,}000\ S}{\pi D} = \frac{1{,}000 \times 60}{\pi \times 60}$$

$$= 318 \text{ r.p.m.}$$

$$\text{No. of passes} = \frac{(60 - 40)}{2 \times 2.5} = 4$$

$$\text{Time} = \frac{50}{0.7 \times 318} \times 4 = 0.9 \text{ min.}$$

$$\text{Total time} = 2.38 + 0.90 = 3.28 \text{ min.}$$

Example 2 : A mild steel bar 100 mm long and 38 mm in diameter is turned to 35 mm dia. and was again turned to a diameter of 32 mm over a length of 40 mm as shown in the Fig. 5.23. The bar was machined at both the ends to give a chamfer of 45° × 5 mm after facing. Calculate the machining time. Assume cutting speed of 60 m/min and feed 0.4 mm/rev. The depth of cut is not to exceed 3 mm in any operation.

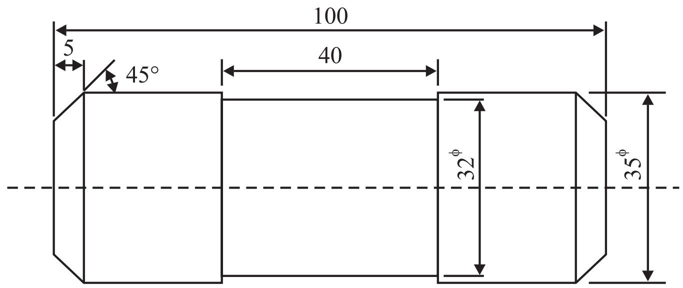


Fig. 5.23

Solution : ***Ist operation*** **:** Turning from f 38 mm to f 35 mm

$$S = 60 \text{ meters/min.}$$

$$D = 38 \text{ mm}$$

$$N = \frac{1{,}000\ S}{\pi D} = \frac{1{,}000 \times 60}{\pi \times 38}$$

$$= 503 \text{ r.p.m.}$$

$$\text{Time taken} = \frac{\text{Length of cut}}{\text{r.p.m.} \times \text{Feed/rev.}}$$

$$= \frac{100}{503 \times 0.4} = 0.5 \text{ min.}$$

2nd operation **:** External relief

$$L = 40 \text{ mm.}$$

$$D = 35 \text{ mm.}$$

$$S = 60 \text{ m/min.}$$

$$N = \frac{60 \times 1{,}000}{\pi \times 35} = 545 \text{ r.p.m.}$$

$$\text{Time taken for second operation} = \frac{\text{Length}}{\text{r.p.m.} \times \text{Feed/rev.}}$$

$$= \frac{40}{545 \times 0.4} = 0.18 \text{ min.}$$

***3rd operation* :** Facing of both ends

$$L = \text{Length of cut}$$

$$= \frac{35}{2} = 17.5 \text{ mm}$$

$$D = 35 \text{ mm}$$

$$S = 60 \text{ m/min}$$

$$N = \frac{60 \times 1{,}000}{\pi \times 35} = 545 \text{ r.p.m.}$$

$$\text{Time for facing one end} = \frac{17.5}{0.4 \times 545} = 0.08 \text{ min}$$

$$\text{Time for facing both ends} = 2 \times 0.08 = 0.16 \text{ min}$$

***4th operation* :** Chamfering 45° × 5 mm

$$\text{Length of cut} = 5 \text{ mm}$$

$$N = 545 \text{ r.p.m.}$$

$$\text{Time taken for chamfering on one side} = \frac{5}{545 \times 0.4} = 0.02 \text{ min}$$

$$\text{Time taken for chamfering on both sides} = 0.02 \times 2 = 0.04 \text{ min}$$

$$\text{Total machining time} = 0.50 + 0.18 + 0.16 + 0.04$$

$$= 0.88 \text{ min}$$

Example 3 : A mild steel shaft, shown in Fig. 5.24 is to be turned from a 24 mm dia bar.

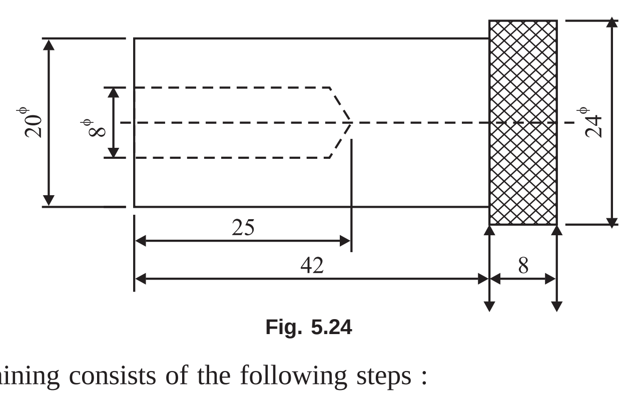


Fig. 5.24

The complete machining consists of the following steps :

(*i*) Facing 24 mm f on both sides

(*ii*) Turning to f 20 mm.

(*iii*) Drilling ϕ 8 mm hole

(*iv*) Knurling.

With H.S.S tool the cutting speed is 60 m/min. The feed for longitudinal machining is 0.3 mm/rev. The feed for facing, 0.2 mm/rev., feed for knurling 0.3 mm/rev., and feed for drilling is 0.08 mm/rev. Depth of cut should not exceed 2.5 mm in any operation. Find the machining time to finish the job.

Solution : *Step I* : Facing 24 ϕ bar on both ends

$$\text{Cutting speed} = 60 \text{ m/min}$$

$$\text{Diameter} = 24 \text{ mm}$$

$$\text{Length of cut (for facing)} = \frac{24}{2} = 12 \text{ mm}$$

$$f = 0.2 \text{ mm/rev.}$$

$$N = \frac{60 \times 1{,}000}{24 \times \pi} = 796 \text{ r.p.m.}$$

$$\text{Time taken to face on one side} = \frac{L}{f \times N} = \frac{12}{0.2 \times 796}$$

$$= 0.07 \text{ min.}$$

$$\text{Time to face on both ends} = 2 \times 0.07 = 0.14 \text{ min.}$$

***Step 2* :** Turn ϕ 20 mm from ϕ 24 mm

$$\text{Length of cut} = 42 \text{ mm}$$

$$f = 0.3 \text{ mm/rev.}$$

$$N = \frac{60 \times 1{,}000}{\pi \times 24} = 796 \text{ r.p.m .}$$

$$\text{Time taken} = \frac{42}{0.3 \times 796} = 0.17 \text{ min.}$$

***Step 3* :** Drilling 8 mm dia hole

$$D = 8 \text{ mm}$$

$$L = 25 \text{ mm}$$

$$f = 0.08 \text{ mm/rev.}$$

$$N = \frac{60 \times 1{,}000}{8 \times \pi} = 2{,}388 \text{ r.p.m.}$$

$$\text{Time taken} = \frac{25}{0.08 \times 2{,}388} = 0.13 \text{ min.}$$

***Step 4* :** Knurling

$$D = 24 \text{ mm}$$

$$L = 8 \text{ mm}$$

$$f = 0.3 \text{ mm/rev.}$$

$$N = \frac{60 \times 1000}{\pi \times 24} = 796 \text{ r.p.m.}$$

$$\text{Time taken} = \frac{8}{0.3 \times 796} = 0.03 \text{ min.}$$

$$\text{Total machining time} = 0.14 + 0.17 + 0.13 + 0.03$$

$$= 0.47 \text{ min.}$$

Example 4 : Calculate the machining time required to produce one piece of the component shown in Fig. 5.25 starting from f 25 mm bar. The following data is available.

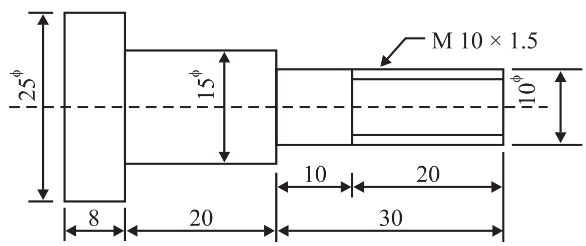


Fig. 5.25

For turning :

Cutting speed = 40 m/min.

Feed = 0.4 mm/rev.

Depth of cut = 2.5 mm/per pass

For thread cutting :

Cutting speed = 8 m/min.

Solution : ***Step I*** **:** Time for turning to 15 mm dia from 25 mm dia.

As depth of material to be removed is

$$\frac{(25 - 15)}{2} = 5 \text{ mm.}$$

it will be accomplished in 2 cuts.

$$\text{Average Dia} = D_{av} = \frac{25 + 15}{2} = 20 \text{ mm.}$$

$$\text{Spindle r.p.m.} = \frac{40 \times 1,000}{20 \times \pi} = 637 \text{ rev/min.}$$

$$\text{Time taken} = \frac{50}{637 \times 0.4} = 0.2 \text{ min.}$$

$$\text{For 2 cuts time taken} = 0.4 \text{ min.}$$

Step 2 **:** Turning from 15 mm to 10 mm dia over a length of 30 mm in one pass

$$N = \frac{40 \times 1,000}{\pi \times 15} = 850 \text{ rev/min.}$$

$$\text{Time taken} = \frac{30}{0.4 \times 850} = 0.09 \text{ min.}$$

***Step 3* :** Threading

$$N = \frac{8 \times 1{,}000}{\pi \times 10} = 255 \text{ r.p.m.}$$

$$\text{Feed} = \text{pitch} = 1.5 \text{ mm}$$

$$\text{Threads per cm} = \frac{10}{1.5} = \frac{100}{15}$$

$$\text{No. of cuts} = \frac{25}{\text{Threads per cm}}$$

$$= \frac{25 \times 15}{100} = 3.75 = 4 \text{ cuts}$$

$$\text{Time for one cut} = \frac{\text{Length of cut}}{\text{Feed/rev.} \times \text{r.p.m.}}$$

$$= \frac{20}{1.5 \times 255} = 0.05 \text{ min.}$$

$$\text{Time for 4 cuts} = 0.05 \times 4 = 0.2 \text{ min.}$$

$$\text{Total time for producing one component} = 0.4 + 0.09 + 0.2$$

$$= 0.69 \text{ min.}$$

Example 5 : Estimate the time taken to drill a 25 mm dia × 10 cm deep hole in a casting. First a 10 mm dia drill is used and then the hole is enlarged by a 25 mm dia drill. Assume :

Cutting speed	= 15 m/min.
Feed for f 10 mm drill	= 0.22 mm/rev.
Feed for f 25 mm drill	= 0.35 mm/rev.

Solution :

(*i*) To calculate the time to drill f 10 mm hole — 10 cm deep

$$S = 15 \text{ m/min.}$$

$$f = 0.22 \text{ mm/rev.}$$

$$\text{Dia of drill } D = 10 \text{ mm}$$

$$\text{Length of cut} = 10 \text{ cm} = 100 \text{ mm}$$

$$\text{r.p.m. of drill } N = \frac{15 \times 1{,}000}{\pi \times 10} = 478$$

$$\text{Time taken} = \frac{\text{Length of hole}}{\text{Feed/rev.} \times \text{r.p.m.}}$$

$$= \frac{100}{0.22 \times 478} = 0.95 \text{ min.}$$

(*ii*) To calculate time for enlarging 10 mm dia hole to 25 mm dia hole

$$\text{Dia of drill} = 25 \text{ mm}$$

$$f = 0.35 \text{ mm/rev.}$$

$$N = \frac{15 \times 1{,}000}{\pi \times 25} = 190 \text{ r.p.m.}$$

$$\text{Time taken} = \frac{100}{0.35 \times 190} = 1.5 \text{ min.}$$

$$\text{Total time to drill the hole} = 0.95 + 1.5 = 2.45 \text{ min.}$$

Example 6 : Calculate the machining time to drill four 8 mm dia holes and one 40 mm dia central hole in the flange shown in Fig. 5.26.

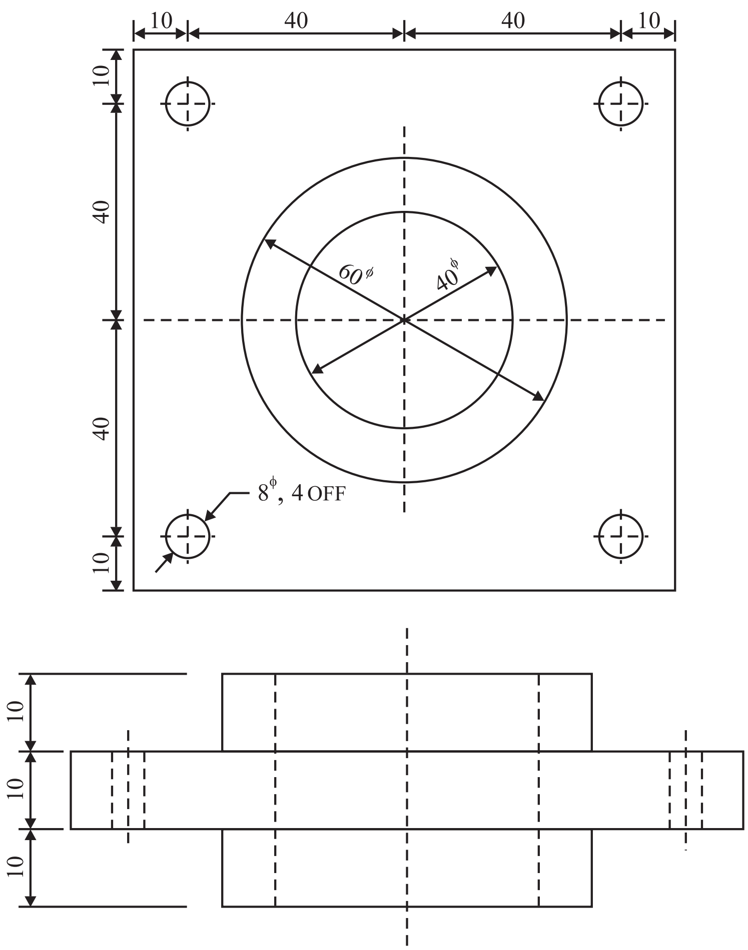


Fig. 5.26

20 mm dia hole is drilled first and then enlarged to 40 mm f hole. Take cutting speed 10 m/min, feed for 8 mm drill 0.1 mm/rev, for 20 mm drill feed is 0.2 mm/rev. and for 40 mm f drill feed is 0.4 mm/rev.

Solution :

(*i*) Time to drill four 8 mm dia holes

$$S = 10 \text{ m/min.}$$

$$\text{Dia of drill } D = 8 \text{ mm.}$$

$$L = 10 \text{ mm}$$
$$f = 0.1 \text{ mm/rev.}$$
$$N = \frac{S \times 1,000}{\pi D} = \frac{10 \times 1,000}{\pi 8}$$
$$= 398 \text{ r.p.m.}$$
$$\text{Time taken to drill one hole} = \frac{L}{f \times N} = \frac{10}{0.1 \times 398}$$
$$= 0.25 \text{ min.}$$
$$\text{Time to drill 4 holes} = 0.25 \times 4 = 1 \text{ minute.}$$

(*ii*) Time to drill one hole of 40 mm diameter :

This hole is made in two steps :

(*a*) Drill 20 mm φ hole — 30 mm long

$$N = \frac{10 \times 1,000}{\pi \times 20} = 159 \text{ r.p.m.}$$
$$\text{Time taken} = \frac{30}{0.2 \times 159} = 0.95 \text{ min.}$$

(*ii*) Enlarge 20 mm φ hole with 40 mm φ drill

Here
$$N = \frac{10 \times 1,000}{\pi \times 40} = 80 \text{ r.p.m.}$$
$$f = 0.4 \text{ mm/rev.}$$
$$\text{Time taken} = \frac{30}{0.4 \times 80} = 0.94 \text{ min.}$$
$$\text{Total time taken to drill all the holes} = 1.0 + 0.95 + 0.94 = 2.9 \text{ min.}$$

Example 7 : Calculate the time required to tap a hole with 25 mm dia tap to a length of 30 mm having 3 threads per cm. The cutting speed is 10 m/min. For return stroke the speed is 2 times the cutting speed.

Solution :

$$L = 30 \text{ mm}$$
$$D = 25 \text{ mm}$$
$$S = 10 \text{ m/min}$$
$$\text{No. of threads per cm} = 3$$
$$\text{Pitch of thread} = \text{Feed/rev.}$$
$$= \frac{1}{3} \text{ cm} = \frac{10}{3} \text{ mm}$$
$$N = \frac{10 \times 1,000}{\pi \times 25} = 127 \text{ r.p.m.}$$
$$\text{Time taken for tapping} = \frac{L + \frac{D}{2}}{N \times \text{Feed/rev.}}$$

$$= \frac{30 + 12.5}{127 \times \frac{10}{3}} = \frac{42.5 \times 3}{127 \times 10}$$

$$= 0.1 \text{ min.}$$

$$\text{Return time} = \frac{1}{2} \times 0.1 = 0.05 \text{ min.}$$

$$\text{Time for one pass} = 0.1 + 0.05 = 0.15 \text{ min.}$$

$$\text{Total time for tapping (3 passes)} = 0.15 \times 3 = 0.45 \text{ min.}$$

Example 8 : A 300 mm × 50 mm rectangular cast iron piece is to be face milled with a carbide cutter. The cutting speed and feed are 50 m/min and 50 mm/min. If the cutter dia is 80 mm and it has 12 cutting teeth, determine :

(*i*) Cutter r.p.m.

(*ii*) Feed per tooth

(*iii*) Milling time

Solution :

Dimensions of slab = 300 mm × 50 mm.

Cutting speed S = 50 meters/min.

Feed F = 50 mm/min.

No. of teeth on cutter = 12

Cutter dia = 80 mm

(*i*)
$$\text{Cutter r.p.m.} = \frac{\text{Cutting speed}}{\pi \times \text{Dia of cutter}}$$

$$= \frac{50 \times 1000}{\pi \times 80} = 200 \text{ r.p.m.}$$

(*ii*)
$$\text{Feed per tooth} = \frac{\text{Feed per min}}{\text{r.p.m.} \times \text{No. of teeth}}$$

$$= \frac{50}{200 \times 12} = 0.02 \text{ mm/tooth}$$

(*iii*) For face milling – since dia of cutter (D) is greater than width of work piece (W)

$$\text{Over travel} = \frac{1}{2}\left(D - \sqrt{D^2 - W^2}\right)$$

$$= \frac{1}{2}\left(80 - \sqrt{80^2 - 50^2}\right) = 8.8 \text{ mm}$$

$$\text{Total cutter travel} = 300 + 8.8 = 309 \text{ mm (approx.)}$$

$$\text{Time taken for milling} = \frac{\text{Total cutter travel}}{\text{Feed per min.}}$$

$$= \frac{309}{50} = 6.18 \text{ min.}$$

Example 9 : A T-slot is to be cut in a C.I. slab as shown in Fig. 5.27. Estimate the machining time. Take cutting speed 25 m/min, feed is 0.25 mm/rev. Dia of cutter for channel milling is 80 mm.

Solution : The T-slot will be cut in two steps :

***Step I* :** Cut a 20 mm wide and 35 mm deep channel along the length

$$\text{Dia of cutter} = 80 \text{ mm}$$

$$\text{Cutting speed} = 25 \text{ m/min}$$

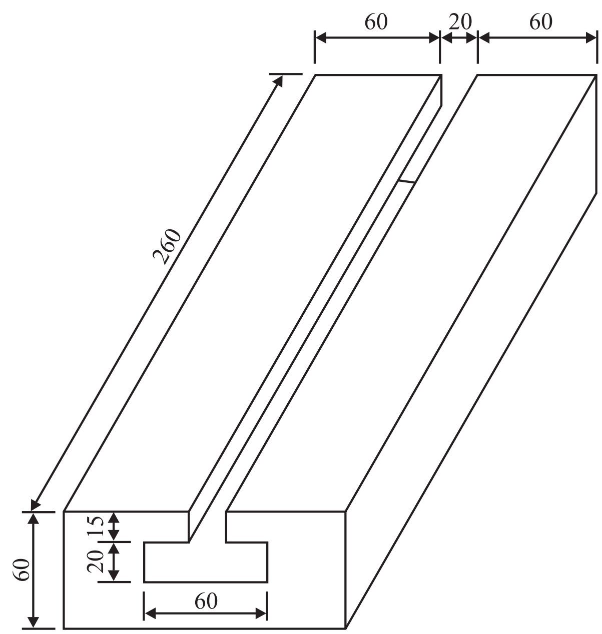


Fig. 5.27

$$\text{Length of job} = 260 \text{ mm}$$

$$\text{r.p.m. of cutter} = \frac{25 \times 1000}{\pi \times 80} = 100$$

$$\text{Over travel} = \sqrt{\text{D}d - d^2}$$

$$= \sqrt{80 \times 35 - 35^2} = 40 \text{ mm}$$

$$\text{Total tool travel} = 260 + 40 = 300 \text{ mm}$$

$$\text{Time for cutting slot} = \frac{\text{Length of cut}}{\text{Feed/min.}}$$

$$= \frac{300}{0.25 \times 100} = 12 \text{ min.}$$

***Step II* :** Cut T-slot of dimensions 60 × 20 with a T-slot cutter

Here $\text{dia of cutter} = 60 \text{ mm}$

$$\text{r.p.m. of cutter} = \frac{25 \times 1{,}000}{\pi \times 60} = 133$$

$$\text{In this case the over travel of tool} = \frac{1}{2} \text{ Dia of cutter,}$$

since dia of cutter = width of slot

$$\text{Over travel} = \frac{60}{2} = 30 \text{ mm}$$

$$\text{Total tool/Table travel} = 260 + 30 = 290 \text{ mm}$$

$$\text{Time taken} = \frac{290}{0.25 \times 133} = 8.7 \text{ min}$$

$$\text{Total time to cut T-slot} = 12 + 8.7$$

$$= 20.7 \text{ minutes.}$$

Example 10 : Find the time required on a shaper to machine a plate 600 mm × 1,200 mm, if the cutting speed is 15 meters/min. The ratio of return stroke time to cutting time is 2 : 3. The clearance at each end is 25 mm along the length and 15 mm on width. Two cuts are required, one roughing cut with cross feed of 2 mm per stroke and one finishing cut with feed of 1 mm per stroke.

Solution :

$$S = 15 \text{ m/minute}$$

$$\text{Length of stroke} = L = \text{Length of plate + clearance on both sides}$$

$$= 1200 + 2 \times 25 = 1{,}250 \text{ mm.}$$

$$\text{Cross travel of table} = W = \text{Width of job + clearance}$$

$$= 600 + 2 \times 15 = 630 \text{ mm.}$$

$$K = \frac{2}{3} = 0.67$$

$$\text{Cross feed for rough cut} = 2 \text{ mm/stroke}$$

$$\text{Cross feed for finish cut} = 1 \text{ mm/stroke}$$

$$\text{Time for one complete stroke} = \frac{L(1 + K)}{1000 \times S}$$

$$= \frac{1{,}250\,(1 + 0.67)}{1{,}000 \times 15}$$

$$= 0.14 \text{ min}$$

$$\text{No. of strokes for roughing cut} = \frac{\text{Cross travel of table}}{\text{Feed/stroke (Roughing)}}$$

$$= \frac{630}{2} = 315$$

$$\text{No. of strokes for finishing cut} = \frac{\text{Cutting travel of table}}{\text{Feed/stroke (Finishing)}}$$

$$= \frac{630}{1} = 630$$

$$\text{Total no. complete strokes required} = 630 + 315 = 945$$

$$\text{Total machining time} = 945 \times 0.14 = 132 \text{ min.}$$

Example 11 : Mild steel shaft 30 cm long is to be rough ground from 43.3 mm dia to 43 mm dia using a grinding wheel of 40 mm face width. Calculate the time required to grind the job assuming work speed of 12 m/min and depth of cut 0.02 mm per pass.

Solution :

$$L = 300 \text{ mm}$$

$$W = 40 \text{ mm}$$

$$D = 43.3 \text{ mm}$$

$$\text{Work surface speed} = S = 12 \text{ m/min.}$$

$$N = \frac{12 \times 1000}{\pi \times 43.3} = 89 \text{ r.p.m.}$$

$$\text{Depth of material to be removed } d = 43.3 - 43.0 = 0.3 \text{ mm.}$$

$$\text{Depth of cut } `t\text{'} = 0.02 \text{ mm per pass}$$

$$\text{No. of passes required} = \frac{0.3}{0.02 \times 2} = 8$$

$$\text{Now longitudinal feed for roughing} = \frac{W}{2}$$

$$= \frac{40}{2} = 20 \text{ mm per rev.}$$

$$\text{Time taken for one cut} = \frac{L - W + 5}{\text{feed/ rev.} \times \text{r.p.m.}}$$

$$= \frac{300 - 40 + 5}{20 \times 89} = 0.15 \text{ min .}$$

$$\text{Time taken for 8 cuts} = 8 \times 0.15$$

$$= 1.20 \text{ minutes.}$$

OVERHEAD EXPENSES : Instructional Objectives

After studying this unit, the student will be able to :

(i) Explain overhead expenses and differentiate between three types of overhead expenses.

(ii) Calculate and apportion the share of overhead expenses for a particular job from the given data.

(iii) Calculate depreciation charges for the equipment using different methods.

OVERHEAD EXPENDITURE

Overhead expenses are those costs which are incurred by the manufacturer but cannot be identified and charged directly to any order or product. Overhead expenses include all expenditure incurred by the manufacturer on the product except the direct material cost, direct labour cost and direct chargeable expenses.

In most of the manufacturing organisations the overhead expenses are more than the direct labour costs. In some cases it may be 100 percent of direct labour cost but in other cases these may range from 300 percent to 400 percent of direct labour cost.

The overhead expenses include :

1. Indirect material expenses.
2. Indirect labour expenses.
3. Other indirect expenses.

1. Indirect Material Expenses

Indirect materials are those materials which are used or consumed in the operations and processes in the factory but cannot be identified as a part of an end product. The expenditure incurred on such materials, which do not form a part of the final product but are used and consumed in the process of conversion of raw material into the finished product, are called indirect material expenses. The indirect material expenses include the cost of oils, grease, lubricants, coolants, emery papers, cotton waste, etc. The indirect materials are weighed, counted or measured and then issued to the shop against requisition slip. The cost of such materials may then be worked out to assess the total cost of indirect materials used in manufacture and allocated to the product/products.

2. Indirect Labour Expenses

Indirect labour is one who is not actually employed in the manufacturing of the product but his services are used in some indirect manner. The indirect labour includes supervisors, inspectors, foremen, storekeeper, gatekeepers, repair and maintenance staff, crane drivers, sweepers, administrative office staff and sales and distribution staff, etc. Salaries and wages paid to indirect labour in the entire year may be calculated from the records and distributed on the product/products.

3. Other Indirect Expenses

All other expenses except direct and indirect materials, direct and indirect labour and direct expenses, incurred on a product are called “other indirect expenses”. The other indirect expenses include depreciation of plant and machinery, water and electricity charges, rent of factory building, licence fee, insurance premia, stationery, legal expenses, audit fee etc. The cost of all the above may be calculated on yearly basis and charged to the product/products.

ALLOCATION OF OVERHEAD EXPENSES OR DISTRIBUTION OF OVERHEAD COSTS

As we know the overhead charges or on-costs cannot be directly charged to a specific job or item produced in the factory. In industries producing single product the total overhead costs may be simply divided by the number of items produced. However, in the industries where two or more items are produced, the distribution of overheads *i.e.*, determination of overhead charge per unit, is a complicated task. There are several methods used for allocation of overheads to different jobs and the choice of method depends on the type of organisation. Following are some important methods of allocation of overhead costs :

1. Allocation by cost proportion.
2. Allocation by hourly rate.
3. Allocation by unit rate.

1. Allocation by Cost Proportion

This method is sub-divided into three categories :

(*a*) **Proportional to prime cost :** In this method the total overhead costs of the industry are expressed as a fraction or percentage of the prime cost. This percentage multiplied by the prime cost of individual item gives the part of total overheads to be allocated to that item of manufacture. The formula for calculating the percentage of overheads is :

$$\text{Percentage of overheads} = \frac{\text{Total overhead cost}}{\text{Total prime cost}} \times 100$$

This method of distribution of overhead costs ignores the difference in labour rates and material and machines employed for the manufacture of different items.

Example 1 : A factory has total overheads of Rs. 12,000 and total prime cost Rs. 25,000 for the year 2003–04. Find out the share of overheads to be allocated to products X and Y by proportional to prime cost method using the following data :

	Product X	***Product Y***
Direct material cost	Rs. 60	Rs. 100
Direct labour cost	Rs. 80	Rs. 40
Direct other expenses	Rs. 30	Rs. 30

Solution :

$$\text{Percentage of overheads} = \frac{\text{Total overhead cost}}{\text{Total prime cost}} \times 100$$

$$= \frac{12{,}000}{25{,}000} \times 100 = 48\%$$

Product X :

$$\text{Prime cost} = 60 + 80 + 30 = \text{Rs. } 170$$

$$\text{Overheads} = \frac{170 \times 48}{100} = \text{Rs. } 81.60 \simeq \text{Rs. } 82$$

Product Y :

$$\text{Prime cost} = 100 + 40 + 30 = \text{Rs. } 170$$

$$\text{Overheads} = \frac{170 \times 48}{100} = \text{Rs. } 81.60 \simeq \text{Rs. } 82$$

(*b*) **Proportional to direct labour cost :** In this method the percentage of overhead costs to be allocated is given by

$$\text{Percentage of overheads} = \frac{\text{Total overhead cost}}{\text{Total direct labour cost}} \times 100$$

This percentage of overheads multiplied by the direct labour cost on the manufacture of the item gives the part of total overhead costs allocated to that item.

This method is used where parctically all the work is done by hand (manually) and the wages paid to direct labour are quite uniform.

Example 2 : Total overheads of a manufacturing concern for the year 2003-04 were Rs. 54,000 and total direct labour wages during that year were Rs. 36,000. Find out the overheads allocation to a product for which direct labour cost is Rs. 72. Use allocation by proportional to direct labour cost method.

Solution :

$$\text{Percentage of overheads} = \frac{\text{Total overhead cost}}{\text{Total direct labour cost}} \times 100$$

$$= \frac{54{,}000}{36{,}000} \times 100 = 150\%$$

If P = The overhead costs to be allocated to the item with direct labour cost of Rs. 72

$$P = \frac{72 \times 150}{100} = \text{Rs. } 108$$

(*c*) **Allocation proportional to direct material cost :** According to this method, the percentage of overhead cost equals the total overhead cost of the factory expressed as a fraction of the total direct material costs.

$$\text{Percentage of overheads} = \frac{\text{Total overhead cost}}{\text{Total direct material cost}} \times 100$$

The percentage of overhead costs multiplied by the direct material cost of the manufacture of the item gives overhead costs to be allocated to that item. This method does not consider the fact that values of materials used in different items of manufacture are different.

Example 3 : Calculate the selling price of a product from the following data :

Direct material cost per component	=	Rs. 16
Direct labour cost per component	=	Rs. 12
Total direct material cost during one year	=	Rs. 48,000
Total overheads of the factory	=	Rs. 12,000
Profit	=	25 percent on total cost

The overheads are to be allocated on the basis of percentage on direct material cost.

Solution :

$$\text{Percentage of overheads} = \frac{\text{Total overhead costs}}{\text{Total direct material cost}} \times 100$$

$$= \frac{12,000}{48,000} \times 100 = 25\%$$

For the component

Direct material cost = Rs. 16

Direct labour cost = Rs. 12

$$\text{Overheads} = \frac{25}{100} \times 16 = \text{Rs. } 4$$

Total cost = 16 + 12 + 4 = Rs. 32

Profit = 0.25 × 32 = Rs. 8

Selling price = 32 + 8 = Rs. 40

2. Allocation by Hourly Rate

This method is again sub-divided into two categories :

(*a*) **By man-hour rate :** The rate of overhead is obtained by dividing the total overhead costs by the total production man-hours worked during that period.

$$\text{Rate of overhead} = \frac{\text{Total overhead costs for entire factory}}{\text{Total production man-hours employed}}$$

This factor multiplied by production man-hours used in manufacture of the item, gives the overhead costs to be allocated to the item under consideration. This method does not take into consideration use of different types of equipment in manufacture of different products.

Example 4 : The total on cost of a factory for a period of 6 months is Rs. 5,400. The factory employs 50 workers and average working days per month is 25 days. 10 percent of total time is allowed for various allowances. Calculate the share of overheads to be allocated to a product requiring $3\frac{1}{2}$ man-hours. Take 8 hours of working per day.

Solution :

Total production man-hours = 25 × 8 × 6 = 1,200 hrs.

Allowances = 0.10 × 1,200 = 120 hrs.

Effective production man-hours = 1,200 – 120 = 1,080 hrs.

$$\text{Rate of overheads} = \frac{5,400}{1,080} = \text{Rs. 5 per man-hour}$$

Overheads to be allocated to the product which consumes $3\frac{1}{2}$ man-hours

$$= 5 \times 3\frac{1}{2} = \text{Rs. } 17.50$$

(*b*) **By machine hour rate :** In this method the overhead costs are allocated on the basis of fraction of the time used on particular machine in the manufacture of an item.

$$\text{Rate of overhead per machine-hour} = \frac{\text{Overhead expenses for specific machine}}{\text{Number of machine-hours}}$$

Rate of overhead multiplied by number of machine-hours used in the manufacture of the item, gives part of total overhead costs to be allocated to that item. This method takes into account variation in type and size of equipment, power required etc., for manufacture of different products.

This method is used where most of the work is done with machines. The on-cost for a machine is calculated by taking into account the depreciation of machine, power consumed by the machine, building expenses on the basis of floor area occupied by the machine and other indirect charges.

Example 5 : If the total on-cost for a milling machine for the year 2003–04 is Rs. 10,000 and machine works for 2,500 hours in year, calculate the on-cost allocated to product using $1\frac{1}{2}$ machine-hours by machine-hour rate method.

Solution :

$$\text{Rate of overheads} = \frac{10,000}{2,500} = \text{Rs. 4 per machine hour}$$

On cost to be allocated to the product = Rate of overheads × m/c hours consumed by the product

$$= 4 \times \frac{3}{2} = \text{Rs. } 6$$

3. Allocation by Unit Rate

In this method of allocation of overhead costs, it is assumed that the overhead expenses are proportional to the total output.

$$\text{Overheads costs/unit produced} = \frac{\text{Total Overhead charges for the entire factory}}{\text{Number of units produced}}$$

This method is applied in concerns where one type or similar products are manufactured. This method gives a standard rate of overheads for all the components produced.

Example 6 : A manufacturing concern produces 600 machines per year. If the total overheads during that year are Rs. 1,80,000, calculate the overhead cost for each machine.

Solution : By unit rate method

$$\text{Overheads/unit} = \frac{\text{Total Overhead charges}}{\text{Number of units produced}}$$

$$= \frac{1,80,000}{600} = \text{Rs. } 300$$

Overhead charges per machine = Rs. 300

TYPES OF OVERHEAD COSTS

Indirect costs are the costs of those factors which can only be indirectly attributed to the manufacture of a specific product. They are sometimes called overheads or oncosts. Overhead charges can be subdivided for convenience under three headings :

1. **Works overheads :** These consist of the cost of the salary of works manager, works superintendents, foreman, inspectors, operators, labourers etc. cost of cutting oil, depreciation of machines, lighting, rent of factory buildings, insurance and electricity bills etc.
2. **Office overheads :** These consist of the salary of office manager, office staff, postage, FAX, telephone, legal expenses, depreciation of office equipment and rent of office building etc.
3. **Sales overheads :** These consist of the cost of salary of all sales staff, advertising, sales commissions etc.

Therefore, it can be seen that indirect costs are the total costs of running the organization less the direct material costs and the direct labour costs. The major difficulty in dealing with indirect costs is to decide accurately how much of the total overheads should be borne by a particular component or batch of components. If this is not done reasonably accurately then the sales price of the product will be unrealistic, since

$$\text{Sales price} = \text{Direct costs} + \text{Overheads} + \text{Profit}$$

Overheads are based on past experience and in many engineering works, it is always expressed as a % of the direct labour cost. Overhead are 300% to 500% of direct labour costs.

Example 1 : A batch of 500 components is produced on a capstan lathe. The piece work rate/piece is Rs. 2.50 and the indirect material cost/piece is Rs. 4.00. Overheads are 450% of direct labour cost. What is the total cost of the batch of component ?

Solution :

$$\text{Direct material cost} = 500 \times \text{Rs. } 4.00 = \text{Rs. } 2{,}000$$

$$\text{Direct labour cost} = 500 \times \text{Rs. } 2.50 = \text{Rs. } 1{,}250$$

$$\text{Overheads} = 450\% \text{ of direct labour cost}$$

$$= \frac{450}{100} \times \text{Rs. } 1{,}250$$

$$= \text{Rs. } 5{,}625$$

(Indirect costs are overhead costs)

$$\text{Total cost of the batch} = \text{Rs. } 2{,}000 + \text{Rs. } 1{,}250 + \text{Rs. } 5{,}625$$

$$= \text{Rs. } 8{,}875$$

As a means to simplify cost estimation, standard ratios have been established between material cost, direct cost (*i.e.* labour, equipment or machine-hour cost, power and the selling price. A typical ratio :

Material cost : Direct cost : Selling price = 1 : 3 : 9

Operational Overhead Ratio :

The ratio between the selling price and the direct cost is sometimes called the operational overhead ratio. This ratio gives an idea of the efficiency and risks involved during the operation. For companies specialized in manufacturing products using advanced technologies, the operational overhead ratios are very high.

EVALUATIVE QUESTIONS ▶ PRODUCTION COST ESTIMATION

1. Explain the following :

(*a*) Distribution of die cost on individual components.

(*b*) Material cost in costing of cast products.

(*c*) Process scarp in a casting process.

2. A foundry unit produces tractor components as cast. Calculate the selling price of a component weighing 50 kgs from the following data :

(*i*) Material of component is cast iron with density 7.2 gms/cc

(*ii*) Cost of molten iron at cupola = Rs. 2.50 per kg

(*iii*) Process scrap = 17 percent of net weight

(*iv*) Scrap return value = Rs. 1.10 per kg

(*v*) Administrative and sales overheads = Rs. 5 per casting

(*vi*) Agents commission = 5 percent of sales price

(*vii*) Profit = 10 percent of total cost

(*viii*) Other expenditure is given in table below :

Operation	*Time per component (minutes)*	*Labour cost component (Rs.)*	*Shop overheads per hour (Rs.)*
Moulding and pattern making	6	0.90	3.00
Core making	8	0.80	4.00
Fettling and cleaning	10	1.00	8.00

3. How will you estimate the material cost involved in the manufacturing a casting ?

4. **(*a*)** What are the various elements considered while calculating the cost of a welded joint ?

(*b*) Explain the terms : direct material cost and direct other expenses in costing of welded joint.

5. Determine the cost of welding of two plates 100 × 100 × 8 mm thick to obtain a plate of dimensions 200 × 100 × 8 mm. The following data is available :

(*i*) Welding is done on both the sides

(*ii*) Electrode diameter = 5 mm

(*iii*) Electrode used per meter of weld = 0.500 kg

(*iv*) Minimum arc voltage = 30 Volts

(*v*) Current used = 225 Amperes

(*vi*) Labour charges = Rs. 10/meter of weld

(*vii*) Electrode price = Rs. 10/kg

(*viii*) Efficiency of welding machine = 50 percent

(*ix*) Welding speed = 2 meters/hour

(*x*) Ratio of operating to connecting time = 1.5

6. Determine the cost of filler material and gases consumed in welding of two plates 8 mm thick and 1.5 m long. Gas cutting is used to make 60°-V on the edges of both the plates. The cost of Oxygen is Rs. 10 per cu meter and cost of acetylene is Rs. 5 per cu meter. The filler rod costs Rs. 6.50/kg. Take other data from the tables. Density of filler metal is 10 gms/cc.

7. A rectangular frame shown in Fig. 5.28 is to be made using plates of 300 cm × 6 cm × 4 mm and 200 cm × 6 cm × 4 mm sizes. Find the cost of filler metal and gases used to make 100 frames. The following data is available for leftward welding :

(*i*)	Dia of filler rod	=	3.00 mm
(*ii*)	Filler rod used per meter of weld	=	2.10 meters
(*iii*)	Density of filler rod material	=	11 gms/cc
(*iv*)	Consumption of Oxygen/hour	=	0.20 cu meter
(*v*)	Consumption of acetylene per hour	=	0.20 cu meter
(*vi*)	Welding speed	=	4.6 metres/hour
(*vii*)	Cost of Oxygen	=	Rs. 80/100 cu meter
(*viii*)	Cost of acetylene	=	Rs. 500/100 cu meter

Welding is to be done on both sides of the frame.

Note : Length to be welded at each corner = $\sqrt{6^2 + 6^2}$ = 8.5 mm

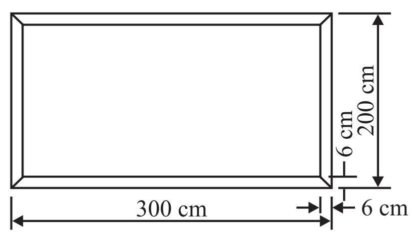


Fig. 5.28. Welded frame

8. (*i*) What are the various losses considered while calculating the material cost for a forged component ?

(*ii*) Discuss the various constituents of cost of a forged component.

9. Calculate the net weight and gross weight for the manufacture of 500 levers shown in Fig. 5.29. The material weighs 7.8 gms/cc and the total losses account for 25 percent of net weight of the lever. Also calculate:

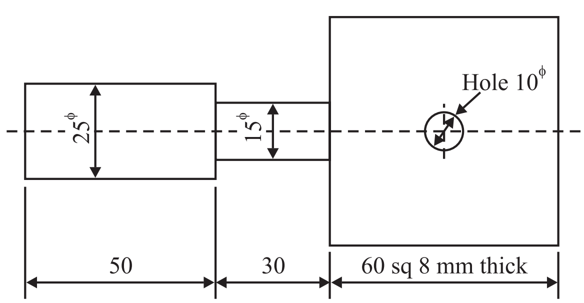


Fig. 5.29. Lever (all dimensions in mm).

(*i*) Length of 3 cm diameter rod required/component.

(*ii*) The cost of forging 500 pieces if the material costs Rs. 80 per kg, labour cost is Rs. 5 per piece and overheads are 25 percent of material cost.

10. Estimate the cost of manufacturing high carbon steel spanner (Fig. 5.30) to be made by die forging. The following data is available :

(*i*)	Batch size	=	500 pieces
(*ii*)	Die cost per batch	=	Rs. 300
(*iii*)	Stock cutting charges	=	Rs. 5 per batch
(*iv*)	Set-up and machine operation cost	=	Rs. 75 per batch
(*v*)	Labour charges	=	Rs. 30 per batch
(*vi*)	Density of steel	=	8.5 gms/cc
(*vii*)	Cost of high carbon steel	=	Rs. 80 per kg

Assume suitable allowances for calculating the weight of the component.

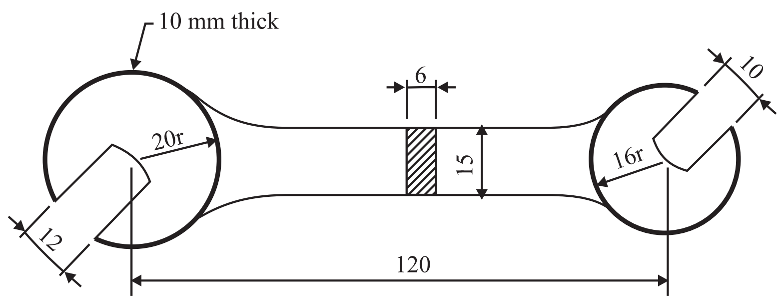


Fig. 5.30. Spanner

11. Explain the following giving examples :

(*a*) Indirect material expenses.

(*b*) Indirect labour expenses.

(*c*) Other indirect expenses.

12. What do you understand by distribution of overhead expenses ? Discuss various methods of allocation of overhead expenses.

13. Explain the following terms w.r.t. machining operations giving examples :

(*a*) Set-up time.

(*b*) Handling time.

(*c*) Unit operation time.

(*d*) Total time.

14. What are the various allowances to be considered while calculating the total time for manufacturing a component ?

15. A m.s. bar of 40 mm diameter is to be turned as shown in the Fig. 5.31.

Estimate the total time to accomplish the task.

Assume Cutting speed = 25 m/min

Feed rate = 0.2 mm/rev.

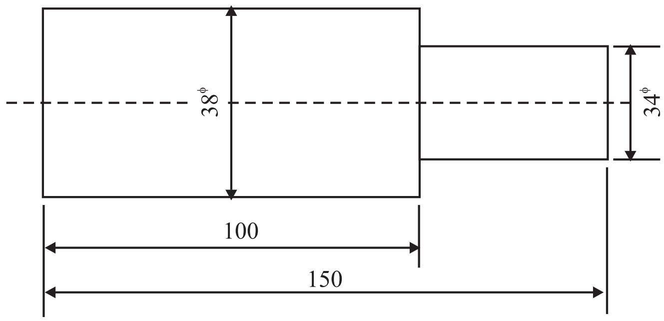


Fig. 5.31

Mounting and setting time = 40 seconds/component

Allowances = 30 percent of unit production time.

16. Calculate the machining time for the manufacture of pins shown in Fig. 5.32. Assume the following data :

Cutting speed for turning = 22 meters/min

Feed rate for turning = 0.8 mm/revolution

Depth of cut not to exceed = 3 mm

Cutting speed for threading = 6 meter/min.

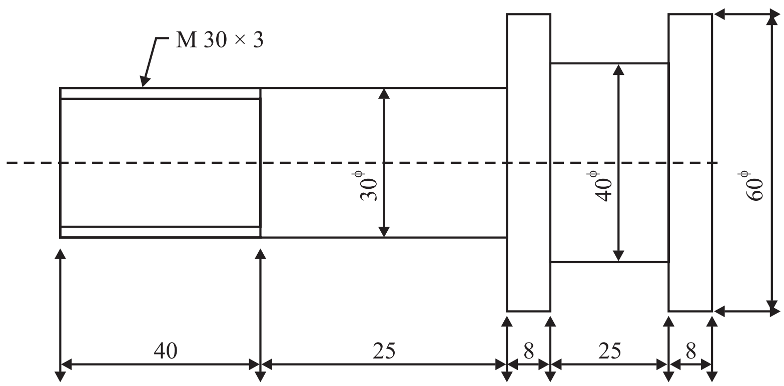


Fig. 5.32

17. 20 mm diameter hole is to be drilled in a metal block with a feed of 0.30 mm per revolution. The thickness of block is 66 mm and cutting speed is 15 m/min. Calculate

(*i*) r.p.m. of spindle, and

(*ii*) machining time.

18. Calculate the time required for drilling a component as shown in Fig. 5.33. Assume the cutting speed as 22 m/min and feed as 0.02 cm/rev for 10 mm f drill and 0.03 cm/rev for 20 mm f drill.

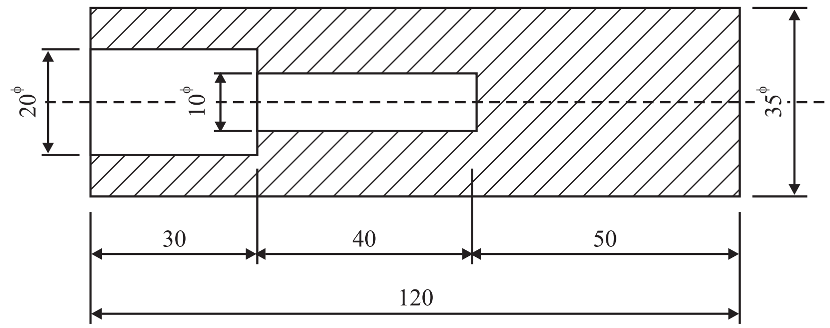


Fig. 5.33

19. Estimate the time required to rough grind a mild steel rod 200 mm long from 28.3 mm dia to 28 mm dia. Width of grinding wheel is 40 mm and job surface speed is 3 meters per minute and depth of cut is 0.1 mm. The longitudinal feed is to be half the wheel width per revolution of work piece.

20. Calculate the machining time to manufacture a component shown in Fig. 5.34 starting from a m.s bar of 42 mm dia. Assume the following data.

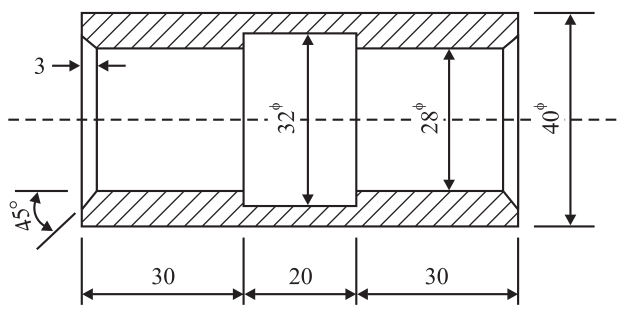


Fig. 5.34

Cutting speed for turning operations	=	18 m/min
Feed rate for turning	=	0.3 mm/rev
Depth of cut not to exceed	=	3 mm per pass
Cutting speed for drilling	=	25 m/min
Feed for 28 mm drill	=	0.2 mm/rev.

21. Calculate the machining time to make a component Fig. 5.35 starting from C.I. blank of 62 mm diameter. The cutting speed for turning is 27 meter/min and for drilling is 36 m/min. The feed for turning is 0.5 mm/revolution and for drilling feed is 0.2 mm/rev. Depth of cut not to exceed 3 mm in any operation.

The various steps involved are :

(*i*) Drill 16 mm dia through hole

(*ii*) Turn to f 60 mm

(*iii*) Turn to f 30 mm over a length of 50 mm

(*iv*) Turn groove

(*v*) Face on both the ends.

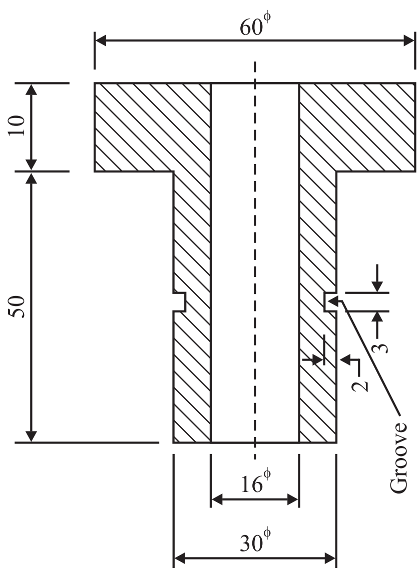


Fig. 5.35

22. Estimate the machining time required for manufacturing a shaft shown in fig. 5.36 from a m.s stock of 26 mm dia.

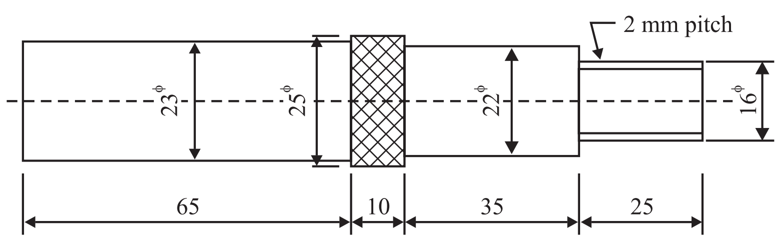


Fig. 5.36

Assume :

(*a*) Feed for turning operations	=	0.2 mm/rev.
(*b*) Cutting speed for turning and knurling operations	=	20 m/min.
(*c*) Cutting speed for threading	=	12 m/min.
(*d*) Depth of cut not to exceed	=	3 mm.
(*e*) No. of cuts for threading	=	5

23. A face milling cutter of 150 mm diameter is used to give a cut on a m.s. block 500 mm × 250 mm. The cutting speed is 16 m/min and feed 0.2 mm/revolution. Calculate the time required to complete one cut.

24. A slot 25 mm deep is to be cut through a work piece 200 mm long with the help of milling cutter with 10 teeth and diameter 150 mm. The cutting speed is 50 m/min, feed is 0.25 mm per tooth. Calculate

(*i*) Table feed in mm/min.

(*ii*) Total cutter travel

(*iii*) Time required to machine the slot.

25. Determine the time required to shape a m.s block 400 mm × 150 mm on a shaper working with cutting speed of 12 meters/minute and cross feed of 0.85 mm/stroke. Ratio of return stroke speed to cutting stroke speed is 3 : 2. Take allowances as 25 mm on length and 5 mm on width.

26. A casting 1200 mm × 600 mm is to be machined on a planer. The cutting speed is 12 meters per min and return speed is 30 m/min. Calculate the planing time if two cuts are required to achieve the final dimensions, one roughing cut with a depth of 3 mm and feed of 0.1 mm/stroke and other finishing cut with a depth of 0.125 mm and feed of 0.25 mm/stroke. Take allowances as 25 mm on each side on length and 10 mm on each side on width.

MODEL QUESTIONS ▶

1. What is Standardisation and Simplification ?
2. State the four main factors that have to be considered in the evaluation of processes and materials.
3. What is routing function ?
4. What is Break-even chart ?
5. Explain the advantages of standardization and simplification in industries.
6. Draw the break-even chart and explain how break-even analysis is helpful in the selection of equipment.
7. What are the various information needed for process planning ?
8. Define simplification and specialization.
9. Define break-even analysis.
10. What are the steps involved in process planning ?
11. Explain Break-even Analysis giving examples.
12. Define Standardization.
13. What is B.E.P. (break-even point) ?
14. What are route sheets ?
15. How do simplification, standardization and specialization help in increasing the efficiency in the utilization of manpower, materials, equipment and capital.
16. A timber products company is currently operating at 70% of its capacity of 40,000 units/ year. At current volume, fixed costs are Rs. 2,20,000, variable costs are Rs. 9 per unit and annual revenue is Rs. 4,50,000.
    (*i*) Determine the current annual profit or loss.
    (*ii*) Find the break-even volume in units.
    (*iii*) What profit or loss would the firm has at 90% capacity.
17. Explain the routing function with the help of a typical route sheet.
18. Prepare a Flow Process Chart for the following activities :

Load bags of cement into truck at rail way yard	= 3 hours
Wait for transport release from the supervisor	= $\frac{1}{2}$ hr.
Transport to covered storehouse by truck	= 1 hr.
Unload at warehouse	= 2 hr.
Inspect for damaged bags	= $\frac{1}{2}$ hr.
Retain in storage until needed in plant 2	= 1 to 10 days
Transfer to plant 2 using fork lift truck	= 1 hr.

19. Give any two examples for continuous production.
20. What are the advantages of process planning ?
21. List the information required for process planning.

22. Explain about standardization, simplification and specialization w.r.t. product development and design.
23. Discuss about the different information generated as a result of process planning.
24. State at least two important disadvantages of continuous production.
25. What are fixed costs ? Give some examples.
26. What are variable costs ? Give some examples.
27. What information do route sheets contain ?
28. What is process planning ? In a manufacturing industry who does this work ?
29. Differentiate between Route sheet and Process sheet.
30. Distinguish between intermittent and continuous types of production. What are their merits and demerits ?
31. An operator at an ABC company is expected to take 2 minutes to load and 1 minute to unload a moulding machine. There are several machines of this type, all doing the same thing, and the automatic run time on each is 4 minutes. Respective costs are Rs. 8 per hour for the operator and Rs. 20 per hour for each machine.
    (*a*) Construct a worker-machine chart for the most efficient one-worker and two machine situation.
    (*b*) What is the cycle time ?
    (*c*) What is the total cost per cycle ?
32. Explain the considerations affecting routing procedure.
33. Give examples for job production and batch production.
34. Define standardization.
35. Discuss the steps in Process Planning.
36. What is break-even analysis ?
37. Explain about process planning and routing. Discuss about the information needed for Process Planning.
38. Define the term simplification.
39. What are the factors affecting Routing Procedure ?
40. Standardization and simplification are complementary functions, each with its own characteristics and scope for product success and profitability. Discuss.
41. Differentiate between process planning and production planning. Explain the procedure of process planning listing the advantages of process planning.
42. Draw the break-even chart and explain how break-even analysis is helpful in the selection of equipment.
43. What is Ergonomics ? Where is it used ?
44. What are the two divisions of work study ?
45. What is meant by "Rating" as applied to work measurement ?
46. How is standard time computed ?
47. What are the various allowances considered in the estimation of standard time ?
48. What are the two important approaches to process planning ?
49. What are the three basic factors that affect the design of a manufacturing process ?
50. What are the different methods of classification of cost ?

OBJECTIVE TYPE QUESTIONS ▶ CHOOSE THE CORRECT ALTERNATIVE

1. It is generally recognized that the "Father of Scientific Management" is :

(*a*) Frank Gilbreth. (*b*) Lilian Gilbreth.
(*c*) F.W. Taylor (Frederick Winslow Taylor) (*d*) Peter F. Drucker.

2. The scientific study of the relationship between man and his working environment is known as :

(*a*) Industrial Psychology. (*b*) Ergonomics.
(*c*) Industrial Engineering. (*d*) Work study.
(*e*) Industrial Management.

3. By which *one* of the following methods, productivity of an enterprise can be increased ?

(*a*) By buying additional equipment.
(*b*) By working for an additional shift.
(*c*) By better utilization of existing plant and equipment.
(*d*) By increasing the sales price of the products.

4. In Outline Process Chart the following symbols are used :

(*a*) O, $\square$, and $\rightarrow$ (*b*) O, $\square$ (*c*) $\square$, ∇, and $\rightarrow$ (*d*) O, $\rightarrow$ and ∇
(*e*) D, O, $\square$, and ∇

5. In the construction of a flow process chart the following symbols are used :

(*a*) O, $\square$, and $\rightarrow$ (*b*) $\rightarrow$, D, and $\square$
(*c*) $\rightarrow$, D, and O (*d*) $\rightarrow$, D, O, ∇, and $\square$
(*e*) X, D, O, $\rightarrow$, and $\square$

6. In the construction of two handed process chart, the following symbols are used :

(*a*) O, $\rightarrow$, D, and $\square$ (*b*) $\rightarrow$, $\square$, and ∇
(*c*) O, $\square$, and $\rightarrow$ (*d*) O, $\rightarrow$, D, and ∇

(O stands for Operation, $\rightarrow$ stands for Transport, D stands for Delay, $\square$ stands for Inspection, and ∇ stands for Storage)

7. In Time and Motion study, the fundamental motions of human body are called :

(*a*) Therbligs. (*b*) M.T.M. units.
(*c*) Sequence of steps. (*d*) Sequence of operations.
(*e*) "B" units.

8. The 'THERBLIGS" have been first introduced by :

(*a*) Franck Gilbreth. (*b*) F.W. Taylor.
(*c*) SIMO. (*d*) L.H.C. Tippet.
(*e*) L.H. Gantt.

9. 'Therbligs' are extensively used in the construction of :

(*a*) Two handed process chart. (*b*) Outline process chart.
(*c*) Fiow process chart. (*d*) SIMO chart.

10. The concept of 'Rating' was first introduced by :

(*a*) F.W. Taylor
(*b*) F.B. Gilbreth and L.M. Gilbreth
(*c*) Charles E. Bedaux
(*d*) L.H.Gantt

11. Methods Time Measurement (M.T.M.) was first developed by :

(*a*) L.H.Gantt (*b*) H.B. Maynard (*c*) L.H.C. Tippet (*d*) Gilbreth

12. Work Sampling (or Activity Sampling) as a technique of work measurement was first introduced by :

(*a*) Gilbreth (*b*) L.H. Gantt (*c*) L.H.C. Tippet (*d*) Anne G. Shaw
(*e*) H.B. Maynard

13. Which *one* of the following is *not* an Incentive Scheme ?

(*a*) Straight Salary
(*b*) Halsey 50 — 50 Plan
(*c*) 100% Bonus Plan
(*d*) Straight Piece Work with Guaranteed Base
(*e*) Rowan Premium Plan

14. Greater flexibility in plant layout is achieved in the case of :

(*a*) Layout by fixed position
(*b*) Process Layout
(*c*) Product Layout
(*d*) Group Layout

15. The important objective of using materials handling equipment in manufacturing concerns is :

(*a*) To increase the cost of the product.
(*b*) To improve the operators' safety.
(*c*) To improve the cleanliness of the workplace.
(*d*) To improve the overall productivity of the concern.

16. Conveyors as materials handling equipment are extensively used in the case of :

(*a*) Process Layout
(*b*) Product Layout
(*c*) Layout by fixed position
(*d*) Group Layout

17. The concept of 'ABC' analysis is applied mostly in :

(*a*) Plant Layout and Materials Handling
(*b*) Ergonomics
(*c*) Methods Time Measurement
(*d*) Inventory Control
(*e*) Process Planning

18. A batch of 500 components is produced on a capstan lathe. The piece work rate/piece is 20 Paise, and the direct material cost/piece is 40 Paise. Overheads are 500% of direct labour cost. What is the total cost of the entire batch of the components ?

(*a*) Rs. 100 (*b*) Rs. 200 (*c*) Rs. 500 (*d*) Rs. 800
(*e*) Rs. 1600

19. The method often used to keep a record of the progress of a Project is a :

(*a*) Bar Chart (*b*) P-chart (*c*) PERT chart (*d*) Mollier chart
(*e*) Polar chart

20. The most important aspect in a good engineering report is :

(*a*) Its shortness. (*b*) Its promptness.

(*c*) Its accuracy. (*d*) Its good grammar.

21. Which *one* of the following indicates an increase in productivity ?

(*a*) Increased output as a result of waste reduction.

(*b*) Increased output as a result of working for an additional shift.

(*c*) Increased production owing to addition of machines and equipment.

22. In a decimal minute stop watch the minimum reading is :

(*a*) 1.0 minute (*b*) 0.1 minute (*c*) 0.01 minute (*d*) 0.001 minute

(*e*) 0.0001 minute

23. Job evaluation is :

(*a*) Same as Merit Rating.

(*b*) Evaluating the worth of the person who is holding the job.

(*c*) A system for determining the worth, in monetary terms, of jobs within an organization.

24. Determining and comparing the content of particular jobs without regard to the individuals performing the jobs is the function of :

(*a*) Job evaluation (*b*) Merit rating

(*c*) Incentive schemes (*d*) Method study

25. Work measurement is determining :

(*a*) The basis for introducing wage incentive plan.

(*b*) The employee performance standards.

(*c*) The costs.

(*d*) The production schedules and standards.

(*e*) All the above.

26. The most traditional and most often used work measurement technique is :

(*a*) The work sampling technique.

(*b*) The stop-watch time study.

(*c*) The Predetermined Motion Time Systems (PMTS).

(*d*) The Method-Time Measurement (MTM).

27. The work of a lathe machine operator producing a large number of components/day can be timed accurately by using :

(*a*) The work sampling method. (*b*) The stop-watch time study method.

(*c*) The P.M.T system. (*d*) The analytical estimating method.

28. Work Sampling technique is based on the application of statistical sampling principles to Work Measurement. This technique :

(*a*) Utilizes observations made at regular intervals of time.

(*b*) Utilizes observations made at random intervals of time.

(*c*) Utilizes observations made at equal intervals of time.

29. Work sampling technique (one of the work measurement techniques) can be used most effectively :

(*a*) For measuring long-cycle operations.

(*b*) For measuring short-cycle operations.

(*c*) For situations involving a series of short, complex operations.

30. Which one of the following techniques is most suitable when standards are needed by an office manager who does not have the time to measure each individual's work ?

(*a*) Work sampling. (*b*) Time study using a stop watch.

(*c*) Analytical estimating. (*d*) Methods-Time Measurement (MTM).

31. Under the_________technique, tables of standard unit times for various body motions are used to arrive at the time standards for a given operation :

(*a*) Analytical Estimating.

(*b*) PMT (Predetermined Motion Times).

(*c*) Work sampling.

(*d*) Stop watch time study.

32. The most scientific of all the Work Measurement techniques is :

(*a*) The stop watch time study.

(*b*) The work-sampling techniques.

(*c*) The PMT (Predetermined Motion Times) technique.

(*d*) The analytical estimating.

33. Which *one* of the following work measurement techniques is most suitable when a new assembly process is being introduced ?

(*a*) Analytical estimating. (*b*) PMT system.

(*c*) Time study using a stop watch. (*d*) Activity sampling.

(*e*) Work sampling.

34. _________is perhaps the only way to set time standards in advance in new work situations not tried before.

(*a*) The PMT method. (*b*) The Stopwatch study.

(*c*) The work sampling technique. (*d*) Analytical estimating.

35. The basic objective of introducing wage incentive systems and wage incentive plans is :

(*a*) To reduce the employee's actual earnings.

(*b*) To increase the unit cost of the item produced.

(*c*) To increase the worker effectiveness and to reduce the unit labour cost.

36. In "Taylor Differential Piece Rate System"

(*a*) One piece rate is established for each job.

(*b*) Two different piece rates are established for each job.

(*c*) Three different piece rates are established for each job.

(*d*) No pieces rates are established for the jobs.

37. The Merrick Multiple wage plan is a wage incentive system very similar to the Taylor Differential Piece Rate incentive system. In Merrick Multiple wage plan :

(*a*) No piece rates are established for the jobs.

(*b*) Three different piece rates are established for each job.

(*c*) Two different piece rates are established for each job.

(*d*) Only one fixed piece rate is established for a job.

38. The time required to complete a task is established and a bonus is paid to the worker for every hour he saves from the established time required. This type of incentive plan is known as :

(*a*) Rowan plan
(*b*) Bedaux plan
(*c*) Taylor differential piece rate system
(*d*) Halsey premium plan
(*e*) Day work plan

39. The Time required to complete a job is established and a bonus is paid to the worker based on the exact % of time saved. This type of incentive plan is known as :

(*a*) Day work plan.
(*b*) Halsey Premium Plan.
(*c*) Taylor plan.
(*d*) Bedaux Plan.
(*e*) Roman plan.

40. Which *one* of the following represents a group incentive plan ?

(*a*) Scanlon plan
(*b*) Rowan plan
(*c*) Bedaux plan
(*d*) Taylor Differential piece rate system
(*e*) Halsey premium plan

41. Which *one* of the following represents a group incentive plan ?

(*a*) Halsey Premium Plan
(*b*) Bedaux plan
(*c*) Lincoln Plan
(*d*) Rowan Plan
(*e*) Taylor Plan

42. In Lincoln plan (one type of group incentive plan), the amount of the profit which an employee receives, in addition to the guaranteed basic pay/wages, is based on :

(*a*) A Standard rating system.
(*b*) A Merit rating system.
(*c*) A job evaluation system.
(*d*) His individual performance.

ANSWERS

1. (*c*)	2. (*b*)	3. (*c*)	4. (*b*)	5. (*d*)	6. (*d*)
7. (*a*)	8. (*a*)	9. (*d*)	10. (*c*)	11. (*b*)	12. (*c*)
13. (*a*)	14. (*b*)	15. (*d*)	16. (*b*)	17. (*d*)	18. (*d*)
19. (*a*)	20. (*c*)	21. (*a*)	22. (*c*)	23. (*c*)	24. (*a*)
25. (*e*)	26. (*b*)	27. (*b*)	28. (*b*)	29. (*a*)	30. (*a*)
31. (*b*)	32. (*c*)	33. (*b*)	34. (*a*)	35. (*c*)	36. (*b*)
37. (*b*)	38. (*d*)	39. (*e*)	40. (*a*)	41. (*c*)	42 (*b*)

Model Question Paper - 1

Time : 3 Hours *Maximum marks: 100*

Answer ALL questions

PART A — (10 × 2 = 20 marks)

1. What are the different types of production ?

2. What is computer aided process planning ?

3. Define the term ‘estimating’.

4. What are the constituents of an estimation ?

5. What are indirect expenses ?

6. What do you mean by overhead ? Give any two examples.

7. How do you estimate the time required for forging ?

8. What are actual welding costs involved in estimation in welding shop ?

9. How will you calculate the time required for drilling a hole in an object ?

10. Estimate the milling time to cut 60 teeth on a gear blank 60 mm thick; feed 35 mm/min and take overall set up time as 10 minutes.

PART B — (5 × 16 = 80 marks)

11. (*i*) What is continuous production ? (6)

(*ii*) Explain retrieval type CAPP system with a block diagram. (10)

12. (*a*) (*i*) What are the aims of cost estimation ? (6)

(*ii*) What is meant by classification of costs ? Briefly discuss with examples. (10)

Or

(*b*) (*i*) What are the advantages of efficient costing ? (6)

(*ii*) Describe the procedure for estimating. (10)

13. (*a*) A factory has 15 lathes of same make and capacity and 5 shapers of same make and capacity. Lathes occupy 30 m^2 area while shapers occupy 15 m^2 area. During the calender year, factory expenses for this section are as follows :

(*i*) Building rent and depreciation Rs. 5,000

(*ii*) Indirect labour and material Rs. 15,000

(*iii*) Insurance Rs. 2,000

(*iv*) Depreciation charges of lathes Rs. 5,000

(*v*) Depreciation charges of shapers Rs. 3,000

(*vi*) Cost of power consumed for lathes Rs. 2,000

(*vii*) Power consumption for shapers Rs. 1,000

Find out the machine hour rate for lathes and shapers, if all the lathes and shapers work for 25,000 hours and 8,000 hours respectively. (16)

Or

(*b*) (*i*) A certain piece of work is produced by a firm in batches of 100. The direct materials cost for that 100 piecework is Rs. 160 and the direct labour cost is Rs. 200. Factory on cost is 35% of the total material and labour cost. Overhead charges are 20% of the factory cost. Calculate the prime cost and factory cost. If the management wants to make a profit of 10% on the gross cost, determine the selling price of each article. (10)

(*ii*) What are the causes of depreciation ? (6)

14. (*a*) (*i*) It is required to prepare an hexagonal bolt of 15 mm dia and 25 cm length from a bar stock of 1.8 cm dia. Calculate the length of bar stock required. (8)

(*ii*) Estimate the material cost for welding 2 flat pieces of M.S (mild sheet) 15 cm × 16 cm × 1 cm size at an angle of 90° by gas welding. Neglect edge preparation cost and assume:

1. Cost of O_2 = Rs. 10/m^3
2. Cost of C_2H_2 = Rs. 6/m^3
3. Density of filler metal = 7 gm/cc
4. Cost of filler metal = Rs. 12/kg
5. Filler rod dia = 5 mm
6. Filler rod required 4.5 m/m of welding
7. Assume O_2 consumption = 0.7 cu.m/hr
8. Assume C_2H_2 consumption = 0.5 cu.m/hr
9. Welding time = 30 min/m of welding (8)

Or

(*b*) Estimate the total cost of 20 C.I. (Cast Iron) flanged pipe castings shown in Fig. 1 assuming the following data :

Cost of C.I. = Rs. 5/kg
Cost of process scrap = Rs. 2/kg
Process scrap = 2% of net weight of casting
Moulding and pouring charges = Rs. 2/piece
Casting removal and cleaning = Rs. 0.50/piece
Administrative overheads = 5% factory cost
Selling overheads = 70% administrative overheads (16)

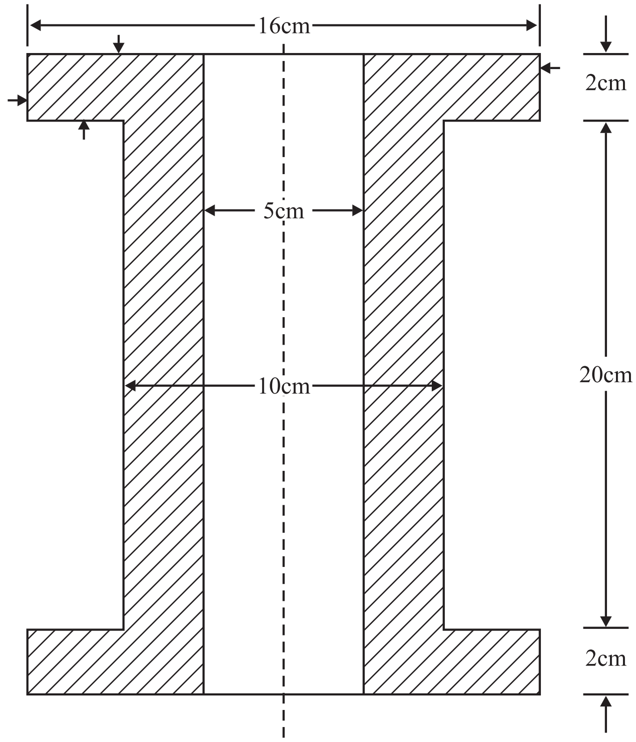


Fig. 1

15. (*a*) (*i*) A 15 cm long M.S bar is to be turned from 4 cm dia in single cut in such a way that for 5 cm length its dia is reduced to 3.8 cm and remaining 10 cm length is reduced to 3.4 cm. Estimate the total time required for turning it assuming cutting speed as 30 m/min., feed as 0.02 cm/revolution and time required for setting and mounting of the job in a three jaw chuck is 30 sec. Neglect the tool setting time. What is the time required for knurling 5 cm length at 20 m/min and feed 0.03 cm/rev. ? (10)

(*ii*) Estimate the time required for cutting 3 mm pitch threads on a mild steel bar of 2.8 cm dia and 8 cm long. Assume the cutting speed for threading as 15 m/min. (6)

Or

(*b*) (*i*) A 20 cm × 5 cm C.I. surface is to be faced on milling machine with a cutter having a dia of 10 cm and 16 teeth. If the cutting speed and feed are 50 m/min and 5 cm/min respectively, determine the milling time, r.p.m. of the cutter and feed per tooth. (8)

(*ii*) Find the time required for doing rough grinding of a 15 cm long steel shaft to reduce its dia from 4 cm to 3.8 cm with the grinding wheel of 2 cm face width. Assume work speed as 15 m/min. and depth of cut as 0.25 mm. (8)

Model Question Paper - 2

Time : 3 Hours *Maximum marks: 100*

Answer ALL questions

PART A — (10 × 2 = 20 marks)

1. Briefly mention about any two types of production.

2. Define direct and indirect material.

3. What are the advantages of generative process planning ?

4. What are the aims of cost estimation ?

5. What is the difference between costing and cost estimation ?

6. What is meant by ladder of cost ?

7. List the methods of depreciation.

8. What is overhead cost ?

9. List the losses to be considered in estimating the gross weight of a forging component.

10. What are the costs to be considered for estimating electric welding cost of a product ?

PART B — (5 × 16 = 80 marks)

11. (*i*) Discuss in detail the retrieval type computer aided process planning system. (10)

(*ii*) Briefly explain standardization and simplification with some examples. (6)

12. (*a*) (*i*) Write the benefits of computer aided process planning (CAPP). (6)

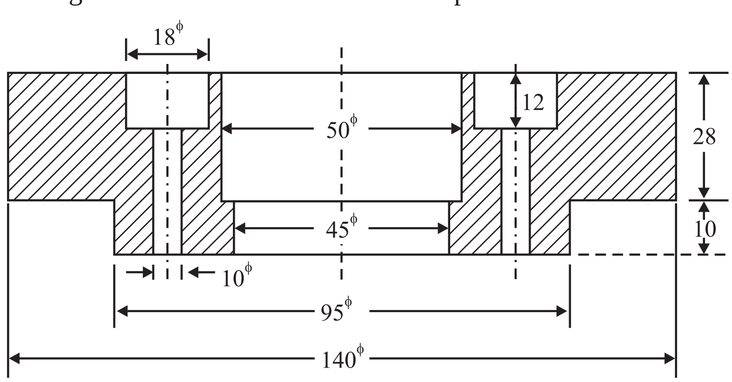
(*ii*) How will you prepare a process chart for a collar bush ?

Material : Mild steel. Assume your own dimensions. (10)

Or

(*b*) (*i*) What are the objectives of cost accounting ? (6)

(*ii*) Find the cost of material for the machine part shown in Fig. 1. Density of material may be taken as 8.2 gm/cu cm. The cost of material is Rs. 2 per kg. Assume 20% wastage of material of the finished component and 6 holes for bolt. (10)



All dimensions are in mm

Fig. 1

13. (*a*) (*i*) What are the causes for depreciation? (6)

(*ii*) For a plant having a depreciation of Rs. 10,000 over a useful life period of 10 years, find out the depreciation charge for all the years according to sum of years digits method. (10)

Or

(*b*) (*i*) What do you understand by direct expenses ? Give examples. (6)

(*ii*) A factory is producing 1,000 bolts and nuts per hour on a machine. Its material cost is Rs. 400, labour cost Rs. 350 and direct expenses is Rs. 75. The factory on cost is 150% of the total labour cost and office on cost is 25% of the total factory cost. If the selling price of each bolt and nut is Rs. 1.75, calculate whether the factory is running in loss or gain and by what amount ? (10)

14. (*a*) What is the material cost of welding two plates of size 300 mm length and 150 mm width and 8 mm thickness to make a piece 300 mm × 300 mm approximately. Use rightward technique with no edge preparation cost. Take overall cost of Oxygen as Rs. 10 per cu. metre, cost of acetylene at Rs. 7 per cu. metre, cost of filler metal Rs. 2.50 per kg and 1 cu. cm of filler metal weighs 11.28 gms.

Assume dia of filler rod = 4 mm.

Filler rod used per metre of weld = 3.4 metres.

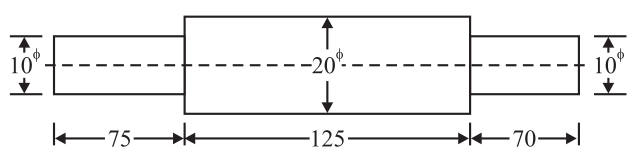
Rate of welding = 2.1 metres/hour.

Consumption of Oxygen = Consumption of acetylene

= 7.1 cu. metre/hr. (16)

Or

(*b*) 150 pieces of shafts as shown in Fig. 2 are to be drop forged from the raw stock of 2 cm diameter. Estimate the cost incurred assuming that material cost = Rs. 5.20 per metre. Cost of forging = Rs. 120.50 per sq. meter of surface area to be forged. Overhead expenses to be 100% of the cost of the forging. Consider all losses. (16)



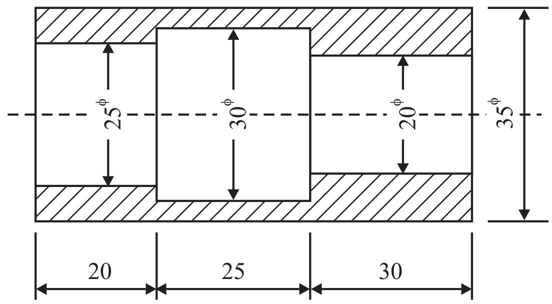
All dimensions are in mm

Fig. 2

15. (*a*) Estimate the time taken to prepare a job as shown in Fig. 3 from M.S (Mild Steel) stock bar 4 cm in diameter and 7.5 cm long. Assume the following data :

Cutting speed for turning and boring operation = 20 m/min.

Cutting speed for drilling operation = 30 m/min.



All dimensions are in mm

Fig. 3

Feed for turning and boring operation = 0.2 mm/rev.

Feed for 20 mm drill = 0.23 mm/rev.

Depth of cut not to exceed 3 mm in any operation. (16)

Or

(*b*) A 3 cm deep slot is to be milled with a 8 cm diameter cutter. The length of the slot is 30 cm. What will be the total table travel to complete the cut ? If the cutting speed is 20 metres/min and feed per tooth is 0.2 mm, estimate the milling time. The cutter has 24 teeth and one cut is sufficient for the slot. (16)

Model Question Paper - 3

Time : 3 Hours | *Maximum marks: 100*

Answer ALL questions

PART A — (10 × 2 = 20 marks)

1. List types of production.

2. Define process planning.

3. Mention the importance of estimating.

4. Define costing.

5. What do you understand by prime cost ?

6. What is fatigue allowance ?

7. How can the gas cutting costs be estimated ?

8. Mention the losses in forging process.

9. List various factors affecting cutting speed.

10. Define cycle time.

PART B — (5 × 16 = 80 marks)

11. (*i*) Explain about standardization. (8)

(*ii*) Compare manual and computer aided process planning (CAPP). (8)

12. (*a*) Explain aims of both estimating and costing. (16)

Or

(*b*) Discuss in detail the cost structure of a product. (16)

13. (*a*) Draw ladder of cost and explain its elements. (16)

Or

(*b*) The catalogue price of a certain machine is Rs. 1,050, the discount allowed to the distributors being 20%. Data collected at a certain period show that the selling cost and factory cost are equal and that the relations among materials costs, labour cost and on cost in the factory are 1 : 3 : 2. If the labour cost is Rs. 200, what profit is being made on the machine ? (16)

14. (*a*) What is the material cost of welding two plates of size 300 mm length and 150 mm width and 8 mm thickness to make a piece 300 mm × 300 mm approximately ? Use right - ward technique with no edge preparation costs. Take overall cost of O_2 as Rs. 10 per cu. meter, cost of C_2H_2 as Rs. 7.00 per cu. meter, cost of filler metal Rs. 2.50 per kg and 1 cu. cm of filler metal weighs 11.28 gms. Assume, consumption of O_2 and C_2H_2 as 0.71 cu. meter/hr.

Diameter of filler rod = 4 mm

Filler rod used per meter of weld = 3.4 m

Rate of welding = 2.1 m/hr. (16)

Or

(*b*) Estimate the size of the stock to forge a M.S. (Mild Steel) hexagonal headed bolt blank. The diameter of the bolt is 25 mm, and length of the stem 100 mm. Assume necessary dimensions for the head. (16)

15. (*a*) Find the time required to manufacture the tapered cylindrical job of dimensions; minor diameter 30 mm, major diameter 80 mm and length 120 mm from a given round bar of 80 mm diameter and 120 mm length. Assume :

Cutting speed = 75 m/min.

Max. feed by compound rest = 0.05 mm/rev

Depth of cut should not exceed 4 mm. (16)

Or

(*b*) Estimate the planing time for a casting 1.25 m long and 0.5 m wide which is machined on a planer having cutting speed of 12 m/min and a return speed of 30 m/min. Two cuts are required, one roughing with a depth of 3.125 mm and a feed of 0.1 mm/rev and other finishing with a depth of 0.125 mm and using a feed of 0.125 mm. (16)