3

Elements of Network

3.1. INTRODUCTION

We have already seen that network technique is one of the most modern tools of project management. It is always possible to break up the entire project into a number of distinct, well defined jobs or tasks (called *activities*). The beginning or end of each such activity constitutes an *event* of the project. A network is a flow diagram consisting of *activities* and *events*, connected logically and sequentially. In the network diagram, an activity is represented by arrows while events are represented, usually, by circles, as shown in Fig. 3.1.

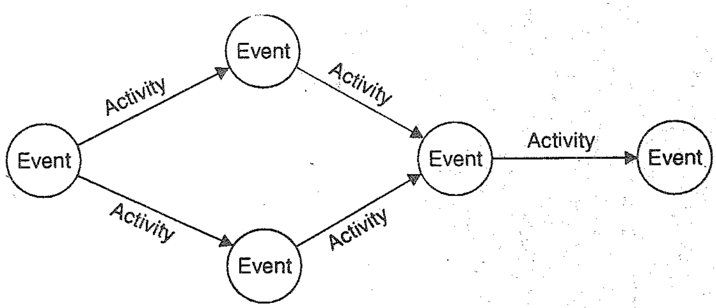


FIG. 3.1. NETWORK DIAGRAM.

Networks are of two types : PERT network and CPM network. PERT network is *event-oriented*, while CPM network is *activity-oriented*. Fundamentally, both CPM and PERT networks are techniques of project management involving graphical and diagrammatic representation, which management can use as an aid in planning, scheduling and controlling of operations in a project.

Characteristics of CPM/PERT Projects

A project to be analysed by CPM or PERT technique should have the following characteristics :

1. The project to be planned by network technique should consist of clearly recognizable jobs or operations, usually called *activities*.

2. These jobs, operations or activities must have definite commencement and completion. The start or end of a job or operation or activity is called an *event*.

3. The *events* must occur in a definite pattern and must be performed in a technological sequence.

Thus, the basic elements of a project network are :

(*i*) Event

(*ii*) Activity.

As an example, consider the project of laying a foundation. The project consists of the following well defined operations :

(*a*) Excavation of foundation

(*b*) Laying side boards

(*c*) Concreting foundation.

All the three operations are to be performed in a sequential order. The simple network will be as shown in Fig. 3.2.

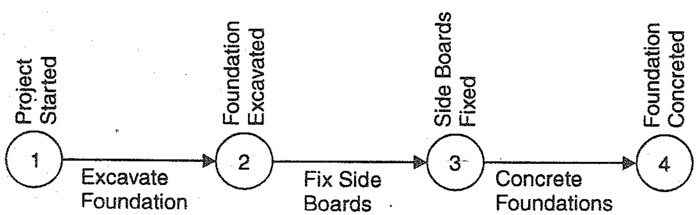


FIG. 3.2

In Fig. 3.2, the *activities* (*i.e.* excavate foundation, fix side boards, concrete foundations) have been shown by arrows. The beginning and end of activities are events and they are shown by circles provided at the nodes. The events of the above project are : (1) project started or excavation started, (2) foundation excavated, (3) side boards fixed and (4) foundation concreted.

As another example, consider the project of purchasing a new heavy duty lathe and disposing of the old lathe. The project consists of the following activities :

(*i*) Await delivery of lathe

(*ii*) Remove existing lathe

(*iii*) Install power supply

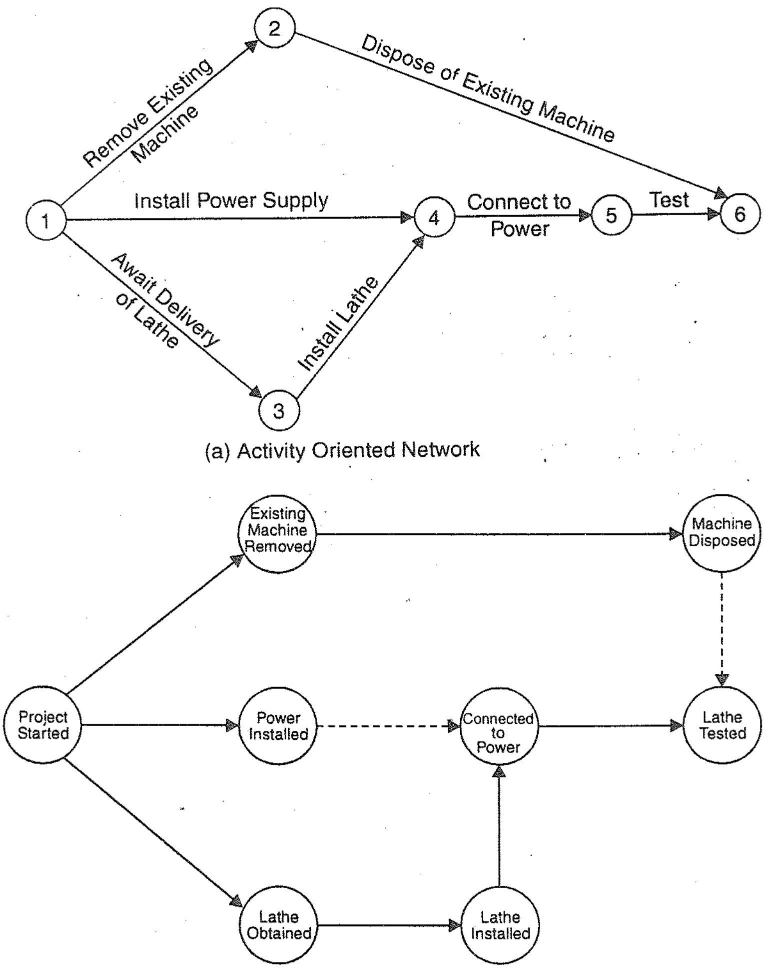
(*iv*) Install lathe

(*v*) Connect to power

(*vi*) Test

(*vi*) Dispose of existing lathe.

The above project can be represented by a network shown in Fig. 3.3 (*a*) which is activity oriented diagram. Fig: 3.3 (*b*) shows an alternative network which is event oriented.



(a) Activity Oriented Network

(b) Event Oriented Network

FIG. 3.3

3.2. EVENT

3.2.1. Definition

The commencement or completion of an activity is called an event. An event is that particular instant of time at which some specific part of a plan has been or is to be achieved. More specifically an event is a specific definable accomplishment in a project plan, recognizable at a particular instant of time.

Examples :

DESIGN COMPLETED	: is an event
EXCAVATION COMPLETED	: is an event
LATHE INSTALLED	: is an event
PARTS ASSEMBLED	: is an event
EXCAVATE FOUNDATION	: is *not* an event
PIPE LINE LAID	: is an event

An *event* has three basic *properties* :

(*i*) An event is either the start or completion of an activity.

(*ii*) An event represents a noteworthy, significant and recognizable point in the project. Events act as control points in a project.

(*iii*) An event is an accomplishment occurring at an instantaneous point in time, but requiring no time or resources itself.

An event must satisfy the following *requirements* :

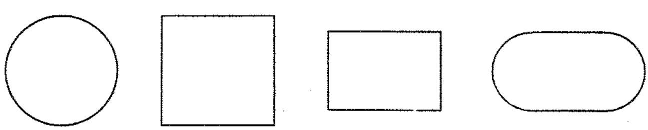
(*a*) A significant event must be positive, specific, tangible and meaningful to the project.

(*b*) It should be definitely distinguishable as a specific point in time.

(*c*) It should be readily understood by all concerned with the project.

3.2.2. Representation of Events

In a network diagram, events are represented by nodes. The shape of the nodes may be (*i*) circular, (*ii*) square, (*iii*) rectangular,



(*i*) Circular (*ii*) Square (*iii*) Rectangular (*iv*) Oval

FIG. 3.4. WAYS OF REPRESENTING EVENTS.

(*iv*) oval, or (*v*) any other regular geometrical figure, as shown in Fig. 3.4.

In this book, events have been represented by a circular node.

Events are numbered for their identification. The number of an event is written inside the node or circle. Events may also be given verbal description whenever meaningful.

3.2.3. Specifying the Events

A particular event out of various events on the network diagram may be specified as :

1. Tail event
2. Head event
3. Dual role event.

1. Tail event

A *tail event* is the one which marks the beginning of an activity. If a particular tail event represents the commencement of the project, it is known as the *initial event*.

Fig. 3.5 (*a*) shows a tail event (No. 10), representing the beginning of a certain activity, while Fig. 3.5 (*b*) shows an *initial event* (No. 1) representing the commencement of the project. Fig. 3.5 (c) shows a tail events marking the *beginning* of three

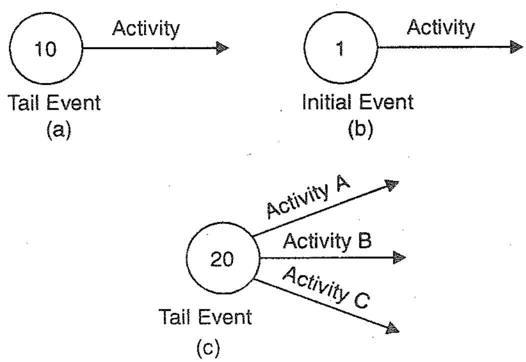


FIG. 3.5. TAIL EVENTS.

activities *A*, *B* and *C*. Suppose activity *A* commences at 6 units of time, *B* commences at 4 units of time and *C* commences at 7 units of time. Hence the *earliest occurrence time is 4 units of time. A tail event, representing the beginning of more than one activity, is said to occur when the first activity starts from it.*

2. Head event

All activities have an ending *i.e.* again a specific point of time and is marked by an event. Such an event is known as head event, because in a network diagram, it is connected to the head or barbed end of an arrow. If a particular head event marks the completion of the project it is known as the *final event* or *end event*.

Fig. 3.6 (*a*) shows a head event while Fig. 3.6 (*b*) shows a final or end event ; in each case they mark the completion of the activity.

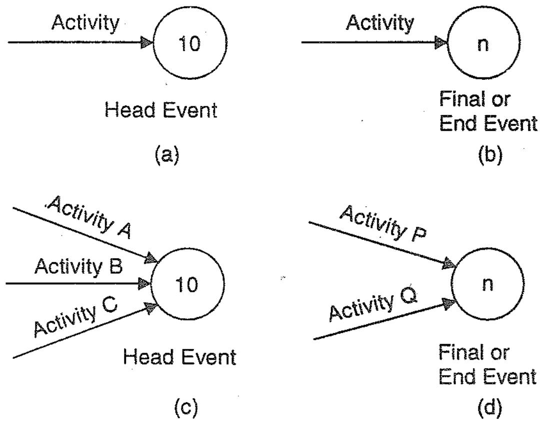


FIG. 3.6. HEAD EVENTS.

Fig. 3.6 (*c*) shows a head event, marking the completion of three activities. Similarly, Fig. 3.6 (*d*) shows a final or end event, having two activities ending in it.

When a head event occurs at the end of more than one activity, *the event is said to have occurred when all activities leading to it are completed*. For example, if activity *A* [Fig. 3.6 (*c*)] is completed at 20 units of time, activity *B* is completed at 16 units of time and activity *C* is completed at 22 units of time, the *earliest occurrence time* for event 10 is 22 units of time.

3. Dual role events

Actually, most of the events serve dual function *i.e.*, they are head event to some activity and tail event to other activity. *All events except initial and final events are dual role events.*

Thus, in Fig. 3.7 (*a*), event 11 is *head event* for activity *A* and *tail event* for activity *B*. Similarly, in Fig. 3.7 (*b*), event 26 is *head event* for activities *A*, *B* and *C*, while it is tail event for activities *P* and *Q*.

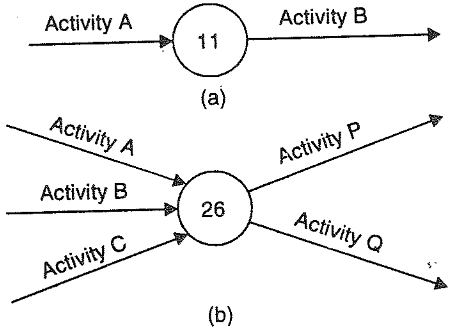


FIG. 3.7. DUAL ROLE EVENTS.

Another example is given in Fig. 3.8, in which :

Event 1 is	:	(*i*) initial event
		(*ii*) tail event for activities *A* and *B*.
Event 2 is	:	(*i*) head event for activity *A*
		(*ii*) tail event for activity *D*.
Event 3 is	:	(*i*) head event for activity *B*
		(*ii*) tail event for activities *C* and *E*.
Event 4 is	:	(*i*) head event for activity *C*
		(*ii*) tail event for activity *F*.
Event 5 is	:	(*i*) head event for activities *D, E, F*
		(*ii*) final or end event.

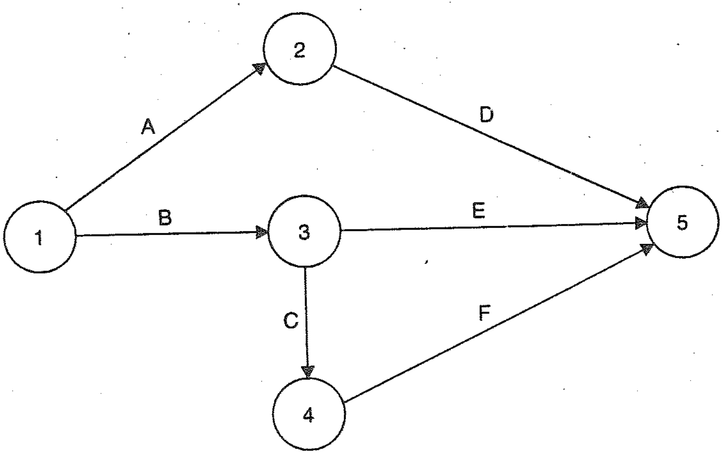


FIG. 3.8

3.2.4. Inter-relationship between Events

The completion of a project, which has been split into a number of activities, passes through a number of events. These events must occur at definite time and in a particular sequence or order. In preparing event oriented network diagram, one must think of the following questions regarding the sequence of events :

(*i*) What event or events must be completed before a particular event under consideration can be started ?

(*ii*) What event or events must follow the particular event under consideration ?

(*iii*) What activities can be accomplished simultaneously ?

The order or sequence relates various events as

(*a*) Successor events

(*b*) Predecessor events.

Successor events

The event or events that follow another event are called *successor events* to that event. Also, the event or events that immediately follow another event without any intervening ones are called *immediate successor events* to that event. In most of the cases, the successor events that are of greater concern are the immediate successor events ; some authors prefer to call the '*immediate successor event*' simply as '*successor event*'.

Predecessor events

The event or events that occur before another event are called predecessor events to that event. Also, the event or events that immediately come before another event without any intervening ones are called *immediate predecessor events* ; some authors prefer to call these simply as predecessor events.

As an illustration, consider network of Fig. 3.9.

(*i*) Events 2, 3, 4 and 5 are *successor events* to event 1.

(*ii*) Events 2, 3 and 4 are *immediate successor events* to event 1.

(*iii*) Event 5 is the *immediate successor event* to events 2, 3 and 4 each.

(*iv*) Events 1, 2, 3 and 4 are *predecessor events* to event 5.

(*v*) Events 2, 3 and 4 are *immediate predecessor events* to event 5.

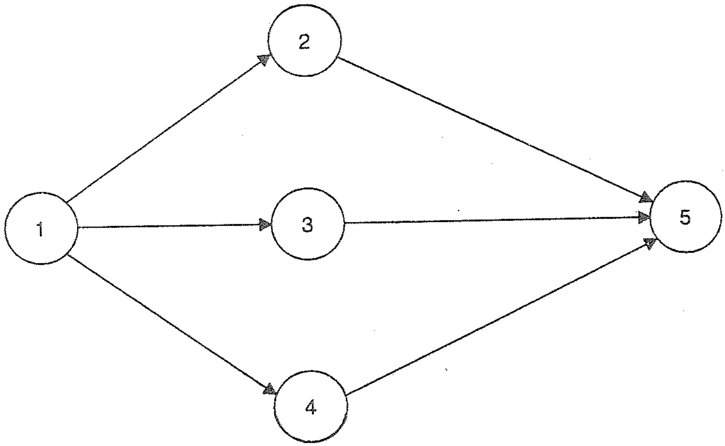


FIG. 3.9

(*vi*) Event 1 is *immediate predecessor event* to events 2, 3 and 4, each.

3.3. ACTIVITY

3.3.1. Definition

An *activity* is the actual performance of a task. It is the work required to complete a specific event. An activity is a recognizable part of a work project that requires *time* and *resources* (manpower, material, space, facilities etc.) for its completion.

Example :

EXCAVATE TRENCH	: is an activity
MIX CONCRETE	: is an activity
PREPARE SPECIFICATIONS	: is an activity
ASSEMBLE PARTS	: is an activity
LATHE INSTALLED	: is *not* an activity
DESIGN COMPLETED	: is *not* an activity
PREPARE BUDGET	: is an activity

A significant activity must be :

(*a*) a positive, specific, tangible and meaningful effort.

(*b*) such that the primary responsibility of effort can be determined, (*c*) having a description understandable by all concerned with the project, and

(*d*) having a time span.

3.3.2. Representation and Identification

In a network diagram, activities are represented by simple arrows, usually drawn from left to right. The length of arrow does neither represent the magnitude of work involved nor the time required for its completion. It is thus not a vector quantity. The length of the arrow is chosen to suit the drafting convenience.

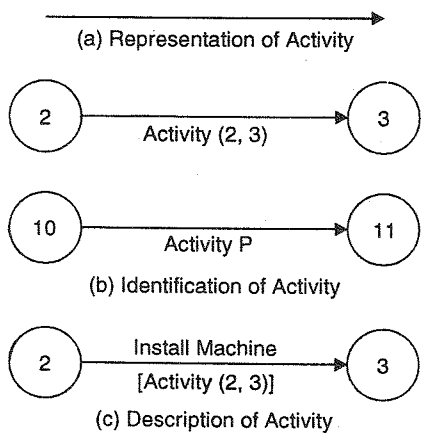


FIG. 3.10. ACTIVITIES.

The identification or description of an activity can be done in either of the following ways :

(*a*) The activities can be identified in terms of the events they connect, by the use of event numbers. Thus, in Fig. 3.10 (*b*), the activity connecting events 2 and 3, is designated as activity (2, 3).

(*b*) Activity can be identified by use of English alphabets, such as activity *P* in Fig. 3.10 (*b*). Such an identification must clearly define or describe the activity. For example :

ACTIVITY A	: excavate trench
ACTIVITY B	: fix side boards
ACTIVITY C	: concrete foundations
ACTIVITY P	: construct roof.

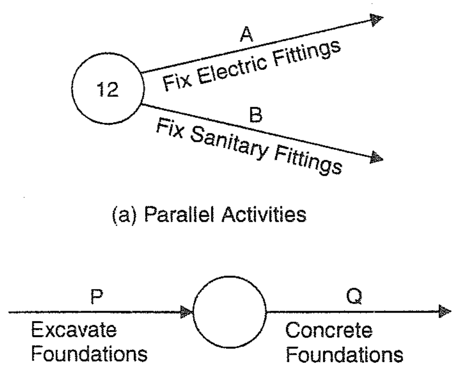
(*c*) Activity can also be described by writing actual performance over the arrow. For example, in Fig. 3.10 (*c*), the activity joining events 2 and 3 may be described as '*install machine*' by writing on the arrow.

3.3.3. Inter-relationships

A project may consist of a number of activities or jobs. Depending upon the interdependency, we can categorise activities as (*i*) parallel activities and (*ii*) serial activities.

Parallel activities

Those activities which can be performed simultaneously and independently to each other are known as parallel activities. For example, in Fig. 3.11 (*a*), activities *A* and *B* are parallel activities since they can be taken up concurrently and executed simultaneously.



(a) Parallel Activities

(b) Serial Activities

FIG. 3.11. PARALLEL AND SERIAL ACTIVITIES.

Serial activities

Serial activities are those which are to be performed one after the other, in succession. These activities cannot be performed independently to each other. For example, activities *P* and *Q* in Fig. 3.11 are serial activities. Activity *Q* cannot be started, unless activity *P* is complete.

Activity *P* is known as *preceding activity*, while activity *Q* is known as *succeeding activity*, in relation to each other.

Predecessor activity

Activity or activities that are required to be performed before another job or activity can begin are called *predecessor activities* to that activity. The activity or activities that are required to be performed immediately before another activity, without an intervening activity are known as *immediate predecessor activities* to that activity.

Successor activity

Activity or activities that can be performed after the performance of other activity are known as *successor activities* to that activity. The activity or activities that immediately follows another activity, without any intervening activity are known as *immediate successor activities* to that activity.

Redundancy exists when among the number of predecessor activities of any given activity, one of the activity is a predecessor to some other activity in the same set. For example, the predecessor activities to activity P contain activities A, B and M, while activity M has A and B as predecessors. The activities A and B are *redundant* in the predecessors list of activity P, and these can safely be eliminated. In other words, jobs A and B are not immediate predecessor to P but are distant ones. *Hence predecessor list should contain only immediate predecessor only*; some writers prefer to call these immediate predecessors by simply 'predecessors'.

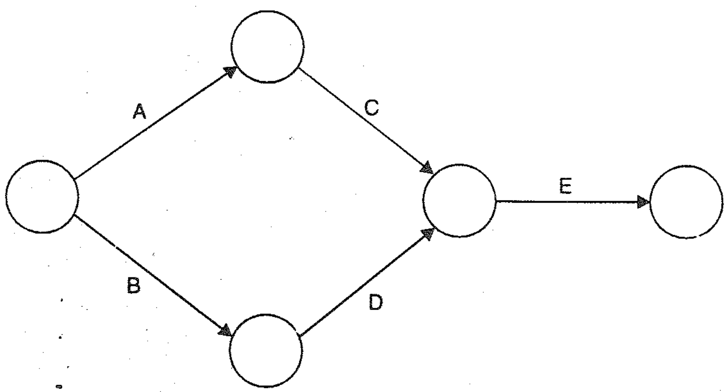


FIG. 3.12

As an example, consider network shown in Fig. 3.12. Table 3.1 gives the list of predecessor and successor activities to each activity.

Table 3.1

Activity	*Predecessor*	*Successor*
A	—	*C** ; *E*
B	—	*D** ; *E*
C	*A**	*E**
D	*B**	*E**
E	*A* ; *C** ; *B* ; *D**	—

Note. * Indicates *immediate* predecessor or successor.

3.4. DUMMY

A *dummy* is a type of operation in the network which neither requires any time nor any resources, but is merely a device to identify a *dependence* among operations. A dummy is thus a connecting link for control purposes or for maintaining uniqueness of activity.

A dummy is also represented by arrow ; but since it is not an activity, it is represented by dashed arrow. A dummy is identified by the numbers of the terminal node.

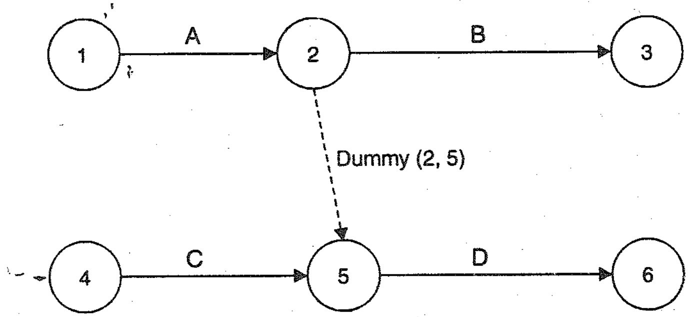


FIG. 3.13. DUMMY OPERATION.

For example, consider the two sets of activities shown in Fig. 3.13.

Set 1. *A*. A wait delivery of new machine.

B. Install new machine.

Set 2. *C*. Remove existing machine.

D. Dispose of existing machine.

Activities *A* and *B* are to be performed serially. Similarly, activities *C* and *D* are to be performed serially. Both the sets are performed simultaneously. However, from practical considerations, we find that activity D of set 2 cannot be performed unless activity A of set 1 is completed. Hence a *dummy link* is used, joining node 2 to node 5, indicating that activity D cannot be started unless event 2 is over.

Uses of dummies

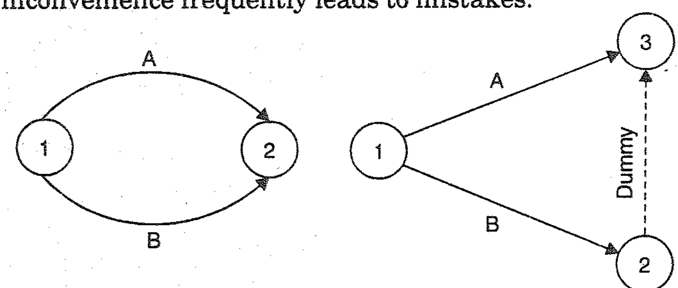
Dummies serve two purposes in a network :

(*a*) Grammatical purpose

(*b*) Logical purpose.

(*a*) **Grammatical purpose**

A dummy is used to prevent two arrows having common beginning and end points. For example, consider the arrows of activities A and B [Fig. 3.14 (*a*)] ; both start from node 1 and end at node 2. Due to this an inconvenience results when the network is used for computations, *i.e.*, uniqueness in the identification is lost. This inconvenience frequently leads to mistakes.



(a) Ambiguous Representation

(b) Grammatically Clear Representation

FIG. 3.14

This trouble can be avoided by using a dummy link as illustrated in Fig. 3.14 (*b*), giving thereby a grammatically correct and clear representation.

(*b*) **Logical purpose**

Dummies are also used to give logical clear representation in a network having an activity common to two sets of operations running parallel to each other. For example, consider two activities Q and R having common end node. Activity Q has O and P as successor activities, while activity R has P and N as successor activities. Fig. 3.15 (*a*) shows the illogical representation of the activities, because activity P cannot have *dual identity*. It should have unique identity.

This uniqueness can be maintained by introducing two dummies P_1 and P_2 as shown in Fig. 3.15 (*b*).

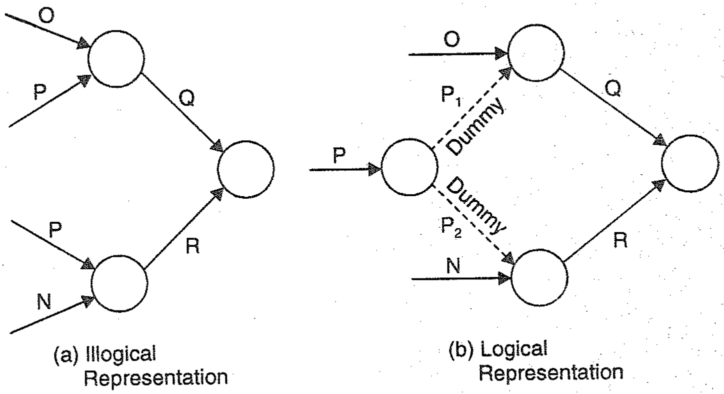


FIG. 3.15. USE OF DUMMIES.

Rules for Provision of Dummies

While planning a network, a natural question that arises is where to provide dummies. Provision of redundant dummies in the network may create confusion. For that, the simple rule is that during the *initial stage* of developing a network, *liberal use* of dummies should be made to fulfil the requirements of inter-relationships between various activities and between various sets of activities. This may result in the introduction of some unnecessary dummies which can be *removed* by the use of following rules :

1. If a dummy job is the only one emanating from its initial

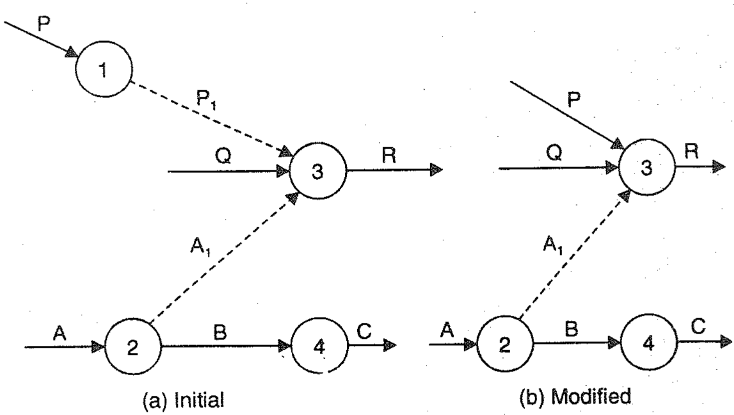


FIG. 3.16

node, it can be removed and the activity terminating at that node can be directly connected to that node to which the dummy was terminating.

For example, consider the initial drawing of the partial network shown in Fig 3.16 (*a*), the dummy P_1 is the only job emanating from its initial node ; it can therefore be removed and activity P can be directly connected to the forward node (3) as shown in Fig. 3.16 (*b*). It should be noted that the same treatment cannot be given to dummy A_1, since other jobs or activities (such as B) are also emanating from the same node.

2. If a dummy job is the only one terminating into a node, the dummy can be removed and the two node at the two ends of the dummy can be merged into one.

For example, activity A was initially joined to activities C, D and B by three dummies A_1, A_2 and A_3 respectively. Since dummy A_3 is the only one terminating into node 2, it can be removed, and nodes 1 and 2 situated at the two ends of dummy A_3 can be combined, as shown in Fig. 3.17 (*b*).

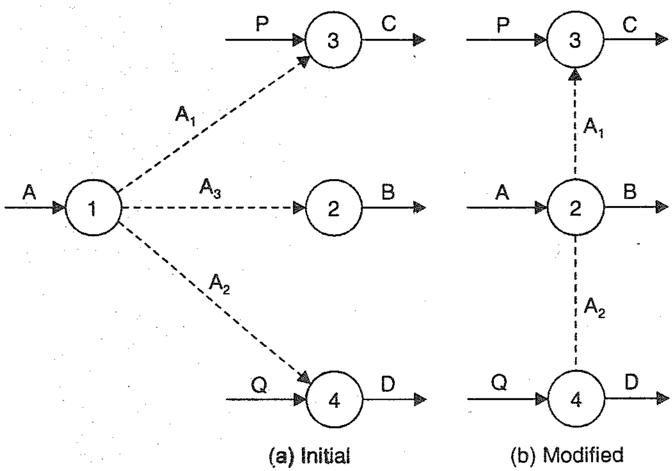


FIG. 3.17

3. If two or more activities, emanating from different nodes, have identical set of predecessors some of which also appear in different predecessor sets of other activities, the two activities

should emanate from a single node. This node can then be connected to their predecessor activities by dummies.

For example, consider a partial network situation shown in Fig. 3.18 (*a*), in which two activities *B* and *D* emanating from two different nodes 5 and 6 have identical sets of predecessors, some of which also appear in different predecessor sets of other activities. In such case, *B* and *D* can be made to emanate from a single node (5) to which the predecessor activities can be joined through dummies. This is shown in Fig. 3.18 (*b*) in which two dummies A_3 and C_3 have been completely eliminated.

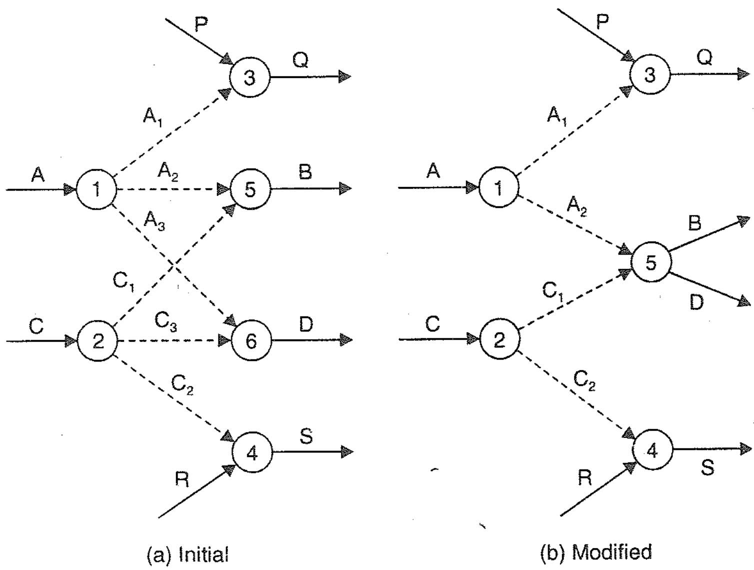


FIG. 3.18

4. If two or more activities, terminating into different nodes, have identical set of successors, the latter having other predecessors as well, the two activities should terminate into one single node. This node can then be connected to their successors through appropriate dummies.

For example, consider two activities *A* and *B*, terminating into two different nodes 1 and 2, as shown in a partial network situation of Fig. 3.19 (*a*). Each one of these have identical set of successors *Q* and *S* having their other predecessors *P* and *R* respectively. In such a case, both *A* and *B* can be made to terminate into one common node (2) and connected to their successors through dummies A_1 and B_1, as shown in Fig. 3.19 (*b*). Thus two dummies A_2 and B_2 have been eliminated.

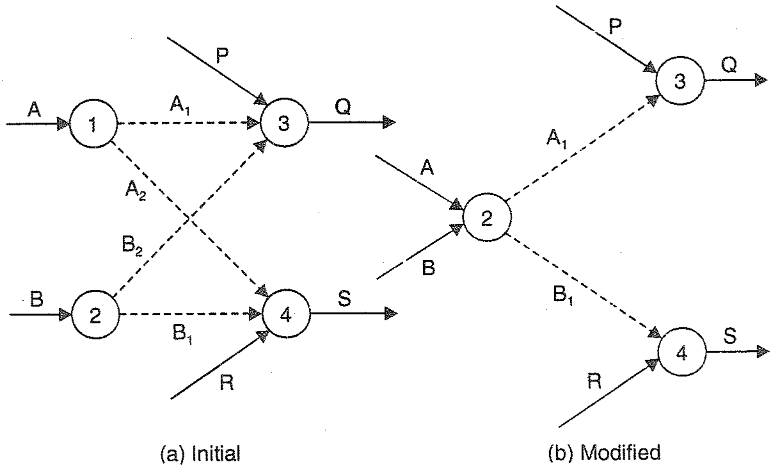


FIG. 3.19

5. Such dummies which are used to show predecessor relations already implied by other activities are known as *redundant dummies*, and can be removed.

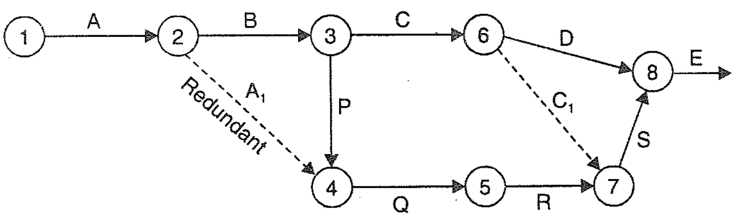


FIG. 3.20

For example, dummy A_1 used to show that activity A is predecessor to activity Q, is redundant since the predecessor relation is already implied by activity P. Hence A_1 can be removed. However, dummy C_1 is not redundant since it has been used to show that activity C is predecessor to activity S ; this predecessor relationship was not implied otherwise.

Example 3.1. *Separate out activities and events from the following list :*

1. Prepare budget.

2. Design completed.

3. Lay railway track.

4. Cure concrete cubes.

5. Commence testing cubes.

6. Material received at site.

7. Distribute invitation cards.

8. Service reservoir filled.

9. Test pipe line.

10. Payment made.

11. Assemble parts of the machine.

12. Prepare estimate.

13. Survey the site.

14. Collect data and prepare check-list.

15. Show room inaugurated.

16. Install pump.

17. Drive piles for right pier of bridge.

18. Specifications prepared.

Solution.

Activities : 1, 3, 4, 7, 9, 11, 12, 13, 14, 16, 17.

Events : 2, 5, 6, 8, 10, 15, 18.

Example 3.2. *Prepare a table showing immediate predecessor activities and events, predecessor activities and events, immediate successor activities and events and successor activities and events for various activities and events of the network shown in Fig. 3.21.*

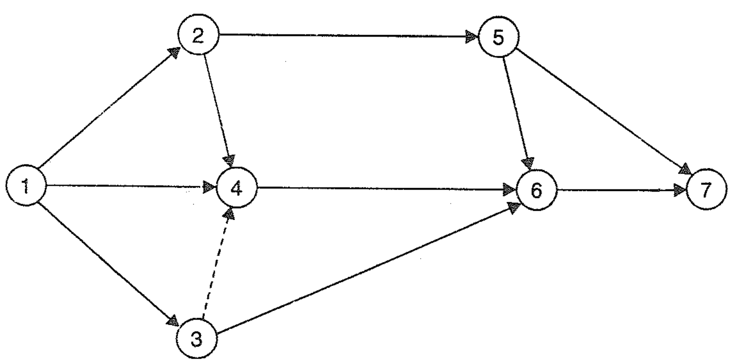


FIG. 3.21

Solution. Table 3.2.

Table 3.2

	Immediate predecessor	*Predecessor*	*Immediate Successor*	*Successor*
(*a*) **Activities**				
(1–2)	—	—	(2–5)	(2–5), (5–6), (6–7), (5–7)
(1–4)	—	—	(4–6)	(4–6), (6–7)
(1–3)	—	—	(3–6), (3–4)	(3–6), (6–7), (3–4), (4–6)
(2–4)	(1–2)	(1–2)	(4–6)	(4–6), (6–7)
(2–5)	(1–2)	(1–2)	(5–6), (5–7)	(5–6), (5–7), (6–7)
(3–4) Dummy	(1–3)	(1–3)	(4–6)	(4–6), (6–7)
(3–6)	(1–3)	(1–3)	(6–7)	(6–7)
(4–6)	(1–4), (2–4), (3–4)	(1–4), (2–4), (3–4), (1–2), (1–3)	(6–7)	(6–7)
(5–6)	(2–5)	(2–5), (1–2)	(6–7)	(6–7)
(5–7)	(2–5)	(2–5), (1–2)	—	—
(6–7)	(3–6), (4–6), (5–6)	(3–6), (4–6), (5–6), (1–3), (1–4), (1–2), (2–5), (2–4), (3–4)	—	—
(*b*) **Events**				
1	—	—	2, 3, 4	2, 3, 4, 5, 6, 7
2	1	1	4, 5	4, 5, 6, 7
3	1	1	4, 6	4, 6, 7
4	1	1	6	6, 7
5	2	2, 1	6, 7	6, 7
6	5, 4, 3	5, 4, 3, 2, 1	7	7
7	5, 6	5, 6, 2, 4, 3, 1	—	—

Example 3.3. *Introduce dummies in the network shown in Fig. 3.22, to identify each activity uniquely.*

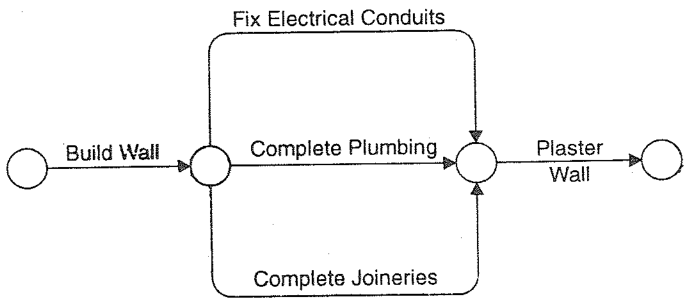


FIG. 3.22

Solution. In the above network, we find that the three activities (fix electrical conduits, complete plumbing and complete joineries) start from one common node and end at some other common node. This gives ambiguous representation, and is grammatically incorrect. Hence, two dummies A_1 and A_2 may be introduced as shown in Fig. 3.23.

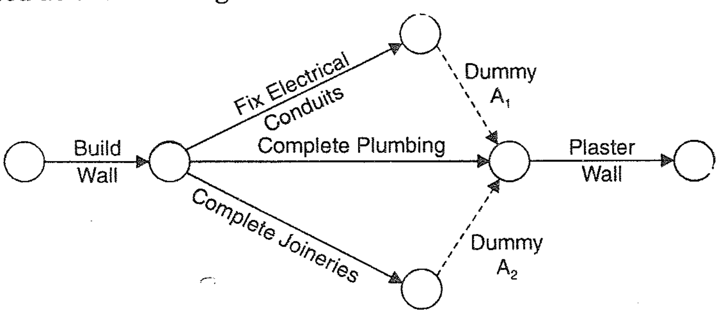


FIG. 3.23

Example 3.4. *In a retaining wall construction, A, B, C represent the shuttering operations for three bays of the wall and P, Q, R represent corresponding concreting operations. Assume that in each case shuttering has to precede concreting. Only one crew for form work operation and another crew for concreting operation is available. Using dummies, show the network, representing the restraints and the consequent interdependencies.*

Solution. The network is shown in Fig. 3.24. Four dummies D_1, D_2, D_3 and D_4 have been used to show the interdependencies of the operations.

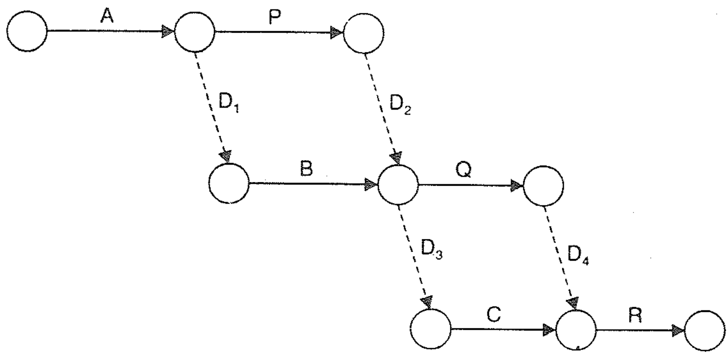


FIG. 3.24

3.5. NETWORK RULES

The following network rules are noteworthy :

1. Initial node has only outgoing arrows. There must be only single initial node in a network.

2. An event cannot occur until all the activities leading to it are completed.

3. An event cannot occur twice, *i.e.* there cannot be any network path looping back to previously occurred event. No event depends, for its occurrence upon the occurrence of a succeeding event. Thus, the network shown in Fig. 3.25 is wrong.

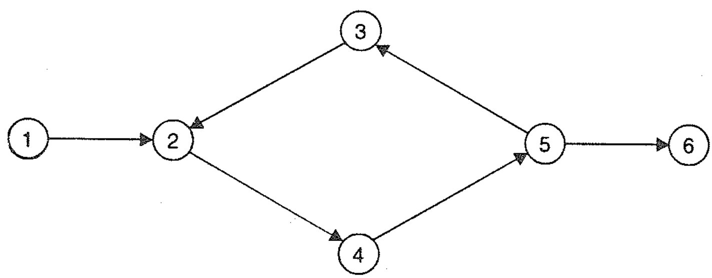


FIG. 3.25. INCORRECT NETWORK.

4. There must not be any dead end left except the final node. Final node has only incoming arrows. There must be only single final node. Thus, the network shown in Fig. 3.26 is wrong because there are two final nodes.

5. No activity can start until its tail end event (preceding event) has occurred.

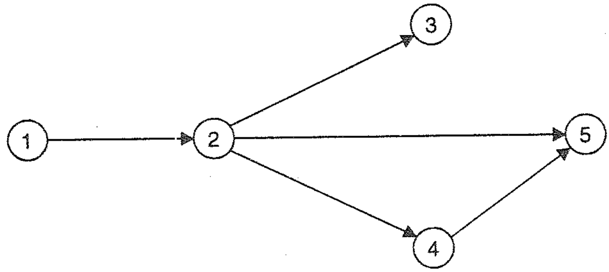


FIG. 3.26. INCORRECT NETWORK.

6. Any arrow should represent singular situation, *i.e.* individuality and separate entity of an activity must be maintained in a network diagram. Particular arrow can emanate from a single event only. Number of arrows should be equal to number of activities in the project. Thus, the network shown in Fig. 3.27 is wrong since activity *P* has two arrows.

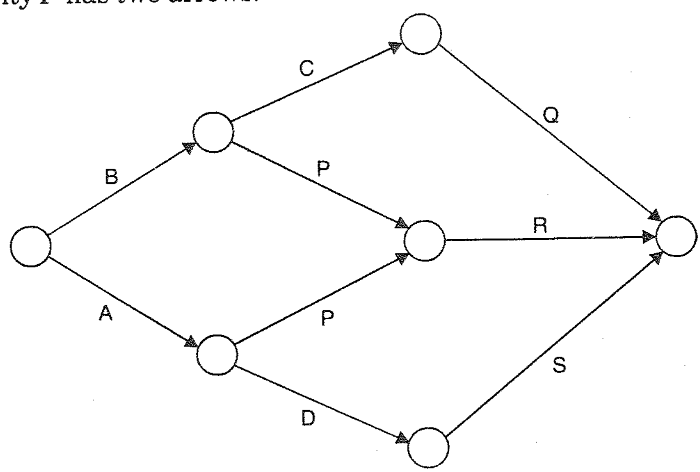


FIG. 3.27. INCORRECT NETWORK.

7. Representation of the network should be such that every activity is completed to reach the end objective.

8. All constraints and interdependencies should be shown properly on the network by use of appropriate dummies.

9. Logic of network should always be maintained, *i.e.* arrow heads point correct way to indicate the true control situation.

10. It is usual practice to show the time flow from left to right.

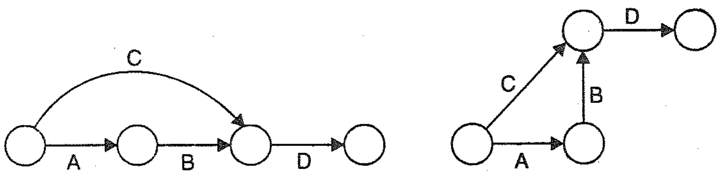
3.6. GRAPHICAL GUIDELINES FOR NETWORK

The following guidelines should be followed for better drawing of network diagrams :

1. Arrows are not vectors. They are never used to indicate duration (or time) through its length. All arrows should be of nearly equal size wherever possible, *i.e.* wide variation is length of arrows should be avoided. Length should be chosen to suit drafting requirements.

2. Orientation or angle between arrows should be chosen to suit drafting convenience. The angle between arrows leaving or joining nodes, should be as large as possible so that more space is available for the addition of other relevant information in the diagram.

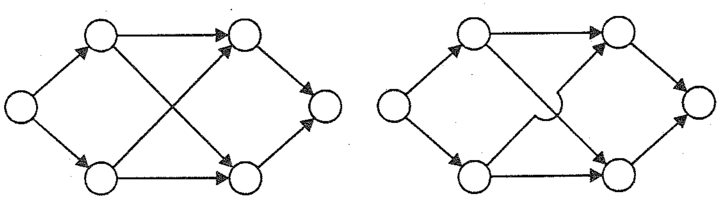
3. As far as possible, straight arrows should be used. Curved arrows are not preferred.



(a) Curved Arrows (b) Straight Arrows

FIG. 3.28

4. Arrows should normally not cross each other. If this crossing is not avoidable, length of the arrow should be broken to bridge over the other, as shown in Fig. 3.29.



(a) Not Desirable (b) Bridging

FIG. 3.29

Rectangular Network Diagram

The graphical guidelines given above are applicable for an *angular* network diagram in which the arrows are at an angle with horizontal or vertical direction. Some people prefer a cigar-shaped or *rectangular network diagram* in which the arrows are either horizontal or vertical. In such a situation, an arrow may, sometimes, be required to give a right angled turn to obtain requisite 'flow' in the network diagram. The network diagram so obtained is always very compact. However, the angular network diagram, using straight arrows gives a better understanding of the various activities of the project. Fig. 3.30 shows the two types of network diagrams for the same project.

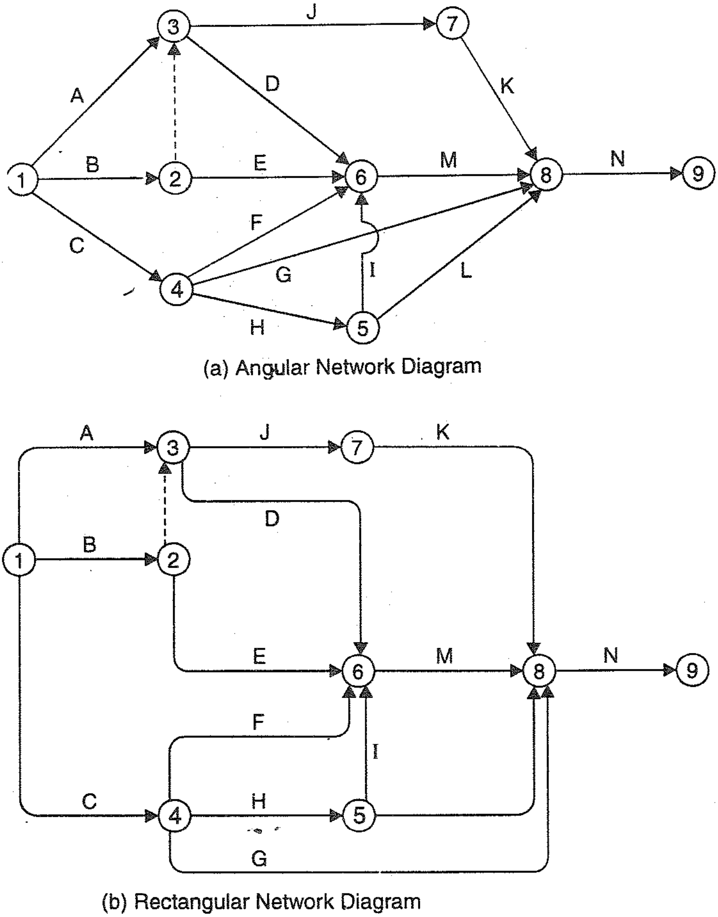


FIG. 3.30

3.7. COMMON PARTIAL SITUATIONS IN NETWORK

Fig. 3.31 gives some common partial situations in a network.

Partial Situation

1. *B* is controlled by *A*. Operation *B* cannot begin until operation *A* is completed.

2. *C* is controlled by *A* and *B*. Operation *C* cannot begin until operations *A* and *B* are completed.

3. Activities *B* and *C* are controlled by activity *A*. Neither of activities *B* and *C* can start unless *A* is completed.

4. Activities *C* and *D* are controlled by activities *A* and *B*. Neither of activities *C* and *D* can start until *A* and *B* are completed. However, *C* and *D* can be started independent of each other.

5. Activity *B* is controlled by *A* and *C*. However, activity *D* is controlled by activity *C* only.

6. Activity *D* is controlled by *A* and *B*, while activity *E* is controlled by activity *B* and *C*.

7. Activity *D* is controlled by *A*, *B* and *C*. However, activity *E* is controlled by *B* and *C*.

Representation

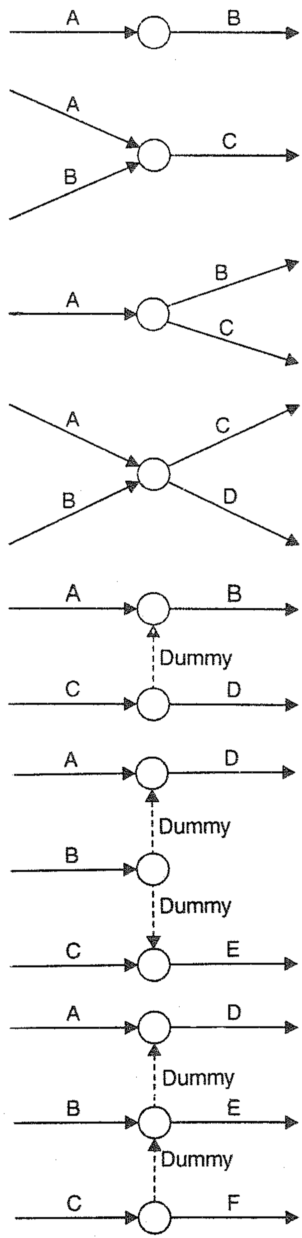
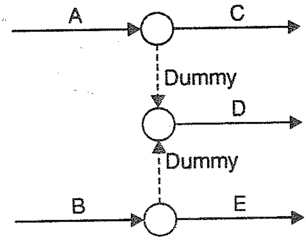


FIG. 3.31 (*a*)

Partial Situation **Representation**

8. Activity *A* controls *C* and *D*, while activity *B* controls *D* and *E*. Thus, *D* is controlled by both *A* and *B*.



9. Activity *X* is controlled by *D* and *A* ; activity *Y* is controlled by *A*, *B* and *C*, while activity *Z* is controlled by *D* only.

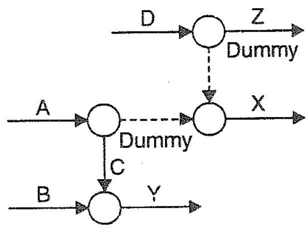


FIG. 3.31 (*b*)

3.8. NUMBERING THE EVENTS

It is essential to number the events or node points. The activities joining the nodes can better be identified on the network by the event numbers or node numbers at the tail and head of the activity. The event numbering should be scientifically done so that they reflect their logical sequence. In a big network, the problem of numbering can be simplified if the rules devised by D.R. Fulkerson are followed. The sequential numbering to the events may be assigned in the following steps :

1. There is a single initial event in a network diagram. This initial event will have arrows coming out of it and none entering it. Number this initial event as 1.

2. Neglect all the arrows emerging out of the initial event numbered 1. Doing so will apparently provide one or more *new* initial events.

3. Number these apparently produced new initial events as 2, 3, 4 etc.

4. Again neglect all emerging arrows from these numbered events ; this will create few more initial events.

5. Follow step 3.

6. Continue this operation until the last event, which has no emerging arrows, is numbered.

Skip Numbering

As a rule, a tail event must have a lower number than the head event. In bigger networks, where extensive modifications are frequently required to be made, *renumbering* can be avoided by numbering the events in the multiple of 10, *i.e.*, numbering the events as 10 (initial), 20, 30, 40 etc. If an event is added later, it can be assigned a number (such as 31, say) which lies between the number of immediate predecessor event and immediate successor event. This process of numbering is known as *skip numbering*. Alternatively, skip numbering can also be achieved by leaving out successive number such as (8, 9), (18, 19), (28, 29) etc. from the numbering of initial network. These left out numbers can later be assigned to newly added events arising out of the modification of the initial network.

Example 3.5. *Using Fulkerson rule, number the events of the network shown in Fig. 3.32.*

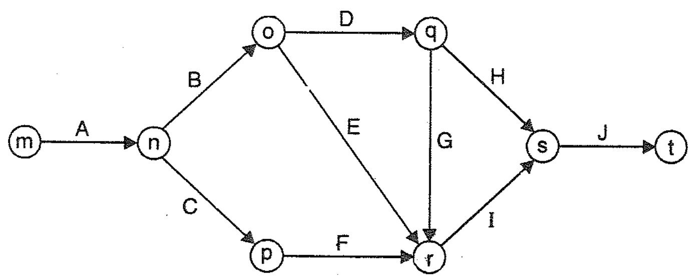


FIG. 3.32

Solution.

1. Event m is the initial event ; hence number it as 1.

2. Neglect the arrow (A) emerging out of the initial event. Due to this event n will be the new initial event. Number it as 2.

3. There are two arrows B and C emerging out of event No. 2. By neglecting these, two more new initial events are obtained at nodes o and p ; number these as 3 and 4 respectively.

4. Consider event 3. Neglect two arrows D and E emerging out of it. This will result in a new event at nodes q ; assign number 5 to it. Note that event r will still have arrows entering to it.

5. Consider event 5 and neglect arrows G and H coming out of it. This will result in two new initial events at nodes r and s. Since node r is predecessor event to node s, number it as 6. Number node s as 7.

6. Finally, event at node t has no arrow emerging out of it. Hence number this final event as 8.

The numbered network diagram is shown in Fig. 3.33.

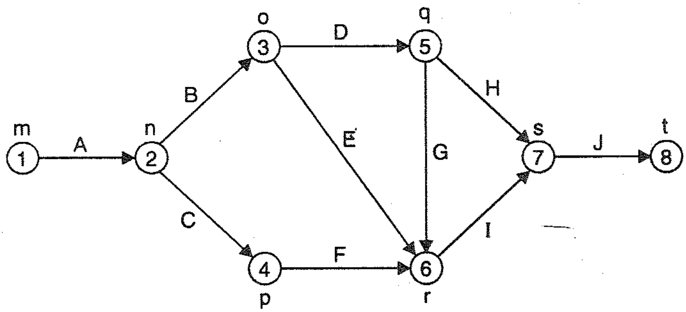


FIG. 3.33

Example 3.6. *Draw the network for a project having four activities labelled A, B, C and D, and related as below :*

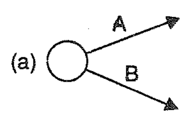
(i) Activity A and activity B can be done concurrently.

(ii) Activity A is the immediate predecessor of activity C, and so is the relation between B and D.

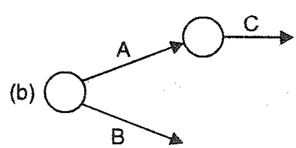
(iii) Accomplishment of C and D marks the completion of the project.

Solution. Arrow network diagram can be drawn step by step as illustrated below (Fig. 3.34) :

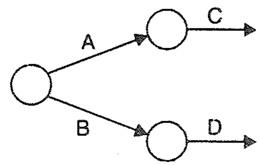
(*i*) Activity A and B being done concurrently. Fig. 3.34 (*a*).



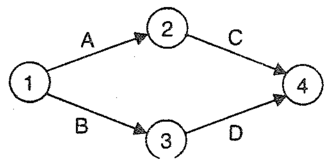
(*ii*) Activity C is the immediate successor activity A. Fig. 3.34 (*b*).



(*iii*) Activity *D* is the immediate successor to activity *B*. Fig. 3.34 (*c*).

(c)


(*iv*) Accomplishment of *C* and *D* marks the completion of the project. Fig. 3.34 (*d*).

(d)


FINAL DIAGRAM
FIG. 3.34

Thus, final network is shown in Fig. 3.34 (*d*), after numbering the events.

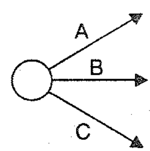
Example 3.7. *Draw the network of a project having seven activities. Activities A, B and C run concurrently. Activities predecessor relationships are as follows :*

Activity	*Immediate Predecessor*
D	*A*
E	*B*
F	*C*

Activity G is the last operation of the project, and is also immediate successor to D, E and F.

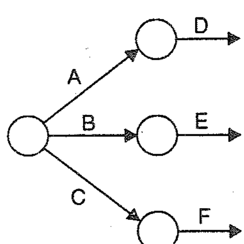
Solution. The network diagram can be developed step by step as follows (Fig. 3.35) :

(*i*) Activities *A*, *B* and *C* run in parallel [Fig. 3.35 (*a*)].



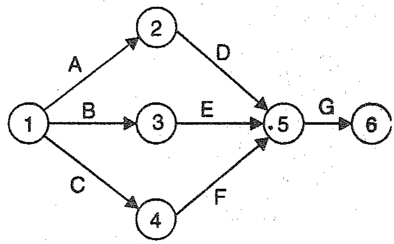
(a)

(*ii*) Activities *D*, *E* and *F* are immediate successors to activities *A*, *B* and *C* respectively [Fig. 3.35 (*b*)].



(b)

(*iii*) The last activity *G* is immediate successor to *D*, *E* and *F* [Fig. 3.35 (*c*)].



(c) Final Net Work

FIG. 3.35

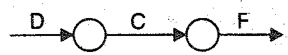
Thus, Fig. 3.35 (*c*) shows the final network, after properly numbering the events.

Example 3.8. *Draw a network diagram for the project having 9 activities, with the following inter-relationships :*

(*i*) *C follows D but precedes F.*
(*ii*) *C follows B but precedes H.*
(*iii*) *G follows F but precedes I.*
(*iv*) *E follows A but precedes I.*
(*v*) *D follows A.*
(*vi*) *H and I terminate at the same time.*
(*vii*) *A and B start at the same time.*

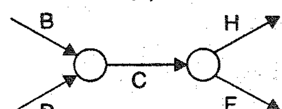
Solution. The network diagram can be developed step by step as under (Fig. 3.36).

(*i*) *C* follows *D* but precedes *F* [Fig 3.36 (*a*)].



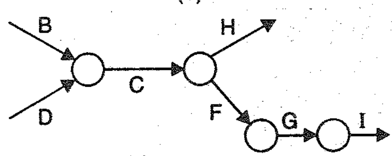
(a)

(*ii*) *C* follows *B* but precedes *H* [Fig. 3.36 (*b*)].



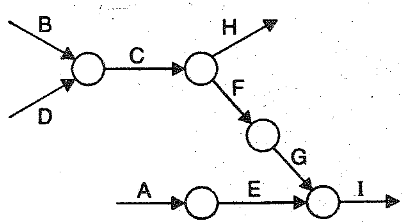
(b)

(*iii*) *G* follows *F* but precedes *I* [Fig. 3.36 (*c*)].



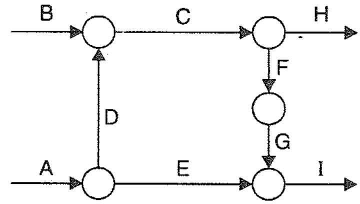
(c)

(*iv*) *E* follows *A* but precedes *I* [Fig. 3.36 (*d*)].



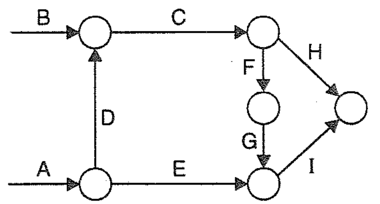
(d)

(*v*) *D* follows *A* [Fig. 3.36 (*e*)].



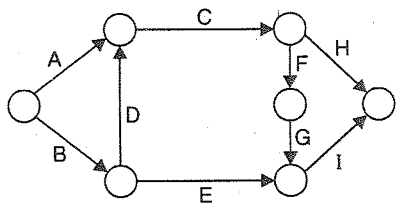
(e)

(*vi*) *H* and *I* terminate at the same time [Fig. 3.36 (*f*)].



(f)

(*vii*) *A* and *B* start at the same time [Fig. 3.36 (*g*)].



(g)

FIG. 3.36

The final network diagram obtained in Fig. 3.36 (*g*) is shown in Fig. 3.37 after numbering the events.

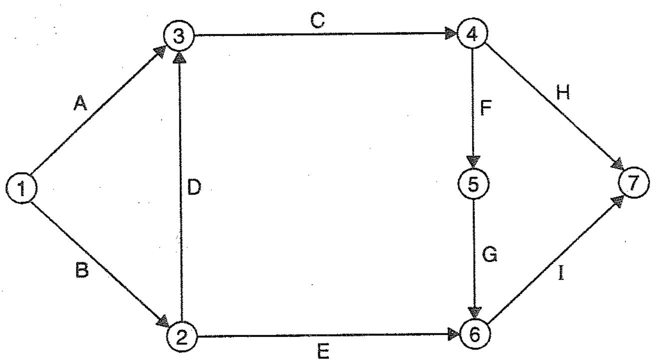


FIG. 3.37

Example 3.9. *A project consists of six activities (jobs) designated from A to F, with the following relationships :*

(*i*) *A is the first job to be performed.*

(*ii*) *B and C can be done concurrently, and must follow A.*

(iii) B must precede D.

(iv) E must succeed C, but it cannot start until B is complete.

(v) The last operation F is dependent on the completion of both. Draw the network diagram.

Solution. The step by step development of the diagram is shown in Fig. 3.38. The final diagram has its events numbered.

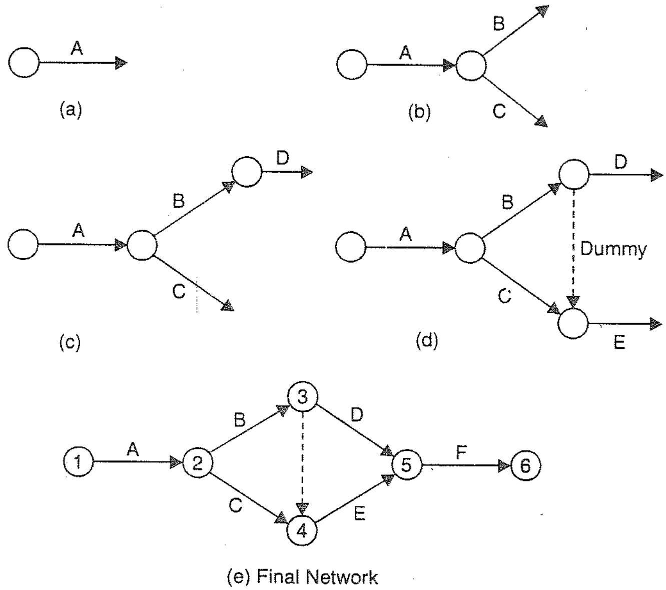


FIG. 3.38

Example 3.10. *The maintenance project of a building consists of ten jobs. The predecessor relationships are identified by their node numbers, as indicated below :*

Job	*Identification*	*Job*	*Identification*
A	*(1, 2)*	*F*	*(4, 5)*
B	*(2, 3)*	*G*	*(4, 7)*
C	*(2, 4)*	*H*	*(5, 8)*
D	*(3, 6)*	*I*	*(6, 8)*
E	*(3, 5)*	*J*	*(7, 8)*

Draw the network diagram for the project.

Solution. The step by step development of the network is given in Fig. 3.39.

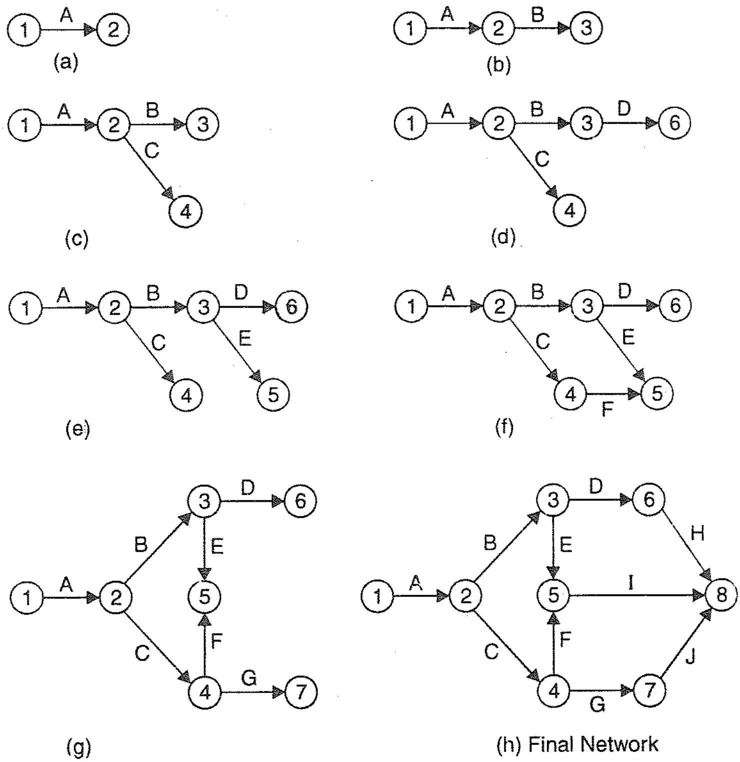


FIG. 3.39

Example 3.11. *A project plan consisting of ten events have predecessor relationships as under :*

Event	*Immediate Predecessor*	*Event*	*Immediate Predecessor*
1	—	*6*	*3, 5*
2	*1*	*7*	*3, 4*
3	*2*	*8*	*3, 7*
4	*2*	*9*	*7*
5	*2*	*10*	*3, 6, 8, 9*

Draw the network diagram for the project plan.

Solution. The step by step development of the network is shown in Fig. 3.40.

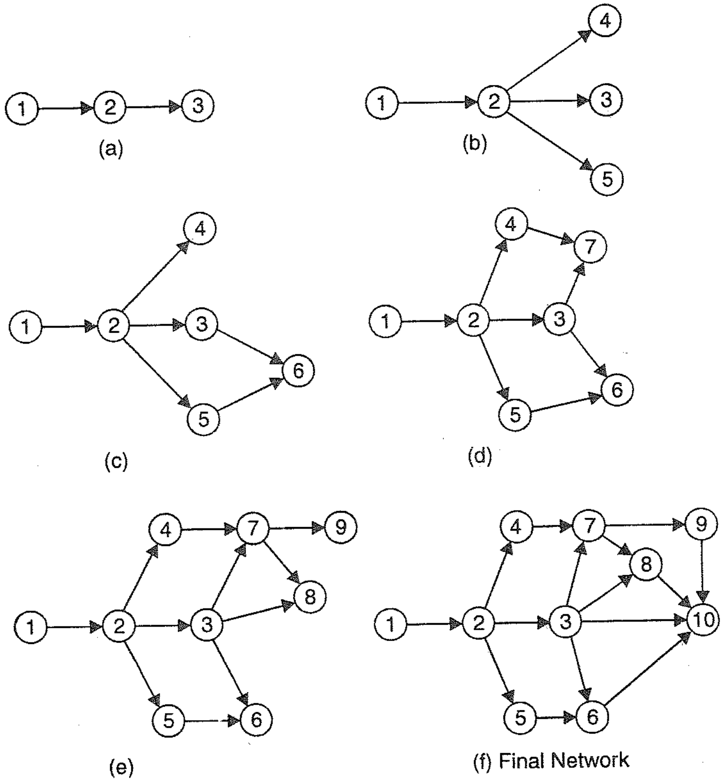


FIG. 3.40

Example 3.12. *A project has fourteen activities A through M. The relationships which obtain amongst these activities are given below.*

(*i*) *A is the first operation.*

(*ii*) *B and C can be performed in parallel and are immediate successor to A.*

(*iii*) *D, E and F follow B.*

(*iv*) *G follows E.*

(*v*) *H follows D, but it cannot start until E is complete.*

(*vi*) *I and J succeed G.*

(*vii*) *F and J precede K.*

(*viii*) *H and I precede L.*

(*ix*) *M succeeds L and K.*

(*x*) *The last operation N succeeds M and C.*

Construct the network diagram.

Solution. The step by step development of the network is shown in Fig. 3.41. Note that a dummy operation has been introduced in Fig. 3.41 (*c*) to fulfil the requirements mentioned in (*v*) above. In the final diagram [Fig. 3.41 (*e*)], the events have been numbered according to Fulkerson's rule.

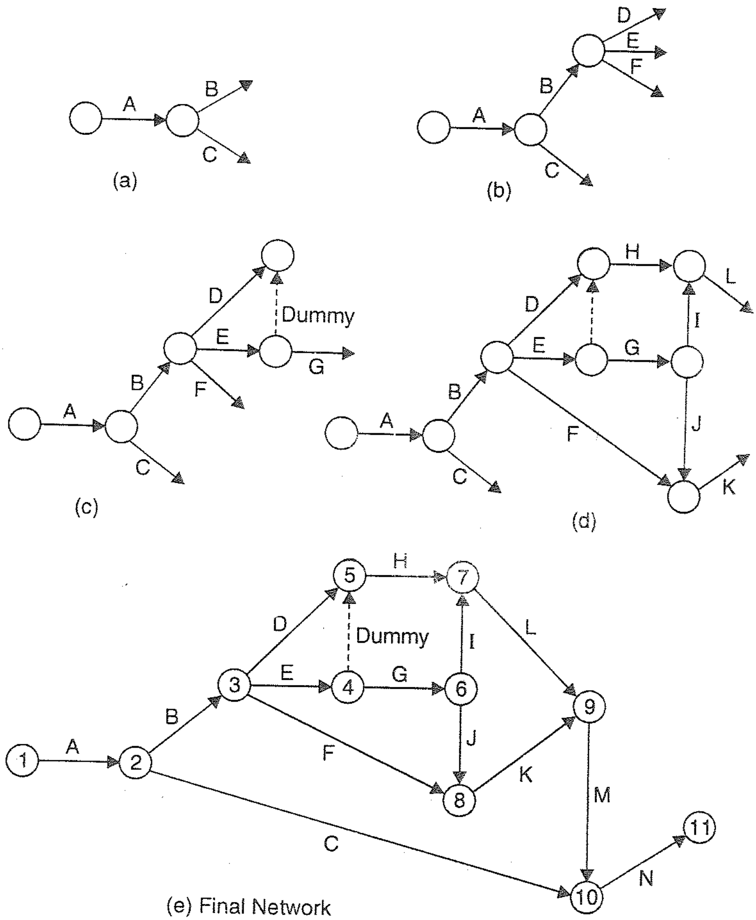


FIG. 3.41

3.9. CYCLES

A *loop network* or *cycle* is any path of activities that leads back into itself. In such a circumstance, an activity shows up a distant predecessor of itself. Cycles cause logical errors in the network. Such a situation *may* occur in a complicated network ; however, cycles should be removed before network calculations are made.

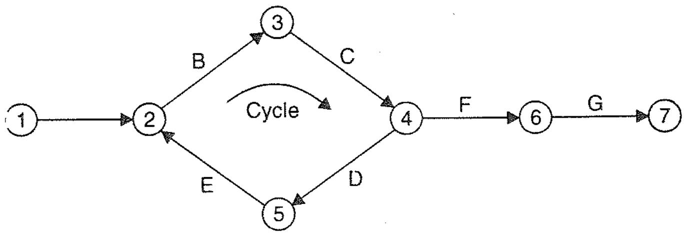


FIG. 3.42. CYCLE.

In Fig. 3.42, we find a cycle between nodes 2, 3, 4 and 5. Event 2 cannot take place unless activity E is complete. Activity E depends upon the completion of event 5. However, event 5 depends upon the completion of event 2. Thus, a loop or cycle is obtained. Such a cycle can be very easily located by numbering the events in logical sequence. Cycles are more serious than simple redundancies. Once a cycle is discovered, the person who compiled the project data must recheck for accuracy of the stated predecessor relationships of jobs in the cycle.

PROBLEMS

1. Define an 'event' and an 'activity'. Differentiate clearly between the two.
2. Differentiate between PERT network and CPM network. Illustrate your answer by drawing the two types of networks for a project.
3. What do you understand by a 'dummy' ? What are its uses ?
4. Choose 'Events' and 'Activities' from the following list :

   (*a*) Survey the site.

   (*b*) Maps prepared.

   (*c*) Invitations mailed.

   (*d*) Print the minutes.

   (*e*) Audit the accounts.

   (*f*) Fabricate screws.

   (*g*) Office inaugurated.

   (*h*) Start interior decoration.

   (*i*) Electrical design completed.

   (*j*) Assemble parts.
5. Define 'head event', 'tail event', 'dual role event', 'successor event' and 'predecessor event'.
6. Write notes on (*a*) redundancies and (*b*) cycles, with reference to a network.

7. Discuss various rules for providing dummies in a network. What are redundant dummies ?
8. Explain Fulkerson's rules for numbering the events of a network.
9. Discuss various network rules.
10. For the network shown in Fig. 3.43, prepare a table showing a list of predecessors, immediate predecessors, successors and immediate successors to each of the events.

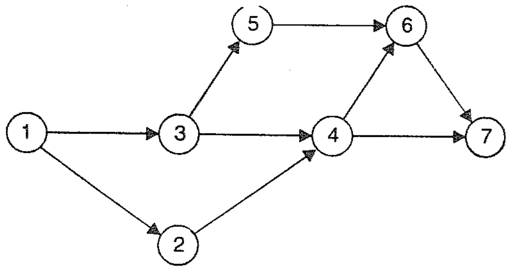


FIG. 3.43

11. A project consists of three operations E, L and F. The network (Fig. 3.44) shows the sequence.

FIG. 3.44

Each of the three operations can be completed in three sections. Draw a network, assuming that the completion of one section in an operation allow beginning of the next operation.

12. Using Fulkerson's rule, number the events of the network shown in Fig. 3.45.

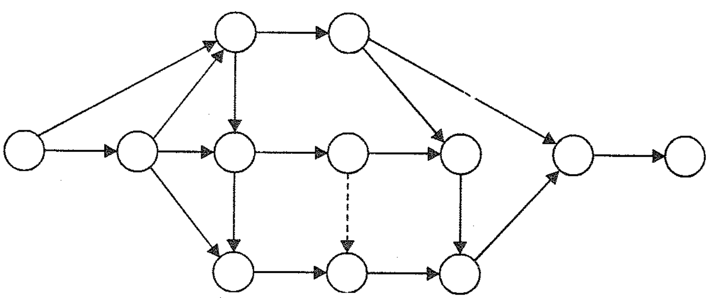


FIG. 3.45

13. Using Fulkerson's rule, number the events of the network shown in Fig. 3.46.

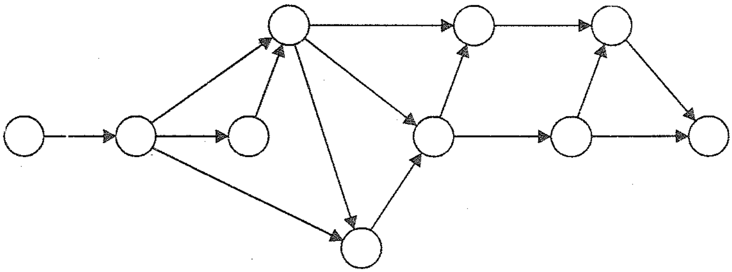


FIG. 3.46

14. A project consists of 16 activities having their predecessor relationship as follows :

(*i*) A is the first activity of the project.

(*ii*) B, C and D follow A and can be done concurrently.

(*iii*) E and G cannot begin until C is completed, and can be performed simultaneously.

(*iv*) F is the immediate successor to activities B and E.

(*v*) H and K run in parallel, and both succeed G.

(*vi*) L succeeds F and H.

(*vii*) I and J are immediate successor activities to activity D.

(*viii*) M and N are immediate successor to I and K. However, both M and N can be performed concurrently.

(*ix*) Activities O and P are the last activities. Activity O is the immediate successor to N and L. Activity P is the immediate successor to M and J. Draw the network and number the events.

15. A construction project consists of 12 activities. The predecessor relationships are identified by their node numbers as indicated below :

Activity	*Identification*	*Activity*	*Identification*
A	(1, 2)	G	(4, 6)
B	(2, 4)	H	(5, 6)
C	(2, 3)	I	(5, 7)
D	(2, 7)	J	(7, 8)
E	(3, 4)	K	(6, 8)
F	(3, 5)	L	(8, 9)

Draw the network diagram.

16. A project consists of eight activities M, N, O, P, Q, R, S and T. Draw the network and number the events if :

(*a*) Activities M, N and Q can start concurrently.

(*b*) Activities O and P are concurrent, and depend on the completion of both M and N.

(*c*) Activities R and S are concurrent and depend on the completion of O.

(*d*) Activity T depends upon the completion of P, Q and R.

(*e*) The project is complete when S and T are done.

17. A project consists of eight events having predecessor relationships as under :

Event	*Immediate Predecessor*	*Event*	*Immediate Predecessor*
1	—	5	3, 4
2	1	6	3, 5
3	1	7	6
4	2, 3	8	4, 7

Draw the network.

4

Development of Network

4.1. INTRODUCTION

In the previous chapters, we have studied the basic principles of network, and have developed the terminology necessary for the understanding of CPM/PERT networks. As stated earlier, a project to be planned by network technique should consist of well specified and clearly definable jobs, operations or activities. In this chapter, we will develop a concept of breaking down a project into activities in order to draw the network. This decomposition is necessary for performing the basic calculations required for scheduling and analysis purpose. The concept associated with the construction and understanding the network diagram, portraying each of the activities and predecessor-successor relations amongst them, will be our major concern.

4.2. PLANNING FOR NETWORK CONSTRUCTION

Depending upon the sense of thinking with respect to the end configuration of the plan, networks can be constructed either by *forward planning* or by *backward planning* or by combination of both forward and backward planning.

1. Forward planning

In this method, the planner starts from the initial event and builds up the events and activities logically and sequentially until the end event is reached. In this method, while considering an activity, a planner asks himself the following questions :

What event comes next ?

What are dependent events ?

What events can take place concurrently ?

The answer to these questions is not that simple, specially in a complex situation.

2. Backward planning

In this method, the planner starts with the end event, and arranges the events and activities until the initial event is reached. Keeping the goal in view, the planner asks himself 'if we want to achieve this, what events or activities should have taken place ?'

3. Combined planning

In practice, a combination of both forward planning and backward planning is followed. At any stage, the planner may need traverse the network back and forth several times until it is found to be satisfactory. In this method, the planner must ask himself the following questions, at any stage of network planning :

(*a*) What event or events must be completed before the particular event can start ?

(*b*) What event or events follows this ?

(*c*) What activities can be accomplished simultaneously ?

4.3. MODES OF NETWORK CONSTRUCTION

There are basically two modes of network diagrams :

(*i*) Event oriented diagrams

(*ii*) Activity oriented diagrams.

Fig. 3.3 (*a*) and (*b*) show respectively the activity oriented diagram and event oriented diagram for a project of purchasing a new heavy duty lathe and disposing the old lathe.

Event Oriented Diagrams

PERT users prepare event oriented network diagram, in which emphasis is placed on the events of the project. One first selects the events that are to be included in the plan. The interest is focussed upon the start or completion of events rather than the activities. The activities that take place between events are not specified. This approach grew out of the desire to report on the project progress via discernible management milestones, as events represent them.

The events in such a network fall in a logical sequence. Where ambiguities are not caused, the 'start' circle is omitted and only the completed event is recorded. It is understood that the start event must have taken place before the completed event can occur. The enumerated events are then connected by arrows to show how they are related to current plans for accomplishing the project.

Activity Oriented Diagrams

CPM users prepare activity oriented diagrams in which emphasis is placed on activities of the project. The activities are arranged in sequential and logical order. A description of the activity is written on the arrow representing it. As diagramming proceeds, additional activities are selected as suggested by the nature of the work and the diagram grows into a co-ordinated whole.

Generally, the importance of events is minimised in such diagrams. However, after a diagram is drawn, one can easily select certain key events one wishes to index and name for the progress reporting purposes.

In a particular network, whether event oriented or activity oriented, one can include both events and activities. Both of these are important for planning. While events are used to show the milestones or stages in a project, activities are the actual performance of a task to achieve the event.

4.4. STEPS IN DEVELOPMENT OF NETWORK

The following steps are found to be useful in the development of a network for a proposed project :

1. OBJECTIVE	:	set down in words.
2. PLAN BREAK-DOWN	:	depending upon the management level of use, activities and events identified and listed in general list.
3. SEQUENCING	:	the activities and events thus prepared, *i.e.* marshalling the data.
4. DEVELOPMENT	:	of predecessor and successor relationship in events through *location* of nodes in rough layout, giving events usual relative time effect through position.
5. DRAWING	:	activities by connecting pair of events with arrows.
6. CHECK	:	network diagram (*a*) in respect of content, sequence and sense, and (*b*) for degree of detail.

7. REDRAW	:	network diagram to eliminate errors and attain style.
and		
INTRODUCE	:	uniqueness dummies for grammar of network.
8. NUMBER	:	events for identification.

Each of the steps in the construction of network require some discussion and will involve some perception to establish the conditions under which task will be performed.

STEP 1 : OBJECTIVE

During the planning of a project, the first and foremost step is (*i*) to define the project, and (*ii*) to decide the way in which it is to be carried out. The task to be undertaken requires to be set down as *specific, definite, complete and well-defined verbal statement*. Specific verbal statement means the specific description of particular dimensions, type of materials, plants etc. necessary for the project.

Objective specifies the task to be undertaken and policy of its execution. This *specification* defines the project and determines the way in which it is to be carried out.

Example. ***Specification for a lathe installation project.***

"A new lathe is to be installed at a location by removing the existing machine to clear the floor. Existing machine is to be disposed off and the complete installation is to be tested."

STEP 2 : PLAN BREAKDOWN

After establishing objective of the task, the planner has to adopt either forward planning or backward planning (or mixed planning) to achieve the goal. This backward or forward thinking will give a list of activities or jobs to be performed to achieve the task and also stages in the project execution. To obtain a list of activities and/or events, the specification has to be examined under three headings :

(*a*) What are the difficulties that will have to be overcome.

(*b*) What facilities will assist in the removal or circumvention of the obstacles.

(*c*) What safeguards will have to be taken in using the facilities.

The result of the examination will create a list of activities and/or events.

Example. ***For the lathe installation project, plan breakdown is done by examining specification under the above mentioned questions :***

(*a*) *What is the way in reaching the objective ?*

New lathe is to be purchased. Existing machine is to be removed and disposed off.

(*b*) *What is the help available ?*

Power supply for testing.

Finance for purchasing the lathe.

Implements for removal of existing machine.

Disposal facilities.

(*c*) *What safeguards are necessary ?*

Removal of existing machine is necessary to clear off the site for installation. Also, installation of power supply is necessary.

From the above, the following list is obtained.

General List

Events	*Activities*
Order for new machine placed.	Await delivery of lathe
Existing machine removed.	Install lathe
Power supply installed.	Remove existing machine
Existing machine disposed.	Dispose off existing machine
Lathe installed.	Install power supply ; connect the lathe to power.
Installation tested.	Test complete installation.

Note that activities in the above list are not in any particular order. It is convenient, however, to enter the earlier activities near the head of the list.

In large projects, several methods of carrying out projects may be possible, but only one sequence must be followed and used in a particular case, best suited to the specific set of conditions. This often occurs in construction industry, where identical buildings can be erected in very different activity orders.

STEP 3 : SEQUENCING—MARSHALLING THE DATA

In the second step we have obtained a general list of various activities and events necessary for the completion of the project.

This general list is to be reviewed so that in each of the main group, those with definite similarities can be put in suitable subgroups. The marshalled list for the lathe project is given below :

Marshalled List

Events	***Activities***
(*i*) *Subgroup 1E*	(*i*) *Subgroup 1A*
Order for new lathe placed	Await delivery of lathe
Lathe received	Install lathe
Lathe installed	Connect to power
Lathe tested	Test the installation.
(*ii*) *Subgroup 2E*	(*ii*) *Subgroup 2A*
Existing machine removal	Remove existing machine
commenced	Dispose existing machine
Existing machine removed	
Existing machine disposed	
(*iii*) *Subgroup 3E*	(*iii*) *Subgroup 3A*
Power supply applied	Obtain power supply
Power supply obtained	Install power supply
Power supply installed	

STEP 4 : LOCATION OF NODES

Now the events listed above are required to be located on paper so that a visual effect of movement along a time scale is obtained. Events should be located in such a way that they represent initial picture of the relation amongst them. This relationship results from the proposed use of manpower, money, material and other resources during a particular period of time. For obtaining the relationships amongst events, the planner must ask himself the following three questions regarding the sequence :

1. What event or events must be completed before the particular events can occur ?

2. What event or events should follow this ?

3. What events can be accomplished simultaneously ?

This way, he will be able to get the logical sequence of events in the network.

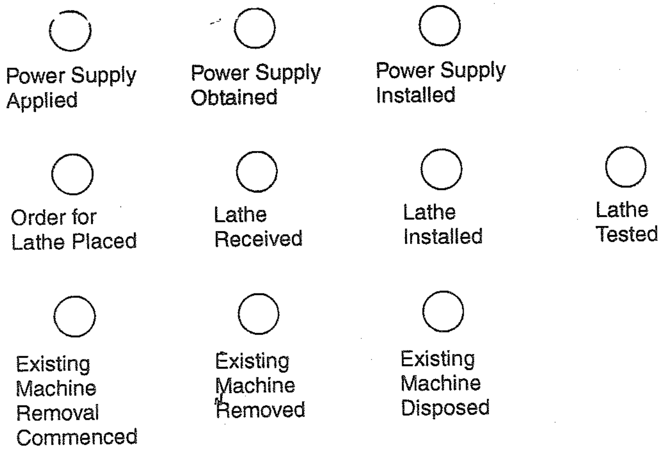


FIG. 4.1. LOCATION OF NODES.

The following points must be kept in view while locating the nodes :

(*i*) First event must be located by the left most node.

(*ii*) Events occurring earlier must be represented to the left side with respect to the events occurring later.

(*iii*) Serial events must be represented by nodes along horizontal plane while simultaneous events are represented up or down the vertical plane.

(*iv*) No event should be located in position to the left of (*i.e.* behind) the vertical axis of any preceding event.

For the example of lathe project, the location of nodes is shown in Fig. 4.1.

STEP 5 : DRAWING ARROWS

Events having close and direct relationship are joined to each other by arrows representing activity to be performed for passing from one stage of the project to the other. These activities should fall in a logical sequence. The planner should ask himself the following three questions regarding the sequence of activities :

1. What activity or activities should be completed before a particular activity can start ?

2. What activity or activities follow this ?

3. What activities can be accomplished simultaneously ?

For the lathe project, the network diagram, after drawing of arrows, is shown in Fig. 4.2. Note that the activity inter-relationships between the three groups are also obtained at this stage by

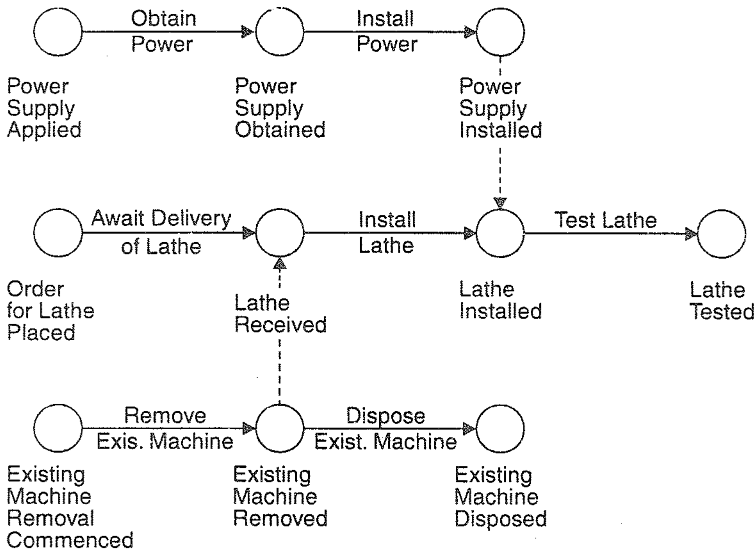


FIG. 4.2. DRAWINGS ARROWS.

suitable use of dummies (represented by dotted arrows). The activities may be listed on the corresponding arrows.

STEP 6 : CHECKING

At this stage, the diagram is checked with respect to

(*a*) Content, sequence and sense.

(*b*) Degree of detail.

CONTENT : In the above diagram, the operation 'test lathe' cannot commence before connecting the lathe to power. Hence one operation 'connect to power' is missing.

SEQUENCE : It is essential to check the diagram for events and activities in respect of (*i*) logic and (*ii*) accuracy. Particular attention should be paid to multiple events, *i.e.* those events at which more than one arrows enters and/or more than one arrows leave, since it is at this point that errors are most likely to occur. The checking ensures that the network correctly represents the sequence.

SENSE : It should be ensured that the network does not contain 'loops' or 'cycles'. If located, these should be removed.

Also, it should be checked whether there is any event (other than the first) which has only outgoing arrows, or whether there is any event (other than the last one) which has only incoming arrows. Such situation, if found, should be rectified. There should be no dead ends left. With this check, it is revealed that :

Start Project event indicates commencing of operations : (*i*) obtain power, (*ii*) 'await delivery of lathe' and (*iii*) 'remove existing machine'. Thus, these three operations should start from the same node.

Project Completed event indicates completion of operation : (*i*) 'test lathe' and (*ii*) dispose existing machine. Thus, these two operations should end at the same node.

DEGREE OF DETAILS : An arrow should always represent singular situation but an event may represent commencement of more than one operations. In respect of sufficient detail, a ratio, known as E/A ratio defined as under :

$$\frac{E}{A} \text{ ratio} = \frac{\text{Total no. of events}}{\text{Total no. of activities}}.$$

In a good network, its value should lie between 1 to 1.6.

STEP 7 : REDRAW

The errors found in the previous step are removed, and the diagram is redrawn, by introducing uniqueness dummies, if necessary. The redrawn diagram is shown in Fig. 4.3.

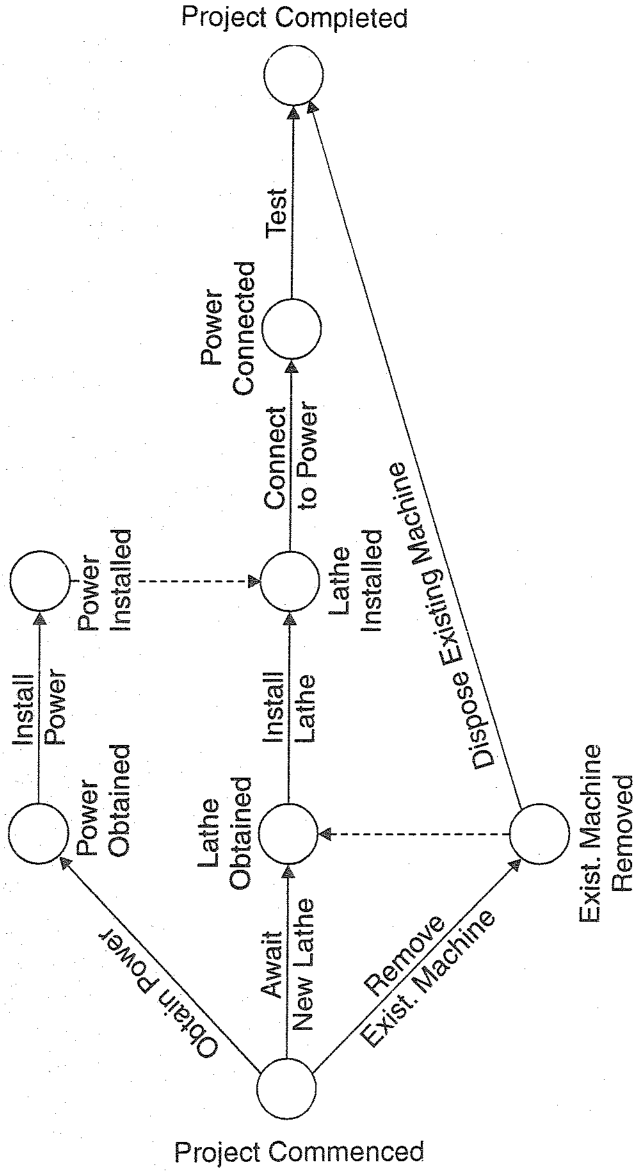


FIG. 4.3

STEP 8 : NUMBER

After having drawn the final network, the events are numbered, using Fulkerson's rule.

4.5. WORK BREAKDOWN STRUCTURE

In Art. 4.4 we have studied various steps in the development of network, out of which the second step is the *plan breakdown* to identify the activities and events necessary for the completion of the project. This is a very important step, which should be studied in greater details. In the first step, the *objective(s)* should be specified in terms of 'end items'. The subsequent division of each end item creates a work break-down structure (or schedule) which serves as the *framework* for developing the network. Work breakdown structure or schedule is a pictorial representation of the entire program. It is a preliminary diagram illustrating the way in which all the supporting objectives go together and mesh to ensure the attainment of the major objective. Such a breakdown structure is more essential in complex projects consisting of hundreds of events and activities.

In work breakdown structure, the *top-down* approach to planning is adopted. Such an approach ensures that the total project is fully planned, and that all derivative plan contribute directly to the desired end objectives. The work breakdown schedule aids in the identification of objectives and allows the planner to see the total picture of the project.

The development of the work breakdown structure begins at the highest level of the program with the identification of project end items. The major end items are then divided into their sub-component parts (*i.e.* systems, sub-systems, components) and the component parts are further divided into their more detailed units. The subdivision of the work breakdown structure continues to successively lower levels, reducing the value (cost) and complexity of the units at each level, until it reaches the level where the end item subdivisions finally become manageable units for planning and controlling purposes. The end items subdivisions appearing at this last level in work breakdown structure are then divided into major work packages (*i.e.* engineering, manufacturing, testing etc.). A typical work breakdown structure of a project is shown in Fig. 4.4.

Work packages at the lowest level are generally represented by a number of activities that are used in the preparation of network. A work package may be represented either by one activity, with a beginning and event, or by a number of activities separated by

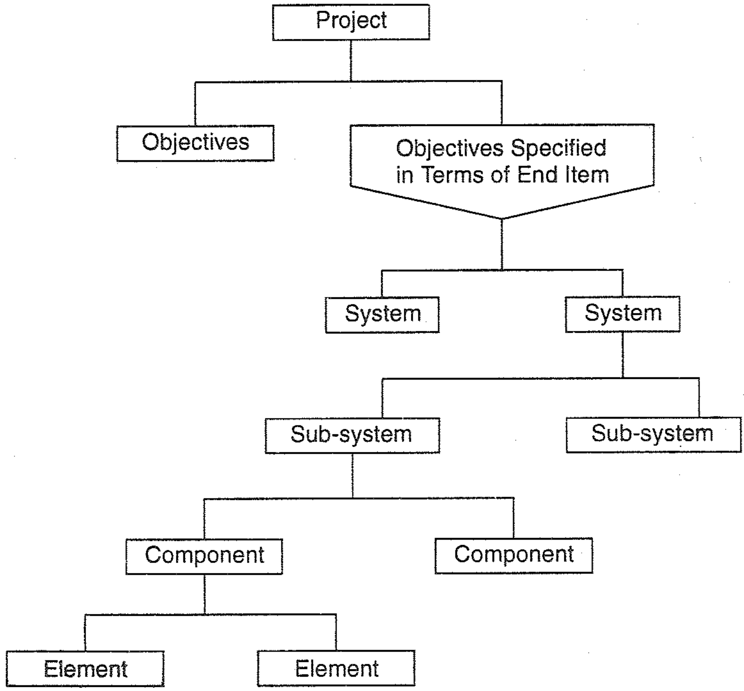


FIG. 4.4. WORK BREAKDOWN STRUCTURE.

events which serve as beginning or end points for other activities in the project.

Let us now take a typical example of house construction project. The major or total objective in this case is '*house constructed*' which goes on the top of the work breakdown structure (level 1). The supporting objectives or stages are : (*i*) Survey and land levelling, (*ii*) Masonry work, (*iii*) Carpentry work, (*iv*) Electric fitting, (*v*) Water and sanitary fittings, (*vi*) Finishing and interior decoration. All these objectives are at level 2.

Now if we take any one of the second level objective, such as masonry work, there may be following phases : (*i*) foundations, (*ii*) pillars, (*iii*) walls, (*iv*) partitions, (*v*) roof etc. All these phases are thus at level 3.

Now take any one of the 3rd level phase, say foundation, which can be further subdivided into following sub-phases : (*i*) excavation, (*ii*) laying forms, (*iii*) mixing concrete and placing concrete, (*iv*) curing concrete, (*v*) removal of forms etc. These sub-phases are at level 4.

All these stages are shown below.

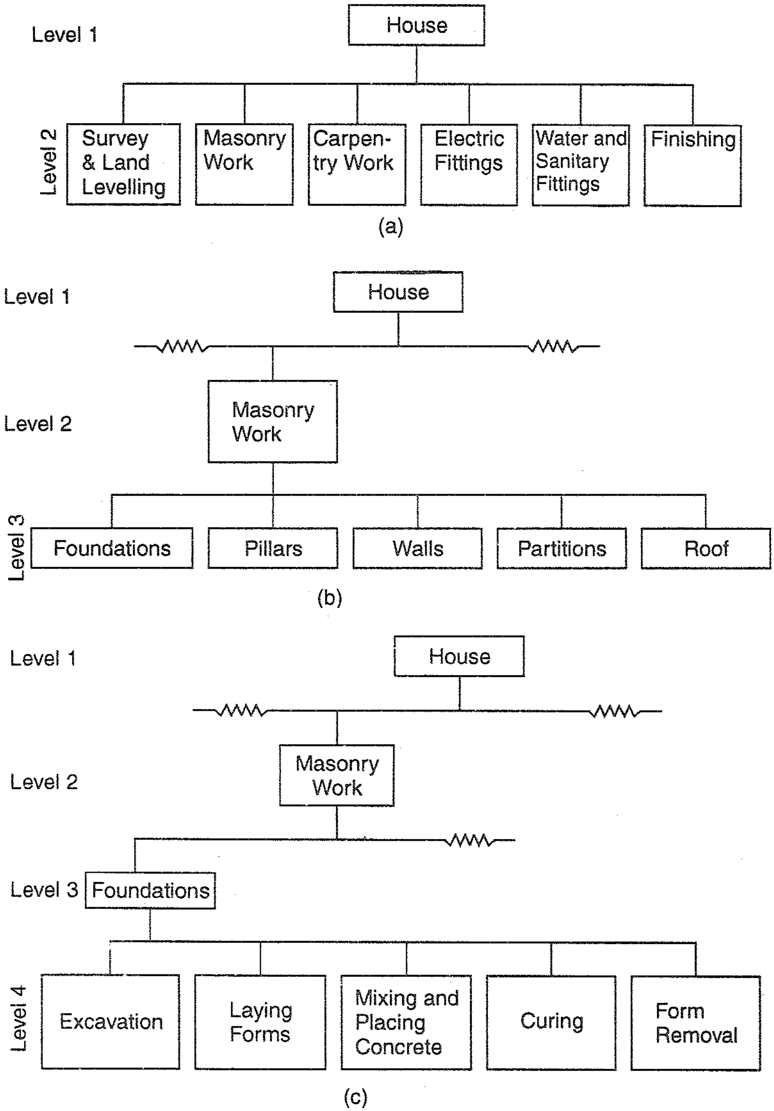


FIG. 4.5. WORK BREAKDOWN STRUCTURE FOR HOUSE CONSTRUCTION PROJECT.

This way, the planner can go from one level to the other. The number of levels into which the project has to be splitted depends upon the type and complexity of the project itself. The basic requirement is that the work breakdown schedule should be detailed enough to allow the eventual construction of PERT/CPM network which will precisely reflect the inter-relationship among all the events and activities which make-up the entire project. In a large complex project, there may be ten or even more levels of sub-objectives. The work breakdown schedule so obtained presents the entire project in a systematic way so that inter-relationships among all phases of the projects are easily seen. As the work progresses, the project work breakdown schedule or structure also serves as the framework for summarising data from the bottom up, so that the amount of detail presented at any level in the project is commensurate with the decision-making requirements of management at that level.

4.6. HIERARCHIES

Large and complex networks contain more than two to five hundred work operations. If all of these operations are represented on one single network diagram, it will become clumsy. Since all of these work operations are to be represented, one can successfully use a *hierarchy or family of networks* of increasing detail. There may be several stages in the hierarchy, each to be used by different set of people, *i.e.* top management people, middle, and upper-management people etc. The number of stages in the hierarchy may reflect not only the complexity of the project but also the structure of the company management, and the systems of control and reporting that are in use.

The hierarchy may have generally two or three *stages* or *levels*. The number of *arrows* (work operations) at each stage of the hierarchy will depend on the following factors :

(*i*) Purpose of the diagram,

(*ii*) Degree of control desired,

(*iii*) Extent of available information, and

(*iv*) How the diagram is to be used.

The *first level diagrams* are primarily used for general information. The purpose is to describe in general terms to top management, clients or the public, the over all nature of the project and how it is to be accomplished. The diagram will contain very few arrows, each representing a piece of work of fairly broad scope. The diagram at this stage need not be strictly correct logically. Each arrow may represent a *project* itself for the second level diagram.

As an example, consider the network of Fig. 4.6 for the project of development and marketing of a new product of a company. The *First Stage* network is intended for the top management of the company. The activities '*develop product*' and '*prepare marketing plan*' run concurrently, and are operated by different groups or divisions of the company.

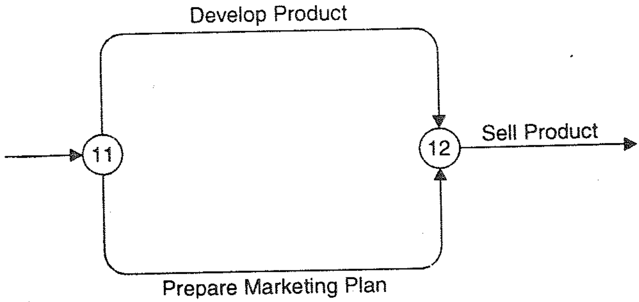


FIG. 4.6. FIRST STAGE NETWORK.

Each division concerned can now breakdown the corresponding activity into finer details, at the *Second Stage* of the network. Thus the activity '*develop product*' becomes a project '*develop product*'. Similarly, the activity '*prepare marketing plan*' becomes another project, '*prepare marketing plan*'. Each one of these second stage networks may contain several activities. The details of second stage network for each of the two activities is shown in Fig. 4.7.

It will be seen that both the second stage networks are *independent* and they run parallel. However, they have common starting and finishing events. The network diagrams at the second stage are used by middle management with the information for cost and time control in classical sense. The work packages at this stage are better defined than at first level, and the diagram should be logically correct.

Small and middle size projects may contain only two stages. However, large projects may have even the *third stage*. The third level of detail has the purpose of directing the efforts of small groups of individuals at the site (construction or manufacturing). It is only at this level that true project control can be achieved.

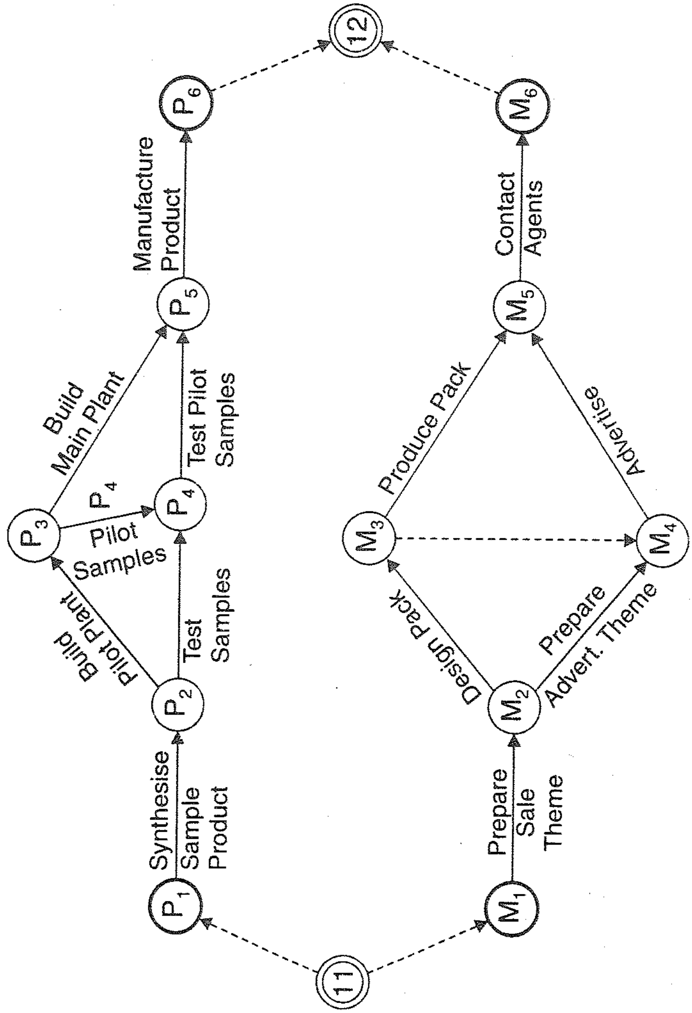
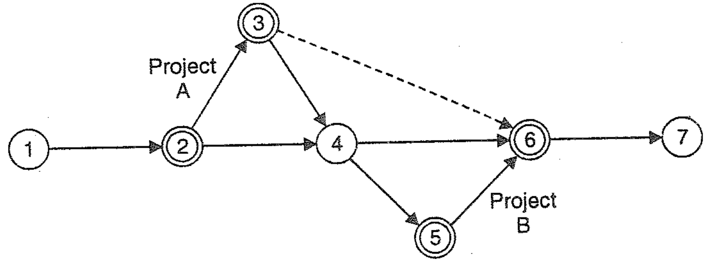


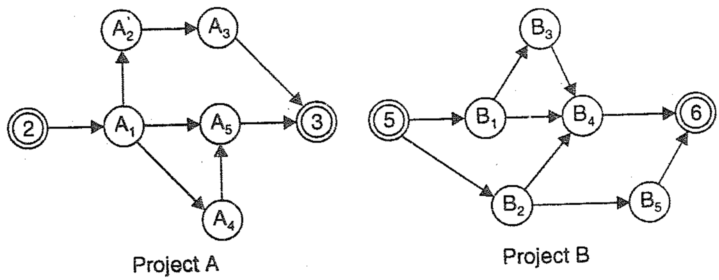
FIG. 4.7. SECOND STAGE NETWORK.

Fig. 4.8 shows the *three stages* of networks for a certain building construction company.

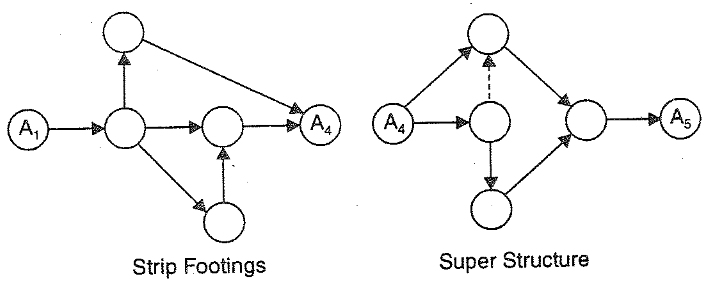
When hierarchy principle is used for large project to split it up, the first level or overall network should be prepared by the top administrator, in consultation with the representatives of various divisions so that inter-departmental constraints are introduced properly. The representatives of each division will then prepare more detailed sub-networks for middle level (project control) and lower level (site/production control) implementation.



(a) Top Level (Management of Several Projects)



(b) Middle Level (Project Control)



(c) Lower Level (Site Control)

FIG. 4.8. HIERARCHIES.

4.7. ILLUSTRATIVE EXAMPLES

Example 4.1. *Write specification, determine plan breakdown and prepare network for the project of 'casting a concrete beam over verandah opening'.*

Solution.

Specification. A concrete beam is to be designed and cast at the site. Mixing to be done by mechanical mixer which is available.

Plan breakdown. The project will consist of the following activities :

Design the beam

Order concrete materials (cement, sand, aggregate)

Order steel

Order timber

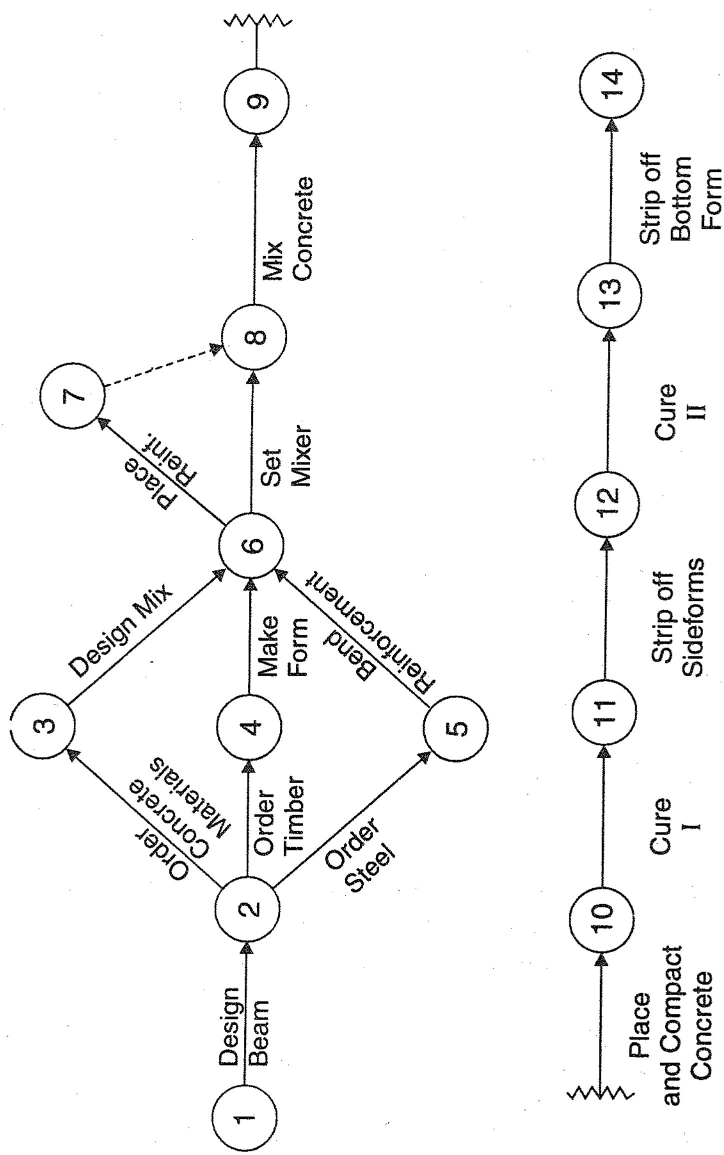


FIG. 4.9

Design mix proportion
Make and fix form
Bend reinforcement
Place reinforcement
Set mixer at site
Mix concrete
Place and compact concrete
Cure stage I
Strip off forms
Cure stage II

Net work Diagram. Shown in Fig. 4.9.

Example 4.2. *Construct the network for the manufacture of a storage cabinet, given the following specification :*

'A simple storage cabinet is to be manufactured by fabrication and assembly of frame and panels. The cabinet is to be painted. Panels and paint are available from the store.'

Solution. The following is the list of activities :

Order material for frame work
Await delivery of material
Obtain panels and paint from store
Set up tools
Fabricate frame
Fix panels

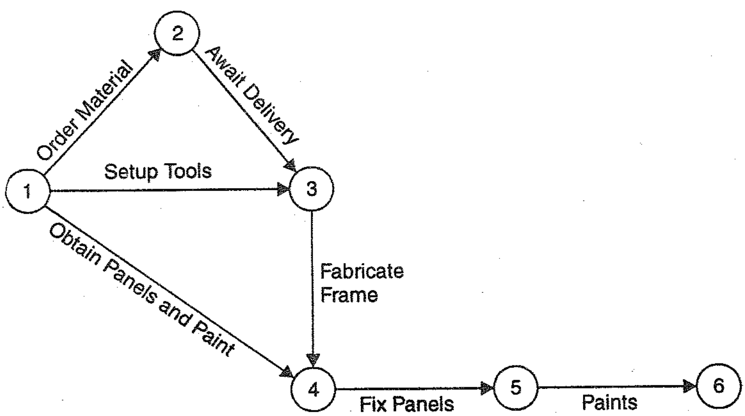


FIG. 4.10

Obtain paint

Paint cabinet.

The network is shown in Fig. 4.10.

Example 4.3. *Construct PERT network for the project using the listed events. The events are not in logical sequence.*

'Building of an aircraft'

Event a	:	*Air craft equipment received.*
Event b	:	*Final fuselage (body of an aircraft to which the engine, wings and tails are fitted) drawing completed.*
Event c	:	*Air craft tested and commissioned.*
Event d	:	*Tail assembly received.*
Event e	:	*Sub-contract for tail assembly awarded.*
Event f	:	*Procurement of engine initiated.*
Event g	:	*Programme go ahead.*
Event h	:	*Wings from sub-contractor received.*
Event i	:	*Plans and specifications completed.*
Event j	:	*Fuselage-engine assembly completed.*
Event k	:	*Air craft equipment submitted.*
Event l	:	*Manufacture of fuselage completed.*

Solution. After logical sequencing, the network shown in Fig. 4.11 is obtained.

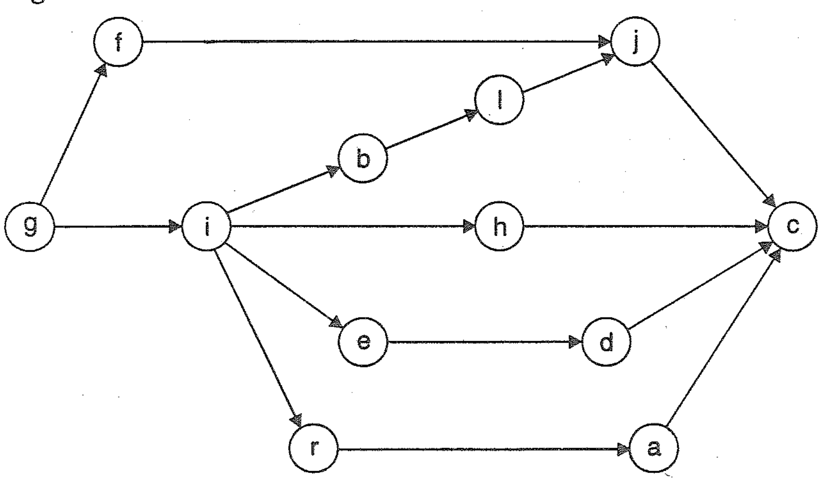


FIG. 4.11

Example 4.4. *Assume that a statue is to be erected in a village square on a stone platform which is to be built on a cement concrete foundation. The statue is to be prepared at another place, moved and erected. The various operations of the entire project are given below. These operations are not in logical sequence.*

A. Make statue

B. Shift statue

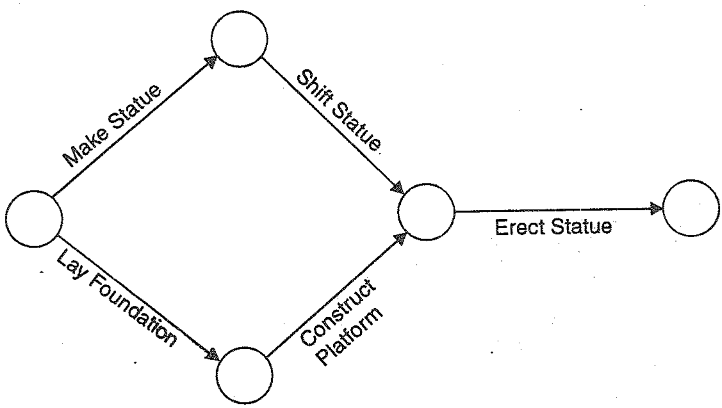
C. Erect statue

D. Lay Foundation

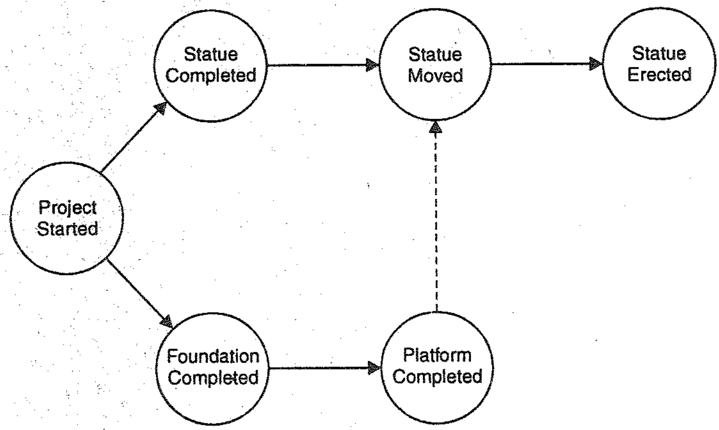
E. Construct Platform.

Represent the above project by (a) activity oriented network and (b) event oriented network.

Solution. The *activity-oriented diagram* is shown in Fig. 4.12 (*a*) while *event oriented diagram* is shown in Fig. 4.12 (*b*).



(a) Activity Oriented Diagram



(b) Event Oriented Diagram

FIG. 4.12

PROBLEMS

1. Differentiate between 'forward planning', 'backward planning' and 'combined planning'.
2. Differentiate between 'activity oriented diagram' and 'event oriented diagram'.
3. Write a note on 'development of networks'.
4. What do you understand by work breakdown structure ? What is its importance in network planning ?
5. Write a note on 'hierarchies'.
6. Write specification, determine plan breakdown and complete by 'numbering the network', for the work 'Answering an official letter'.
7. Write specifications, determine plan breakdown and complete by numbering the network for a 'Budgeting Project' of a large manufacturing firm.
8. Write specification, determine plan breakdown and complete the network for the project 'overhaul of diesel generator'.