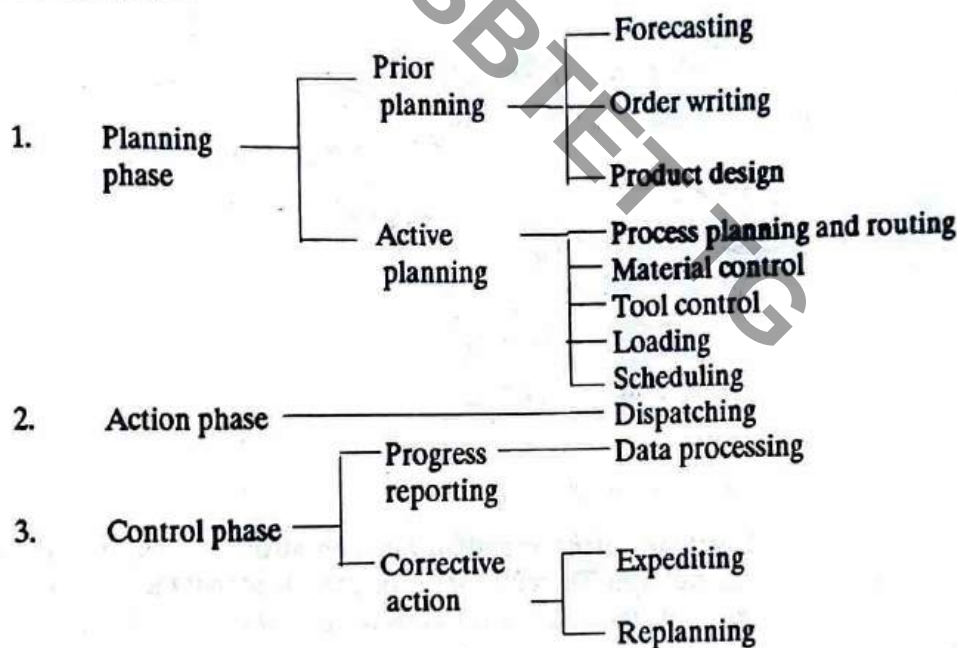


Production Planning and Control

7.1. INTRODUCTION

Products are manufactured by the transformation of raw material (into finished goods). This is how *production* is achieved. *Planning* looks ahead, anticipates possible difficulties and decides in advance as to how the production, best, be carried out. The *control* phase makes sure that the programmed production is constantly maintained.

A production planning and control system has many functions to perform, some, before the arrival of raw materials and tools, and others while the raw material undergoes processing. The various *functions* are as follows :



(a) *Forecasting*. Estimation of type, quantity and quality of future work.

(b) *Order writing*. Giving authority to one or more persons to undertake a particular job.

(c) *Product design*. Collection of information regarding specifications, bill of materials, drawings, etc.

(d) *Process planning and routing*. Finding the most economical process of doing a work and (then) deciding how and where the work will be done.

(e) *Material control*. It involves determining the requirements and control of materials.

(f) *Tool control*. It involves determining the requirements and control of tools used.

(g) *Loading*. Assignment of work to manpower, machinery, etc.

(h) *Scheduling*. It is the time phase of loading and determines when and in what sequence the work will be carried out. It fixes the starting as well as the finishing time for the job.

(i) **Dispatching.** It is the transition from planning to action phase. In this phase the worker is ordered to start the actual work.

(j) **Progress reporting :**

- (i) Data regarding the job progress is collected.
- (ii) It is interpreted by comparison with the preset level of performance.

(k) **Corrective action :**

- (i) Expediting means taking action if the progress reporting (j) indicates a deviation of the plan from the originally set targets.
- (ii) Replanning—Replanning of the whole affair becomes essential, in case expediting fails to bring the deviated plan to its actual (right) path.

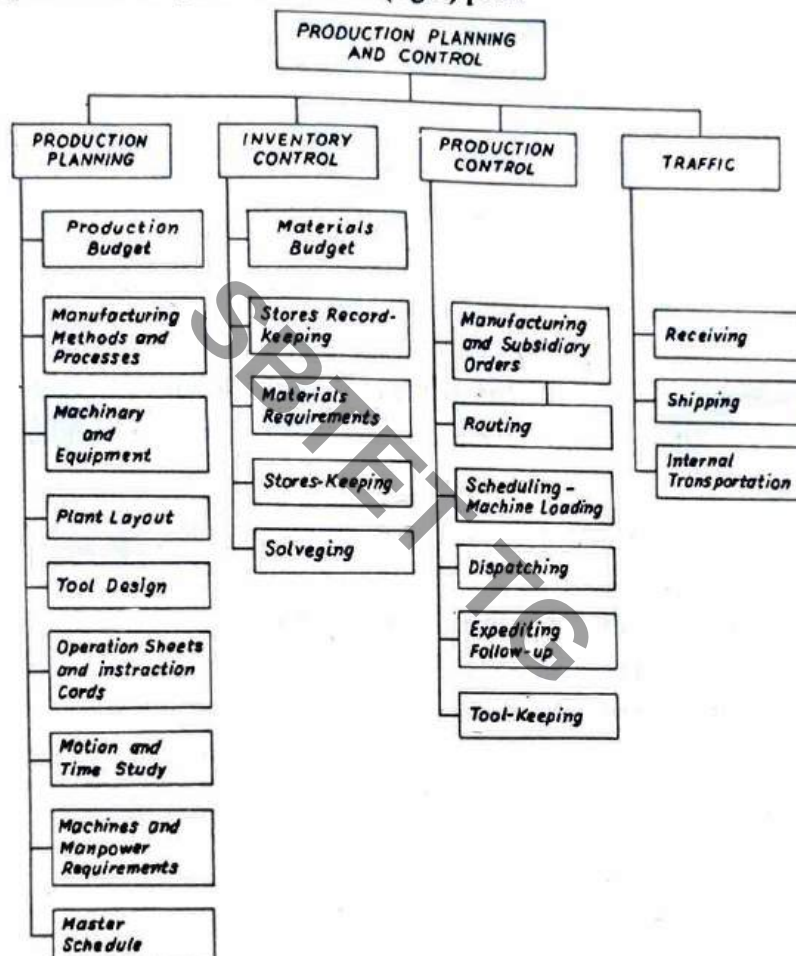


Fig. 7.1. Functional organisation of production planning and control.

7.2. CONTINUOUS AND INTERMITTENT PRODUCTION

Continuous production involves a continuous or almost continuous physical flow of material. It makes use of special purpose machines, and produces standardized items in large quantities. Chemical processing, cigarette manufacturing, and cement manufacturing are some of the industries engaged in continuous production. Continuous production system can be divided into two categories.

- (A) Mass and flow line production,
- (B) Continuous or process production.

An intermittent production system is typified by the intermittent or interrupted flow of material through the plant. It makes use of general purpose machines and produces components different in nature and in small quantities. Machine shops, repair and maintenance shops, welding shops, etc., are some of

S A L E S					CAPACITY
	PERIOD-1	PERIOD-2	PERIOD-3	F.I	
INITIAL INVENTORY	0	5	10	15	20
REGULAR Pdn-1	25	30	35	40	30
OVERTIME Pdn-1	30	35	40	45	25
REGULAR Pdn-2	27	32	37	42	15
OVERTIME Pdn-2	32	37	42	47	40
REGULAR Pdn-3	29	34	39	44	50
OVERTIME Pdn-3	34	39	44	49	45
DEMAND	70	65	50	40	225
					225

Fig. 7.14. Distribution matrix with capacity, demand and cost values.

In order to find optimum solution consider the distribution matrix of Fig. 7.14 where capacities and demands have been shown along with the various cost values. The costs have been calculated by assuming that

$$c = \text{Rs. } 5, \quad r = \text{Rs. } 25, \quad t = \text{Rs. } 30 \quad \text{and} \quad b = \text{Rs. } 2.$$

This distribution matrix can be solved by using the North-West corner method as described in Chapter 11. The solution matrix thus obtained will show the number of units which should be assigned to regular production, and to over-time production in three different periods in order to minimize the total cost.

7.9. PROCESS PLANNING

Definition and Concept

- Process planning means the preparation of work detail plan.
- Since a process is required to manufacture a product, it is necessary to plan the process.
- Process planning is determining the most economical method of performing an operation or activity.
- Process planning comes after it has been decided as what is to be made.
- Process planning develops the broad plan of manufacture for the component or product.
- Process planning takes as its input the drawings or other specifications which show what is to be made and forecasts or orders which indicate the product quantity to be manufactured.

Information Required to do Process Planning

- Quantity of work to be done along with product specifications.

- Quality of work to be completed.
- Availability of equipments, tools and personnel (giving dates, etc.).
- Sequence in which operations will be performed on the raw material.
- Names of equipments on which the operations will be performed.
- Standard time for each operation.
- When the operations will be performed.

Process Planning Procedure

The different steps involved are :

1. Selection of Process :

- A process is necessary in order to shape, form, condition and join materials and components with the help of machines and labour in order to convert raw material into a finished product.
- One should select the most economical process (A breakeven chart similar to one discussed in Chapter 27 may be useful for the purpose) and sequence that satisfies the product specifications.
- The selection of process depends upon :

(a) *Current production commitments.* If enough work has already been allocated to more efficient equipments, the current work may have to be passed on to less efficient machines to complete the same in time.

(b) *Delivery date.* An early delivery date may :

- (i) Force the use of less efficient machines,
- (ii) Rule out the use of special tools and jigs as they will take time for design and fabrication.

(c) *Quantity to be produced :*

- Small quantity will not probably justify the high cost of preparation and efficient set-ups. Thus, quite possible they may have to be made on less efficient machines and *vice-versa*.

(d) *Quality standards :*

- Quality standards may limit the choice of making the product on a particular machine, etc.

2. Selection of Material

- Material should be of right quality and chemical composition as per the product specifications.
- Shape and size of material should restrict the scrap (*i.e.*, material removed for getting the product shape).

3. Selection of Jigs, Fixtures and Other Special Attachments. These supporting devices are necessary :

- to give higher production rate ;
- to reduce cost of production per piece.

4. Selection of Cutting Tools and Inspection Gauges. They, respectively, are necessary to :

- Reduce production time.
- Inspect accurately and at a faster rate.

5. Make the *process layout* indicating every operation and the sequence in which each operation is to be carried out.

6. Find *set-up time* and standard time for each operation.

7. Manifest process planning by documents such as *Operation and Route sheets*, which summarize the operations required, the preferred sequence of operations, auxiliary tools required, estimated operation times etc. (Refer Fig. 7.27).

7.10. ECONOMIC BATCH QUANTITY

- If the number of components to be produced is very large, they cannot be manufactured in one batch.
- Under such conditions it is required to find out—how many pieces (or components) should be produced in one batch so that it is most economical; and this batch size is known as *Economic Batch Quantity*.
- There are two types of costs (Fig. 7.15)
 - (a) Which increase with the batch size, such as :
 - (i) Working capital investment in materials and labour,
 - (ii) Cost of handling and storing materials,
 - (iii) Insurance and tax charges, and
 - (iv) Interest on capital investment, etc.
 - (b) Which decrease with the batch size, such as :
 - (i) Cost (per unit) of setting up machines,
 - (ii) Cost of preparing paper work that enters and controls the production of the order, e.g., cost of preparing process sheets, issuing shop order, etc.

The above-mentioned costs, i.e., (a) and (b) are plotted and the total cost curve is determined by adding (a) and (b) cost curves graphically (refer Fig. 7.15).

- Mathematically, *EBQ* can be determined as follows :

Assume :

- Q is economic batch quantity.
- R is annual requirements.
- S is preparation and set-up cost, each time a new batch is started.
- C is constant cost per piece (material, direct labour and overheads).
- and I is inventory carrying charge rate per year (it is usually between 0.1 and 0.25).

Therefore,

$$\text{Average inventory} = \frac{Q}{2}$$

Value of average inventory

$$= \frac{Q}{2} \times C$$

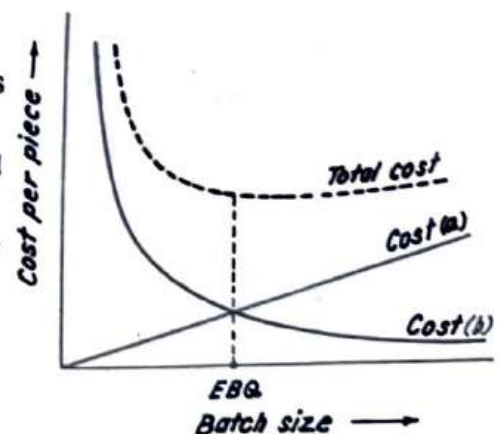


Fig. 7.15. Economic Batch Quantity (EBQ).

Scheduling and Control of production have one stage in between them, which is known as *dispatching* and it will be discussed under Sec. 7.18. In general, first of all the order is scheduled, then it is dispatched for necessary operation (on the raw material) and lastly the progress of the order is tracked, to be certain that the schedule is being met. This (last) phase of tracking the progress of an order and making corrections (if necessary) is known as *control of production*.

7.14. SCHEDULING

Concept. In brief, scheduling means—when and in what sequence the work will be done. It involves deciding as to when the work will start and in a certain duration of time how much work will be finished. Scheduling deals with orders and machines, i.e., it determines which order will be taken up on which machine and in which department by which operator. While doing so, the aim is to schedule as large amount of work as the plant facilities can conveniently handle by maintaining a free flow of material along the production line.

Scheduling may be called the time phase of Loading. Loading means the assignment of task or work to a facility whereas scheduling includes in addition, the specification of time and sequence in which the order/work will be taken up.

A production schedule is similar to a railway time table and shows which machine is doing what and when. A production schedule, is a statement of target dates for all orders or operations in hand and reveals their starting and finishing dates. Scheduling finalises the planning phase of Production Planning and Control System.

Factors Affecting Scheduling. The following factors affect production scheduling and are considered before establishing the scheduling plan.

(a) *External factors :*

1. Customer's demand,
2. Customer's delivery dates, and
3. Stock of goods already lying with the dealers and retailers.

(b) *Internal factors :*

1. Stock of finished goods with the firm,
2. Time interval to process finished goods from raw material. In other words—how much time will be required to manufacture each component, subassembly and then assembly (i.e., the final product),
3. Availability of equipment and machinery ; their total capacity and specifications,
4. Availability of materials ; their quantity and specifications,
5. Availability of manpower (number, type and kind of skills),
6. Additional manufacturing facilities if required, and
7. Feasibility of economic production runs.

Scheduling Procedure and Techniques. Scheduling normally starts with the *Master Schedule*. Figure 7.18 shows the master schedule for a foundry shop.

A master schedule resembles central office which possesses information about all the orders in hand. Master schedule, in Fig. 7.18, is a weekly breakdown of the production requirements. The total capacity in any week is of 100 hours of work in the foundry shop.

As the orders are received, depending upon their delivery dates (or priorities, if any) they are marked on the master schedule. When the shop capacity is full for the present week the newly acquired orders are carried over to the next week and so on. A master schedule is thus updated continuously, it depicts a running total of the production requirements and shows the work ahead—yet to be completed. Master

schedule is actually the basis for all subsequent scheduling techniques.

MASTER SCHEDULE FOR THE FOUNDRY SHOP Maximum Production 100 hrs Minimum Production 8 hrs			
WEEK-1	WEEK-2	WEEK-3	WEEK-4
15	18	20	15
25	25	12	10
20	20	12	
35			

Fig. 7.18. Master schedule for a foundry shop.

A Master Schedule possesses the following advantages, disadvantages and applications.

Advantages

1. It is simple and easy to understand,
2. It can be kept running (i.e., current),
3. It involves less cost to make it and maintain,
4. It can be maintained by non-technical staff, and
5. A certain percentage of total weekly capacity can be allocated for rush orders.

Disadvantages

1. It provides only overall picture, and
2. It does not give detailed information.

Applications

It finds applications :

1. In big firms, for the purpose of loading the entire plant,
2. In Research and Development organisations, and
3. For the overall planning in foundries, computer centres, repair shops, etc.

After framing the overall picture of production requirements through a Master Schedule chart, the detailed schedules are thought of and made for each component, and subassemblies so that all parts are available at the time of assembly. There are a number of visual aids and techniques, both in the form of conventional charts and commercially available boards, which aid in detailed scheduling. The technique to be employed for scheduling purposes depends upon the type of production (intermittent or continuous), type and frequency of tasks, demand patterns, etc. A useful scheduling device normally portrays planned production, actual performance and their comparison. Actually, the Gantt Chart (refer Fig. 7.20) forms the basis of commonly used scheduling techniques.

Some of the techniques (besides master schedule) employed for Loading and Scheduling purposes are :

- (a) Perpetual schedule ;
- (b) Order schedule ;
- (c) Loading by schedule period ;

(d) Commercial devices.

(a) **Perpetual Scheduling.** Like master scheduling, it is also simple and easy to understand, is kept current, involves less costs and can be maintained by clerical staff. But, the information which it provides is very gross and at the same time it is not clear from the chart—when the work will take place.

Making of perpetual schedule involves two steps :

(i) Preparation of Load Analysis sheet from the orders in hand. Figure 7.19 shows a load analysis sheet.

LOAD ANALYSIS SHEET			
ORDER NO.	LOAD IN HOURS/DAYS		
	SECTION A	SECTION B	SECTION C
X-520	25	10	16
Y-210	10	15	10
Y-314	18	20	8
Z-150	8	25	—
...	...	...	...

Fig. 7.19. Load analysis sheet.

(ii) The total load against each section is added up and knowing the weekly capacity of a section (department), the number of weeks load against each department is calculated and plotted on a Gantt load chart as shown in Fig. 7.20.

GANTT LOAD CHART				
	WEEK-1	WEEK-2	WEEK-3	WEEK-4
SECTION A	[Shaded bar]			
SECTION B	[Shaded bar]			
SECTION C	[Shaded bar]			

Fig. 7.20. Gantt load chart.

The shaded bars show the actual work load against each section.

Additional information, if any (regarding the work load), can be indicated by dotted line.

(b) **Order Scheduling.** It is a most elaborate technique. Fig. 7.21 shows an order schedule chart. Time is marked horizontally and the vertical axis shows the particular facility (say a machine). The information required to generate an order schedule is, regarding the number of parts to be manufactured, name of the machines, their set-up times, total production time and the date of completion of the order.

The scheduling is started by placing the last operation at the date of completion and then working

backwards. For example, if order *X* takes 3 days to complete and it is to be delivered to the customer on 7th of January, the work will be started on 5th of January.

Order schedule chart has the following advantages and limitations.

Advantages

- (1) It is very detailed.
- (2) The earliest possible completion dates can be met.

Limitations

- (1) It is very costly.
- (2) It requires accurate (production) time standards and good communication system.
- (3) It is difficult to maintain effectively if there are many active orders.

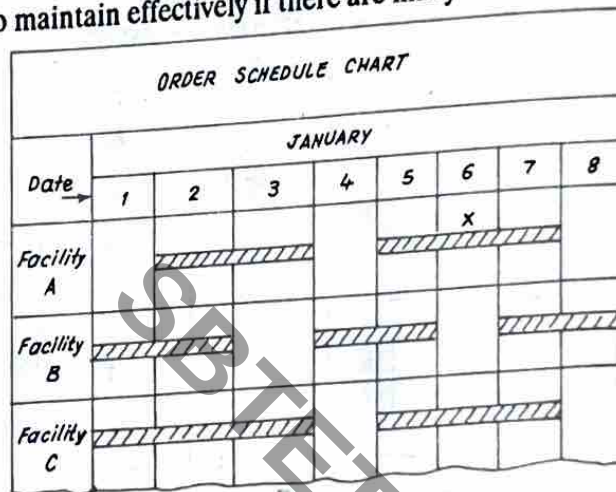


Fig. 7.21. Order schedule chart.

(c) **Loading by Schedule Period.** The task is broken into different operations which will be required to turn raw material into finished product. A Gantt type of chart (See Fig. 7.22) is employed for scheduling purposes. The rows, mark different facilities and each column denotes a time period (TP). There are as many time periods as the number of operations. The first operation is carried out in the time period-1, second operation in time period-2 and so on. It is however not specified that, within the time period, when the operation will start and finish; but the operation is very much supposed to be completed during that particular time period. The shop supervisor does the detailed scheduling within the framework of the specified time period.

The shaded bars show the work ahead of each facility.

This type of scheduling involves a longer in-process (total) time because only one operation is to be performed in one time period. However, this makes it more flexible as an operation can be taken up at the most convenient time within the specified time period.

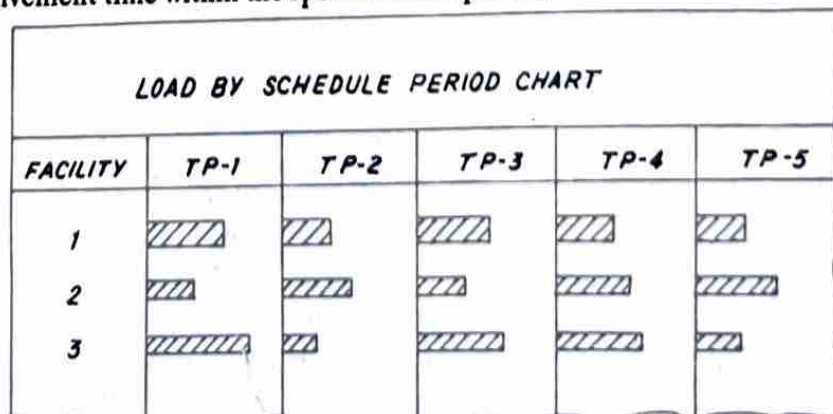


Fig. 7.22. Load by schedule period chart.

(c) Some of the Commercial Devices for Loading and Scheduling are :

- (a) Produc-Trol Board,
- (b) Sched-U-Graph,
- (c) Board master,
- (d) Magnetic boards, and
- (e) Roll charts, etc.

(a) **Produc-Trol Board.** Fig. 7.23 show a Produc-Trol board.

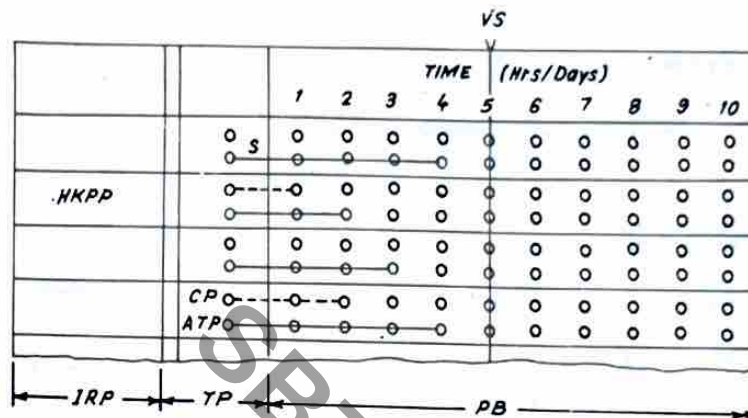


Fig. 7.23. Produc-Trol Board.

IRP : Index record panel.

TP : Tape pegs.

S : Strings.

PB : Peg board having two rows of holes for each pocket.

HKPP : Heavy craft paper pockets. Each machine is assigned a pocket. A card bearing information pertaining to the machine is inserted in the pocket.

ATP : It is a tape peg showing actual work load for each machine.

CP : It is a coloured peg (shown dotted) that gives special information ; for example last week's load.

VS : Vertical string showing today's date and the work load position.

(b) **Sched-U-Graph.** It is shown in Fig. 7.24.

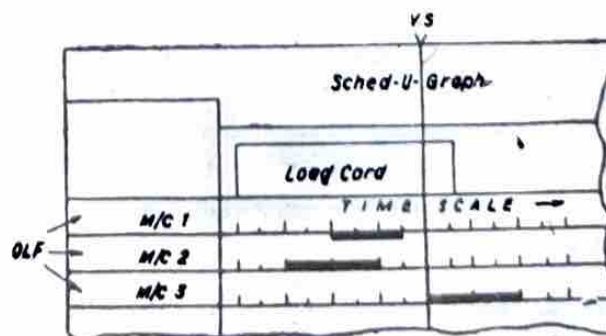


Fig. 7.24. Sched-U-Graph.

OLF : *Overlapping flap*. Every flap is projecting about 12 mm below (out) the previous one, and has bottom (12 mm) portion transparent. A card is made for each operation (to be done) on a machine. The card has written on it every thing about a job.

The bottom (12 mm) of the card is coloured and the card is cut to a length depending upon the time the job will take on a particular machine. The black strips in Fig. 7.24 correspond to the coloured bottoms of the cards and indicate which machine will be busy during which period. The progress made against each order can also be shown by strips of other colours.

7.15. MANUFACTURING SCHEDULE

- A master schedule is too general to permit adequate day-to-day planning by line supervision, and is usually unnecessary in a small organisation.
- Weekly departmental *manufacturing schedules* supplement the master schedule and must be made to reflect immediate factors, some of which are
 - (1) Tool downtime due to broken and worn tools,
 - (2) Equipment downtime for repair and maintenance,
 - (3) Shortages and defects in materials,
 - (4) Absenteeism and
 - (5) Cancellations and rush orders.
- The weekly schedule should take advantage of the most economical setup sequence in a process where more than one part is produced on the same line. It is important to arrange the order of work on the weekly schedule, to minimize setup time.

Sometimes much of the same tooling can be used for certain operations on parts *A* and *C*. Part *B*, requiring a different setup on the same machine, should then follow part *C* rather than precede it. The operating supervisor can help greatly in working out these combinations.

- Successive master schedules are corrected from the variations reflected in the manufacturing schedules. Weekly manpower requirements are based on the manufacturing schedules and excessive fluctuations must be avoided.

7.16. SCHEDULING AND THE COMPUTER

- Since Scheduling is the main process carried out in production control, it is worth to consider the relationship between the computer and scheduling.
- The computer is an extremely versatile tool which can be programmed to undertake almost any *data processing* task.
- In many types of industry, much of the data required for scheduling is relatively *fixed* in relation to time. In this category can be included the data contained in parts lists, route cards and plant lists. Many of the data processing needs of production control use this type of data. Examples are, *explosion** to find *parts* requirements, *implosion*** to find the requirement of common *materials* and *loading* to calculate forward loads on machines and direct workers. For these types of data processing, the computer is ideal.
- *Continuous data* (such as store receipts, store issues, products dispatched etc.) is used by production control in the compilation of stock records, shortage lists and operations statistics.

* An *explosive industry* produces a *small* number of different products, by joining a large number of different components e.g. Machine Assembly.

** An *implosive industry* produces a *large* number of different products from a small number of different material items or components e.g. Foundry.

Computer, again, can do the actual data processing much more accurately and quickly than is possible manually.

A.B.C. Co., Ltd.	Period : 2nd Quarter 1991		
Production order	Date : 15.3.1991		
Item	April	May	June
1 Ton Air conditioners	550	450	350
1.5 Ton Air conditioners	600	500	400
Water coolers	500	400	300
Approval	PPC Manager _____ Sales Manager _____ Production Manager _____		

Fig. 7.25. Production order.

7.17. CONTROL OF PRODUCTION (PRODUCTION CONTROL)

Scheduling completes the planning phase of Production Planning and control. The next is 'Dispatching', the action phase which has been discussed under Section 7.18. After dispatching is the control phase or control of production which consists of two parts (a) Progress reporting, and (b) Corrective action. Both these parts have been discussed in the Section 7.20 under Progress control. Production control phase or progress control means the same thing. The concept of control and control of production is as follows :

A control system involves four stages namely : (i) Observation, (ii) Analysis, (iii) Corrective action, and (iv) Post-operation evaluation. A production control system considers these elements in its different functions.

The control of production is necessary to be sure that the production schedules are being met and the job will be delivered as per the predecided (scheduled) plans. Production control involves an information feedback mechanism and a system of corrective action. Production control follows up the scheduled plans, compares the actual output with the planned one, and points out deviation, if any, so that the same can be corrected through the adjustments of men, materials and machines.

In brief, a production control group:

- (a) receives work progress reports;
- (b) compares them with the scheduled plans;
- (c) removes causes of delays in production;
- (d) modifies the schedules or plant capacities; and
- (e) expedites the work.

7.18. DISPATCHING

Introduction. Dispatch function executes planning function. It is concerned with getting the work started. Dispatching ensures that the plans are properly implemented. It is the physical handing over of a manufacturing order to the operating facility (a worker) through the release of orders and instructions in accordance with a previously developed plan of activity (time and sequence) established by the scheduling section of the production planning and control department. Dispatcher transmits orders to

the various shops. Dispatch function determines—by whom the job shall be done and it co-ordinates production. It is the key point of a production communication system. It creates a direct link between production and sales.

A dispatcher is familiar with the productive capacity of each equipment. He always keeps an eye over the progress of orders which move at different speeds on different routes.

Dispatch Procedure. The product is broken into different components and components into operations. A route sheet for the part (component) C having three operations on it is shown in Fig. 7.26. The various steps of dispatch procedure for each operation are listed below, in sequence.

ROUTE SHEET PART C
Material
Operation-1
Operation-2
Operation-3

(a) *Store Issue Order.* Authorise stores (department) to deliver required raw material.

(b) *Tool Order.* Authorise tool store to release the necessary tools. The tools can be collected by the tool room attendant.

(c) *Job Order.* Instruct the worker to proceed with the operation.

(d) *Time Ticket.* It records the beginning and ending time of the operations and forms the basis for worker's pay.

Fig. 7.26. Route sheet.

(e) *Inspection Order.* Notify the inspectors to carry out necessary inspections and report the quality of the component.

(f) *Move Order.* Authorise the movement of materials and components from one facility (machine) to another for further operations.

In addition, there are certain other dispatch aspects which have to be taken care of,

1. All production information should be available before hand.
2. Various order cards, and specification drawings should be ready.
3. Equipments should be ready for use.
4. Progress of various orders should be properly recorded on the Gantt charts or display boards.
5. All production records should be properly maintained.

Centralized and Decentralized Dispatching. Dispatch function may be centralized or decentralized.

In a *Centralized* dispatch system, a central dispatching department, orders directly to the work station. It maintains a full record of the characteristics and capacity of each equipment and work load against each machine. The orders are given to the shop supervisor, who runs his machines accordingly. In most of the cases, the supervisor can also give suggestions as regards loading of men and machines under him. A centralized system has the following advantages :

1. A greater degree of overall control can be achieved.
2. Effective co-ordination between different facilities is possible.
3. It has greater flexibility.
4. Because of urgency of orders, changes in schedules can be affected rapidly without upsetting the whole system.
5. Progress of orders can be readily assessed at any time because all the information is available at a central place.
6. There is effective and better utilization of manpower and machinery.

In a *Decentralised* dispatching system the shop supervisor performs the dispatch functions. He decides the sequence of handling different orders. He dispatches the orders and materials to each equipment and worker, and is required to complete the work within the prescribed duration. In case he

suspects delay, with due reasons of the same, he informs the production control department. A decentralised dispatching system has the following *advantages* :

1. Much of the red tape is minimized.
2. Shop supervisor knows best about his shop, therefore, the work can be accomplished by the most appropriate worker and the machine.
3. Elaborate reports and duplication of postings can be avoided.
4. Communication gap is reduced.
5. It is easy to solve day-to-day problems.
6. It keeps the natural urge of a section to be self-sufficient.

The advantages of a centralized system, more or less give an idea about the disadvantages of the decentralized system and *vice versa*.

Level of Dispatch Office. Dispatching can be introduced at Plant Manager's level, Shop Superintendent's level, at the level of Shop Supervisor or at a Specialist's level.

Dispatching, at the level of *Plant Manager* though keeps him informed about all the plant activities and seeks his guidance, yet it may not work very well; because, firstly he (Plant Manager) does not have time to go through each and every detail carefully and secondly it takes a long time for the information to pass down the line to the workers.

Dispatching at *Shop Superintendent's* level, again, though keeps him better informed, but does not function well because his basic nature of duties (to look whether the operating facility is performing the scheduled work at an acceptable level of performance or not) do not leave much spare time with him to take care of the overall dispatch function in detail.

Dispatching when introduced at *Shop Supervisor's* level, seems to be the best. This system possesses the following *Advantages* :

1. Higher levels are not disturbed.
2. Shop supervisor knows best about his shop and thus dispatching can be more effective.
3. The schedule is passed on to the workers in no time.

The *Disadvantage* in this case is that clerical work for the supervisor increases.

Introducing dispatching at the level of a *Specialist* (a dispatcher not from within the line organization) has the following advantages and disadvantages.

Advantages

- (1) Shop supervisor is relieved of the clerical work.
- (2) The system provides extra manpower.
- (3) The system provides special guidance and advice.
- (4) Dispatching is done more efficiently.
- (5) Effective co-ordination can be attained.

Disadvantage

The traditionally acceptable practice, that a supervisor assigns the job to the workers under him and supervises them, is lost.

7.19. ROUTING

Introduction. Routing lays down the flow of work in the plant. It determines what work is to be done and where and how it will be done. Taking from raw material to the finished product, routing decides the path and sequence of operations to be performed on the job from one machine to another. The purpose is to establish the optimum sequence of operations. Routing is related to considerations of layout,

temporary storage of in-process inventory and material handling.

Routing in continuous industries does not present any problem because of the product type of layout, where the equipment is laid as per the sequence of operations required to be performed on the components (from raw material to the finished products).

In open job shops, since, every time the job is new, though operation sheets (sometimes) may serve the purpose, but the route sheets will have to be revised and this involves a greater amount of work and expertise.

Routing Procedure. Various procedural steps are as follows :

(a) The finished product is analysed from the manufacturing standpoint in order to decide how many components can be made in the plant and how many others will be purchased (Make/Buy decision) from outside through vendors, by subcontracting, etc. Make/buy decision depends upon the work load in the plant, availability of equipment and personnel to manufacture all components, and the economy associated with making all components within the plant itself.

(b) A parts list and a bill of materials is prepared showing name of the part, quantity, material specifications, amount of materials required, etc. The necessary materials, thus, can be procured.

(c) From production standards—machine capacities, machine characteristics and the operations which must be performed at each stage of manufacture are established and listed in proper sequence on an operation and route sheet, (See fig. 7.27). The place where these operations will be performed is also decided.

Actually, operation sheet and route sheet are separate. An operation sheet shows every thing about the operations, i.e., operation description, their sequence, type of machinery, tools, set up and operation times, whereas a route sheet besides listing the sequence of operations and relation between operation and machine, also details the section (department) and the machines to whom the work will flow. First two columns of Fig. 7.27 are mainly those of route sheet which show the manufacturing route for given component.

OPERATION & ROUTE SHEET								
Component No.			Drawing					
Name of Component			Quantity					
Material			To be completed on					
ROUTING		OPERATION NO.	OPERATION DESCRIPTION	TOOLS REQD.	FIXTURES & OTHER ACCESSORIES	TIME		
SECTION	MACHINE					SET UP	OPERATION	TOTAL

Fig. 7.27. Operation and route sheet.

The difference between an operation sheet and a route sheet is that an operation sheet remains same for the components if the order is repeated but the route sheet may have to be revised if certain machines are already committed to other orders (jobs) on hand. Except this small difference, both the sheets contain practically the same information and thus are generally combined into one sheet known as 'operation and route sheet'.

(d) The next step is to determine the lot size or the number of components to be manufactured in one lot or batch. In the case of an order from a particular customer, it is generally equal to a number within 10% of the order quantity. In other cases the principle of economic batch quantity can be applied (refer Chapter 24) to determine the batch size.

(e) Standard scrap factors (single or cumulative) and the places (*i.e.*, after a particular operation or assembly) where scrap is very likely to occur are identified. The actual scrap in each batch can be recorded on the control chart. Causes for points out of control limits are explored and corrected. The variables like workers, machinery and schedules may also be adjusted to minimize scrap.

(f) The cost of the component is analysed and estimated through the information obtained in steps (a) to (e) above. The cost consists of material and labour charges, and other specific and general indirect expenses.

7.20. PROGRESS CONTROL

Introduction. Once the actual production has started, it becomes essential to keep an eye at the progress of the work so that, if required, timely corrective action can be taken. Progress control means—trying to achieve the standards set, *i.e.*, a certain level of efficiency or a certain volume of production in a specified duration. The system of progress control should be such that it furnishes timely, adequate and accurate information about the progress made, delays and under- or over-loading.

Steps Involved in Progress Control

(a) Setting up a system to watch and record the progress of the operating facility (production section).

(b) Making a report of the work progress or work accomplishment.

(c) Transmission of report to :

1. Control group for necessary control action, and
2. Accounting group for recording material and labour expenditures.

(d) Interpretation of the information contained in the progress report by the control group.

(e) Taking corrective action, if necessary.

The above-mentioned five steps have been briefly discussed as under :

(a) **System to Record the Work Accomplishment.** Progress charts are normally employed for this purpose. They compare the work progress against a prescribed target, and point out the failure to achieve the same; thus progress charts draw attention for an action or investigation.

The chart construction may have the following four forms :

1. The Bar chart,
2. The Curve chart,
3. The Gantt chart, and
4. Mechanical chart.

1. **The Bar Chart** (Fig. 7.28) consists of a number of bars. Each bar has its length proportional to the activity duration. A bar chart is generally used to point out and analyze interrelated data which otherwise is difficult to read.

2. **A Curve Chart** is a graph between two variables (like, number of days and number of items produced) marked along *X* and *Y* axis. As the days pass, the number of items being produced are marked over the graph. When all such points are joined they indicate the production trend (See Fig. 7.29).

Both the bar and curve charts show the past data. They are not readily adaptable to current or future action.

(c) **Follow Up or Expediting.** The manufacturing activity of a factory is said to be *in control* when the actual performance is as per the planned performance. Follow up or expediting regulates the progress of materials and the components through the production process. Follow up serves as a catalytic agent to fuse the various separate and unrelated production activities into the unified whole that means progress. Follow up is concerned with the reporting of production date and the investigating of any deviation from the predetermined production (or time) schedules. Follow up ensures that the promise (*i.e.* of delivery dates) is backed up by performance.

— The work within the organisation can be expedited by the following two principles :

- (i) The exception principle, and
- (ii) The fathering principle.

In *exception principle*, the scheduling group (on the basis of progress reports), explores the jobs behind the schedule. The expediting group takes up such jobs, procures necessary materials, tools, etc., *i.e.*, (expediting group) solves all problems related to these jobs and intimates the scheduling group to reschedule them.

According to *fathering principle* each expeditor is made responsible for a job or a group of jobs for which he arranges the tools, materials, equipment, etc. Such a system works very well for controlling large projects.

7.21. FLOW CONTROL OF MATERIAL, COMPONENT PARTS AND SUBASSEMBLIES TO MATCH THOSE OF FINISHED (FINAL) PRODUCT

The function of Flow (Production) Control is to match up the rates of flow of parts, subassemblies and final assemblies. Each part should be ready before the time of subassembling and each subassembly should be made available at the time and place of assembly in order to make the final product. Flow control achieves this by keeping the parts and subassemblies flowing to the assembly line.

Flow control can be perfected through the following :

(a) **Operation Time.** It amounts the time required to manufacture each part, to make one subassembly and to execute one assembly. This information can be had from the operation sheet.

(b) **Line Balancing.** The assembly line should be balanced, (refer Chapter 4). Each work station should have the same operating time and the various operations should be sequenced properly. There should be perfect balance between the output rates of the parts and the subassemblies. However, it is not always possible that the parts reach in a steady stream immediately before subassembly. This may be because of the limitations as regards materials, men and equipments or it may be economical to manufacture and supply parts in batches. The flow control section has to cope with such situations and thus carry big inventories and arrange facilities for storage.

(c) **Routing and Scheduling.** A combination route and schedule chart showing the fabrication of parts subassemblies and final assembly (See Fig. 7.32) in proper sequence, upon a time scale proves to be very advantageous, especially, when there is smooth flow of work. The chart shows that the fabrication of parts *V* and *W* starts on the 4th day and the work on parts *U*, *X*, *Y*, and *Z* is taken up on the fifth day. All the components should be ready to make subassembly at the beginning of the 8th day and subassemblies should be made available for the assembly of final product on the 12th day. The assembly is over at the end of 13th day and the final product can be shipped on the 14th day.

Knowing the delivery date and the time required to fabricate each part, subassembly and assembly, the chart can be worked out from right to left. Thus obtained date for starting the fabrication of parts and then modified in the light of existing shop loading conditions (known from Production board or Scheduling-Graph, (section 7.14) is used to arrive at the actual date to start the manufacture of each part.

10.1. INTRODUCTION

Planning by network analysis, probably, got recognition in the year 1955 when dramatic reductions in time (about 70%) were experienced in connection with the overhaul of generating plant by Central Electricity Generating Board in Great Britain.

Network analysis is a system which plans projects both large and small by analysing the project activities. Projects are broken down to individual tasks or activities, which are arranged in logical sequence. It is also decided as which tasks will be performed simultaneously and which others sequentially. A network diagram is constructed, which presents visually the relationship between all the activities involved. Time, costs and other resources are allocated to different activities.

Network analysis helps designing, planning, coordinating, controlling and in decision making in order to accomplish the project economically in the minimum available time with the limited available resources.

Network techniques were developed from the Milestone chart and Bar chart. These conventional planning methods, because of their inherent limitations could not be utilized for planning large and complex projects. They had the following *Disadvantages*:

- (a) A bar chart becomes too cumbersome while dealing with big and complex projects when the activities are to be considered in detail and their interaction or interdependencies are to be studied clearly.
- (b) A bar chart does not point out as which tasks should be given priorities as regards the resources (*i.e.*, men, money, materials, and machinery).
- (c) The effects of changes in schedule cannot be evaluated with the help of a bar chart.
- (d) A bar chart neither satisfactorily tells the times at which the activities begin and end nor it indicates tolerances in activity timings.
- (e) A bar chart does not show the continuing interrelationship of the activities, especially if the number of activities is large and they change in time scale and resources.
- (f) A bar chart does not predict satisfactorily, well in advance the effects of inevitable snags and thus a corrective action cannot be taken in time.
- (g) Bar charting is simply a scheduling operation, whereas network techniques plan as well as schedule.
- (h) A bar chart does not normally indicate work progress, which is very essential.

10.2. NETWORK TECHNIQUES

A number of network techniques have been developed and a few of them are named below :

1. P.E.R.T. : Programme Evaluation and Review Technique.
2. C.P.M. : Critical Path Method.
3. R.A.M.S. : Resource Allocation and Multiproject Scheduling.
4. P.E.P. : Programme Evaluation Procedure.
5. C.O.P.A.C. : Critical Operating Production Allocation Control.

6. M.A.P. : Manpower Allocation Procedure.
7. R.P.S.M. : Resource Planning and Scheduling Method.
8. L.C.S. : Least Cost Scheduling.
9. M.O.S.S. : Multi-operation Scheduling System.
10. P.C.S. : Project Control System.
11. G.E.R.T. : Graphical Evaluation Review Technique.

The most commonly known and used Network Techniques are PERT and CPM; and they will be discussed in brief.

10.3. TERMS RELATED TO NETWORK PLANNING METHODS

(a) **Event.** An event is a specific instant of time which marks the start and the end of an activity. Event consumes neither time nor resources. It is represented by a circle and the event number is written within the circle (Fig. 10.1). Event and node are synonyms. Examples of events are--start the motor, loan approved, etc.

(b) **Activity.** Every project consists of a number of job operations or tasks which are called activities. An activity is an element of project and it may be a process, a material handling or material procurement cycle, etc. For example, 'Instal machinery', 'Arrange foreign exchange' are activities.

An activity is shown by an arrow and it begins and ends with an event. Unlike event, an activity consumes time and resources. An activity may be performed by an individual or a group of individuals. An activity is normally given a name like, A, B, C, etc., which is marked below the arrow and the estimated time to accomplish the activity is marked above the arrow (Fig. 10.1).

Activities are classified as :

(i) **Critical activities.** In a network diagram, critical activities are those which if consume more than their estimated time, the project will be delayed. An activity is called critical if its earliest start time plus the time taken by it is equal to the latest finishing time. A critical activity (e.g., A, C or E) is marked either by a thick arrow or as in Fig. 10.1, to distinguish it from a non-critical activity.

(ii) **Non-critical activities.** Such activities have provision (float or slack) so that, even if they consume a specified time over and above the estimated time, the project will not be delayed. In Fig. 10.1, activities B and D are non-critical activities.

(iii) **Dummy activities.** When two activities start at the same instant of time (like activities C and D in Fig. 10.1), the head events are joined by a dotted arrow and this is known as a dummy activity (activity F in Fig. 10.1). Dummy activity does not consume time. A dummy activity may be non-critical or critical. It becomes a critical activity when its earliest start time (EST) is same as its latest finishing time (LFT).

(c) **Critical Path.** It is that sequence of activities which decide the total project duration. Critical path is formed by critical activities. In Fig. 10.1, path 1-2-4-5 is the critical path. A critical path consumes maximum resources. It is the longest path and consumes maximum time. A critical path has zero float. The expected completion dates cannot be met, if even one critical activity is delayed. A dummy activity joining two critical activities is also a critical activity. A critical path reveals those activities which must be manipulated by some means or the other if the scheduled completion dates are to be met.

(d) **Duration.** Duration is the estimated or actual time required to complete a task or an activity.

(e) **Total project time.** It is the time which will be taken to complete a project and is found from the sequence of critical activities. In other words it is the duration of critical path.

(f) **Earliest start time (EST).** It is the earliest possible time at which an activity can start and is calculated by moving from first to last event in a network diagram (Fig. 10.1).

(g) **Earliest finish time (EFT).** It is the earliest possible time at which an activity can finish.

$$EFT = EST + \text{duration of that activity.}$$

(h) **Latest finish time (LFT)**. It is calculated by moving backward, i.e., from last event to first event of the network diagram. It is the last event time of the head event.

(i) **Latest start time (LST)**. It is the latest possible time by which an activity can start.

$$LST = LFT - \text{duration of that activity.}$$

Example 10.1 explains the method of calculating *EST*, *EFT*, *LFT* and *LST*.

(j) **Float or slack**. Slack is with reference to an event and float is with respect to an activity. In other words, slack is used with PERT and float with CPM--but in general practice, they may be used interchangeably. It may be float or slack, it means spare time, a margin of extra time over and above its duration which a non-critical activity can consume without delaying the project. Float is the difference between the time available for completing an activity and the time necessary to complete the same.

(i) **Total Float**. It is the additional time which a non-critical activity can consume without increasing the project duration. However, total float may affect the floats in previous and subsequent activities.

$$\text{Total float} = (LST - EST) \text{ or } (LFT - EFT) \text{ and it can be negative also.}$$

(ii) **Free Float**. If all the non-critical activities start as early as possible, the surplus time is the free float. Free float if used, does not change the float in later activities. In other words if an activity is delayed by the free float period, the succeeding activity will not be delayed, in turn.

$$\text{Free float} = EST \text{ of tail event} - EST \text{ of head event} - \text{activity duration.}$$

(iii) **Independent Float**. The use of independent float of an activity does not change the float in other activities. Independent float can be used to advantage if one is interested to reduce the effort on a non-critical activity in order to apply the same (effort) on a critical activity thereby reducing the project duration. The independent float associated with an activity is not reduced by delaying previous operations whereas such a reduction can be noticed with free float.

$$\text{Independent float} = EST \text{ of tail (succeeding) event} - LFT \text{ of head (preceding) event} - \text{activity duration.}$$

Independent float, if it turns out to be negative, is taken as zero.

(k) **Network diagram or Arrow diagram**. Network diagram is the basic feature of network planning. It is a diagram (Fig. 10.1) which represents all the events and activities in sequence (in which they are required to be performed to complete the project), along with their interrelationships and interdependencies.

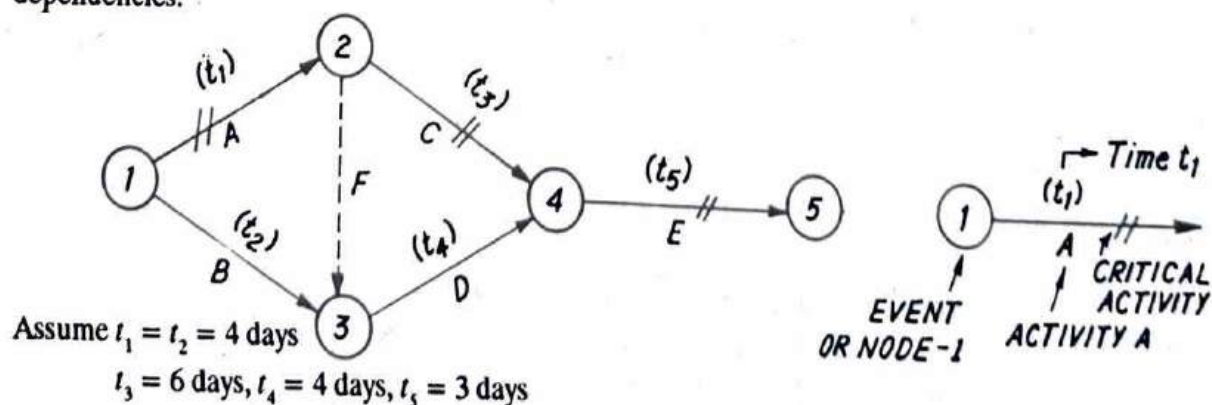


Fig. 10.1. Network (Arrow) diagram.

Arrow diagram is the visual presentation of the complete task (activities) by means of arrows. It is the most frequently used form of network diagram where every activity is represented by an arrow and the activity sequences are indicated by the direction of arrows. For example, Fig. 10.1 shows that activity C and D can start only after A and B are complete. Dotted arrow (dummy activity) shows that A and B finish at the same time (i.e., $t_1 = t_2$) and C and D start at the same time. There are two paths to complete the project and they are 1-2-4-5 or 1-3-4-5.

In an arrow diagram, the length or the inclination of the arrow does not have any significance.

Arrow diagrams are very useful as they provide detailed information for making decisions in connection with large and complex projects.

Example 10.1. A small engineering project consists of 6 activities namely *A, B, C, D, E* and *F* with duration of 4, 6, 5, 4, 3 and 3 days respectively. Draw the network diagram and calculate *EST, LST, EFT, LFT* and floats. Mark the critical path and find total project duration.

Solution :

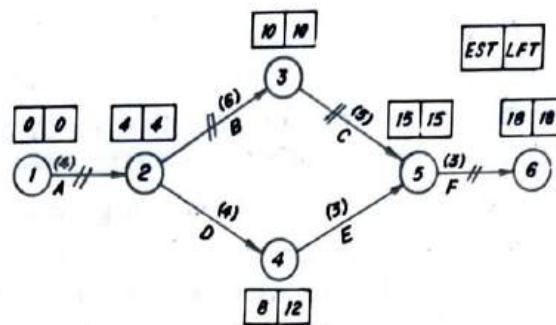


Fig. 10.2. Network diagram.

(1) *EST* is calculated by starting from event-1, i.e., activity *A* and giving it a time 0 (*EST*).

Now *EST* of activity *B* = 0 + duration of activity *A* = 4

EST of activity *C* = *EST* of activity *B* + duration of activity *B* = 4 + 6 = 10 and so on.

EST of activity *F* can be found by following two paths, i.e., 1-2-3-5 and 1-2-4-3. The path 1-2-3-5 gives 15th day whereas the path 1-2-4-5 estimates 11th day as *EST* of activity *F*.

TABLE 10.1

Activity	Duration (days)	EST	LST	EFT	LFT	Total Float	Free Float	Independent Float
A	4	0	0	4	4	0	0	0
B	6	4	4	10	10	0	0	0
C	5	10	10	15	15	0	0	0
D	4	4	8	8	12	4	0	0
E	3	8	12	11	15	4	4	0
F	3	15	15	18	18	0	0	0

Col. 1	Col. 2	Col. 3 from N.W. diagram	Col. 4 <i>LFT</i> - <i>D</i>	Col. 5 <i>EST</i> + <i>D</i>	Col. 6 from N.W. diagram	Col. 7 <i>LST</i> - <i>EST</i> or <i>LFT</i> - <i>EFT</i>
--------	--------	-----------------------------------	------------------------------------	------------------------------------	-----------------------------------	--

Naturally the bigger value (15) is selected because until activity *C* is completed which ought to finish on 15th day, activity *F* cannot be started.

EST for other activities is calculated by proceeding similarly, in the forward direction from the first event to the last event.

(2) *LFT* is calculated in a similar manner as *EST* but by proceeding backward from the last event to

the first one. For example

LFT for activity $F=18$

LFT for activity C and $E=18$ —duration of activity $F=15$

LFT for activity $D = LFT$ for activity E —duration of activity E
 $= 15-3=12$ and so on.

(3) LST for each activity is calculated from the relation,

$LST=LFT$ of an activity—duration of that activity.

For example, LST of activity $D=12-4=8$.

(4) EFT for each activity is calculated from the relation

$EFT=EST$ of an activity+duration of that activity.

For example, EFT of activity $D=4+4=8$.

(5) Total float= $(LST-EST)$ or $(LFT-EFT)$

For example, total float for activity

$D=(8-4)$ or $(12-8)=4$.

(6) Free float= EST of tail event— EST of head event—activity duration.

For example, free float for activity D (Fig. 10.2)

$= 8-4-4=0$

(7) Independent float= EST of tail event— LFT of head event—activity duration.

For example, Independent float for activity D

$= 8-4-4=0$

(8) Critical path is one which consumes maximum time and it is 1-2-3-5-6. The total project duration, therefore, is

$4+6+5+3=18$ days.

10.4. PROGRAMME EVALUATION REVIEW TECHNIQUE (PERT)

Introduction. PERT was first used in 1957 as a method of planning and controlling the Polaris Missiles Programme by Booz, Allen and Hamilton together with U.S. Naval department. The aim was to finish the project two years in advance. PERT describes basic network technique which includes planning, monitoring and control of projects. PERT finds applications in planning and control of complex set of tasks, functions and relationships. It is a very important technique in the field of project Management. PERT is commonly employed for conducting the initial review of a project. PERT is a very useful device for planning the time and resources. It represents an important step in the development of managerial science. It points out potentially troublesome areas (which may disrupt programme objectives) against which a timely action can be taken to prevent their occurrences. PERT helps in decision making.

PERT, actually, developed as a research and development planning tool where activity timings could not be estimated with enough certainty. To some extent a similar situation occurs in design work also. PERT can be employed at those places where a project cannot be easily defined in terms of time or resources required. Of course, events can be readily defined which means it is known that, first, part A will be manufactured, only then subassembly S can be built and so on. PERT technique proves very much advantageous when used for non-repetitive type of projects, $R \ \& \ D$, prototype production, defence projects, etc.

Because of the uncertainty of activity timings, PERT acquired the shape of a probabilistic model. It uses linear programming and probability concepts for planning and controlling activities. Probability concept helps in estimating activity timings ; and the maximization of (attainment of) the predefined

objectives is achieved through the Linear programming feature of PERT. The statistical probability feature of PERT foretells the probability of reaching the specified target dates. PERT is mainly concerned with events and is thus an event-oriented system.

The basic tool used in PERT technique is the network or flow plan. Network consists of a series of related events and activities. An important point is that, as a person plans the activities in his mind, so the flow plan (or diagram) evolves and, it even points out the gaps in the drawing. The network thus drawn shows, how various activities of a project depend on each other and that certain activities have to be completed before the others can start.

Techniques. The PERT planning technique consists of the following steps:

- (1) The project is broken down into different activities systematically.
- (2) Activities are arranged in logical sequence.
- (3) The network diagram is drawn. Events and activities are numbered.
- (4) Using three times estimate, the expected time for each activity is calculated.
- (5) Standard deviation and variance for each activity are computed.
- (6) Earliest starting times and latest finishing times are calculated.
- (7) Expected time, earliest starting time, and latest finishing times are marked on the network diagram.
- (8) Slack is calculated.
- (9) Critical path(s) are identified and marked on the network diagram.
- (10) Length of critical path or total project duration is found out.
- (11) Lastly, the probability that the project will finish at due date is calculated.

Example 10.2 explains in detail the PERT planning technique.

Example 10.2 : A small engineering project consists of 9 activities. Three time estimates for each activity are given in Table 10.2.

- (a) Calculate values of expected time (t_e), standard deviation (S_e) and variance (V_e) for each activity.
- (b) Draw the network diagram and mark t_e on each activity.
- (c) Calculate *EST* and *LFT* and mark them on the network diagram.
- (d) Calculate total slack for each activity.
- (e) Identify the critical path(s) and mark on the network diagram.
- (f) Find the length of critical paths or the total project duration.
- (g) Calculate variance of critical path.
- (h) Calculate the probability that jobs on critical path will be finished by the due date of 38 days.
- (i) Calculate the approximate probability that the jobs on the next most critical path will be completed by the due date of 38 days.
- (j) Estimate the probability that the entire project will be completed by the due date of 38 days. Explain it.
- (k) If the project due date changes to 35 days what is the probability of not meeting the due date.
- (l) Find the due date which has a probability of 94.5% of being met.

Solution : The concept of expected time and the estimation of variability of activity times (which is necessary before solving the problem) is given below.

1. Estimation of Activity Time. For dealing with uncertainties associated with different activities, PERT approach computes expected time for each activity from the following three time estimates :

- (a) *Optimistic time* (t_o). It is the shortest possible time in which an activity can be completed if everything goes exceptionally well.

(b) *Most likely time* (t_m). It is the time in which the activity is normally expected to complete under normal contingencies.

(c) *Pessimistic time* (t_p). It is the time which an activity will take to complete in case of difficulty, i.e., if mostly the things go wrong. It is the longest of all the three time estimates.

The t_o , t_m and t_p are combined statistically to develop the expected time (t_e) for an activity. The fundamental assumption in PERT is that the three time estimates form the end points and mode of Beta distribution (Fig. 10.3). It is further assumed that t_p and t_o are about equally likely to occur whereas the probability of occurrence of t_m is 4 times that of t_p or t_o .

Therefore, t_e is given by,

$$t_e = \frac{t_o + (t_m \times 4) + t_p}{6} \quad \dots(i)$$

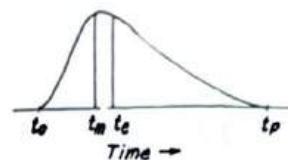


Fig.10.3. PERT time estimates - Beta distribution.

(2) **Estimation of Variability of Activity Times.** The purpose is to find, how reliable - ' t_e ' as got from equation (1) is

Assume

Case I

$$t_o = 5$$

$$t_m = 6$$

$$t_p = 7$$

$$t_e = \frac{5 + (6 \times 4) + 7}{6}$$

$$t_e = 6$$

$$t_e = t_m$$

Case II

$$t_o = 5$$

$$t_m = 10$$

$$t_p = 21$$

$$t_e = \frac{5 + (10 \times 4) + 21}{6}$$

$$t_e = 11$$

$$t_e \text{ is not equal to } t_m$$

This indicates that, if the time required for an activity shows high variability (Case II) and there is wide range of (21-5=16) three times estimates, the certainty and confidence to correctly anticipate the actual time from relation (1) decreases and thus the need to measure the variability in the time of an activity arises. Knowing the variability, the reliability of t_e values can be assessed. PERT, using statistical probability concept, employs standard deviation (S) and variance (V) as measures of variability. They are given by,

$$S_t = \left[\frac{t_p - t_o}{6} \right] \quad \dots(2)$$

$$V_t = \left[\frac{t_p - t_o}{6} \right]^2 = (S_t)^2 \quad \dots(3)$$

Thus for cases I and II above

$$(S_t)_1 = \left[\frac{7 - 5}{6} \right] = \frac{1}{6} ; (S_t)_2 = \frac{21 - 5}{6} = 2.66$$

$$(V_t)_1 = \left[\frac{1}{6} \right]^2 = \frac{1}{36} ; (V_t)_2 = 7.1$$

This supports the above concept.

Coming to the actual problem :

(a) the Table 10.2 gives the values of t_o , t_m and t_p for each activity. The values of t_e , S_t and V_t are calculated by using equations (1), (2), and (3) and have been added in the Table 10.2.

Path (b) involves much less time, so its probability of completing in 38 days is very high.

Paths (a) and (c) are independent of each other and the probabilities of paths (a) and (c) to complete in due time of 38 days are 0.841 and 0.888 respectively. Therefore the probability of their both being completed in 38 days is $= 0.841 \times 0.888 = 0.7468$.

$$(k) \text{ Again } Z = \frac{D - T_e}{S_t} = \frac{35 - 33}{5} = 0.4$$

From Table 10.4 for $Z = 0.4$, the probability of meeting due date is 0.655; and hence the probability of not meeting the due date

$$= 1 - 0.655 = 0.345$$

(l) From Table 10.4, for the probability of 94.5% or 0.945, the value of $Z = 1.6$

$$\text{and } Z = \frac{D - T_e}{S_t}, \text{ therefore } 1.6 = \frac{D - 33}{5}$$

and thus $D = 41$ days.

10.5. CRITICAL PATH METHOD (CPM), CRITICAL PATH PLANNING (CPP), CRITICAL PATH ANALYSIS (CPA)

Introduction. The E.I. du Point de Nemours Company (USA) in the year 1958 while overhauling a chemical plant employed a technique called Critical Path Method to schedule and control the project and experienced a good amount of saving. Unlike PERT, CPM developed in civilian business and engineering industry where activity timings were relatively well known.

CPM is applicable to both large and small projects, taking from space programmes to wedding or horse shows. It is widely recognized and is the most versatile and potent management planning technique.

CPM is a technique, used for planning and controlling the most logical and economic sequence of operations for accomplishing a project. The project is analysed into different activities whose relationships, as in PERT, are shown on the network diagram. The network is then utilized for optimising the use of resources, progress and control.

Difference between PERT and CPM. The fundamental network of PERT and CPM are though identical, yet there are (certain) differences in details as mentioned below :

PERT

- (1) A probabilistic model with uncertainty in activity duration. Expected time is calculated from t_o , t_m and t_p .
- (2) An event-oriented approach.
- (3) PERT terminology uses words like network diagram, events, and slack.
- (4) The use of dummy activities is required for representing the proper sequencing.
- (5) PERT basically does not demarcate between critical and non-critical activities.
- (6) PERT finds applications in projects where resources (men, materials and specially money) are always made available as and when required.

CPM

- A deterministic model with well-known activity (single) times based upon past experience. It assumes that, the expected time is actually the time taken.
- An activity-oriented system.
- CPM terminology employs words like arrow diagram, nodes, and float.
- The use of dummy activities is not necessary. The arrow diagram thus becomes slightly simpler.
- CPM marks critical activities.
- CPM is employed to those projects where minimum overall costs is of primary importance. There is better utilization of resources.

- (7) Especially suitable in defence projects and R & D where activity times cannot be reliably predicted.

Suitable for problems in industrial setting, plant maintenance, civil construction projects, etc.

Technique. CPM employs the following steps for accomplishing a project planning.

- (1) Break down the project into various activities systematically.
- (2) Label all activities.
- (3) Arrange all the activities in logical sequence.
- (4) Construct the arrow diagram.
- (5) Number all the nodes (events) and activities.
- (6) Find the *time* for each activity.
- (7) Mark the activity times on the arrow diagram.
- (8) Calculate early and late, start and finishing times.
- (9) Tabulate various times and mark EST and LFT on the arrow diagram.
- (10) Calculate total float for each activity.
- (11) Identify the critical activities and mark the critical path on the arrow diagram.
- (12) Calculate the total project duration.
- (13) If it is intended to reduce the total project duration, *crash* the critical activities of the network.
- (14) *Optimise the cost*
- (15) *Update the Network*
- (16) *Smooth the network resources.*

Example 10.3 explains CPM technique in detail.

Example 10.3 : It is required to fabricate tanks for an electroplating shop. The activities involved are as follows :

(a) Order material for the tanks, (b) Await delivery of the material, (c) Collect tooling equipment for tank fabrication, (d) Fabricate the tanks, (e) Test the tanks against leakage, (f) Obtain precut rubber lining from the market, (g) Fix lining on the inside of the tanks, and (h) Paint the tanks from outside.

Using the activities listed above construct an arrow diagram for the fabrication of tanks and explain in detail the CPM-planning scheduling and control technique.

Solution : From the given data, the following arrow diagram has been constructed (Fig. 10.5)

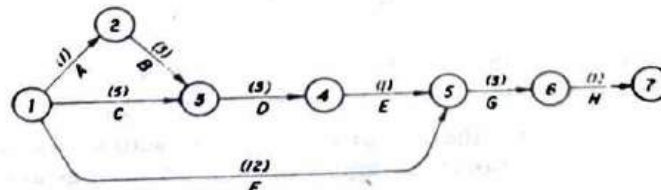


Fig. 10.5. Arrow diagram.

E. 10.3 (a). ESTIMATING ACTIVITY TIME (DURATION)

After the arrow diagram has been drawn and various activities marked on the same, the next step is to estimate time for each activity. The time estimate should be as realistic as possible and preferably based upon past experience, i.e., time values can be taken from similar/same activities accomplished earlier. Estimation of duration is no problem for an experienced estimator, but for a new person if past data is not available, it is better to use PERT technique for estimating time. The estimator after consulting