Production Planning and Control

10.1 INTRODUCTION

The efficiency of a production system can be improved by manufacturing the required quantity of the product of the right quality at the right time by the cheapest method of production. Production planning and control (PPC) is a tool to coordinate all the manufacturing activities and looks after the manufacturing activities. Broadly, PPC consists of planning, routing and dispatching in the manufacturing process. Planning and control are two basic and interrelated managerial functions. They are so interrelated that they can be considered as being one function. Planning is the preparation activity while control is the post-operation function. Planning sets the objectives, goals, targets on the basis of available resources with their given constraints. Similarly, control involves assessment of the performance; such an assessment can be done effectively only when some standards are set in advance. Planning involves setting up to such standard. The controlling is made by comparing the actual performance with these present standard and deviations are ascertained and analysed.

Production is an organized activity of converting raw materials into useful products, but before starting that work of actual production, production planning is done in order to anticipate possible difficulties and decide in advance as to how production should be carried out in the best and economical way. Since only the planning of production is not sufficient, hence the management takes all possible steps to see that project or plan chalked by the planning department are properly adhered to and the standards set and are attained in order to achieve it. At the same time, control over production is exercised. The aim of production control is to produce the products of the right quality, in the right quantity at the right time by using the best and least expensive methods. The major functions of PPC are shown in Figure 10.1.

Process planning is a process of routing and preparation of route sheet. Scheduling is the part of planning and concerned with the schedule when an activity will start and when the same will be finished. Loading is a prose of assigning the jobs to the machines and the personal. While it is easy to define 'where' as process planning, 'how much work' as loading, and 'when as scheduling' separately, but in actual operations these three functions are often combined and performed concurrently. Dispatching is the execution of the planned functions. It is action and controlling phase of the PPC. Reporting or follow-up is the activity to follow the planned activity and report it. The manufacturing activity of a plant is said to be 'in control' when the actual performance is within the objectives of the planned performance. Corrective action is a controlling activity. A plant in which all manufacturing activity runs on schedule in all probability is not

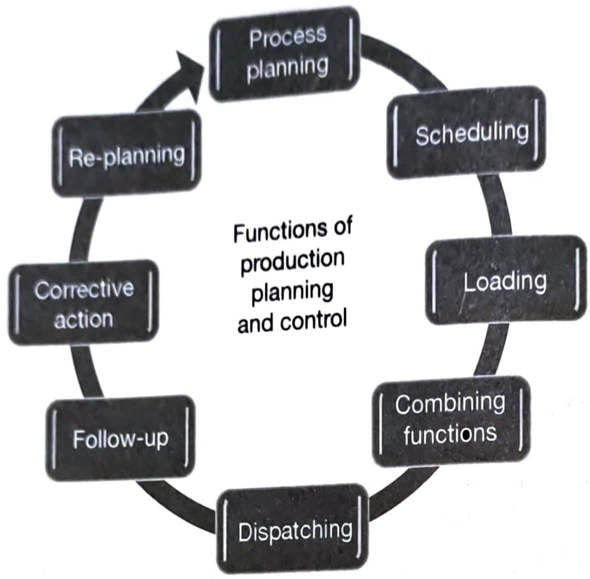

Figure 10-1: Functions of production planning and control

being scheduled to its optimum productive capacity. With an optimum schedule, manufacturing delays are the rule, not the exception. Re-planning revises routes, loads and schedules; a new plan is developed, if it is required. All the above PPC functions can be grouped into three classes: planning phase, action phase and controlling phase as shown in Figure 10.2.

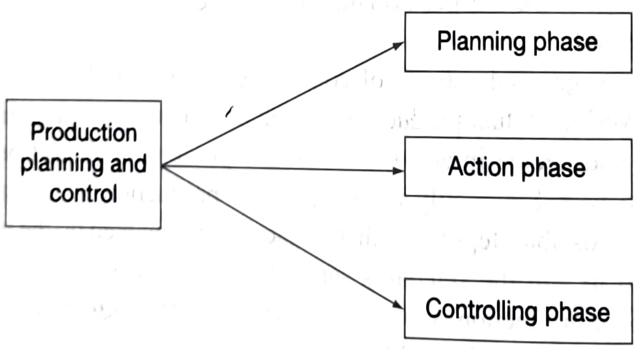

Figure 10-2: Three phases of production planning and control

10.2 OBJECTIVES OF PRODUCTION PLANNING AND CONTROL (PPC)

The objectives of PPC are enumerated as follows.

1. To utilize the resources effectively.
2. To ensure the steady flow of production.
3. To estimate the resources.
4. To ensure optimum inventory.

5. To coordinate activities of the departments.
6. To minimize wastage of raw materials.
7. To improve the labour productivity.
8. To help capture the market.
9. To provide a better work environment.
10. To facilitate quality improvement.
11. To improve the consumer satisfaction.
12. To reduce the production costs.

Now let us discuss each objective of production planning one by one.

10.3 PRODUCTION PLANNING

The production planning and control again can be subdivided into preplanning, planning and control phases. The activities of preplanning, planning and control may be considered to take place in a time sequence. The preplanning is completed before production. Planning takes place immediately before the start of production and control is exercised during production. The main operational functions under preplanning are forecasting, order writing and product design. Similarly, the operational functions under planning phase are process planning and routing, material planning and control, tool control, loading, and scheduling. In the control phase, the main operational functions are dispatching. These operational functions are shown in Figure 10.3.

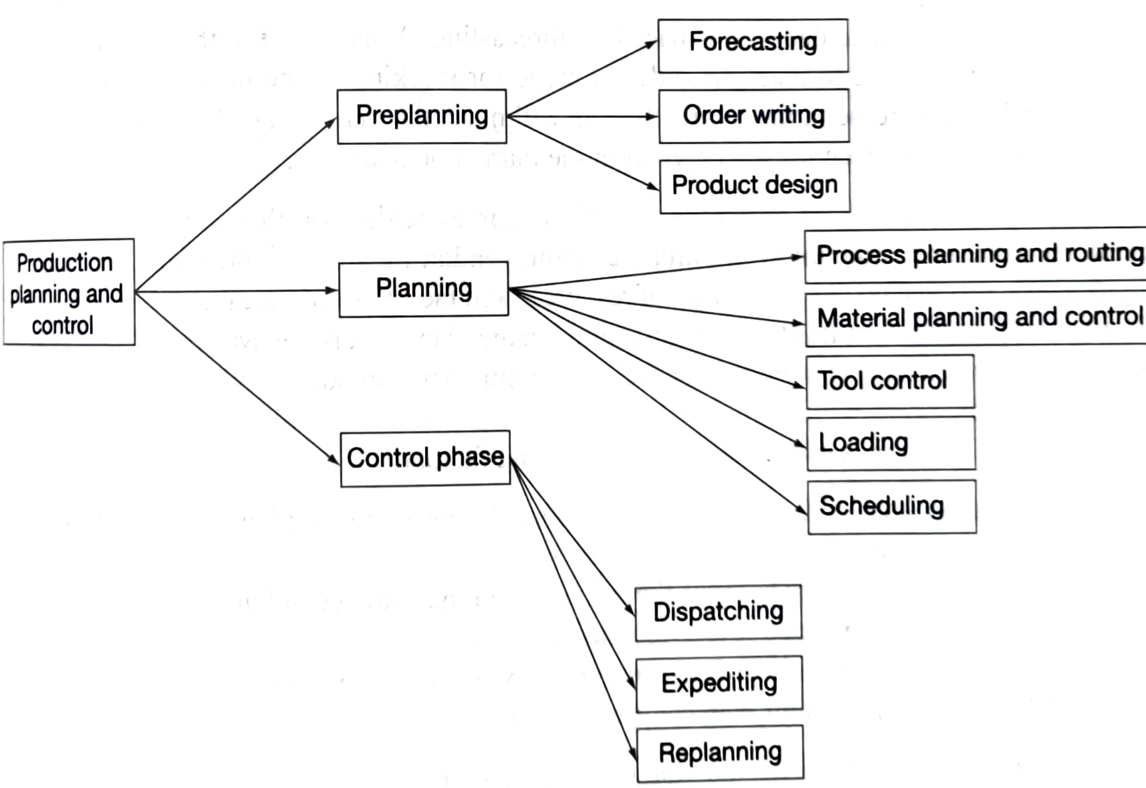

Figure 10-3: Preplanning, planning and control phases

Preplanning

It is the procedure followed in developing and designing a work or production of a developing and installing a proper layout or tools. It may involve many functions of the organization and draws upon forecasting, product design, jigs and tool design, machine selection and estimating to enable the proper design to be made. In short, preplanning decides what shall be made and how it shall be made. In respective manufacturing, a large uneconomic output could be produced if preplanning is not done in an effective manner.

Forecasting: It is an important function before planning. It may be sales forecasting, technology forecasting or demand forecasting. It sets a target before starting the production activities, i.e. what and how much should be produced. Forecasting has already been discussed in detail in Chapter 3 in this book.

Order writing: It is a process to authorize one or more persons to take charge of a particular job or task.

Product design: It is another important process. Product design and development has already been discussed in detail in Chapter 7 in this book. Once a product is designed, it prevails for a long time, therefore various factors are to be considered before designing it. These factors are standardization, reliability, maintainability, servicing, reproducibility, sustainability, product simplification, quality commensuration with cost, product value, consumer quality and needs and tastes of consumers.

Volume decision: Volume decision is based on forecasting. Also, it is seen that it is decided on the basis that it is made to meet the order or made for stocking. If the manufacturer observes that demand will increase in the future, then he will make the items in stock; otherwise, he will manufacture only on receiving the order from the market or customers.

Make or buy decision: After designing a product, it is to be decided that what are to be made inside the plant and what are to be purchased from vendor, i.e. make or buy decision. Make or buy decision is based on the availability of resources and facility inside the plant. If it is available in sufficient amount, then it is to be manufactured in the plant. If it is not available, then it is to be observed the availability of vendors for the same components or subassembly and to be bought from the vendor.

The make decision is influenced by the following factors:

1. The lower cost of the components because the firm does not have to pay for vendor's overhead or profit.
2. Improved availability because the firm does not have to depend on vendors.
3. Better quality control of the components.
4. Availability of manufacturing resources to produce the components.
5. Maintaining the design secrecy or trade secrecy.

The buy decision is influenced by the following factors:

1. The provision of lower cost, higher quality with faster delivery by the vendor.
2. Requirement of special machine to produce that item.

3. Purchasing cost is lower than the manufacturing cost.
4. Holding the patent of manufacturing of that item by the vendor.
5. Ability of the vendor to meet the buyer's need regarding quality, quantity, price and delivery period.

Planning

This stage decides where and when the product shall be made. It includes the sequencing of operations, routing and the time schedule for manufacturing. It also states procedures for material planning and supplies, machine loading and deliveries. To perform the functions properly, it will need past records of performance and to control statistic which may be obtained from pre-planning, cost control or progress.

Routing: Under this function, the path and sequence of operations are established. To perform these operations, the proper class of machines and personnel required are also worked out. The main aim of routing is to determine the best and cheapest sequence of operations and to ensure that this sequence is strictly followed. The main aim of the sequencing of jobs on different machines is to minimize the idle time on the machines. The details of the sequencing with the Johnson's rule has been discussed in Chapter 17 in this book.

Route sheet: It is a document providing the information and instruction for converting the raw materials into finished products. It defines each step of the operation and the paths through which the product or job will follow during the operations. Route sheet consists of the following information:

1. The required operations and desired sequence
2. Machines or equipments to be used
3. Set-up time and operation time
4. The required tools, jigs and fixtures
5. Detailed drawing of pars, sub-assemblies and final assemblies
6. Design specifications of the product
7. Specification of raw material to be used
8. Manufacturing and operations parameters and their specifications
9. Inspection procedure and metrology tools used for inspection
10. Packing and handling instruction of the parts or sub-assemblies.

Estimating: Estimating is concerned with the requirement of resources required to produce an item. When production orders and detailed operation sheet are available with specification feeds, speed and use of auxiliary attachments and method, the operation time can be worked out. It may consequently result in wide scatter of operation times and unduly large fluctuations and perhaps instabilities in time schedules. Estimating manpower, machine capacity and materials required meeting the planned targets are the key activities before budgeting for resources.

Loading: Loading is the process of assigning specific jobs to the machines, men or work centre on relative priorities and capacity utilization. It ensures maximum utilization of resources such as men and machines and avoid bottlenecks in production. Overloading and underloadings are avoided. The load chart can be shown using Gantt chart as shown in Figure 10.4. Using the Gantt load chart, it can be observed that when the machines are busy and are available or unscheduled. It also shows that when machines are not available due to the certain reason like a breakdown or repairing activity.

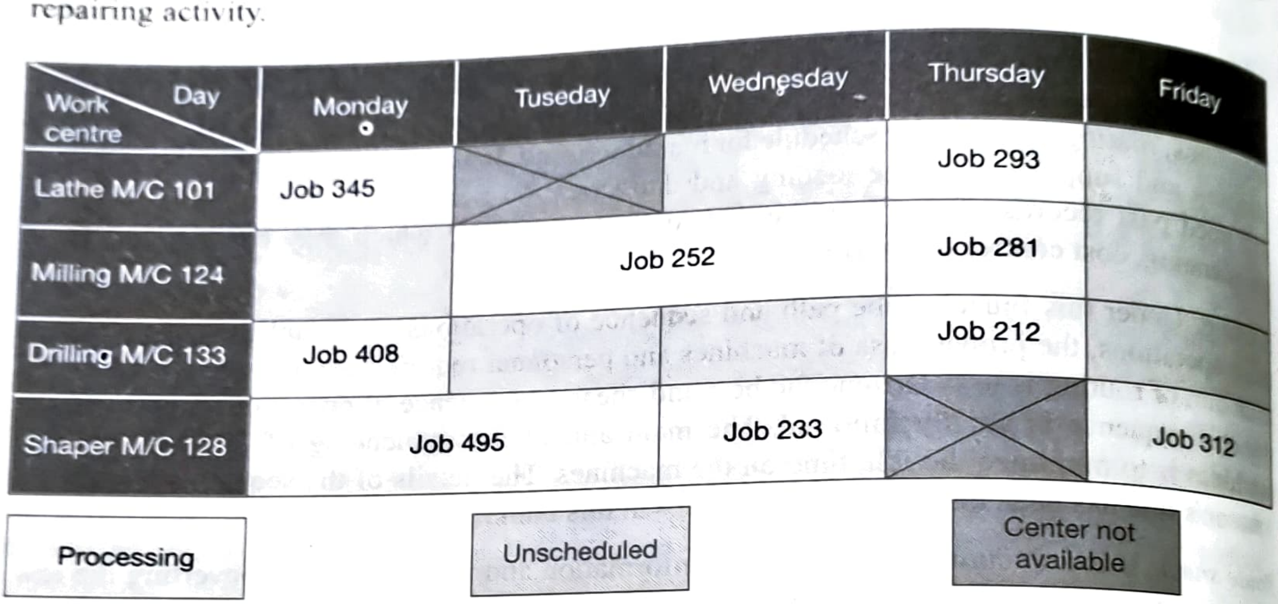

Figure 10-4: Gantt load chart

Scheduling: Scheduling provides the information that when an activity will start and when the same will be finished. It ensures that the products are completed as per the schedule. It means working out of time that should be required to perform each operation and also the time necessary to perform the entire series as routed. It mainly concerns with time element and priorities of a job. It is not an independent decision as it takes into account the following factors.

1. Physical plant facilities of the type required to process the material being scheduled.
2. Personnel who possesses the desired skills and experience to operate the equipment and perform the type of work involved.
3. Necessary materials and purchased parts.

Forward and backward scheduling: Forward scheduling starts just the requirements are known and produces a feasible schedule, though it may not meet the due dates. It frequently results in excessive work-in-process inventory. Backward scheduling begins from the due date and schedules the final operation first. It is produced by working backward through the processes. Resources may not be available to accomplish the schedule.

Master schedule: Scheduling starts with preparation of master schedule which is weekly or monthly breakdown of the production requirement for each product for a definite time period by having this as a running record of total production requirements. The entrepreneur is in a better position to shift the production from one product to another as per the changed production requirements. A master schedule is followed by the operator schedule which fixes the total time required to do a piece of work with a given machine or which shows the time required to do each detailed operation of a given job with a given machine or process.

Scheduling can be shown on the Gantt chart as shown in Figure 10.5. The various symbols have been used in this chart. ┌ is used to start an activity; ┐ is used to end an activity; ┌┐ is used to show the scheduled activity time or the total activity time; ▬ shows the actual progress of the activity; ▭ shows the non-production time and; Ʌ shows the time at which the chart is reviewed.

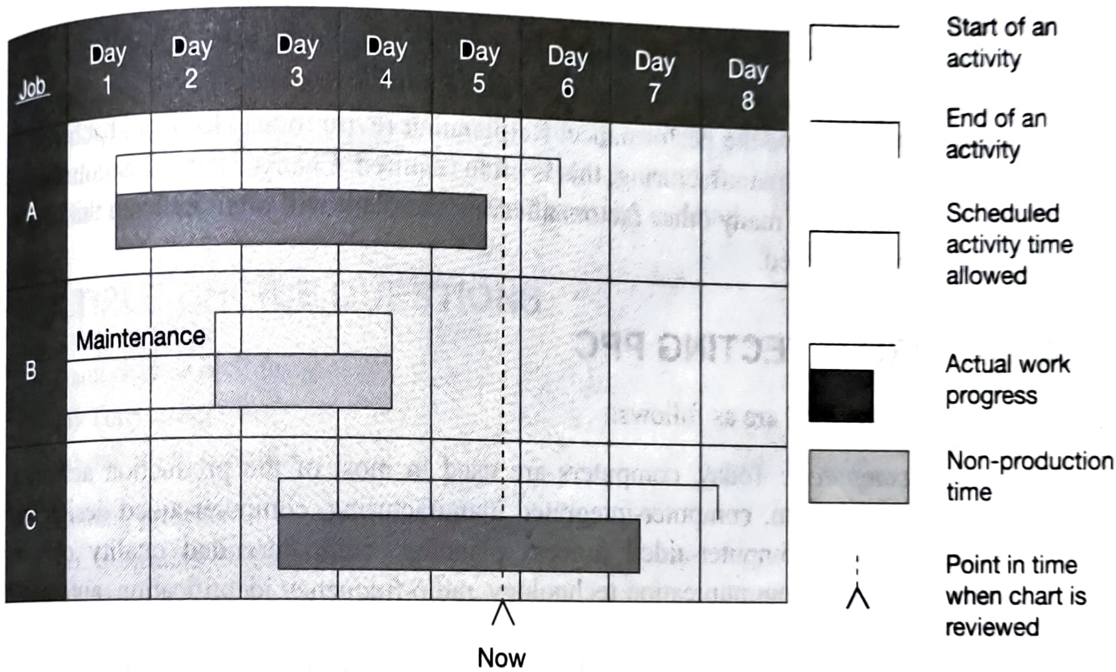

Figure 10-5: Gantt scheduling chart

Production Control

Production control determines whether resources to execute the plan have been provided and if not, takes action to correct the deficiency. This refers to the stage of ensuring that the planned action is intact carried out. Control initiates the plan at the right time using dispatching and there after control makes appropriate adjustments through progressing to take care of any unforeseen circumstances that might arise. It includes the measurement of actual results, comparison of the same with the planned action and feeding back information the planning stage to make any adjustments required. The pattern of control is seen in material control, machine utilization, labour control, cost control and quality control.

Dispatching: It is the execution of the planned functions. This authorizes to start a work which has already been planned under the above discussed planning functions that are mainly routing and scheduling. It is releasing of orders and instructions for the starting of production in accordance with the route sheets and schedule charts.

Expediting/Follow-up/Progressing: Expediting ensures that the work is carried out as per the plan and delivery schedules are met. Expediting includes activities such as status reporting, attending to bottlenecks or holdups in production removing the same, controlling variations or deviations from planned performance levels, following up and monitoring progress of work through all stages of production, coordinating with purchase, stores, tool room and maintenance departments and modifying the production plans and re-plan if necessary.

Inspection and replanning: Inspection is the process of examining an object for identification or checking it for verification of quality and quantity in any of its characteristics. It is an important tool for ascertaining and controlling the quality of a product. Inspection is an appraisal activity that compares goods or services to a standard.

If there is any gap between the existing and planned performance level, replanning is done to fill the gap and to improve the performance. Re-planning revise routes, loads and schedules; a new plan is developed. In manufacturing, this is often required. Changes in market conditions, manufacturing methods, or many other factors affecting the plant will often indicate that a new manufacturing plan is needed.

10.4 FACTORS AFFECTING PPC

There factors affecting PPC are as follows:

1. *Use of computers:* Today, computers are used in most of the production activities, such as automation, computer-integrated manufacturing, computer-aided design and manufacturing, computer-aided process planning, computer-aided quality control, information and communication technology, radio frequency identification, automated storage and retrieval systems, etc.
2. *Seasonal variations in the demand:* Demand for certain products is affected by seasons, for instance, umbrellas, woolen clothes and raincoats. PPC must take such changes into consideration while planning and control activities of inputs and outputs.
3. *Test marketing:* With an aggressive marketing strategy, new products are to be test-marketed in order to know the trends. This is a short-cycle operation, intermittent in nature and often upsets regular production.
4. *After sales service:* This has become an important parameter for expansion of the target markets. In supporting the after sales services, many items are returned for repair. These are unscheduled work and also overload the production line.
5. *Losses due to unpredictable factors:* Losses may occur due to accidents, fire, earthquakes, tsunami and theft of production inputs, mainly materials and components. These are unpredictable. Shortage of input or disruption in the supply of the inputs due to such factors upsets the planned production schedule in time and quantity.
6. *Losses due to predictable factors:* There are losses of inputs, due to natural engineering phenomena like production losses and changes in consumption of materials and occurrence of defective.
7. *Production of order:* There are many occasions when in the last minute prioritization of existing orders takes place due to external pressure. These changes in priority are often decided by sufficiently high level of management.

8. *Design changes:* Design changes by R & D and the engineering department forces the PPC to change the input materials and process.
9. *Rejection and replacement:* There are many occasions when sub-assemblies or finished goods are rejected during production stage or final inspection. PPC must cater for contingency plans to take care of rework without affecting scheduled quality.

SUMMARY

In this chapter, we have discussed all the functions of PPC. The production planning is divided into three parts: preplanning, planning and control. Preplanning covers the functions performed before production of the components, and planning consists of the functions performed during production, and control is used to alter the process to meet the target of the performance level. Objectives and factors affecting the PPC are discussed in detail.

MULTIPLE-CHOICE QUESTIONS

1. Gantt chart is used for
   (a) Forecasting
   (b) Production schedule
   (c) Inventory control
   (d) Routing
2. Routing presents
   (a) Utilization of manpower
   (b) Utilization of machine
   (c) Flow of materials in plant
   (d) Inspection of materials
3. The routing function is a production system design, which is concerned with
   (a) Production schedule
   (b) Loading of the machine
   (c) Quality assurance of the product
   (d) None of the above
4. Scheduling
   (a) prescribes the sequence of operations to be performed
   (b) is concerned with the starting of processes
   (c) determine the programme for the operations
   (d) none of the above
5. In manufacturing management, the term 'dispatching' is used to describe
   (a) dispatch of sales order
   (b) dispatch of factory mail
   (c) dispatch of work order through shop floor
   (d) none of the above
6. Loading is the process of
   (a) calculating the workload on the machine
   (b) assigning specific jobs to the machines
   (c) balancing the load on the machines
   (d) none of these

7. Make or buy decision is a part of
   (a) Production planning
   (b) Production control
   (c) Preproduction planning
   (d) None of these
8. Forecasting is a part of
   (a) Production planning
   (b) Production control
   (c) Preproduction planning
   (d) None of these
9. Production planning includes
   (a) sequencing of operations
   (b) routing
   (c) time schedule for manufacturing
   (d) all the above
10. Expediting ensures that,
    (a) the production is carried out as per the plan and delivery schedules are met
    (b) product are delivered to the customer as per schedule
    (c) materials are purchased as per date of receipt
    (d) none of these
11. Production planning and control (PPC)
    (a) is tool to coordinate all the manufacturing activities
    (b) is used to recognize the need of customers
    (c) is used to chase the competitors in the market
    (d) none of the above
12. Which of the following is NOT a part of production control?
    (a) dispatching
    (b) expediting
    (c) replanning
    (d) master schedule
13. Which of the following is NOT a part of preproduction planning?
    (a) Forecasting
    (b) Make or buy decision
    (c) Loading
    (d) Product design
14. Order writing is a part of
    (a) preproduction planning
    (b) production planning
    (c) production control
    (d) none of these
15. Route sheets consist of the following information
    (a) the required operations and desired sequence
    (b) machines, tools, jigs and fixtures or equipments to be used
    (c) set-up time and operation time
    (d) all the above

Answers

1. (b)	2. (c)	3. (d)	4. (c)	5. (c)	6. (b)	7. (c)	8. (c)	9. (d)
10. (a)	11. (a)	12. (d)	13. (c)	14. (a)	15. (d)			

Scheduling

Detailed day-to-day planning of operations is called scheduling. It deals with questions such as:

(a) Which work centres will do which job?
(b) When should an operation/job be started? When should it end?
(c) On which equipment should it be done, and by whom?
(d) What is the sequence in which jobs/operations need to be handled in a facility or on an equipment?

'Day-to-day' implies a short time horizon and not the literal meaning, although scheduling is often done on a daily basis. As is obvious by now, while the long-range and intermediate plans are of much use at higher or middle organisational levels, scheduling is of immediate significance for the lower managerial and first-line supervisory positions. Needless to mention again, production scheduling operates within the framework of flexibilities of the aggregate intermediate range plan.

Continuous production systems such as the process plants or mass production systems such as assembly lines may not have much need for day-to-day planning because the operations are repetitive or continuous for several days together. Of course some of the activities that cannot be anticipated earlier and other minor deviations need to be planned and accommodated on a daily basis. The production levels, the necessary production facilities, inputs and manpower requirements have to be planned for a long stretch of time, as long as the production run. Techniques such as Line Balancing could be used for optimum utilisation of the resources.

In the project type of production system, Network Analysis helps is planning and controlling the component jobs. Everything can be planned much ahead of time. Even within an activity there may be need to subdivide and plan for the micro-activities. (But this has limited managerial significance.)

JOB-SHOP TYPE PRODUCTION

The job-shop type of production system is more concerned with day-to-day scheduling. There would be a variety of jobs. Each job has a variety of operations to be performed. The operations are not usually the kind that last for days; most of them are done within hours or fractions of hours. The variety of jobs and operations generate a multiplicity of semi-finished items which may have to wait for further operations to be done on them. When hundreds or thousands of such variations in operations-or-materials are to be handled, a systematic detailed daily plan is called for. Scheduling involves basically:

(i) Assigning different jobs to different facilities.

(ii) Sequencing the jobs and the operations at a facility or on a machine, so as to achieve the production departments' objectives; and

(iii) Monitoring the achievement and accordingly revising the schedule or changing the priorities of jobs/operation so as to rectify the deviation (this is the 'control' action).

Item (i) above is called Shop Loading. If two or more facilities (or machines) are equally capable of performing the same job or set of jobs, and if the different facilities (a) take different times to complete the same job and (b) have different total production capacities, then the first problem that arises in scheduling is that of assigning jobs to facilities. Note that 'sequencing' of jobs or operations is only the next step, i.e. after the said assignment. This 'assignment' is called Shop Loading. If such a choice of equally capable work centres does not exist, then the shop-loading problem is only one of checking on available capacity. One needs then to concentrate on sequencing of jobs/operations on a facility/machine.

It must be clarified here that despite the manufacturing-oriented terminology, all these principles and techniques are equally applicable for scheduling the operations in the service industries.

SHOP LOADING METHODS

Shop loading can be done using simple charts as depicted in Figs. 34.1 and 34.2.

Facility/Work Centre		1	2	3	4
Time available (capacity)		90	45	135	45
Job No:					
108	Hours Required	9	14	4	10
	Hours Available	1	31	131	35
117	Hours Required	11	9	19	7
	Hours Available	70	22	112	28
126	Hours Required	8	5	11	7
	Hours Available	62	17	101	21
135	Hours Required	4	3	5	5
	Hours Available	58	14	96	16
144	Hours Required	10	7	6	9
	Hours Available	48	7	90	7
153	Hours Required	2	2	5	2
	Hours Available	46	5	85	5
..		..	..	..	..
..		..	..	..	..

Figure 34.1 Shop Loading Register

One may even use simple charts for loading purposes, as shown in Fig. 34.2.

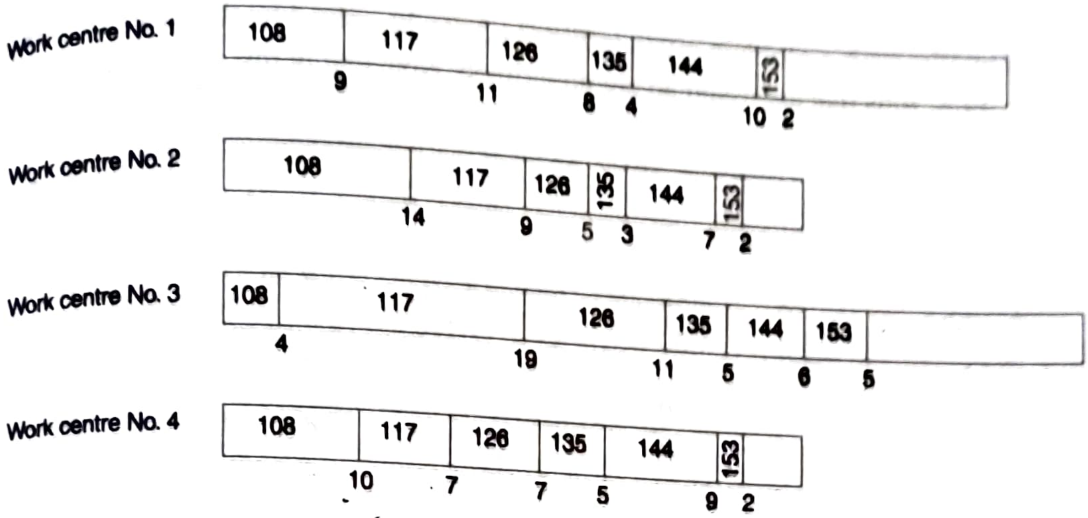

Figure 34.2 **Shop Loading Chart**

Strictly speaking, in cases such as mentioned in Figs. 34.1 and 34.2 where loading is of finite type, the loading problem needs to be solved simultaneously with the accompanying sequencing problem. However, when the same jobs (or operation) can be done by a number of work centres (although with different efficiencies), the problem is distinctly one of assigning the jobs to work centres based on appropriate criteria such as minimum cost or time.

Index Method

A heuristic method of loading, which would yield better results than the simple and intuitive methods shown in Figs. 34.1 and 34.2 is the Index Method. Supposing time is the criterion, 'indices' are calculated for the different process times (if done in different work centres) with the lowest process time having the base index of 1.0. The lowest index jobs are then assigned to the work centres, keeping in view the limitations of the capacities of the centres. The next lowest index jobs are then assigned to the work centres (without exceeding the constraints on capacities), and this process is repeated till all the jobs are assigned. This is a heuristic method and the solution obtained may not be optimal; however, it could be near optimal. The Index Method is illustrated by means of Fig. 34.3.

Job	Work Centre			
	1	2	3	4
	Days	Days	Days	Days
A	10	9	8	12
B	3	4	5	2
C	25	20	14	16
D	7	9	10	9
E	18	14	16	25
No. of days available	20	20	20	20

Figure 34.3 **Shop Loading—Illustrative Problem**

The illustrative problem given in Fig. 34.3 can be solved by the Index Method, as shown in Fig. 34.4. Jobs that are assigned are underlined. Note that in this example, time is the criterion.

	Work Centre							
	1		2		3		4	
Job	Days	Index	Days	Index	Days	Index	Days	Index
A	10	1.25	9	1.13	<u>8</u>	1.00	12	1.50
B	3	1.50	4	2.00	5	2.50	<u>2</u>	1.00
C	25	1.78	20	1.42	14	1.00	<u>16</u>	1.14
D	<u>7</u>	1.00	9	1.28	10	1.42	9	1.28
E	18	1.28	<u>14</u>	1.00	16	1.14	25	1.78
Days available	20		20		20		20	
Days assigned	7		14		8		18	

Assumption: Jobs cannot be split.

Figure 34.4 **Solution by Index Method**

In a different context, this method is useful when a worker can operate different machines and he can be so assigned.

Assignment **Problem**

The OR technique of Assignment Problem can be very useful in loading. The gist of this technique is given in a flow diagram (34.5).

Let us apply this algorithm to our earlier problem (Fig. 34.3)

(a) Matrix for the problem is drawn. The problem is one of minimisation (of time).

	Work Centre				
Job	1	2	3	4	(5)
A	10	9	8	12	0
B	3	4	5	2	0
C	25	20	14	16	0
D	7	9	10	9	0
E	18	14	16	25	0

(b) Column subtraction gives:

	1	2	3	4	(5)
A	7	5	3	10	0
B	0	0	0	0	0
C	22	16	9	14	0
D	4	5	5	7	0
E	15	10	11	23	0

(c) Row subtraction gives the very same result as in the earlier step.

(d) Let us cover the zeros.

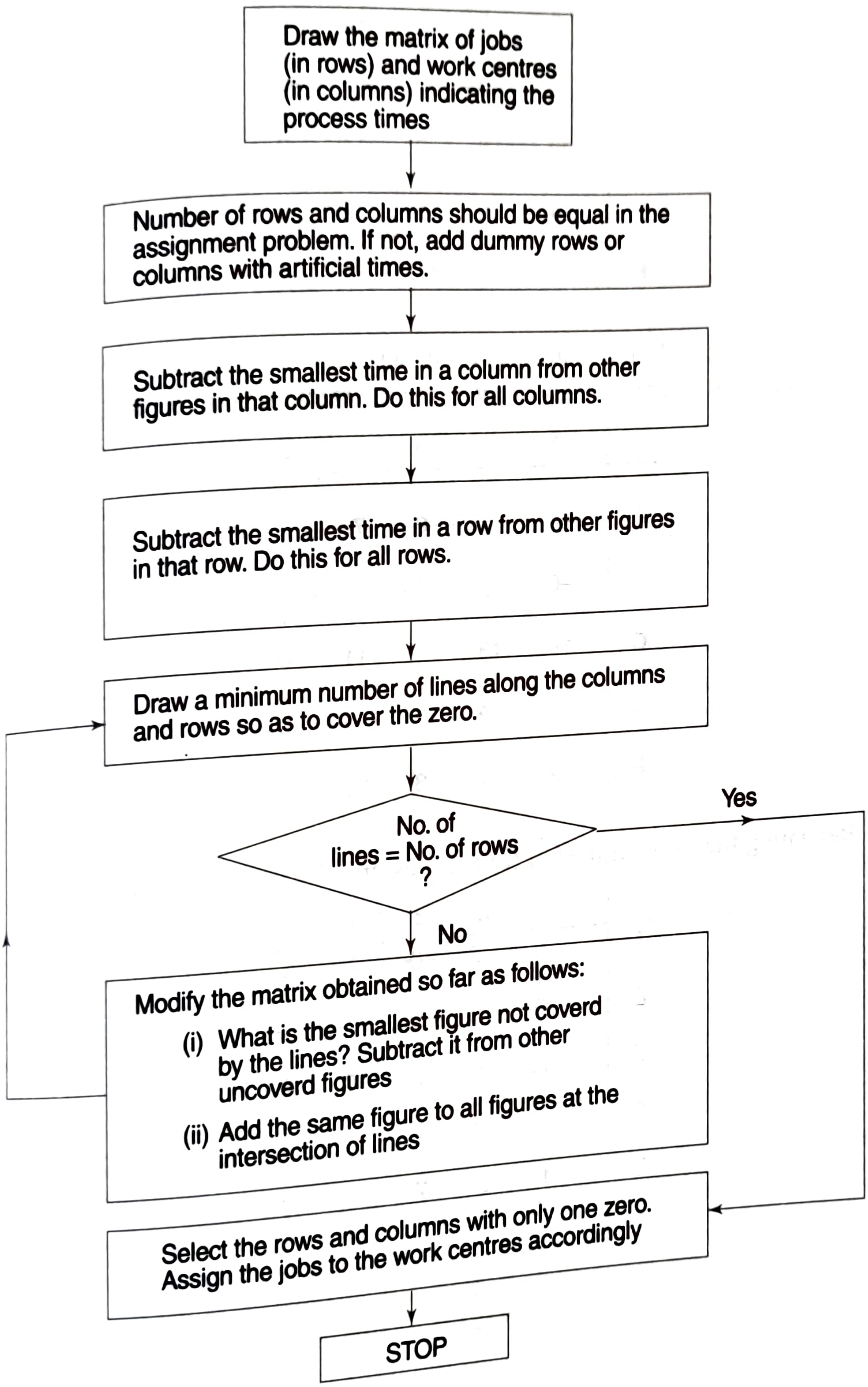

Figure 34.5 **Assignment Problem: Flow Diagram of the Steps Involved**

	1	2	3	4	(5)
A	7	5	3	10	0
B	0	0	0	0	0
C	22	16	9	14	0
D	4	5	5	7	0
E	15	10	11	23	0

(e) We need to modify the matrix. The smallest uncovered figure is 3. Subtracting it from all uncovered figures and adding it to the intersection point of the lines, we get:

	1	2	3	4	(5)
A	4	2	0	7	0
B	0	0	0	0	3
C	19	13	6	11	0
D	1	2	2	4	0
E	12	7	8	20	0

(f) Repeating the step outlined in (e) is necessary. According, we get

	1	2	3	4	5
A	4	2	0	7	1
B	0	0	0	0	4
C	18	12	5	10	0
D	0	1	1	3	0
E	11	6	7	19	0

and next

	1	2	3	4	5
A	5	2	0	7	2
B	1	0	0	0	5
C	18	11	4	9	0
D	0	0	0	2	0
E	11	5	6	18	0

This is further modified:

	1	2	3	4	5
A	3	0	0	5	2
B	1	0	2	0	7
C	16	9	4	7	0
D	0	0	2	2	2
E	9	3	6	16	0

Further modification yields:

	1	2	3	4	5
A	3	0	0	5	5
B	1	0	2	0	10
C	13	6	1	4	0
D	0	0	2	2	5
E	6	0	3	13	0

Now the number of lines are equal to the number of rows. So, the final assignment is:

C : Centre 5 (fictitious centre; hence, in effect, not assigned)
E : Centre 2
D : Centre 1
B : Centre 4
A : Centre 3

This result is not at all surprising since we could have obtained the same by a visual check of the time matrix.* The Assignment Problem corresponds one row member with one column. Thus the dropping of one job is inevitable. The reader may consider the whether, why and how of the capacity constraints having/not having been taken into account.

SEQUENCING OR PRIORITISATION

While scheduling the job-shop type of operations system in addition to deciding which job should go to which work centre, it is also necessary to decide on the sequence in which the jobs are to be processed in any work centre. This relative prioritization determines the actual time schedule of the individual jobs. The priorities can be decided based upon one or a number of criteria. What these criteria can be, and their relative usefulness, shall be discussed in the coming pages.

How does any job priority rule influence the production output performance? Given a situation where there is one machine and a number of jobs waiting to be processed on that machine, the total time to process all the jobs is the same irrespective of the priority rule.

* Such visual checks do not usually give optimal results. With the number of rows and columns increasing, there will be greater difficulty in arriving at an optimal solution based only on visual inspection.

However, if other characteristics of performance such as the average waiting time per job or average number of jobs waiting in line (and therefore the amount of work-in-process inventory) are relevant, then the priority rule does matter.

Now, imagine a set of jobs requiring the use of two machines, which are to be used one after the other. Depending upon the sequencing rule, even the total time for that set of jobs will vary. This is so because the jobs interfere with another; and while one job is being performed on a machine, the other job/jobs may have to wait. In an actual factory or any operations situation, a job involves a number of operations with the use of a number of machines. Therefore, the priority rules will have a significant effect on the shop performance. A job-shop can be thought of as a complex queueing system with probabilistic times, multiple channels, multiple servers, with different jobs requiring the use of different sets of servers. The priority rule or queue discipline has a very important role to play in a queueing system. In addition to being a complex queueing system, a job shop is a dynamic system where the relative urgency of the jobs is forever changing. This makes the situation even more complicated and less amenable to the use of analytical techniques of Queueing Theory for the scheduling of jobs and operations.

Simulation

Research has concentrated on the priority rules by simulating the production shop and determining the relative worth of the different rules. These shall be discussed in the latter part of this chapter. In addition to simulation, there are some optimisation methods available (such as Johnson's Rule), and also visual aids in the form of charts (such as the Gantt Chart).

The basic question to ask would be: Why do we need all these aids to find better ways of work flow planning and control? The reasons are:

There is pressure on completing the jobs by the promised due date to the customer (or as required by the customer) under the constraints of available machinery, manpower and materials capacity. The objective is to meet the demands with the least cost. If the cost was no problem and the machinery capacity was large, there would be no need to bother about sequencing. However, this is never the case and we need to achieve the best utilisation of machines and manpower, and keep as small work-in-process inventories as possible. The work-in-process is necessary to keep the utilisation of machinery and manpower at a high level. The relationship between this inventory and utilisation of manpower is shown in Fig. 34.6.

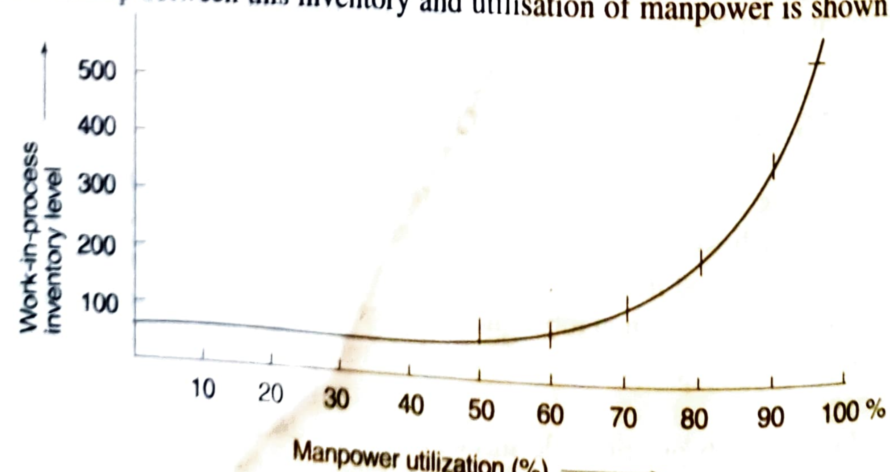

Figure 34.6 **Relationship between Inventory and Efficiency in a Conventional Job Shop***

* *Source*: J.L. Colley, R. Landel and R. Fair, *Production Operations Planning and Control*, Holden-Day, 1977.

Thus, if one cost component is lowered, the other cost component goes up. Therefore, a balance needs to be struck between them so as to have lowest total costs while meeting the market demands. And for this, the strategies available to us are that of assignment and sequencing of jobs in the shops.

Objectives of Sequencing

The objectives of appropriate sequencing are:

(a) Completing by the due date, or with as little delay as possible, as many work orders as possible.

(Note: This has three components: one is completing, another is on-time, and third is minimum delay which could be average delay or a range of delay.)

(b) Utilising the machinery and such other capital investment to the maximum extent possible.

(c) Utilising the manpower capacity to the maximum extent possible.

(d) Minimising the working capital investment in inventories of semi-processed materials.

The various approaches to scheduling and the resulting shop performance need to be measured against the above stated objectives.

Visual Aids

As stated earlier, one of the simplest approaches to scheduling is through the use of various visual aids, facilitating the planning of jobs through work centres and depicting the progress of jobs against what is planned. The earliest of such charts was developed by Henry L. Gantt during the early part of the twentieth century. This chart, called the Gantt chart (modified where necessary) is still a popular device. A Gantt Chart is shown in Fig. 34.7.

A Gantt Chart shows how each machine or work-centre is planned for work on different job orders—the scheduled start and finish times, the time reserved (or planned unavailability of the machine), the delays or production bottlenecks that have occurred and the time lost for that reason, the extent of actual completion of various jobs each day. This information could be very useful for diagnosing the problems, if any, and taking appropriate rescheduling action wherever warranted.

Figure 34.7 showing a Gantt Chart indicates that there was a problem in the Mechanical work-centre earlier; at present, the work on the work order no. 701 has lagged behind by two days. Perhaps, the problems in the Mechanical centre have not yet been solved completely. While the Electrical centre has completed the job (Work Order No. 701) on schedule, the problem in the Mechanical Centre is probably affecting the work in the sub-assembly centre. The work on order no. 701 has lagged behind the schedule by one day. This has, in a chain reaction, affected the work in assembly by a delay of one day. The assembly centre is ready to start work on order no. 701. Testing activities are on schedule for other jobs—testing for order no. 701 is not yet done. The Shipping centre also has problems; it is lagging behind by four days.

The shipping senior supervisor feels that there are deliberate delays on the part of the workers in his department. Is this true? It needs to be investigated. If it is true, is it of any significance that the majority of the Mechanical and Shipping Centre workers belong to the same labour union? The problems identification process is thus helped by these scheduling and progress charts so that appropriate control action can be taken by the concerned managers.

Figure 34.8 shows a Sequencing Chart.

There are a number of versions of the Gantt Chart and other charts. Many 'Sched-U-Graphs' and similar large boards display the planned and actual status information in colours for better visual effect.

SCHEDULING IN MASS, CONTINUOUS AND PROJECT TYPE PRODUCTION SYSTEMS

The scheduling aspects mentioned so far have been concerned with the job-shop (open and closed shop) type of production, in the main. It has been mentioned earlier that for a mass assembly line production (or continuous type), the planning problem, in both the time horizons—intermediate and short-term—is one of setting the rate of production from the line and arranging the various production centres on the line accordingly. Line Balancing would be helpful in equalising the output rates from the various work-points on the mass production line and in reducing the idle-time of labour. Unlike the job-order situation, here the production control activity does not consist of following up each particular job-order from one work centre to another; rather, it consists of maintaining an uninterrupted flow of the identical items as they go through the number of operations on the assembly/process line. It is like seeing that a stream of water flowing through a system of channels (converging into a major channel) does not get logged at any place. In a project type of production system, where one complex unit or item is to be produced involving a number of operations—many of them to be done one after the other in a sequence dictated by technology or limitations of resources, hence, the product developing its shape and getting value added as the time flows—the network analysis techniques such as PERT/CPM are quite useful in scheduling, monitoring and control of production. While in a continuous or line production the 'flow' is with respect to space, in the project type production the flow is with respect to time.

LINE OF BALANCE (LOB) TECHNIQUE

There is one variation of the project type production—a system where the project consists of producing a single batch of products where the delivery of the product is not at one point in time but is spread over many intervals of time according to a prior-agreed schedule between the manufacturer and the customer. For example, a batch of boilers, a batch of combat aircraft, a batch of computers to be delivered according to a schedule, are the type of situations which fall into this category. For the scheduling and control of it, a graphic technique called Line Of Balance (LOB) is quite useful.

As is obvious from the above discussion, for LOB the following information is needed:

(i) The contracted schedule of delivery.
(ii) The key operations, in the making of the product, which need to be controlled.
(iii) The sequence in which the key events (of start or completion of operations) are connected.
(iv) The expected/observed lead times of these events with respect to the completion of the final event, i.e. delivery of the finished product.

Based on the above, a diagram pictorially comparing the planned vs actual progress at each control point (i.e. key event) can be constructed for any particular review date. This diagram which looks like a 'line' with steps for the planned achievements, along with bars showing actual progress on the review date, is called the Line Of Balance diagram.

Example No-defects Electric Company has entered into contract with Never-fail Power Board for the supply of transformers, as shown in the table below.

Date	Number of Units to be Delivered	Cumulative Number to be Delivered
1st Jan. 1987	2	2
1st Feb. 1987	2	4
1st Mar. 1987	3	7
1st Apr. 1987	4	11
1st May 1987	5	16
1st June 1987	5	21
1st July 1987	5	26
1st Aug. 1987	5	31
1st Sept. 1987	5	36

The schedule of delivery is expressed in the form of an 'objective chart' as shown in Fig. 34.12.

The detailed flow of operations and the fabrication plan can be quite complex especially in terms of the number of details. However, the purpose of LOB is for progress control and accordingly suitable 'key' control points or events may be selected. It is also necessary to estimate the 'lead times' of these events with respect to the final delivery, i.e. how long before this final event should each other event take place? These times are the latest possible completion times of these various activities or, in other words, the late times for the occurrence of these events.

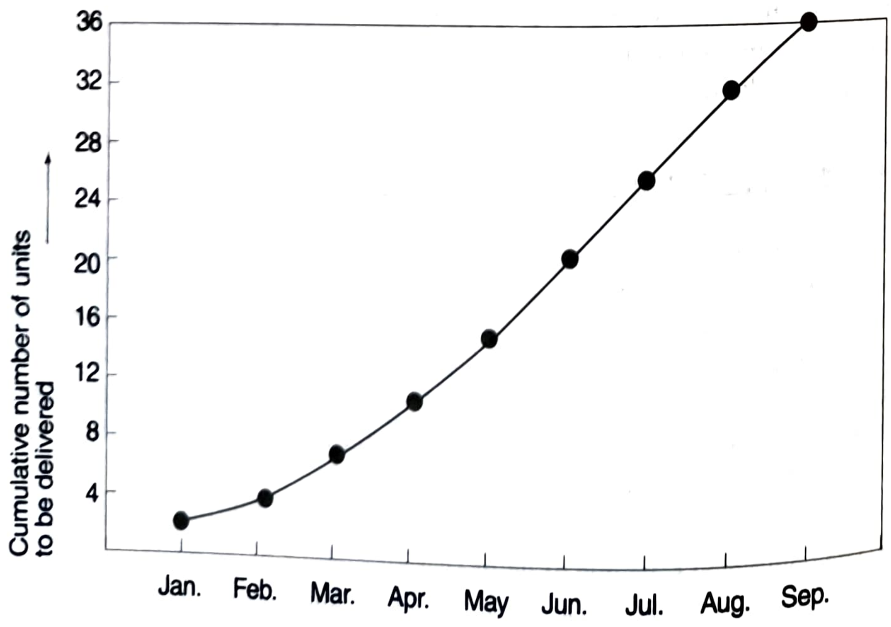

Figure 34.12 **Objective Chart– LOB**

The various 'key' events are then linked in a *precedence diagram* (Fig. 34.13). In order to keep our example simple, let us have the key events and their lead times as given in Table 34.3 followed by Fig. 34.13.

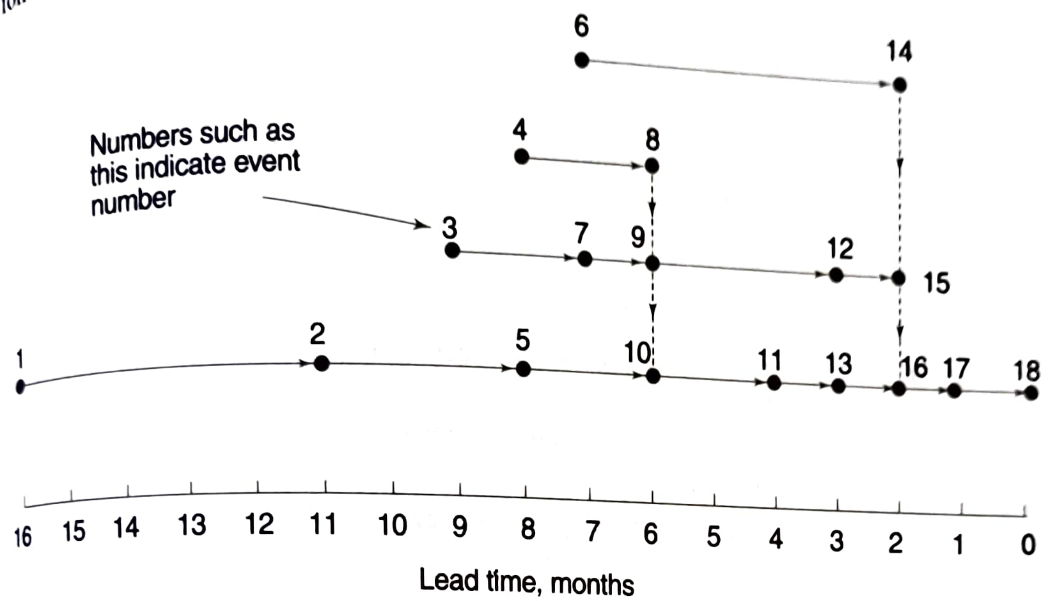

Figure 34.13 **Precedence Diagram – LOB**

Based on the Objective Chart and the Precedence Diagram, the progress is monitored at the various control points in terms of comparing, the extent of completion that *should have been*, to the observed *actual* extent of completion of the various key events *on a review date*. The 'should have been' extent of completion for the receipt of sub-contracted steel items (event number 8) on November 1, 1986 (review date) is computed as given in Fig. 34.14. Marking the lead time of 6 months (for event 8) from the review date onwards, we see that this event must be completed for 16 transformers. Similarly, for event 5, the raw materials for the manufacture of Cu-components should have been received, so far, for 26 transformers. From the bill of materials we can calculate what 26 transformer—equivalents mean. For all

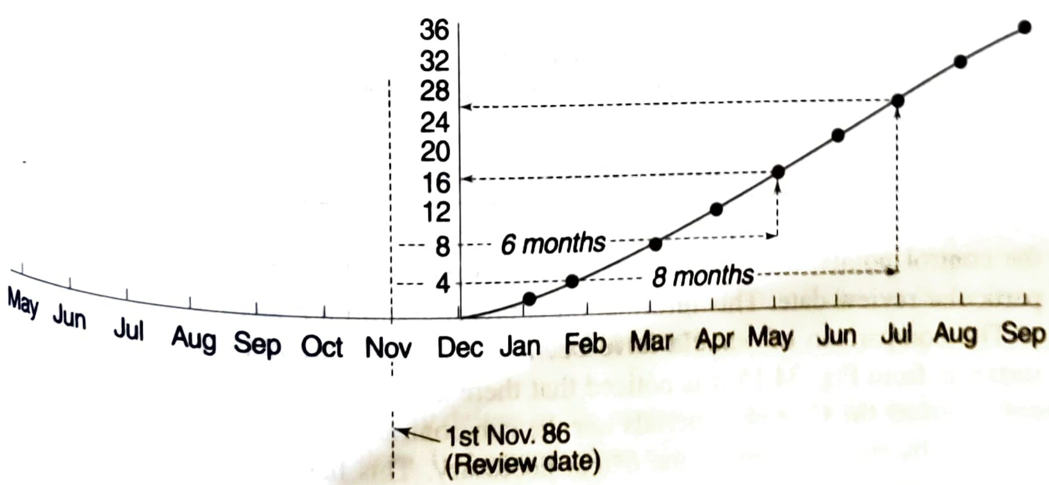

Figure 34.14 **Computation to Determine the LOB**

TABLE 34.3 **Control Points – LOB**

Event Number	Key Event	Lead Time (months)
	Design	
1	Begin design	16
2	Complete design	11
	Cu-Components	
2	Place orders for materials	11
5	Receive the materials and start the manufacturing Step-I	8
10	Complete mfrg Step-I and begin mfrg. Step-II	6
11	Complete mfrg Step-II and Begin mfrg Step-III	4
13	Complete mfrg Step-III and start testing	3
	Steel-Components	
3	Place orders for materials	9
7	Receive the materials and start mfrg Step-A	7
4	Initiate sub-contracting for items	8
8	Receive sub-contracted items	6
9	Complete mfrg Step-A and start mfrg Step-B	6
12	Complete mfrg Step-B, and start testing	3
15	Complete testing	2
	Auxiliaries	
6	Place orders on suppliers	7
14	Receipt from suppliers	2
	Final Assembly	
16	Start of final assembling	2
17	Completion of assembling and start testing	1
18	Start delivery of the final product	0

the control points, the 'should have been' extent can be calculated in a like manner on a particular review date. This information is presented in Fig. 34.15.

The comparison of 'should have been' and 'actual' provides valuable information. For instance, from Fig. 34.15 it is noticed that there are some serious problems in the purchasing area. Neither the Cu-raw materials nor the sub-contracted (bought out) steel items have been received by the company to the extent necessary. This has in turn handicapped the various manufacturing operations in the company. Actually, by now the final assembly work should have started, but it is at a stand-still. The purchase department seems to have sent all the purchase orders on time; so, why the delays from the suppliers?

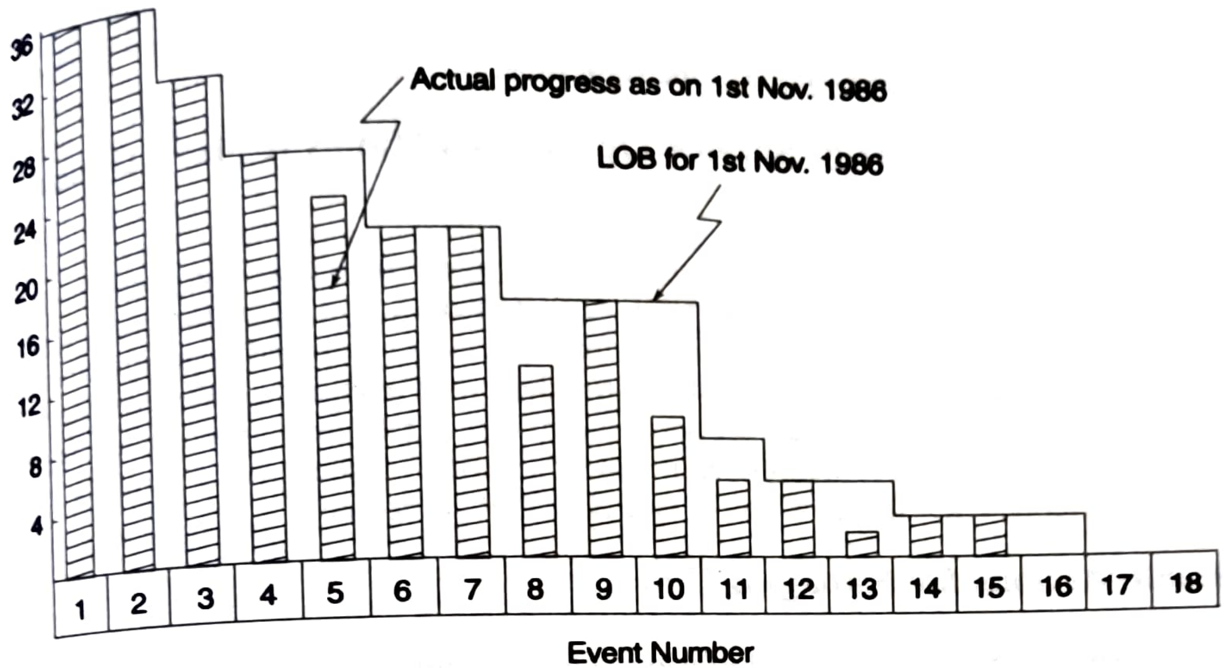

Figure 34.15 **Line of Balance (LOB) and Progress Monitoring**

Besides providing information as to whether the production is low or the inventories are high in certain key areas, the LOB also gives diagnostic information.

LOB helps the top or middle-level production manager/planner in identifying problems such as production bottlenecks, supplier-failures, excess inventories of raw materials and work-in-process, etc., and take appropriate control action. With more number of events or control points, it may be easier to focus on the problem area/s. The more detailed LOB, if used manually loses its value to the extent of the increase in the complexity. However, if the complexity is taken care of with the use of a computer,* the LOB technique of monitoring can be quite useful in the case of single batch production of an important product which is to be delivered in different numbers at different calendar dates as per an earlier established schedule.

SCHEDULING IN SERVICES

Time aspects are very important in services. In fact, punctuality or timeliness is one of the important attributes in service quality. When manufacturing started getting characteristics of service, a whole new paradigm and management technology of Just-in-Time production came into being.

Time Delays in Services are Difficult to Correct

In the manufacturing industry, any delays in the production of an item can be taken care of by holding an inventory of that item. If the production of an item is delayed, the same is supplied

* A case study using a microcomputer is presented in: Y.A. Hosni and F. Guediri, 'LOB using a Microcomputer', *Industrial Engineering*, Aug. 1981.