PROJECT PLANNING

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OBJECTIVES OF PROJECT PLANNING

Planning a project is an administrative process. The objectives of planning are:

- **To forecast the resource requirements of people, material and equipment.**
- **To forecast the financial requirements.**
- **To provide a suitable control tool against which progress can be measured.**
- **To minimize the unproductive time of both men and machine.**
- **To find the time required completing the project.**
- **To establish the time for delivering the materials required.**

PRINCIPLES OF PROJECT PLANNING

Planning techniques range from simple bar charts to computerized network analysis. However all techniques are based on certain principles such as:

i. **The plan should provide information in a readily understood form.**
ii. **The plan should be realistic. There is no point, for example, in planning a building to be completed in six months, if the delivery period for cement is five months.**
iii. **The plan should be flexible. It should be possible to alter certain elements without disrupting the entire plan when circumstances change.**
iv. **The plan should serve as a basis for progress monitoring and control.**
v. **The plan should be comprehensive. It should cover all the stages from briefing to commissioning.**

PLANNING TECHNIQUES

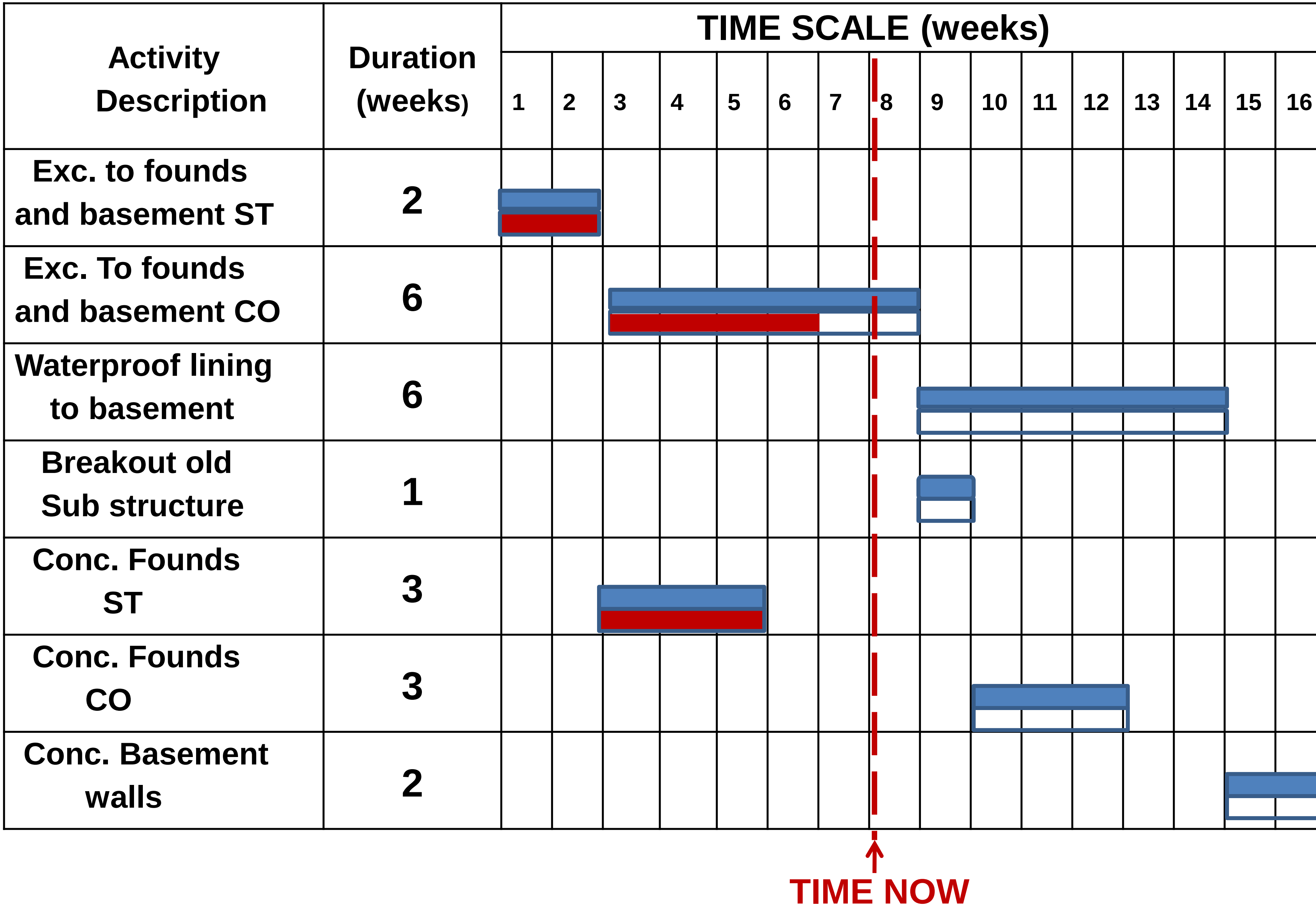
The most common and widely used project planning techniques are:

1. **Bar charts and linked bar charts.**
2. **Network analysis, either activity on the arrow or on the node.**
3. **Line of balance, for repetitive construction work.**

BAR CHARTS AND LINKED BAR CHARTS

- Bar charts are the easiest to understand.
- Most widely used form of planning tool.
- Even when the more sophisticated techniques like network analysis are used the eventual schedule of work is usually presented in bar chart form.
- In the bar chart technique, the list of activities is given and the duration of activities are shown as bars corresponding to each activity.
- The length of the bar determines the duration of activities in a time scale system.
- The unit of time on construction projects are normally days or weeks or months. See Fig. 5.1.

Figure 5.1- Typical Bar Charts



PROGRESS CONTROL CHARTS

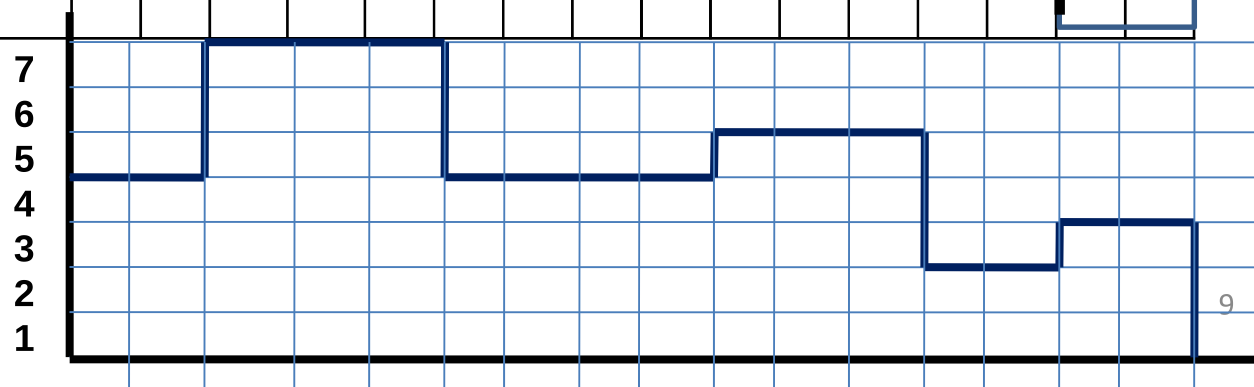
- Bar Charts can be used as a progress control chart.
- The bars are drawn in two sections, the upper section showing the planned time, the lower section left blank for recording progress.
- At the end of each time period the amount of work done in each activity is recorded by shading the lower section.
- Figure 5.1 shows time now as being end of week 7, the shading on the chart shows activities ‘Exc. To founds and basement ST’ and ‘Conc. Founds ST’ are 100% complete.
- Activity ‘Exc. To founds and basement CO’ is shown as being four-sixths or 67% complete whereas, to be on programmed, it should be 83% (five-sixth) complete.
- This means that this activity is unlikely to finish at the end of week 8 as planned.
- Lower section could be extended to show the new time of finishing.
- The effect on the other activities would need to be calculated.
- This effect would be more easily studied by using an extension to the simple bar chart such as the linked bar chart.

LINKED BAR CHARTS

- **The linked bar chart, (shown in Fig. 5.2) shows the links between an activity and the preceding activities which have to be complete before this activity can start.**
- **Similarly the links are shown between the activity and the succeeding activities, which are dependent on the activity being completed.**
- **This illustration of dependency between activities has the advantage that the effects of delays in any activity are easily seen.**
- **The time available for each activity is also displayed: for example, in Fig. 5.2 activity ‘Conc. Founds ST’ is shown as starting on week 3 and finishing on week 5, but it can be seen that the absolute deadline before it interferes with the next succeeding activity, ‘Conc. Founds CO’, is end of week 9.**
- **This activity has some ‘float’ or extra time available before any delay affects other activities.**
- **Activity ‘Exc. to founds and basement CO’ for example has no float and must be completed by week 8; this is usually called a critical activity.**

Figure 5.2- Linked Bar Charts

Activity Description	Duration (weeks)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		TIME SCALE (weeks)															
Exc. to founds and basement ST	2	(4)	(4)														
Exc. To founds and basement CO	6			(4)	(4)	(4)	(4)	(4)	(4)								
Waterproof lining to basement	6									(2)	(2)	(2)	(2)	(2)	(2)		
Breakout old Sub structure	1									(2)							
Conc. Founds ST	3			(3)	(3)	(3)											
Conc. Founds CO	3										(3)	(3)	(3)				
Conc. Basement walls	2															(3)	(3)



RESOURCE (DIAGRAM) HISTOGRAM

RESOURCE HISTOGRAMS

- The bar chart is also useful for calculating the resources required for the project.
- To add the resources, say laborers, to each activity and total them as in Fig. 5.2 is called resource aggregation.
- A resource aggregation chart similar to the one produced in Fig. 5.2 for laborers can also be done separately for other resource types such as carpenters or steel fixers, or cranes.
- The bar chart and the resource aggregation charts are useful for estimating the work content in terms of man-hours or machine hours.
- Similar calculations done on site may be used to check the work content implied by the estimate, so as to determine whether the chosen construction methods will result in a profit or loss.
- Cost control is more effectively based on such assessment of construction method than on simple historical cost checks.
- Bar charts as mean of communication between engineers and foreman are particularly useful and can be improved by color coding the activities, for example blue for carpenters, yellow for steel fixers etc.
- The vertical links indicate dependency between activities; the broken lines indicate ‘float’. Laborers required shown in brackets.

ACTIVITY DEFINITION

Activity definition involves identifying and documenting the specific activities that must be performed in order to produce the deliverables and sub-deliverables identified in the work breakdown structure (bill of quantity) as shown in below table.

ACTIVITY DEFINITION

Item	Activity Description
A1	Excavation
A2	Sand under Footing
A3	Compact Soil
A4	Hardcore
B11	Plain concrete for footings
B12	Plain concrete for slabs on grade
B13	Plain concrete for roof grading
B21	Reinforced concrete for footings
B22	Reinforced concrete for ground beams
C1	Reinforcement For Footing
C2	Reinforcement For Columns

Activity Duration Estimation (continued)

- **If the work is expressed in terms of quantity (m2 of formwork, ton of steel, m3 of concrete etc) then activity duration is estimated as:**

$$\mathbf{D} = \frac{\mathbf{Q_{ij}}}{\mathbf{P_{ij} \times N_{ij}}}$$

- **D_{ij} = Duration of activity in units of time**
- **Q_{ij} = Quantity (m2, m3, ton, pieces etc)**
- **P_{ij} = Average productivity of standard crew**
- **N_{ij} = Number of standard crew assigned to activity**

Activity Duration Estimation (continued)

A small formwork subcontractor is awarded to erect 1000 m2 of formwork. The daily production rate of one crew is 25 m2.

a. Calculate the number of days required to complete the job if the subcontractor has 4 crew.

$$D = \frac{1000}{25 \times 4} = 10 \text{ days}$$

b. Calculate the number of days required to complete the job if the subcontractor has 8 crew.

$$D = \frac{1000}{25 \times 8} = 5 \text{ days}$$

Activity Duration Estimation (continued)

A small formwork subcontractor is awarded to erect formwork. It has been estimated 80 labor-days is required to complete the job.

a) **Calculate the number of days required to complete the job if the subcontractor has 4 crew, each crew is made up of two workers.**

$$\mathbf{D_{ij} = \frac{80}{4 \times 2} = 10\ days}$$

b) **Calculate the number of days required to complete the job if the subcontractor has 8 crew, each crew made up of two workers.**

$$\mathbf{D_{ij} = \frac{80}{8 \times 2} = 5\ days}$$

BEGINNING-OF-DAY OR END-OF-DAY

- **In scheduling there are two conventions for describing days.**
  - **Beginning of day**
  - **End of day**
- **in this course, we follow the end-of-day convention: any date mentioned for an activity means the end of that day.**
- **in beginning of day convention, projects start at the beginning of day l, which becomes the end of day 0.**

End-of-day Convention:

Activity	0	1	2	3	4	5	6	7
A								
B								
C								
D								

Beginning-of-day Convention:

Activity	1	2	3	4	5	6	7	8
A								
B								
C								
D								

BAR CHART Example 5.1

Anadol Construction Company is awarded a contract to construct a medium sized residential building. Project's activity list and their relationships are given in table 5.1 below.

- **Draw linked bar chart.**
- **Find project completion time.**
- **Find critical path(s).**

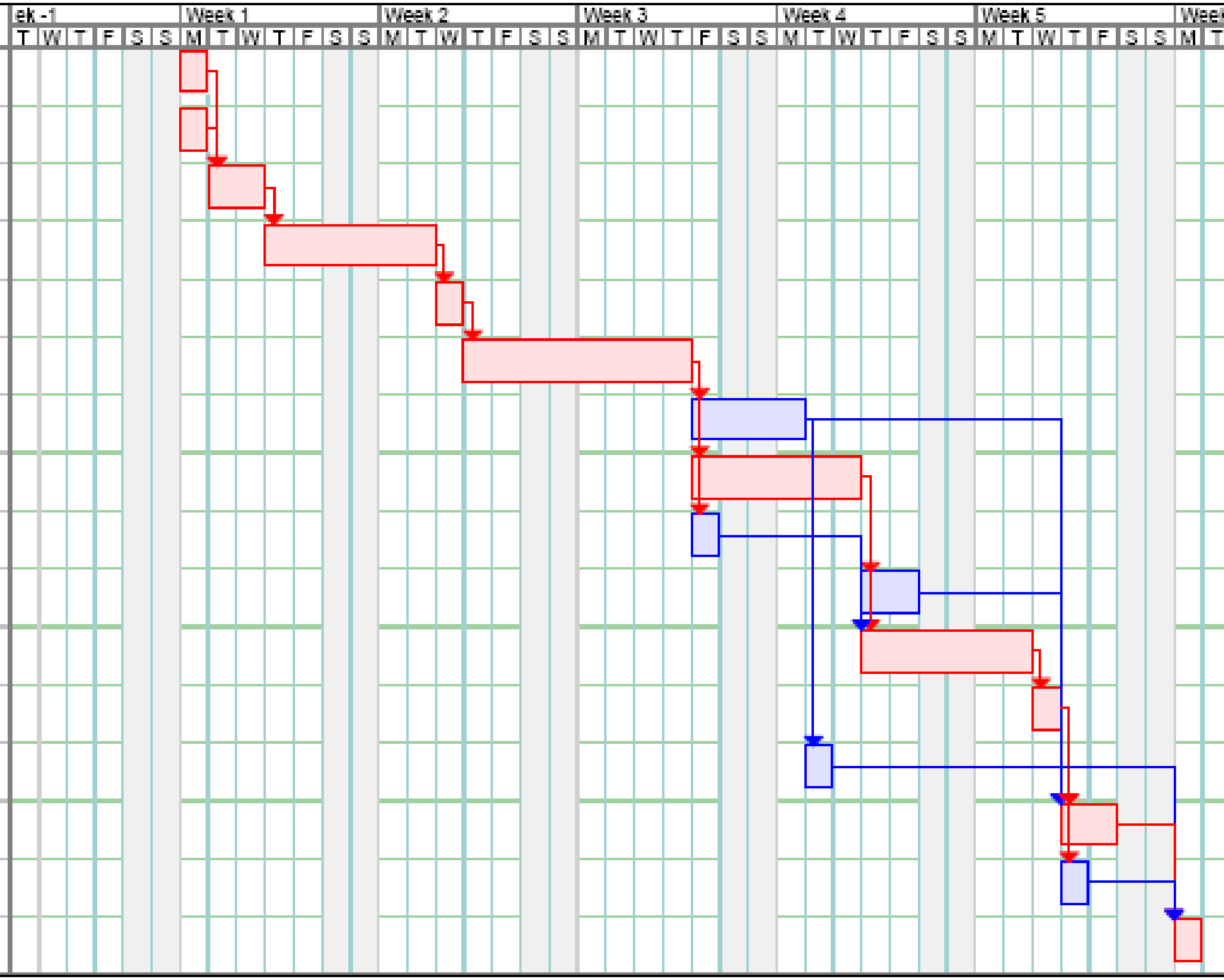
TABLE 5.1 – Activity Table

Activities	Activity Description	Duration (days)	Preceeding
A	Organize	1	-
B	Site layout	1	-
C	Excavation	2	A, B
D	Foundation	4	C
E	Floor slab	1	D
F	Structures	6	E
G	Roof construction	2	F
H	Brick work	4	F
I	Masonry	1	F
J	Plumbing & electrical work	2	H
K	Plastering	4	H,I
L	Door and windows	1	K
M	Roof covering	1	G
N	Painting	2	G,J,L
O	Glazing	1	L
P	Clearing	1	M, N, O

SOLUTION OF EXAMPLE 5.1

a) Linked Bar Chart

ID	Task Name	Duration
1	A. Organize	1 day
2	B. Site layout	1 day
3	C. Excavation	2 days
4	D. Foundation	4 days
5	E. Floor slab	1 day
6	F. Structures	6 days
7	G. Roof construction	2 days
8	H. Brick work	4 days
9	I. Masonry	1 day
10	J. Plumbing & elec. work	2 days
11	K. Plastering	4 days
12	L. Door and windows	1 day
13	M. Roof covering	1 day
14	N. Painting	2 days
15	O. Glazing	1 day
16	P. Clearing	1 day



b) Project completion time is 26 days.

c) Critical Path(s) are : (1) A-C-D-E-F-H-K-L-N-P

: (2) B-C-D-E-F-H-K-L-N-P

Bar Chart Example 5.2

A company is bidding on a work. There are significant liquidated damages if it can not be completed within the scheduled 20 days. The activities, their durations, and relationships are as listed in table 5.2

- **Draw linked bar chart.**
- **Find project completion time.**
- **Find critical path(s).**

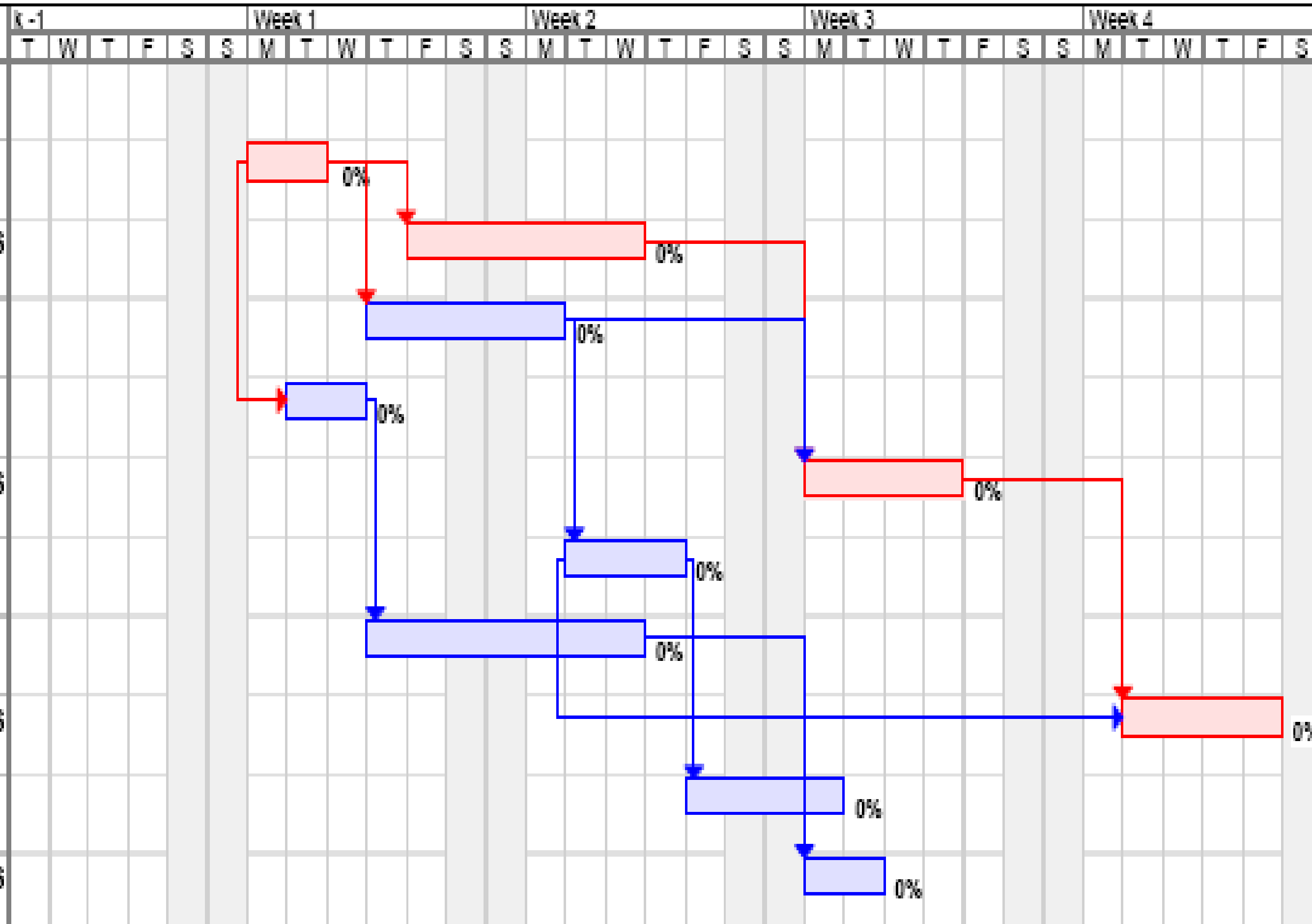
TABLE 5.2 FOR EXAMPLE 5.2

Activity	Preceeding	Duration(days)	Relationship	Lag
A	-	2	-	-
B	A	4	FS	2
C	A	3	FS	1
D	A	2	SS	1
E	B, C	4	FS,FS	2 , 0
F	C	3	FS	0
G	D	5	FS	0
H	E, F	4	FS, SS	2, 2
I	F	2	FS	0
J	G	2	FS	2

SOLUTION OF EXAMPLE 5.2

a) Linked Bar Chart

ID	Task Name	Duration	Predecessors
1			
2	A	2 days	
3	B	4 days	2FS+2 days
4	C	3 days	2FS+1 day
5	D	2 days	2SS+1 day
6	E	4 days	3FS+2 days
7	F	3 days	4
8	G	5 days	5
9	H	4 days	6FS+2 days
10	I	2 days	7
11	J	2 days	8FS+2 days



b) Project completion time 20 days

c) Critical path(s) is : A-B-E-H

NETWORK ANALYSIS

Network analysis offers little more than a linked bar chart, but its protagonists claim, with some justification, that the smaller, self-contained steps of a network are more applicable to complex operations than is the bar chart, and that the greater rigor imposed by the logic diagram produces more realistic models of the proposed work.

POPULAR FORMS OF NETWORK ANALYSIS

- **There are two popular forms of network analysis**
  - **activity on the arrow**
  - **activity on the node (precedence diagram)**
- **Each of these approaches offer virtually the same facilities and it seems largely a matter of preference, which is used.**
- **Enthusiasts of precedence diagrams claim that the technique is more easily understood by the uninitiated.**
- **'Activity on the arrows' will be described first and the differences with 'precedence diagrams' will be highlighted.**

STEPS IN PRODUCING A NETWORK

a) Listing the activities
b) Producing a network showing the logical relationship between activities
c) Assessing the duration of each activity, producing a schedule, and determining the start and finish times of each activity and the float available
d) Assessing the resources required

In producing a bar chart (b) and (c) are taken in one step and therefore in complex projects the various alternatives are unlikely to be considered.

ACTIVITY ON THE ARROW

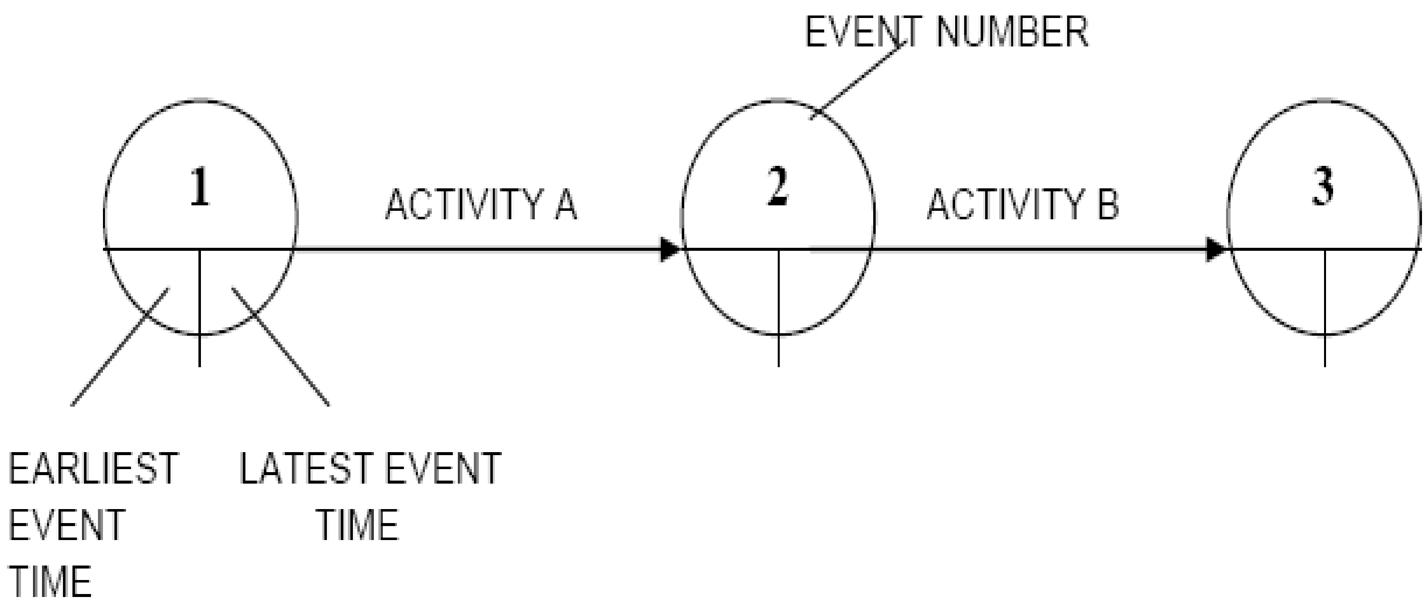
The preparing of a network, activity on the arrow, follows the steps listed above.

a) **Identifying the activities**
b) **Producing schedule.**
c) **Durations Time analysis**
d) **Assessing resources**

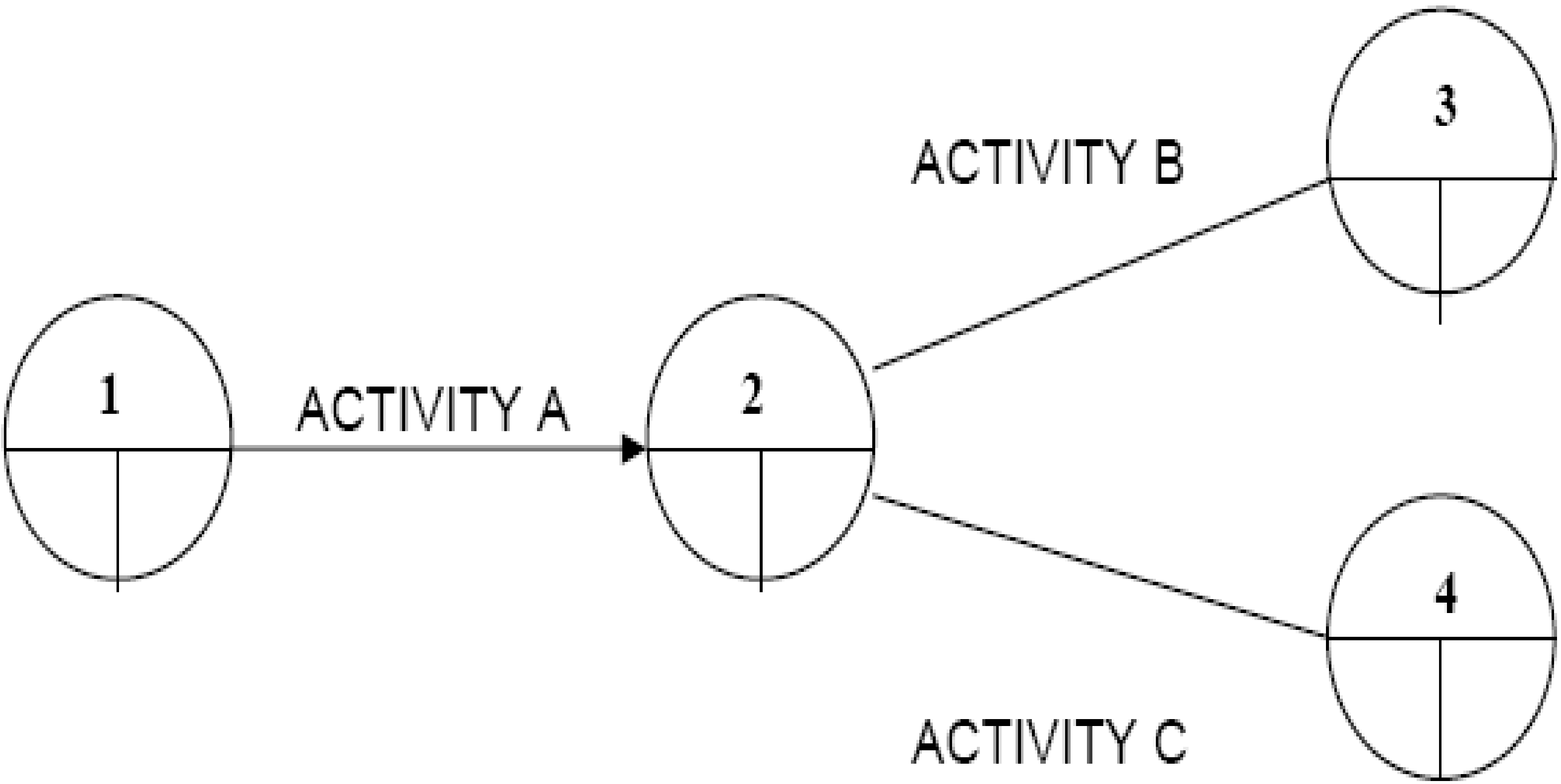
In system of planning, an arrow represents the activity.

The length of the arrow is included in the network has no relations with the duration of the activity.

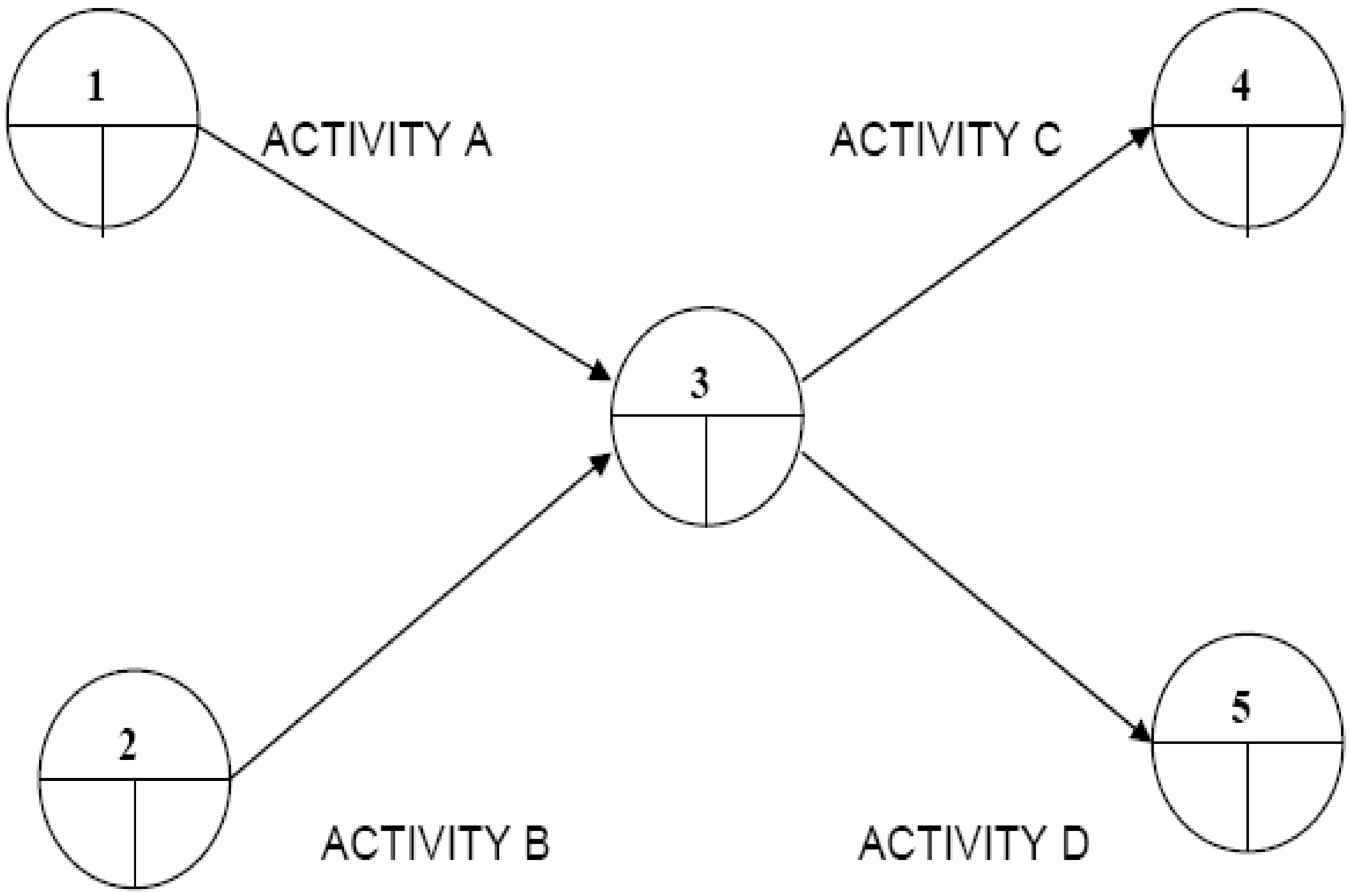
1. **THIS DIAGRAM MEANS THAT ACTIVITY B FOLLOWS THE COMPLETION OF ACTIVITY A.**



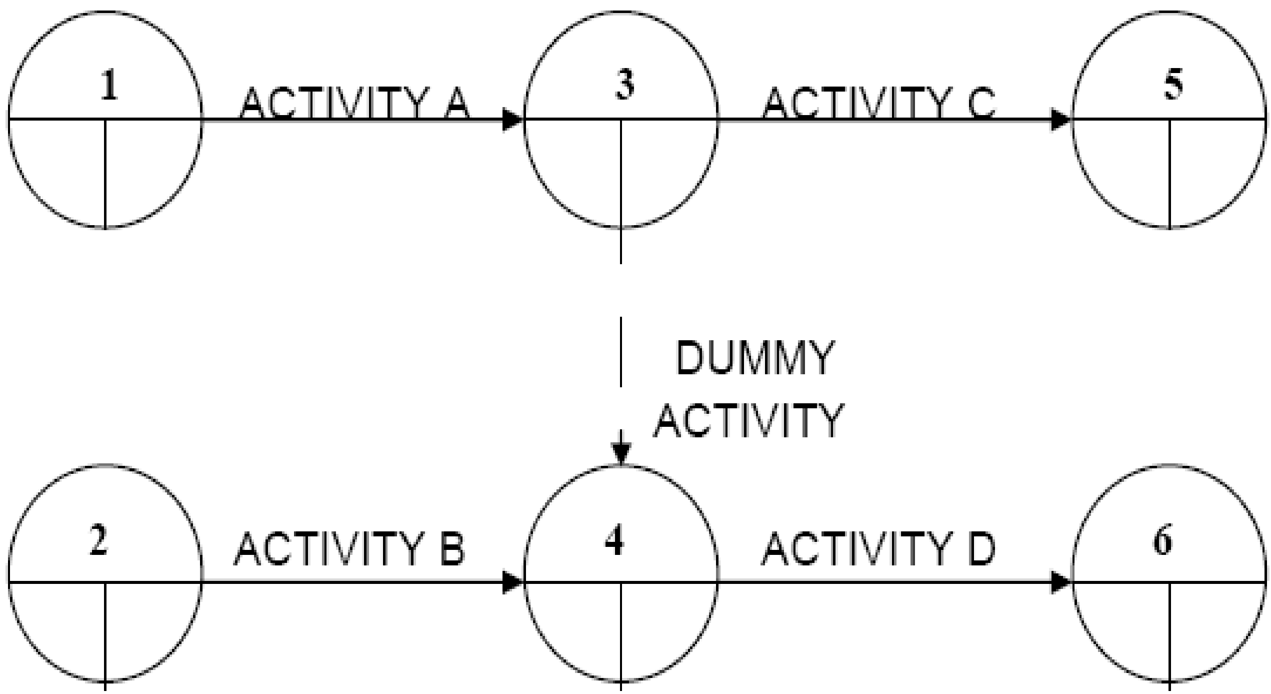
2. **THIS DIAGRAM MEANS THAT BOTH ACTIVITIES B AND C CAN BEGIN ON COMPLETION OF ACTIVITY A.**



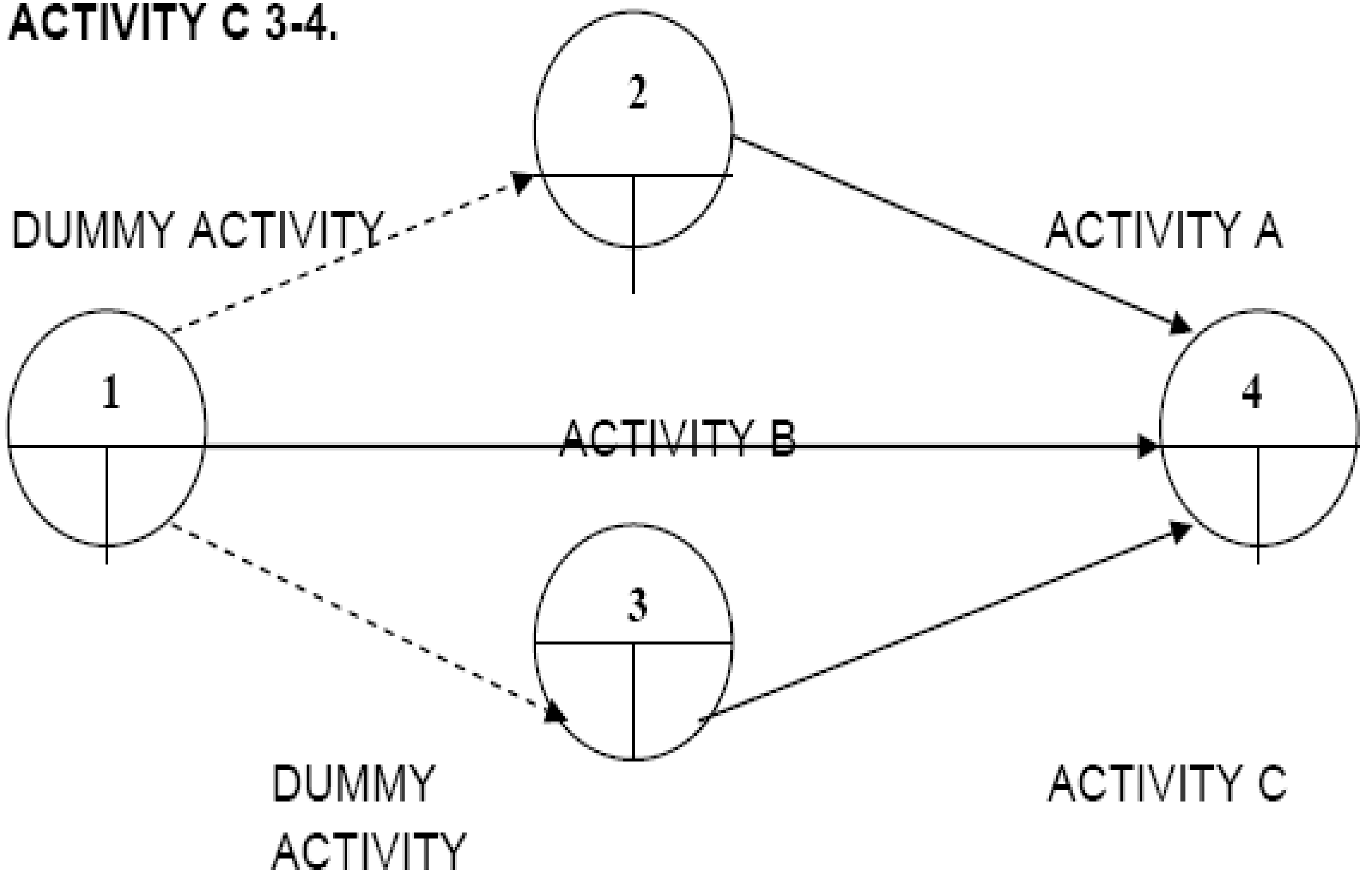
3. THIS DIAGRAM MEANS THAT ACTIVIYIES C AND D FOLLOW A AND B AND CANNOT BEGIN UNTIL BOTH ACTIVITIES A AND B HAVE BEEN COMPLETED.



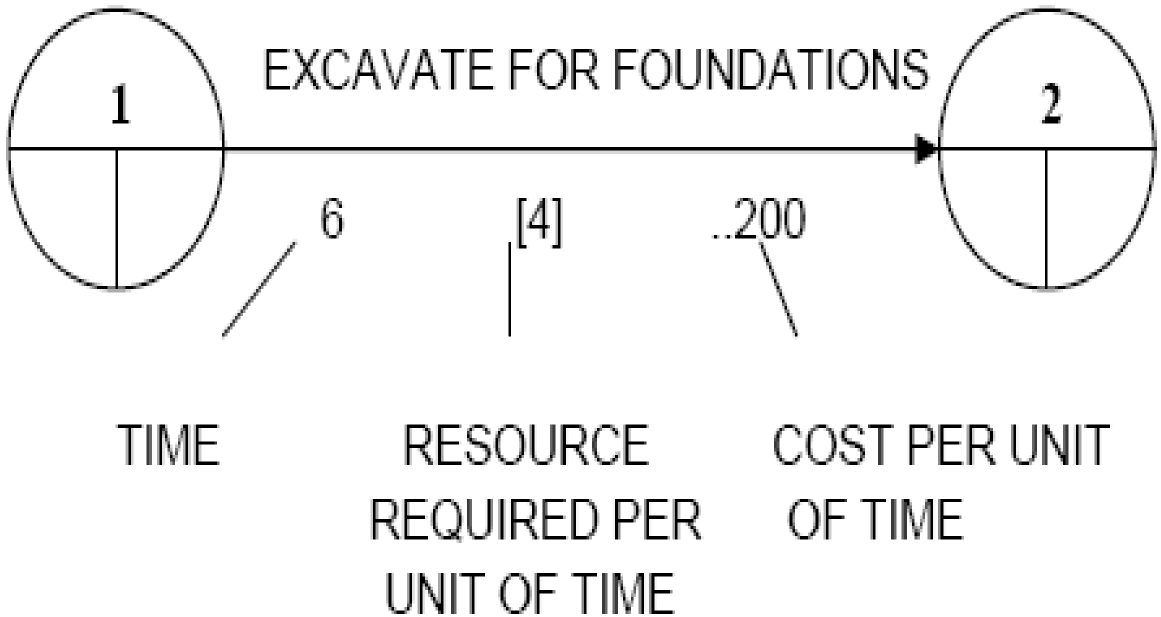
4. THIS DIAGRAM MEANS THAT ACTIVITY D CANNOT START UNTIL BOTH ACTIVITY A AND B ARE FINISHED. ACTIVITY C CAN START ON THE COMPLETION OF ACTIVITY A ONLY. THE START OF ACTIVITY C IS INDEPENDENT OF THE COMPLETION OF ACTIVITY B.



5. **THIS DIAGRAM MEANS THAT ACTIVITIES A, B AND C CAN OCCUR AT THE SAME TIME. THE DUMMY ACTIVITIES ARE USED TO GIVE EACH OF THE ACTIVIYIES A UNIQUE EVENT DEFINITION. ACTIVITY A 2-4, ACTIVITY B 1-4, ACTIVITY C 3-4.**



6. DESCRIPTION OF ACTIVITY WITH TIME RESOURCE AND COST FACTORS.



IDENTIFYING THE ACTIVITIES

- **The points at where arrows start or finish are called events.**
- **The numbering of these events provides a method of identification of activities.**
- **As an example the 'Conc. Basement CO' activity in Fig. 5.4 would be called activity (4)-(5).**
- **Excepting that each event must have a unique number there are no special rules to observe.**
- **Most practitioners begin numbering at the start of the network and progress through the events in numerical order until the end event is reached, ensuring that the number at the tail of an arrow is always smaller than that at the head of the arrow.**

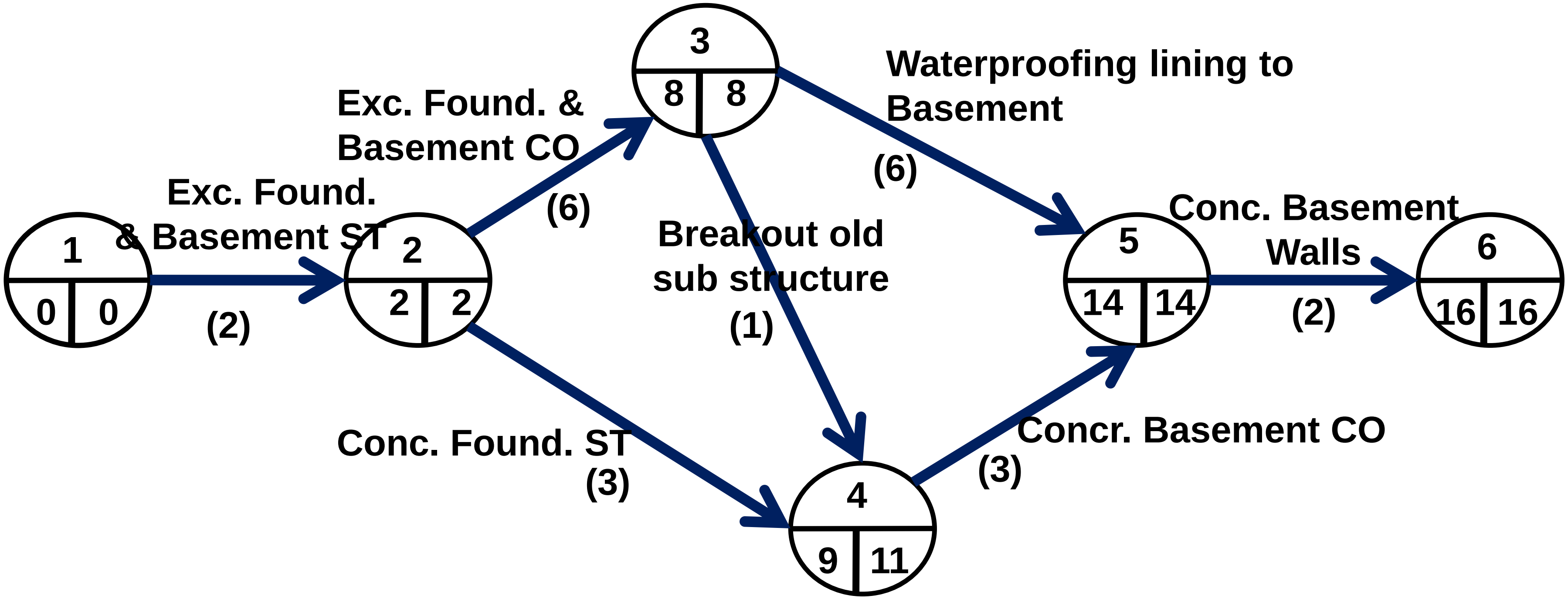
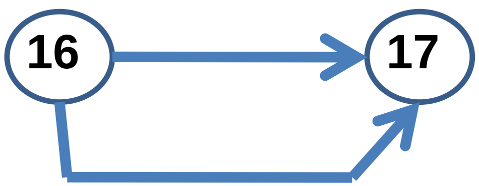


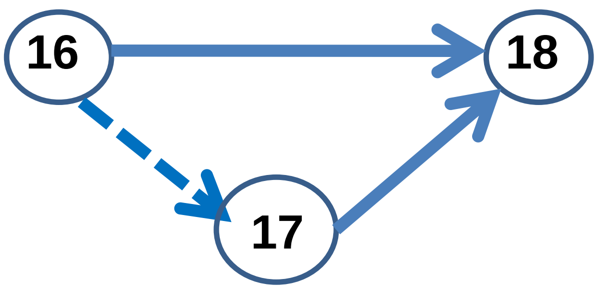
Figure 5.4 – A network showing durations, event numbers and even times

DUMMY ARROWS

- There may be situations where two arrows leave the same event and arrive together at another event.
- In this case the activities would have the same identification numbers.
- To avoid this, a dummy is used and an extra event introduced thus ensuring that each activity has a unique identification.



Two activities having the same identification (reference) number, (wrong).



Extra event and a dummy arrow provided unique identification, (correct).

DUMMY ARROWS

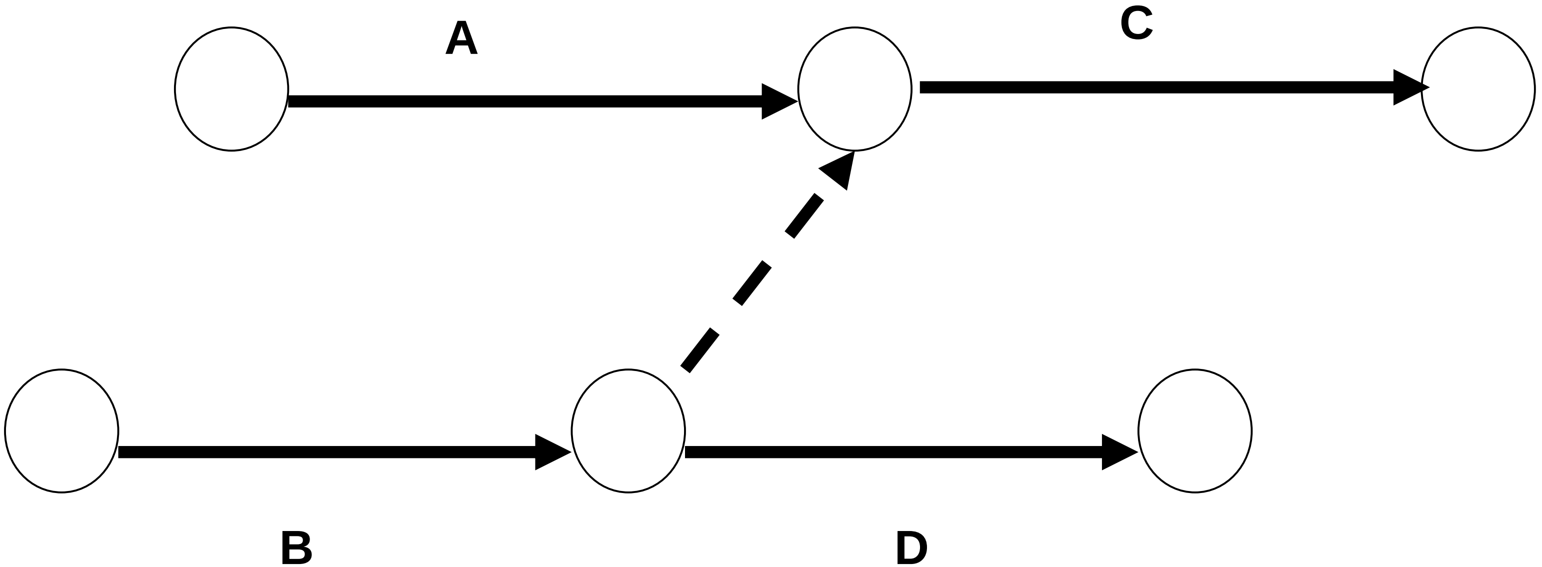


Fig. 5.3. A dummy arrow to maintain correct logic.

CRITICAL ACTIVITIES

- **Critical activities are those that can’t be delayed without extending the project duration.**
- **These are activities with no float.**
- **The early start times and late start times are equal.**
- **Also early finish times and late finish times are equal.**

CRITICAL PATH(S)

- **The path (or Paths) from the first activity to the last activity in the network that passes through only those activities that have zero total float.**
- **Each project has at least one critical path.**
- **If one of more activities on the critical path takes longer than planned, the whole project schedule will slip *unless* corrective action is taken.**
  - **The critical path can change as the project progresses.**
  - **Knowing the critical path helps to make schedule trade-offs.**
  - **Any critical path must be continuous from the start of the project till its end.**

PRODUCING SCHEDULE

- **In producing a schedule the logic of the work must be cleared out.**
- **The meaning of the logic here is which activities will be done first and which activities will be done next.**
- **The sequence of activities can be obtained three questions in asked.**
  - **Which activities must be complete before this activity starts?**
  - **Which activities cannot start until this activity is complete?**
  - **Which activities have no logical relationship with this activity and can therefore take place at the same time?**
- **Ignoring the restraints that will be placed upon the sequence of activities by resources, either labor or plant, the network that satisfies the above questions will show the logical relationship of all activities.**
- **It may be necessary to use dummy arrows, drawn as broken lines, which do not represent any activity but are simply a logical link.**
- **For example, if activity C was dependent on only A and B being completed and activity D was dependent only on B being completed, the network would require a dummy arrow to represent the logic.**

DURATIONS AND TIME ANALYSIS

- The time required for each activity needs to be estimated; the estimate of duration will be based on
  - knowledge of the work;
  - experience, records and work study.
- Once estimated, the duration of each activity is marked against the arrow in the logic network.
- The event numbers are written on the nominator in the event circle.
- The earliest possible time of each event is then calculated and written in the left-hand side of each event denominator.]
- This has determined the earliest possible start time of each activity. (See Figure 5.4).

DURATIONS AND TIME ANALYSIS (Forward Pass)

- **Looking at Figure 5.4,**
- **The earliest time of event (1) is 0, the earliest time of event (2) is 0+2=2, the earliest time of event (3) is 2+6=8 and so on.**
- **The point to watch is that where two paths or chains of activities merge, as for example at event (4) or (5), the longest path determines the earliest possible time of the event.**
- **At event (4) the path via event (3) produces an earliest time of 8:1=9 which is greater than the path direct from (2) a producer an earliest time of 2+3=5.**
- **Therefore, 9 is the earliest time of event (4).**
- **The calculation of the earliest event times is known as the forward pass.**

DURATIONS AND TIME ANALYSIS (Backward Pass)

- The reverse process, the backward pass, determines the latest possible time for event to be finished.
- The latest event time is calculated and written in the right-hand side denominator of each event.
- The calculations are shown in Fig. 5.4.
- The latest time of the finish event, event (5), is taken as 16 weeks; the latest time of event (5) is 16-2=14; and of event (4) it is 14-3=11.
- Event (3) is determined by the earlier or smaller calculated latest time, i.e. one calculation for event (3) from event (4) is 14-6=8 and the other is 11-1=10, therefore the latest time of event (3) is 8.
- If event (3) was any later than 8 the time to complete activities (3)-(5) and (5)-(6) would extend beyond the project end data of 16.

FLOAT

- **Having completed the forward and backward passes, the earliest and latest times of each event are known.**
- **From this, the 'float' or spare time available for each activity can be calculated.**
- **Critical activities, which have no float, are those whose earliest and latest time of start event coincide, whose earliest and latest time of finish event coincide and the time difference between the start event and finish event equals duration of the activity.**

FLOAT (continued)

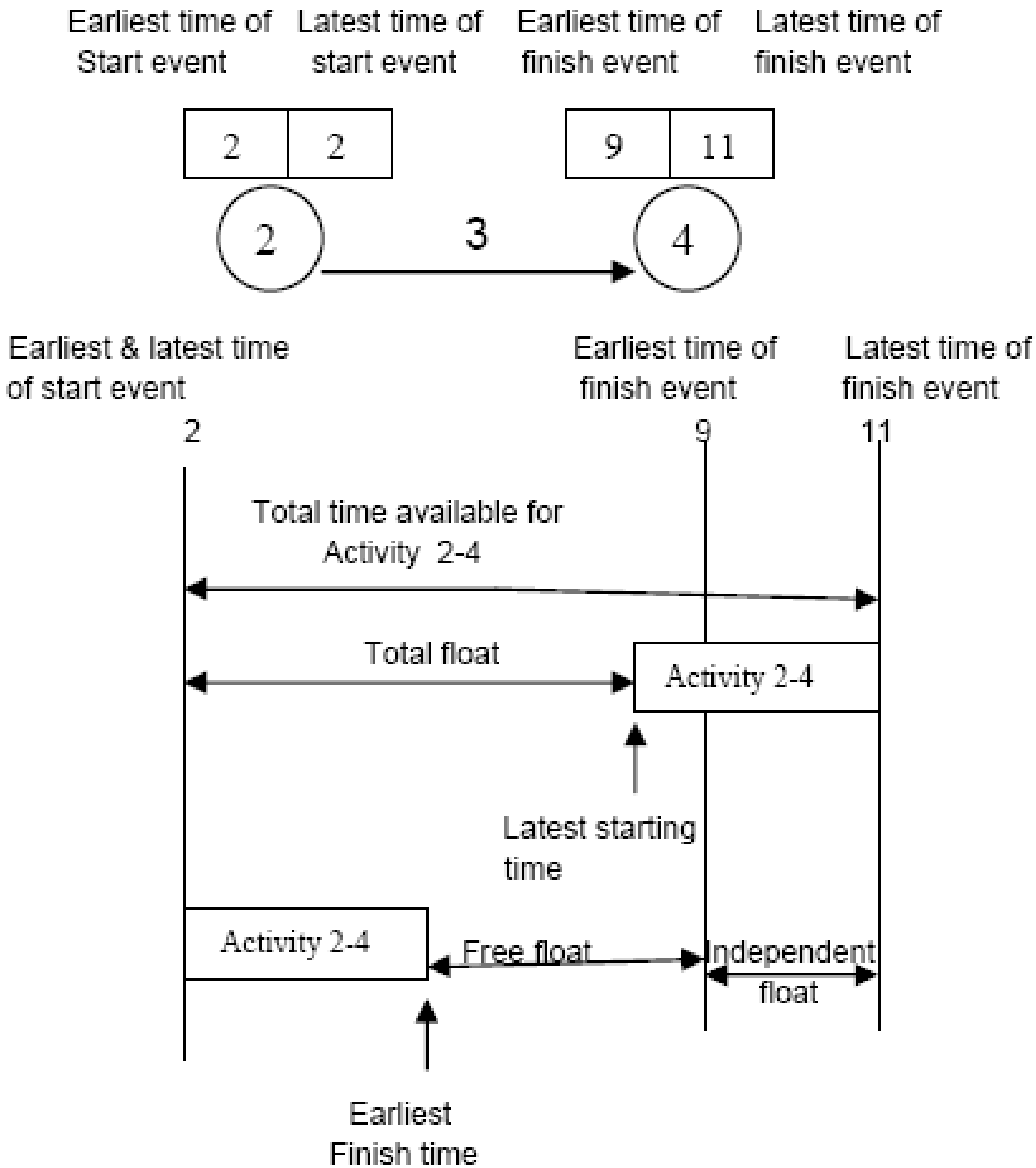
- **Figure 5.6 shows an activity extracted from the network in Fig. 5.4.**
- **The times shown refer to the event times and have the following meanings.**
  - **The earliest time of start event is the earliest possible time the activity can start.**
  - **The latest time of finish event is the latest time the activity can finish without delaying the completion of the project.**
  - **The latest time of start event is the latest time a preceding activity may finish, and**
  - **The earliest time of finish event is the earliest time that a succeeding activity may start.**
- **Knowing these times, the float can be calculated.**

FLOAT (continued)

- **Fig. 5.6 shows the calculation of total float and free float.**
- **Total float is the total amount of time by which the activity could be extended or delayed and still not interfere with the project end date.**
- **Total float is the total time available for the activity less the duration, i.e. the latest time of the finish event less the earliest time of the start event less the duration.**
- **If the total float for one activity is completely used up by the activity then some of the total float of the succeeding activity is also used.**

FLOAT (continued)

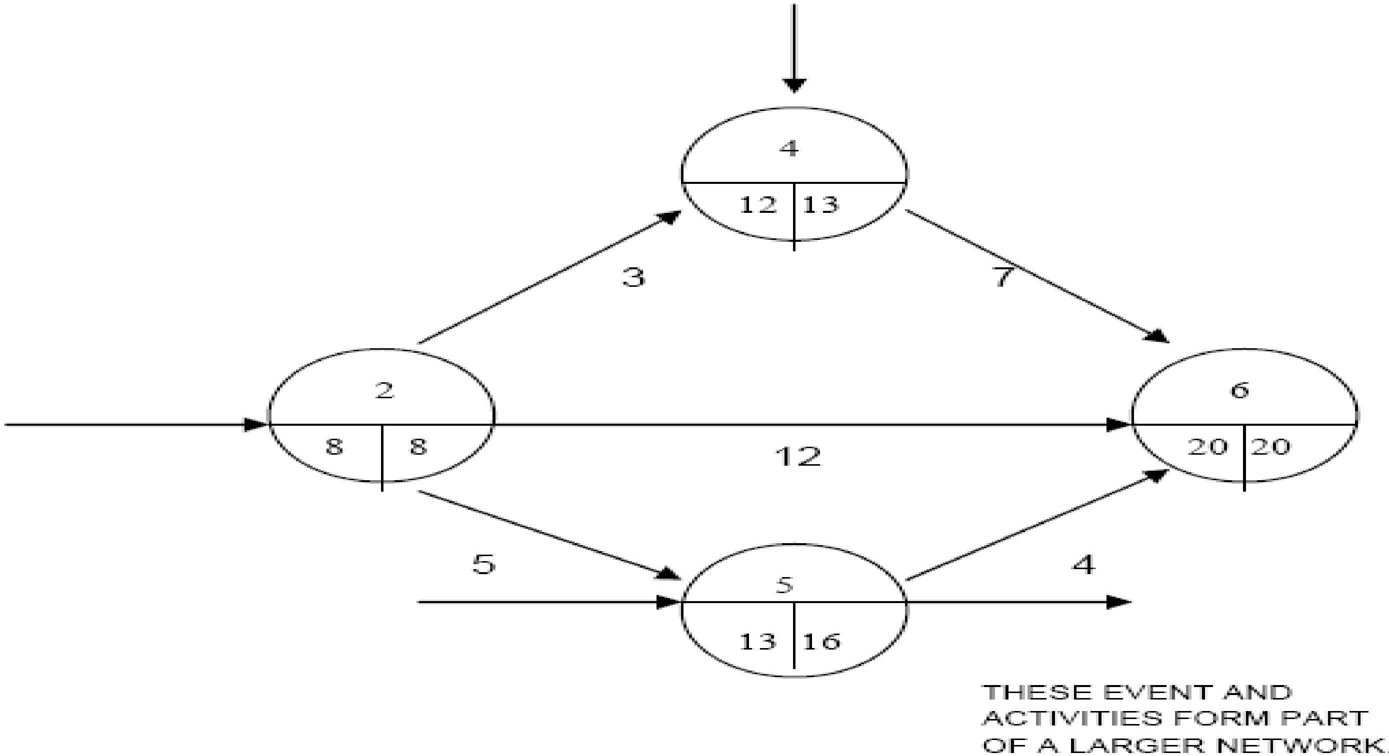
- **Free float,** **however, is the amount of time by which an activity could be extended or delayed without interfering with the succeeding activity.**
- **Free float is calculated by the earliest time of the finish event less earliest time of the start event less the duration.**
- **Free float assumes both the preceding and succeeding activities start as early as early as possible.**
- **Using the example in Fig. 5.6 the total float o activity (2)-(4) is 11-2-3+6, and the free float is 9-2-3=4.**
- **Difference between total float and free float is sometimes referred to as independent float, as shown in Fig. 5.6.**
- **It is the amount of total float shared by the succeeding activity.**



Earliest time of Start event
Latest time of start event
Earliest time of finish event
Latest time of finish event
2
2
9
11
2
3
4
Earliest & latest time of start event
Earliest time of finish event
Latest time of finish event
2
9
11
Total time available for Activity 2-4
Total float
Activity 2-4
Latest starting time
Activity 2-4
Free float
Independent float
Earliest Finish time

Figure 5.6

FLOATS



TOTAL FLOAT: IS THE TIME BY WHICH AN ACTIVITY CAN EXPAND WITHOUT AFFECTING THE CRITICAL PATH.

TOTAL FLOAT

ACTIVITY [2-4] = 13-8-3 = 2

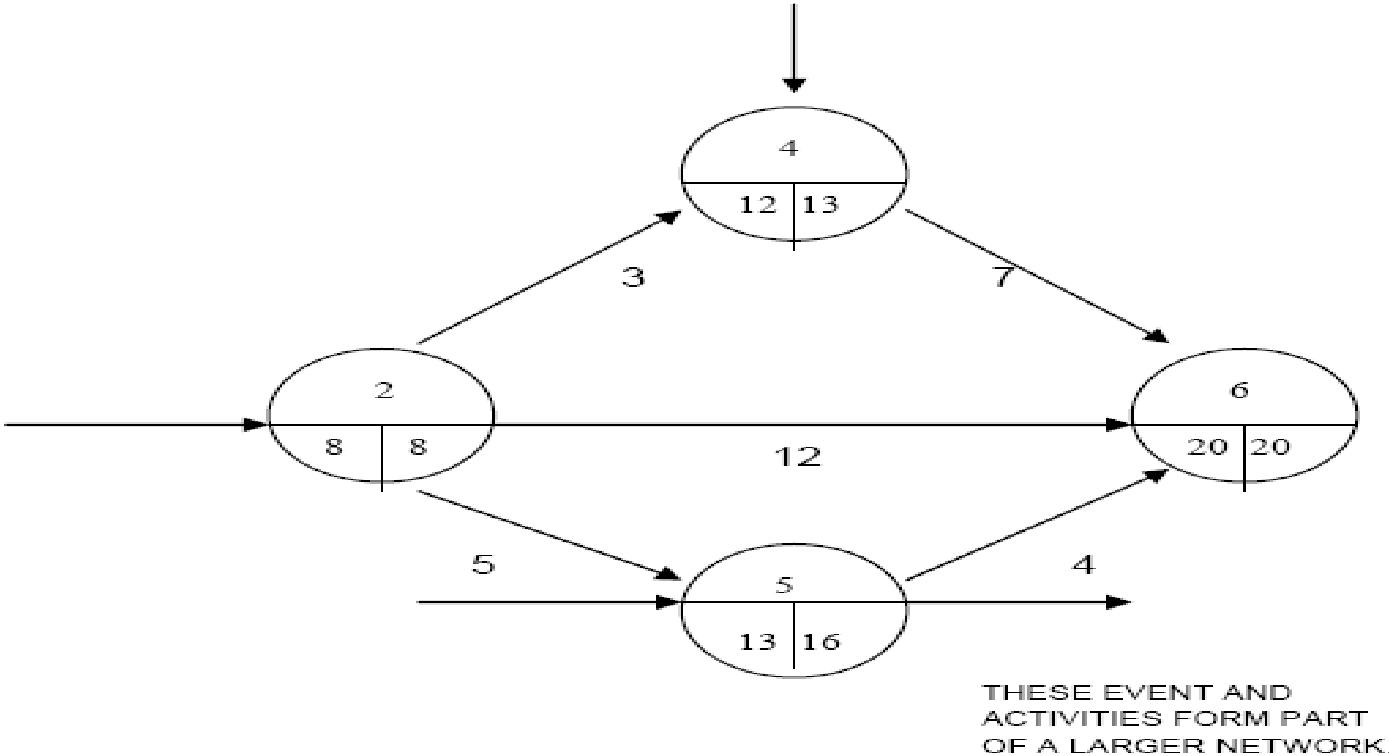
ACTIVITY [2-6] = 20-8-12=0 CRITICAL ACTIVITY

ACTIVITY [2-5] = 16-8-5 =3

ACTIVITY [4-6] = 20-12-7=1

ACTIVITY [5-6]= 20-13-4= 3

FLOATS



FREE FLOAT: IS THE TIME BY WHICH AN ACTIVITY CAN EXPAND WITHOUT AFFECTING SUBSEQUENT ACTIVITIES.

FREE FLOAT

ACTIVITY [2-4] = 12-8-3 = 1

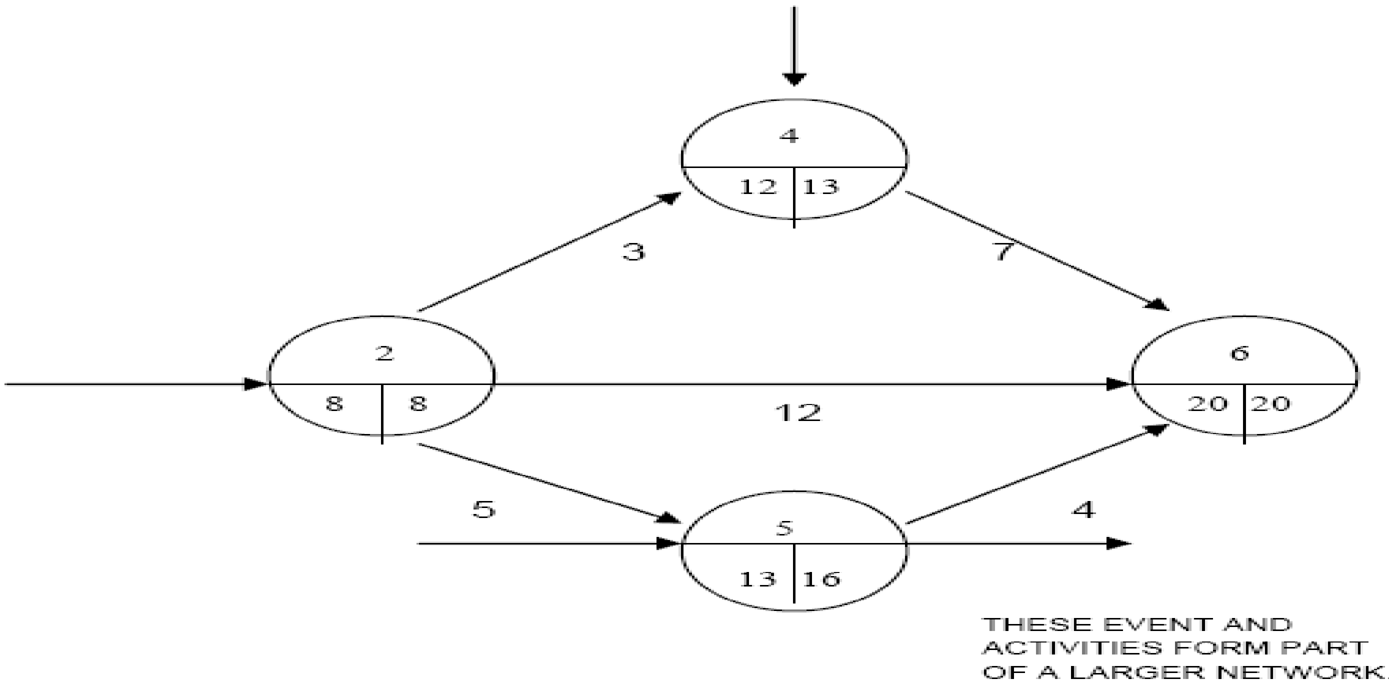
ACTIVITY [2-6] = 20-8-12=0

ACTIVITY [2-5] = 13-8-5 = 0

ACTIVITY [4-6] = 20-12-7=1

ACTIVITY [5-6] = 20-13-4=3

FLOATS



INDEPENDENT FLOAT: IS THE TIME BY WHICH AND ACTIVITY CAN EXPAND WITHOUT AFFECTING ANY OTHER ACTIVITY EITHER PREVIOUS OR SUBSEQUENT.

INDEPENDENT FLOAT

ACTIVITY [2-4] = 12-8-3 = 1

ACTIVITY [2-6] = 20-8-12=0

ACTIVITY [2-5] = 13-8-5 = 0

ACTIVITY [4-6] = 20-13-7=0

ACTIVITY [5-6] = 20-16-4=0

FLOATS (continued)

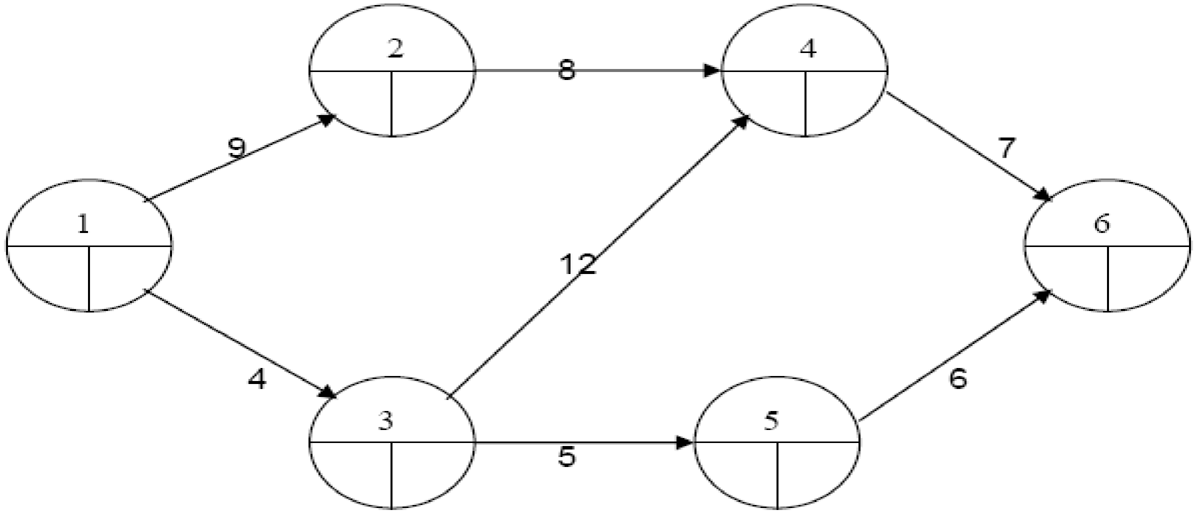
SUMMARY OF CALCULATION PROCEDURE

TOTAL FLOAT: SUBTRACT THE EARLIEST TIME FOR THE TAIL EVENT FROM THE LATEST TIME FOR THE HEAD EVENT, AND FROM THIS DIFFERENCE SUBTRACT THE DURATION TIME.

FREE FLOAT: SUBTRACT THE EARLIEST TIME FOR THE TAIL EVENT FROM THE EARLIEST TIME FOR THE HEAD EVENT, AND FROM THIS DIFFERENCE SUBTRACT THE DURATION.

INDEPENDENT FLOAT: SUBTRACT THE LATEST TIME FOR THE TAIL EVENT FROM THE EARLIEST TIME FOR THE HEAD EVENT AND FROM THIS DIFFERENCE SUBTRACT THE DURATION.

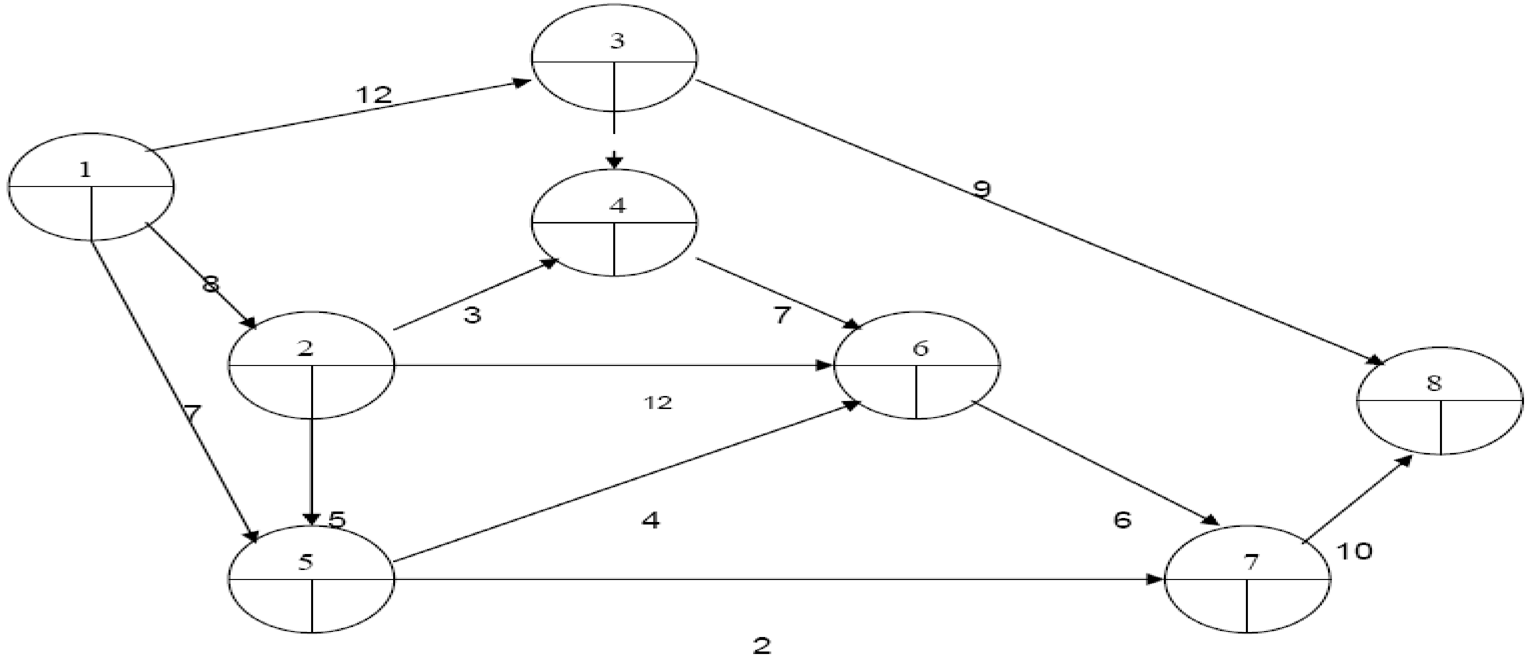
NETWORK ANALYSIS PROBLEM-1



1. CALCULATE THE EARLIEST AND LATEST EVENT TIMES.
2. SHOW THE CRITICAL PATH ON THE NETWORK.
3. CALCULATE THE TOTAL. FREE AND INDEPENDENT FLOAT FOR EACH ACTIVITY. SHOW THE NETWORK IN THE FORM OF A BAR CHART.

ACTIVITY EVENT NOS:	DURATION	EARLIEST		LATEST		FLOAT		
		START	FINISH	START	FINISH	TOTAL	FREE	INDEPENDENT
1-2	9							
1-3	4							
2-4	8							
3-4	12							
3-5	5							
4-6	7							
5-6	6							

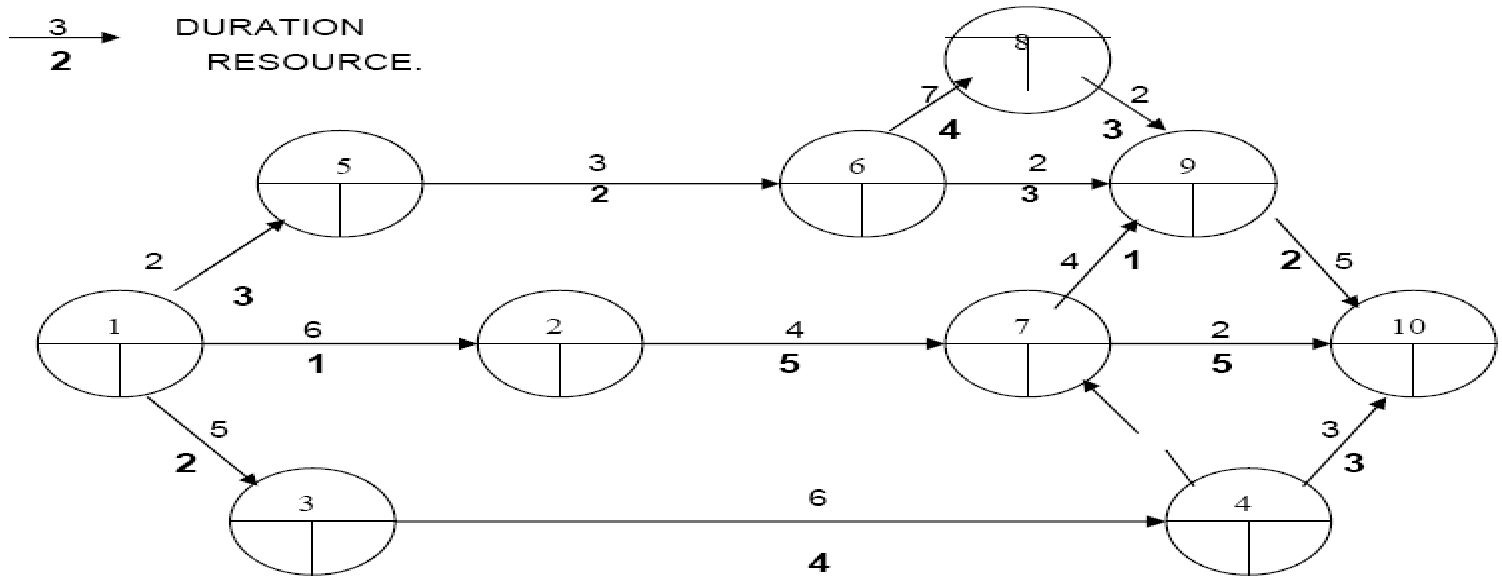
NETWORK ANALYSIS PROBLEM-2



ACTIVITY EVENT NO.	DURATION	EARLIEST		LATEST		FLOAT		
		START	FINISH	START	FINISH	TOTAL	FREE	INDEPENDENT

COMPLETE THE TABLE ABOVE AND SHOW THE NETWORK IN THE FORM OF A BAR CHART.

NETWORK ANALYSIS PROBLEM 3



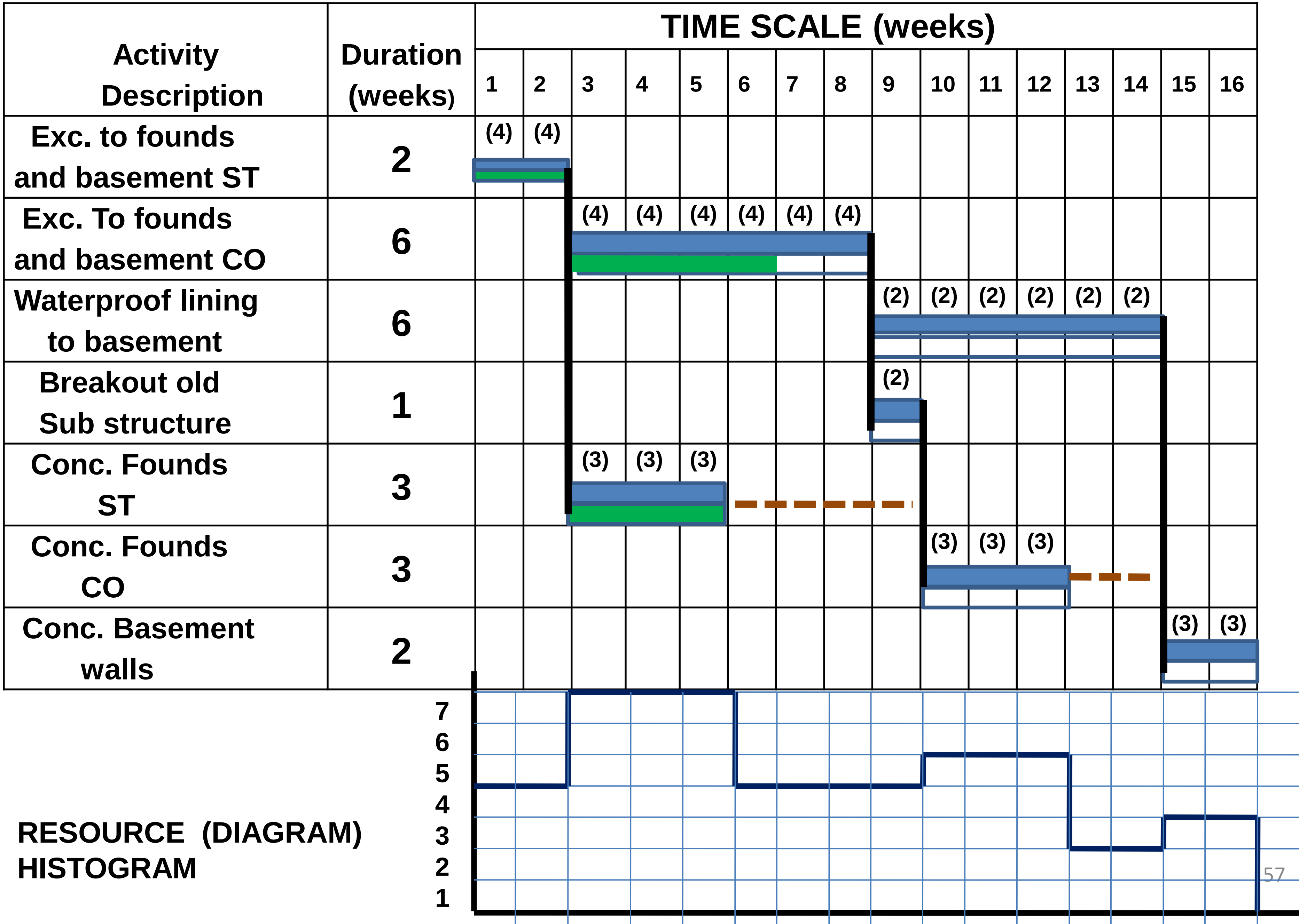
1. ANALYSE THE NETWORK, SHOW THE CRITICAL PATH AND COMPLETE THE TABLE BELOW.
2. DRAW A BAR CHART SHOWING ALL ACTIVITIES AT EARLIEST START DATES.
3. FROM THE BAR CHART SHOW THE RESOURCE REQUIREMENTS IN THE FORM OF A HISTOGRAM.

ACTIVITY EVENT NOS.	DURATION	EARLIEST		LATEST		FLOAT		
		START	FINISH	START	FINISH	TOTAL	FREE	INDEPENDENT
1-2	6							
1-3	5							
1-5	2							
2-7	4							
3-4	6							
4-7	0							
4-10	3							
5-6	3							
6-8	7							
6-9	2							
7-9	4							
7-10	2							
8-9	2							
9-10	5							

ASSESSING RESOURCES

- **In estimating the duration of an activity, the resources required for that activity have to be considered.**
- **For example, an activity with a work content of 20 carpenter-days requires two carpenters for 10 days, the first and most widely used assessment of resources is the aggregation chart.**
- **Figure 5.2 is an example of a resources aggregation chart for laborers.**
- **The resource aggregation chart is useful in assessing work content for estimates and can be used in conjunction with the linked bar chart (fig. 5.2);**
- **float available of activities allows the distribution of peaks of resource demand.**

Figure 5.2- Linked Bar Charts



RESOURCE PROBLEMS

Beyond the use of resource aggregation there are two approaches to assessing resources required.

1. **The time-limited problem, the project must be completed by a specific date; and**
2. **The resource-limited problem, in which the project must be completed with the limited resources available even if this means extending the project deadline.**

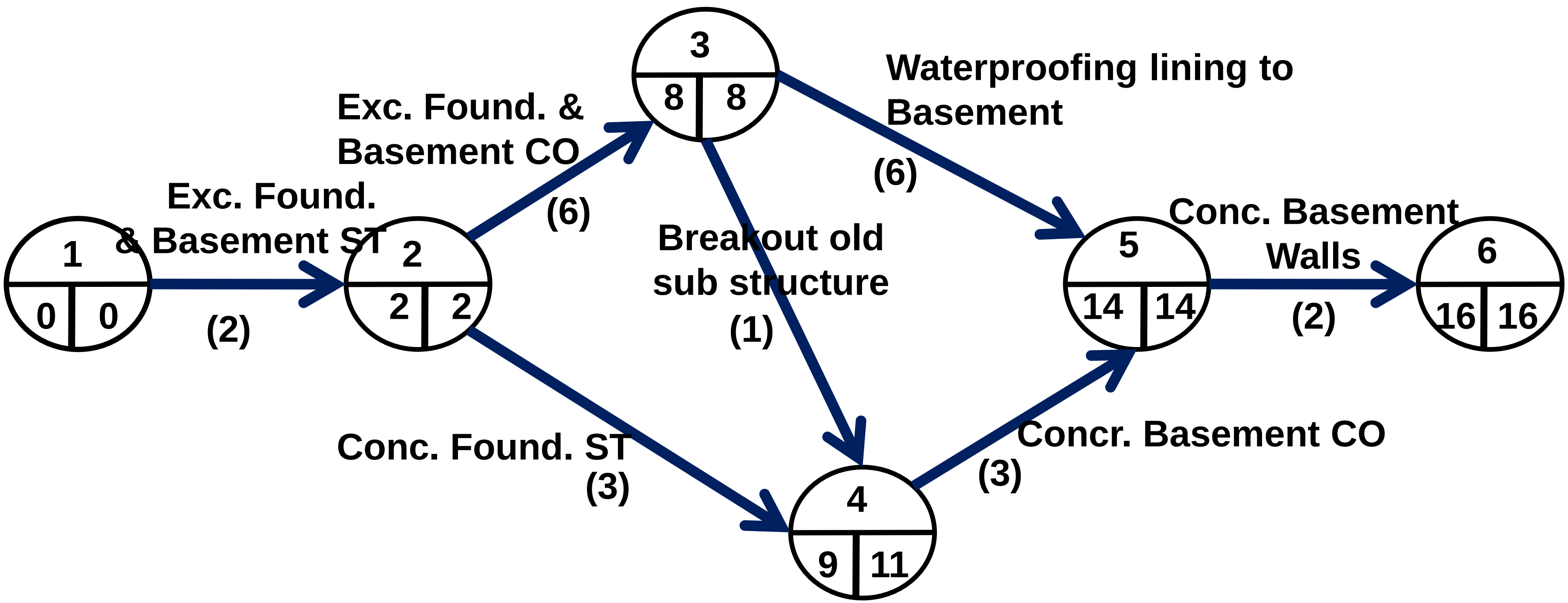


Figure 5.4 – A network showing durations, event numbers and even times

TIME-LIMITED RESOURCE CONSIDERATION
(continued)

1. Prepare a list of activities ranked in order of their earliest start dates.
2. Produce a resource aggregation chart as in Fig. 5.7-a, based on this list of activities in earliest start order and the resources required.
3. Produce a list of activities ranked in order of latest start dates.
4. Produce a resource aggregation chart as in Fig. 5.7- b based on this list of activities starting in the latest start order.
5. Compare the resource aggregation charts from (2) and (4). This provides the two extremes of resource requirements, all activities starting as early and as late as possible. Between these extremes a compromise to produce acceptable resource requirements can be sought by visual inspection and manipulation of activities within the two extremes.

TIME-LIMITED RESOURCE CONSIDERATION

- **Time analysis will provide the minimum time possible for completing the project.**
- **If this minimum is taken as the time limit, adjustments in the timing of any activity that may affect resource requirements must be undertaken within the float available.**
- **The steps in assessing the resource required in a time-limited situation are:**

ACTIVITIES IN EARLY START ORDER

ACTIVITY	EARLIEST START	TOTAL FLOAT	DURATION	RESOURCES (LABOURERS)
1-2	0	0	2	2
2-3	2	0	6	4
2-4	2	6	3	3
3-5	8	0	6	3
3-4	8	2	1	1
4-5	9	2	3	3
5-6	14	0	2	2

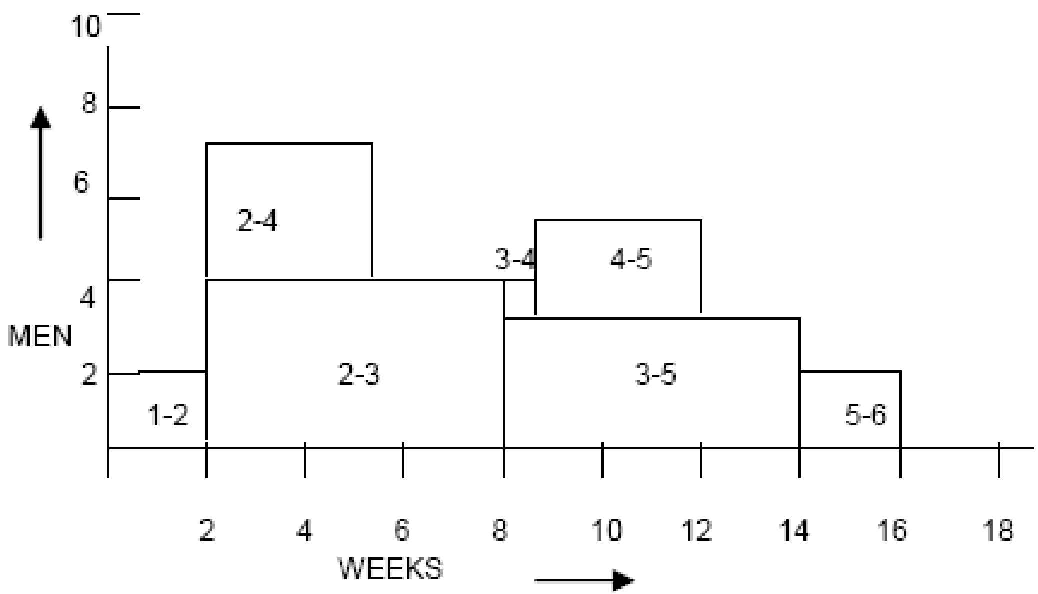


FIGURE – 5.7 - a

ACTIVITIES IN LATE START ORDER				
ACTIVITY	LATEST START	TOTAL FLOAT	DURATION	RESOURCES (LABOURERS)
1-2	0	0	2	2
2-3	2	0	6	4
3-5	8	0	6	3
2-4	8	6	3	3
3-4	10	2	1	1
4-5	11	2	3	3
5-6	14	0	2	2

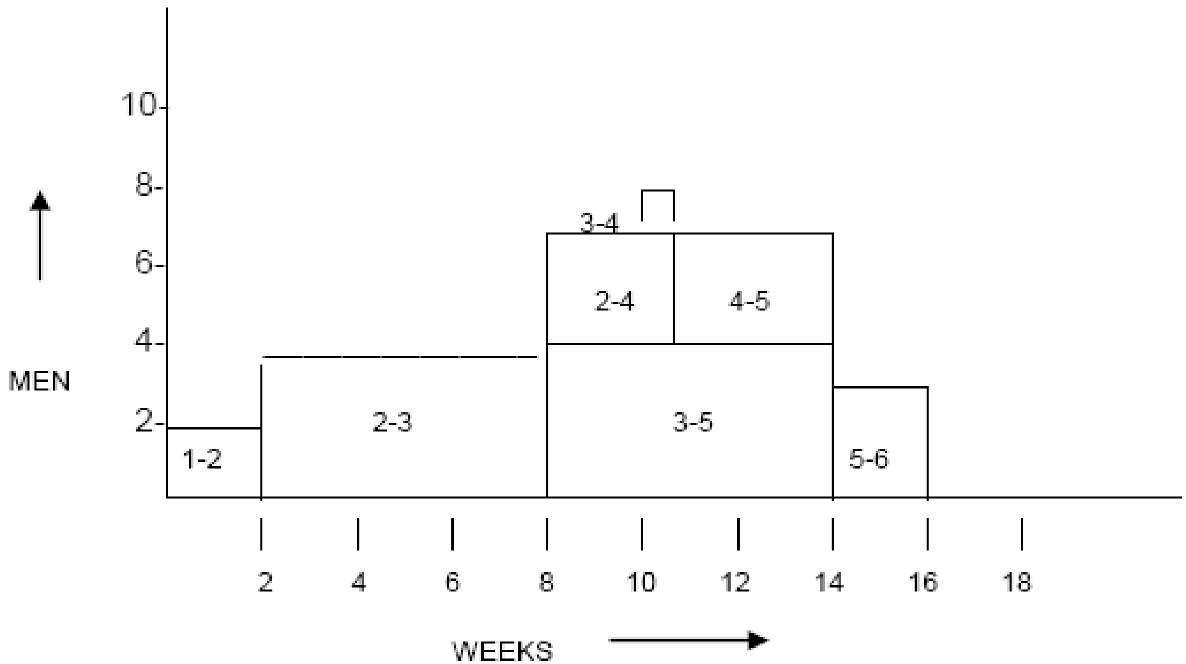


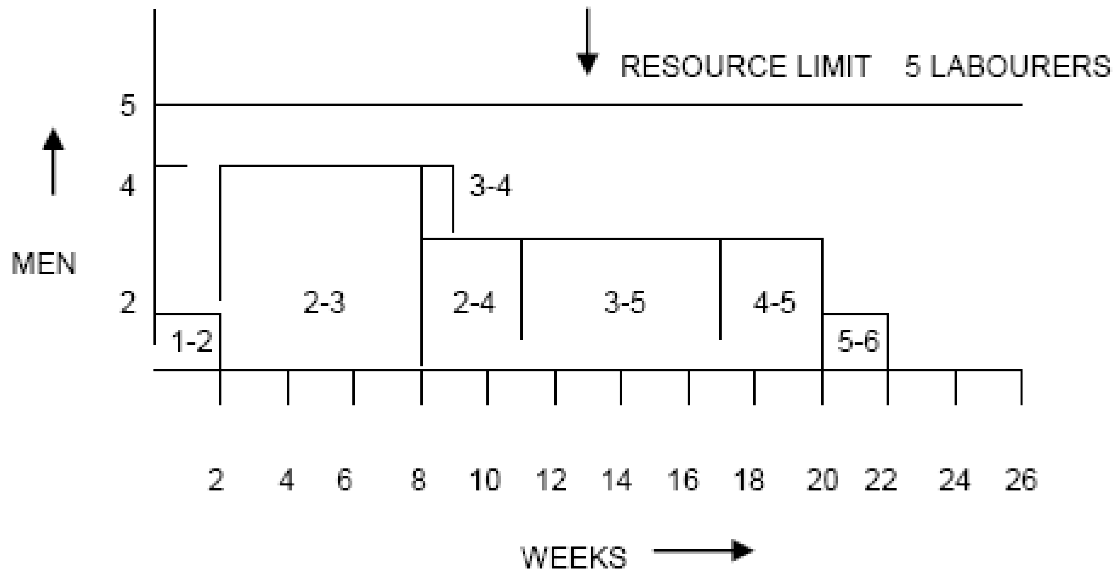
FIGURE 5.7 - b

RESOURCE-LIMITED RESOURCE CONSIDERATIONS

- **The production of a resource-limited aggregation chart is similar to that of the unlimited resource aggregation, expect that if the total resource demand of an activity exceeds the specified limit then that activity must be delayed.**
- **To produce reasonable results, and so that earlier activities are allocated their resources first, the activities must be arranged according to a system of priorities or 'decision rules'.**
- **The decision rule is a device whereby activities are ranked in the order in which their resource demand is added to he resource aggregation chart.**
- **Each activity is thus given its appropriate priority in the queue for resources.**

RESOURCE-LIMITED RESOURCE CONSIDERATIONS

- **Consequently some activities will be delayed until the resources are available.**
- **The ordering according to a chosen priority or decision rule ensures that activities high in the priority list receive their resources first.**
- **Activities low in the priority list may get delayed.**
- **The ranking in a priority order is known as sorting, and one of the more common sorts or decision rules is to sort in order of 'early start time'.**
- **For activities with the same early start time a second sort is required and this could be in order of total float.**
- **The upper part of Fig. 5.7 gives the activities for the network shown in Fig. 5.4 ranked in order of early start.**



Activity No:	Scheduled Start Date
1-2	0
2-3	2
2-4	8
3-5	11
3-4	8
4-5	17
5-6	20

Fig. 5.8 Resource-limited histogram and table of scheduled start dates.

RESOURCE-LIMITED RESOURCE CONSIDERATIONS

- **Fig. 5.9 gives similar examples for two types of resource, for demonstration purposes the decision rule or priority sort used in this case are early start as the major sort and largest duration as the minor sort.**
- **The choice of decision rule or sort is left to the user.**
- **The decision rules in common use are Early start, total float, or Late start, total float.**

ACTIVITY	EARLIEST START	DURATION	RESOURCE	RESOURCE TYPE	SCHEDULED START DATE
1-2	0	2	2	C	0
2-3	2	6	4	L	2
2-4	2	3	3	L	8
3-5	8	6	3	L	11
3-4	8	1	1	C	8
4-5	9	3	3	C	11
5-6	14	2	2	C	17

L- LABOURERS L- Limited to 4 C- CARPENTERS C- Unlimited

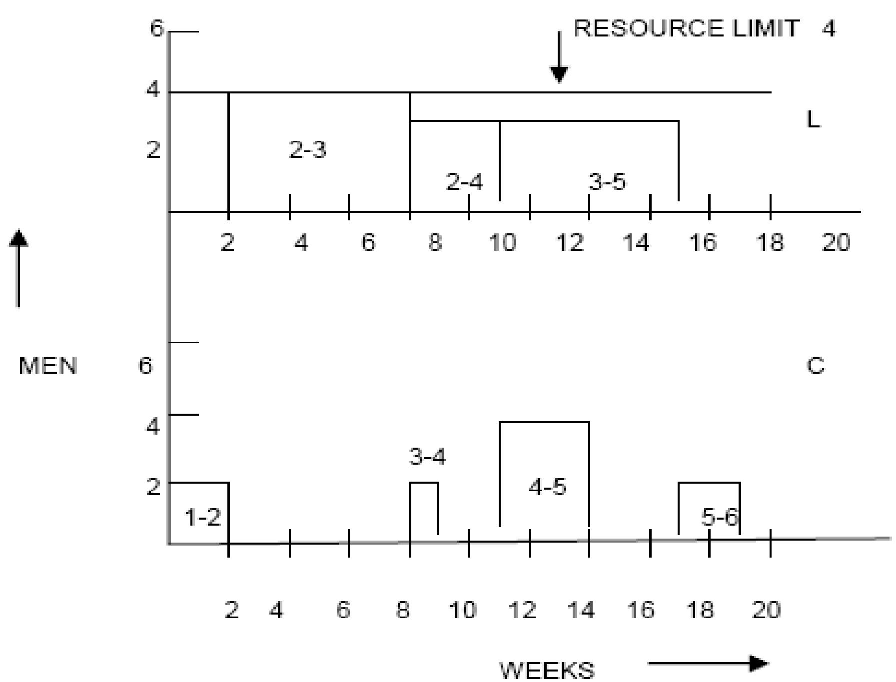


Fig. 5.9 Resource allocation for two resource types

Example 5.3

The table below shows data for construction of steel truss of small industrial building. The required skilled and unskilled labour that would allow the project to be completed on time is given.

Table 5.3

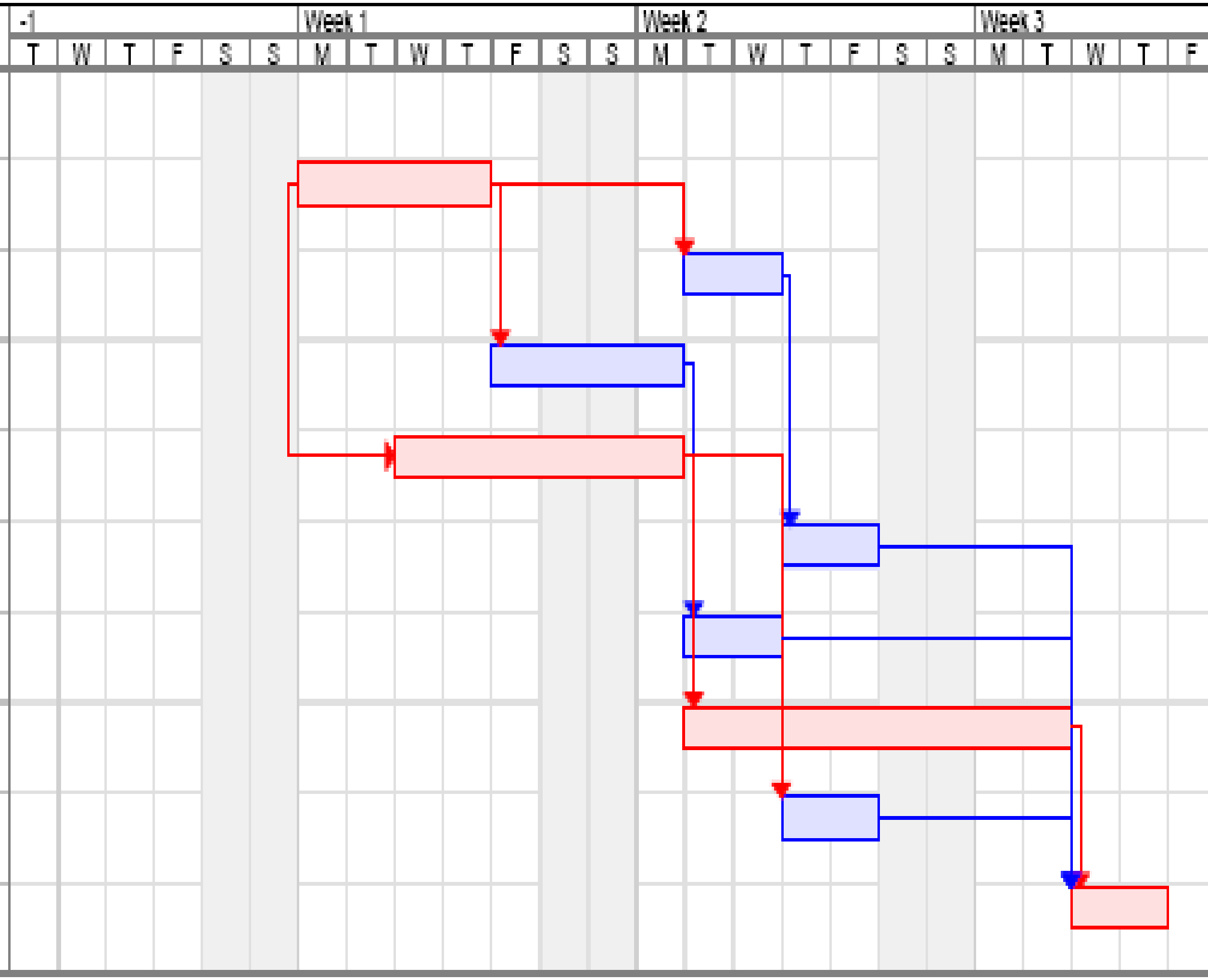
Activity Code	Preceding	Duration days	Relationship	Lag	Skilled Labor	Unskilled Labor
A	-	4	-	-	2	2
B	A	2	FS	2	4	3
C	A	2	FS	0	4	4
D	A	4	SS	2	2	2
E	B	2	FS	0	2	2
F	C	2	FS	0	4	3
G	D	6	FS	0	2	3
H	D	2	FS	2	6	8
I	E,F,G,H	2	FS,FS,FS,FS	0,0,0,0	6	6

a) Find daily skilled and unskilled labour requirements.

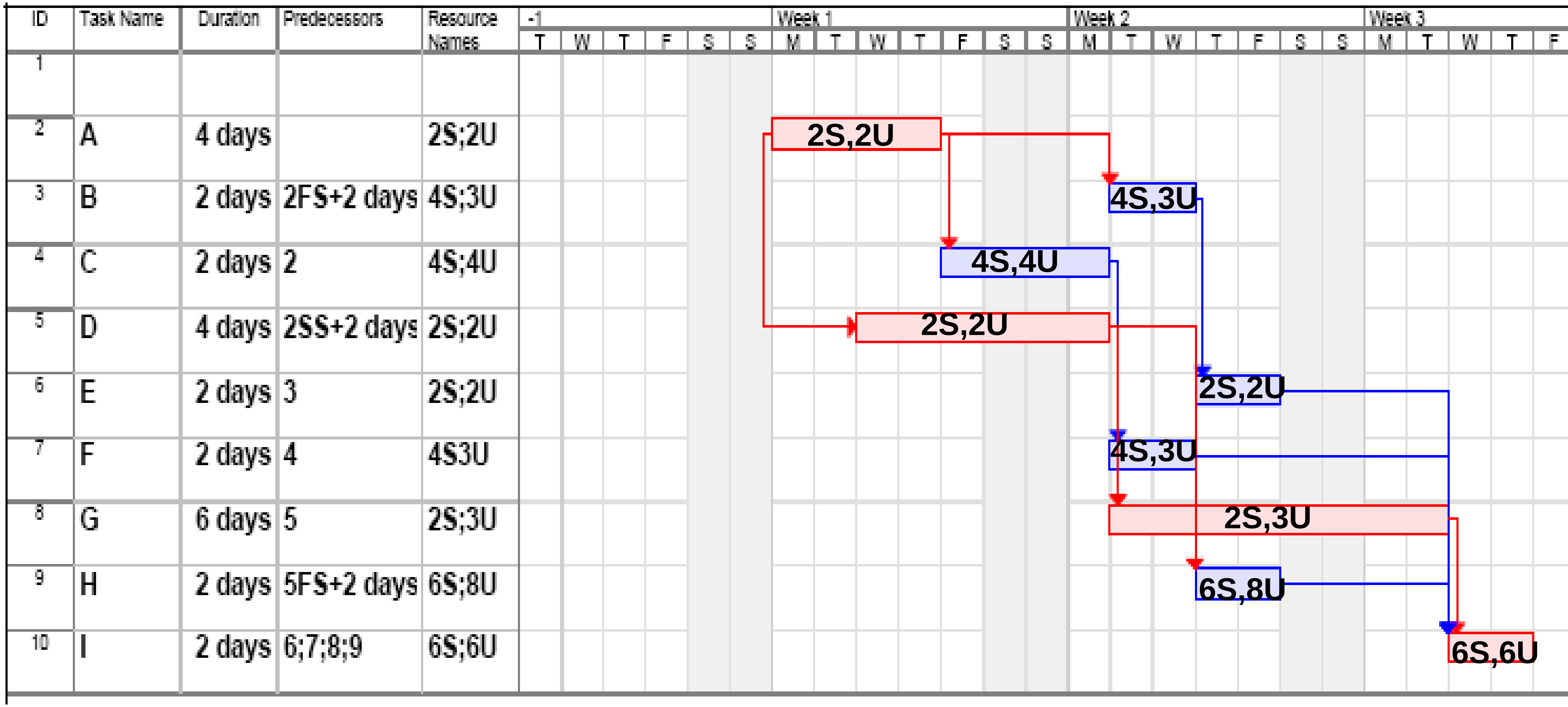
b) Draw resource histogram for both skilled and unskilled labour.

SOLUTION OF EXAMPLE 5.3

ID	Task Name	Duration	Predecessors	Resource Names
1				
2	A	4 days		2S;2U
3	B	2 days	2FS+2 days	4S;3U
4	C	2 days	2	4S;4U
5	D	4 days	2SS+2 days	2S;2U
6	E	2 days	3	2S;2U
7	F	2 days	4	4S3U
8	G	6 days	5	2S;3U
9	H	2 days	5FS+2 days	6S;8U
10	I	2 days	6;7;8;9	6S;6U



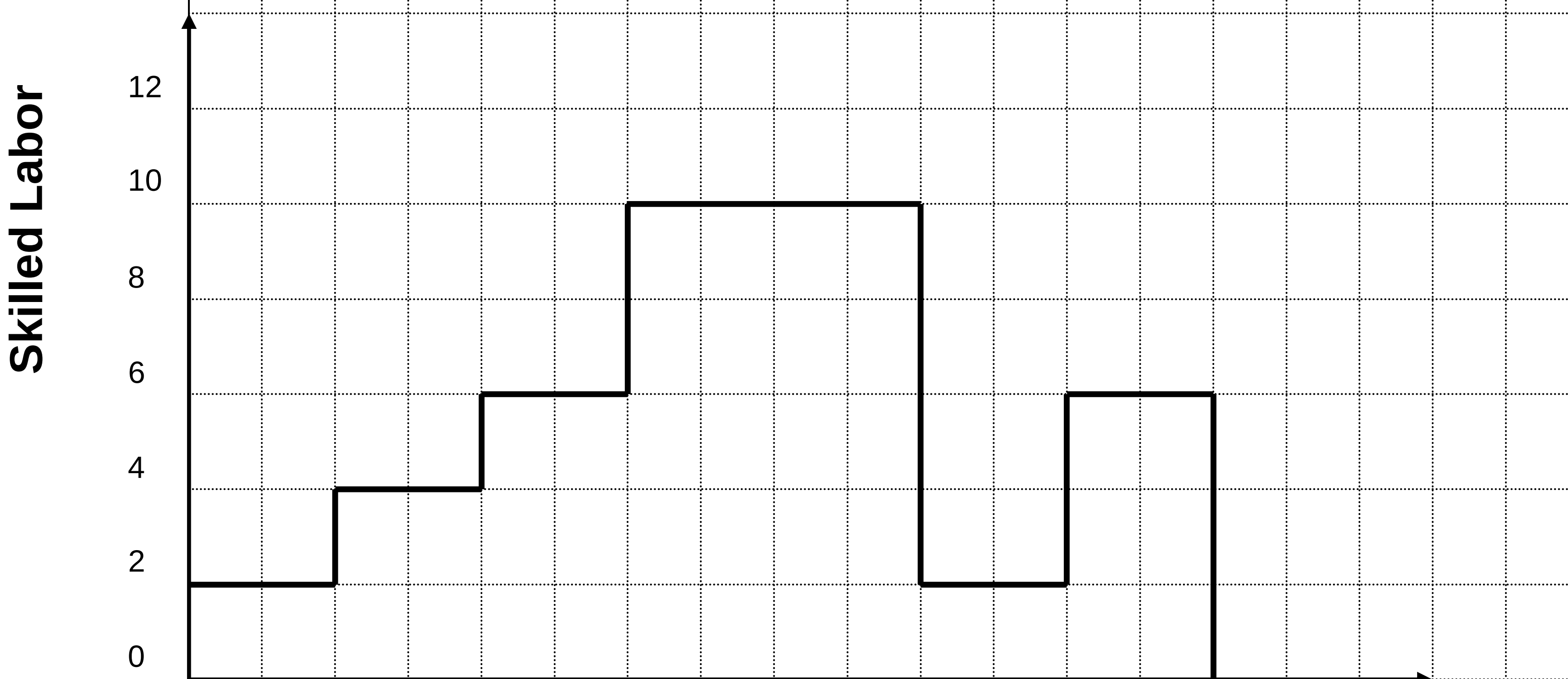
Then the resources for each activity will be written on them (skilled labor on the top of activity and unskilled labor at the bottom of it):
The next step is to add the number of skilled and unskilled labors and write them at the bottom of the bar chart:



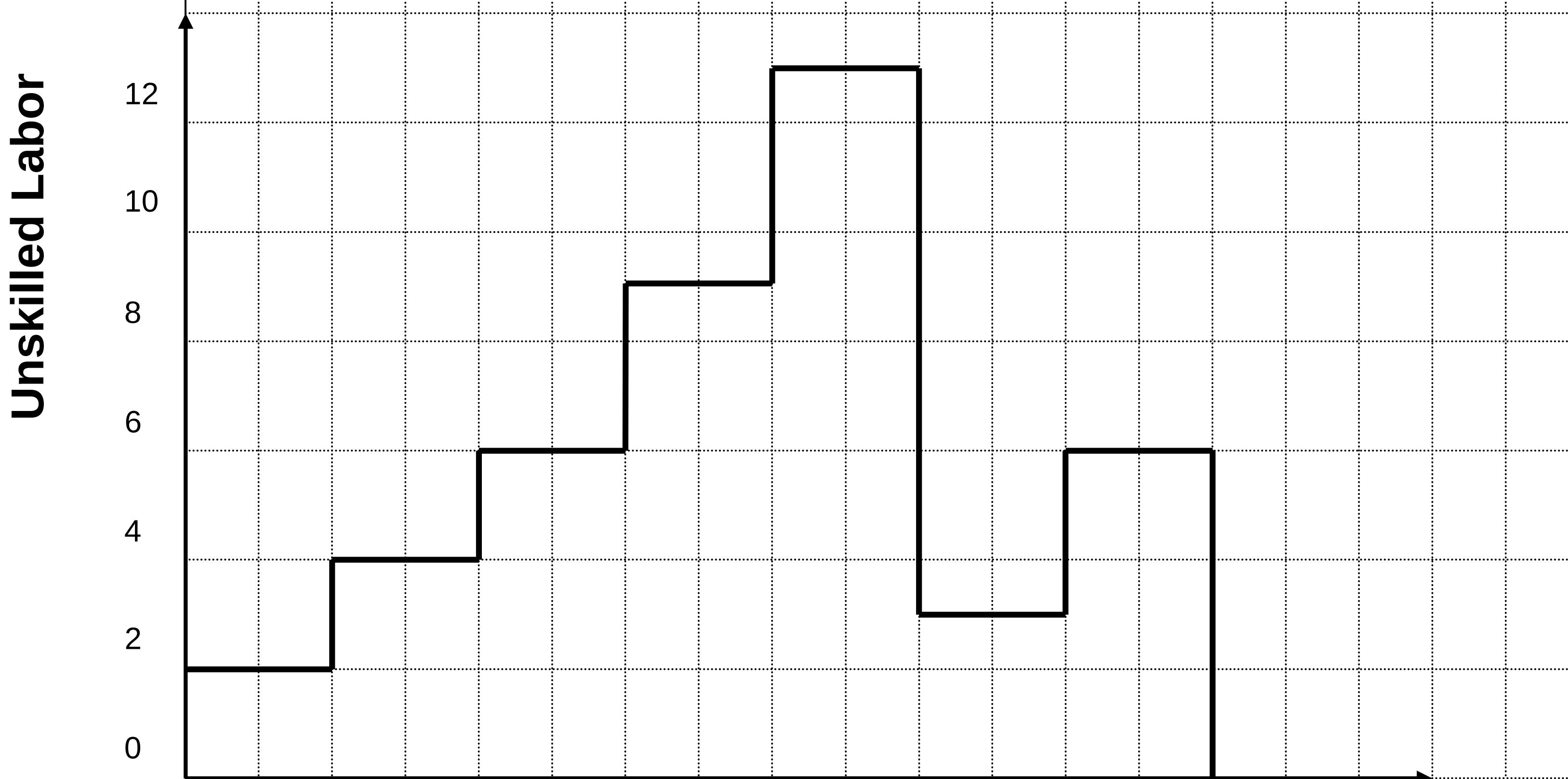
SKILLED LABOR	2	2	4	4	6		6	10	10	10	10		2	2	6	6		
UNSKILLED LABOR	2	2	4	4	6		6	9	9	13	13		3	3	6	6		

For the next step, both of the resources will be drawn as diagrams at the bottom of the bar chart (resource histogram):

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Skilled Labor	2	2	4	4	6	6	10	10	10	10	2	2	6	6					
Unskilled Labor	2	2	4	4	6	6	9	9	13	13	3	3	6	6					



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Skilled Labor	2	2	4	4	6	6	10	10	10	10	2	2	6	6					
Unskilled Labor	2	2	4	4	6	6	9	9	13	13	3	3	6	6					

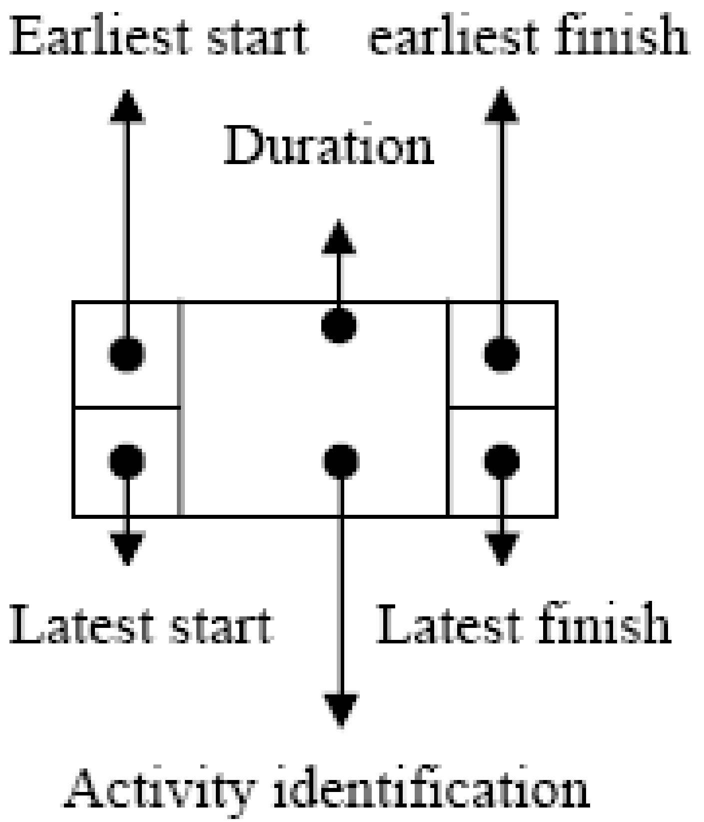


PRECEDENCE DIAGRAM

- **Network analysis by precedence diagram follows the same logical steps as the arrow diagram.**
  - **Listing the activities**
  - **The activity list can be extended to show the dependency between activities, as shown in Fig. 5.10.**
  - **Producing a Logical Network**
  - **Logic: In precedence diagrams the ‘node’ represents the activity and the link or arrow represents only the logical relationship.**
  - **No dummies are needed to maintain correct logic or for unique numbering of activities.**
- **Precedence Diagrams may look more complex at the beginning, but it is more powerful than arrow diagrams.**
- **Fig. 5.10 Precedence list and precedence diagram showing the same network as in Fig. 5.4.**

Identifying the activities

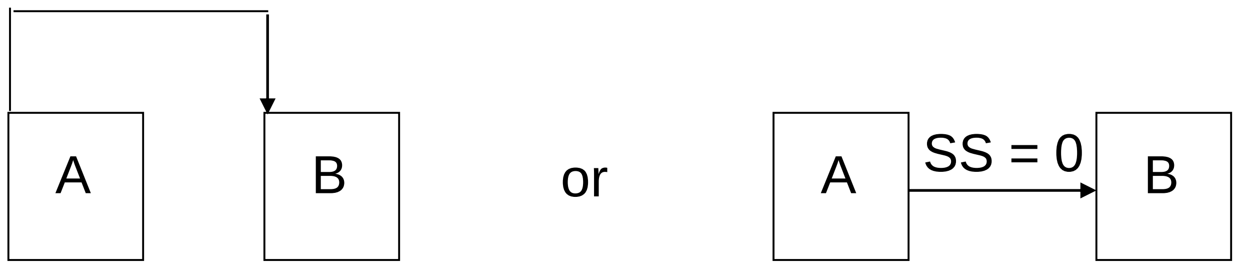
- **Each node representing an activity can be given a single unique number.**



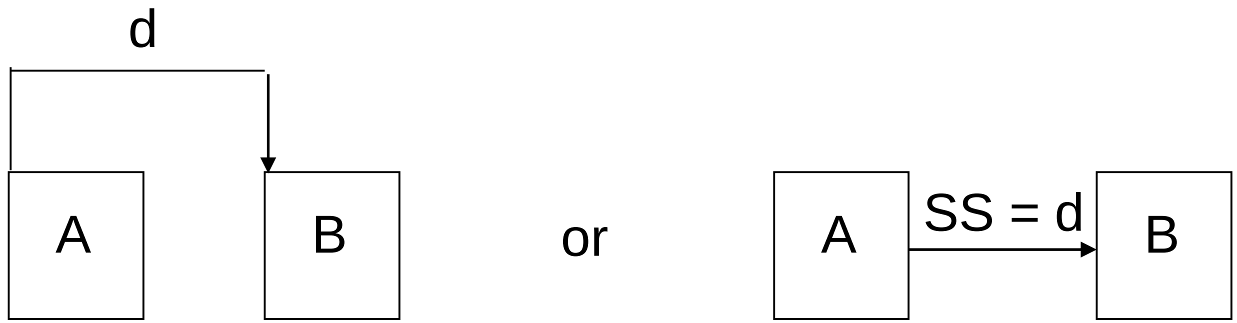
Relationships Between Activities

- **In precedence diagrams a number of different relationships exist between activities, for example:**
  - **Finish-start**
  - **Finish-finish**
  - **Start-start**
  - **Start-finish**
  - **Part complete-start**
  - **Part complete-finish**
  - **Finish-part complete.**

START TO START RELATIONS

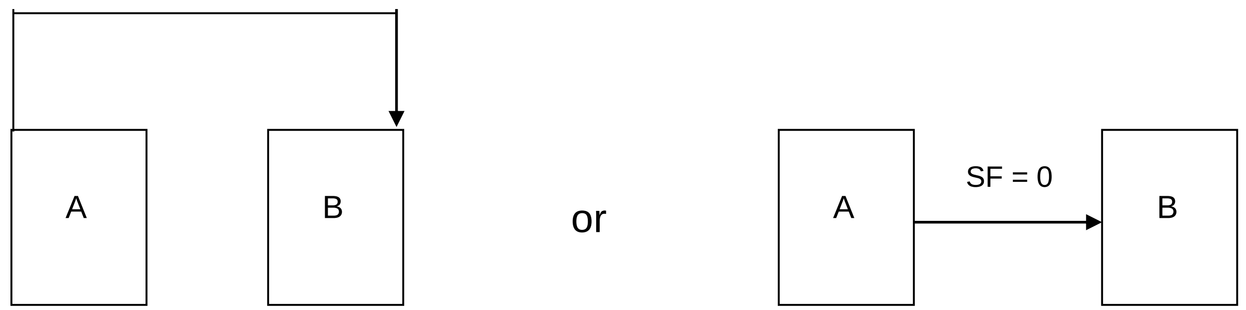


Activity B can start at the same time as activity A but not before.

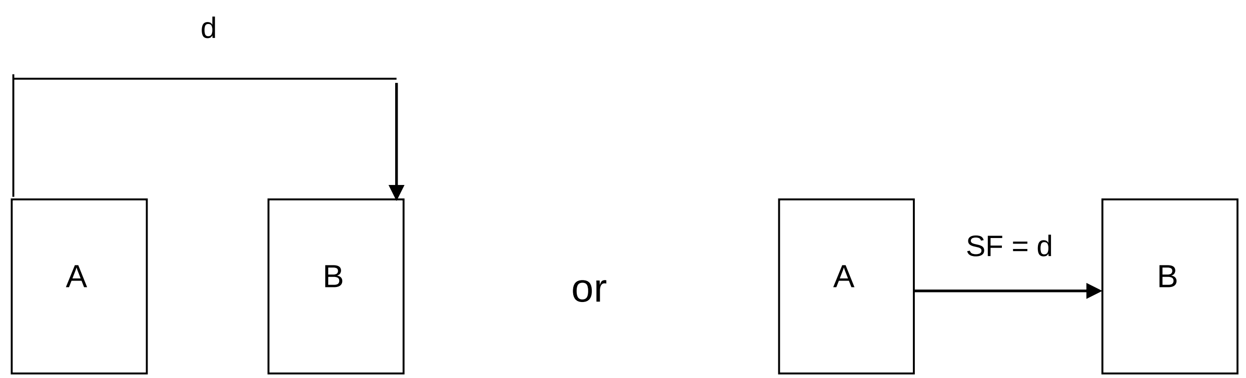


Activity B can not start until d units of time after activity A has started.
Or : Start of activity B must lag d units of time after start of activity A.

START TO FINISH

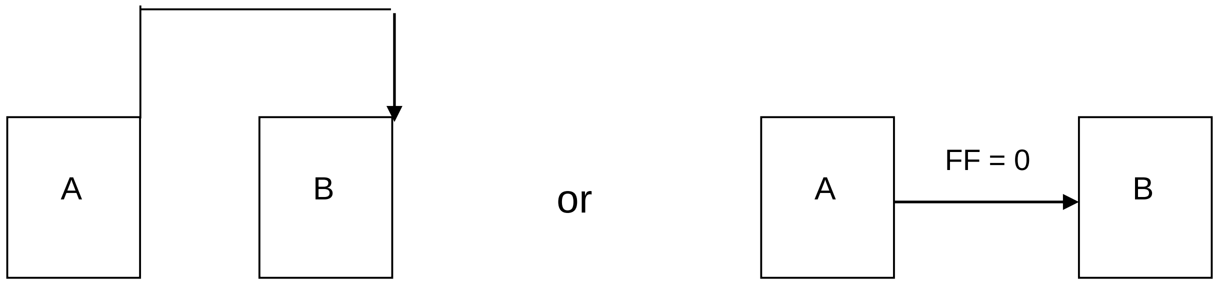


Activity B will finish at the same time that activity A starts.

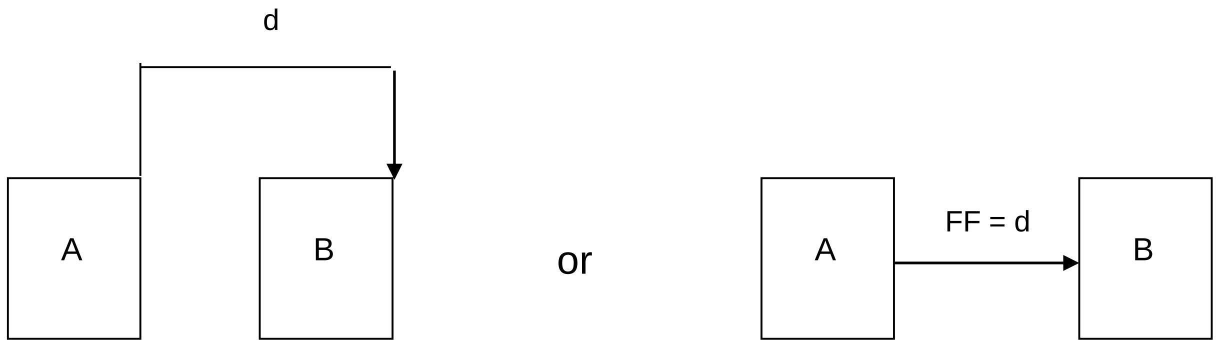


Activity B will finish after d units of time that activity A has started.
Or : Finish of activity B must lag d units of time after start of activity A.

FINISH TO FINISH

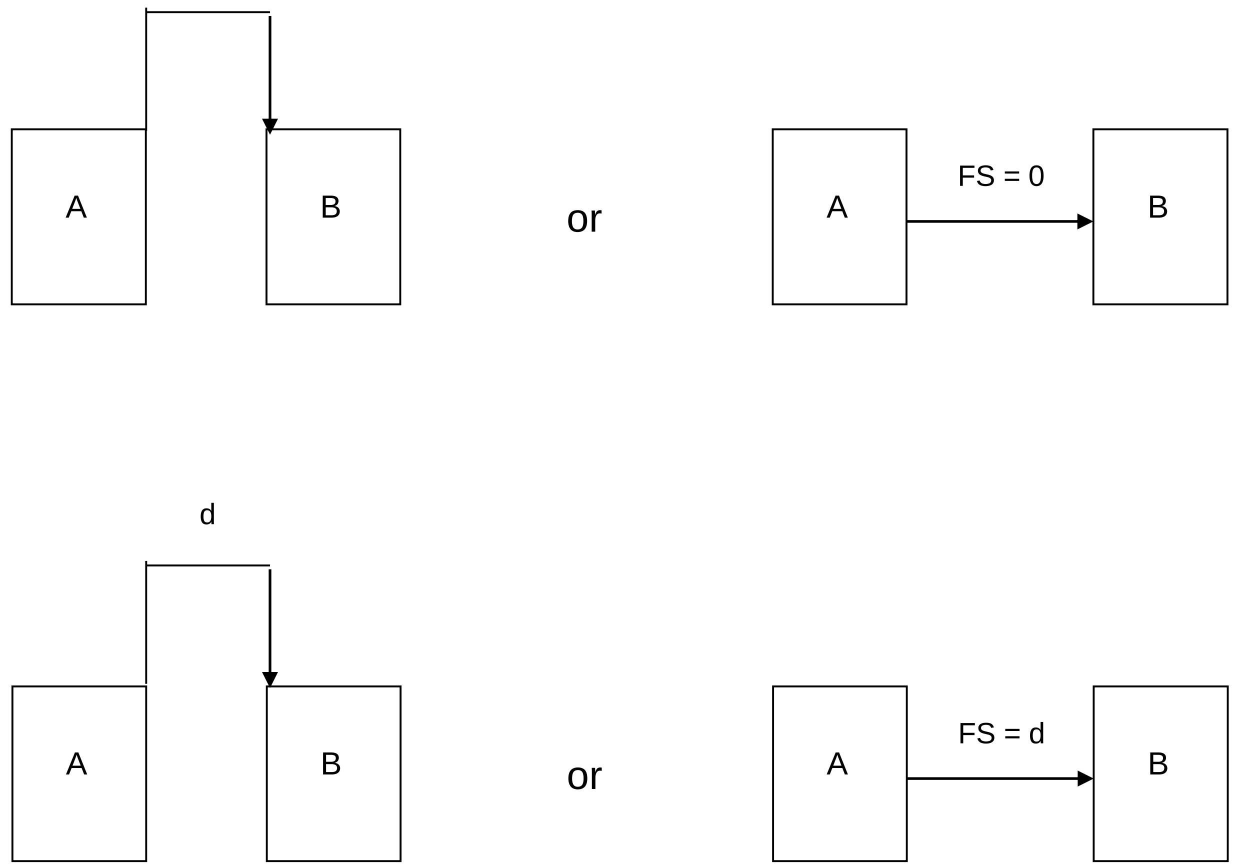


Activity A can not finish until activity B has finished.



Activity B can not finish until d units of time after the completion of activity A.

FINISH TO START



Activity B can not start until d units of time after the completion of activity A.

Duration and time analysis

- **As for arrows, the duration of each activity is estimated and the forward and backward passes are done and the earliest and latest start and finish times of each activity are entered.**
- **These times calculated refer to the activity whereas the calculations for arrows referred to event times.**
- **This is claimed by some to be an advantage of the precedence diagram over the arrow diagram.**
- **Float can be calculated as before, for example in below figure 5.10, the total float of activity No. 5 is latest finishing time less earliest starting time less duration, that is 11-2-3=6.**

Dependency list

Activity	Duration	Dependency Start
1	2	START
2	6	1
3	6	2
4	1	2
5	3	1
6	3	4&5
7	2	3&6

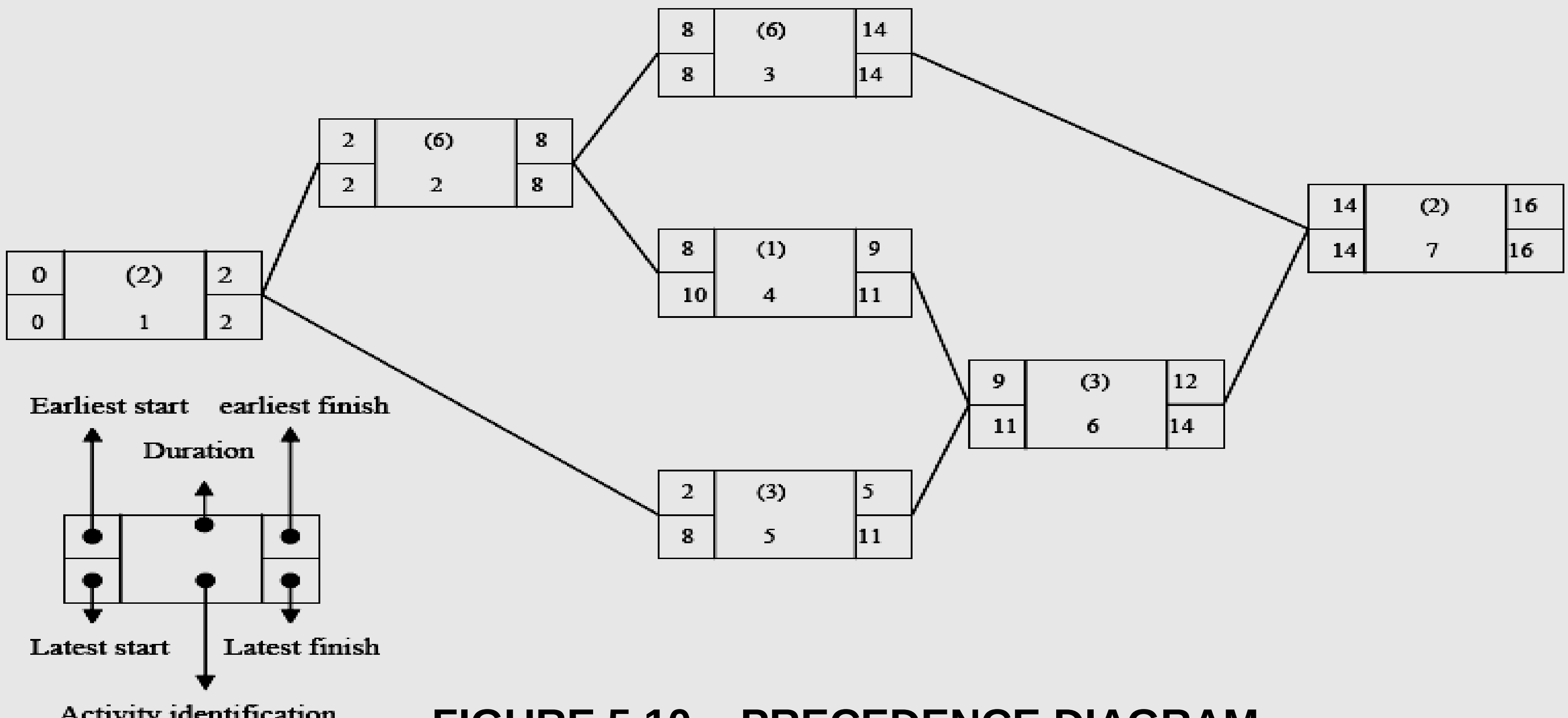
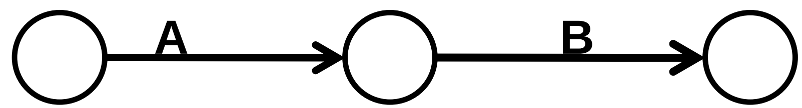


FIGURE 5.10 – PRECEDENCE DIAGRAM

Relationships Between Activities

- **The major advantage offered by precedence diagrams is that the number of relationships that can exist between activities is more than the simple finish-start relationship offered by arrow networks.**
- **The finish-start limitation means that if an activity is to start before the completion of a preceding activity upon which the activity is dependent then the preceding activity must be divided into smaller parts, as in Fig. 5.11 (a);**
- **otherwise, dummies with a time allowance as in Fig. 5.11 (b) must be used to produce overlaps between activities.**

B can not start until **A** is completed



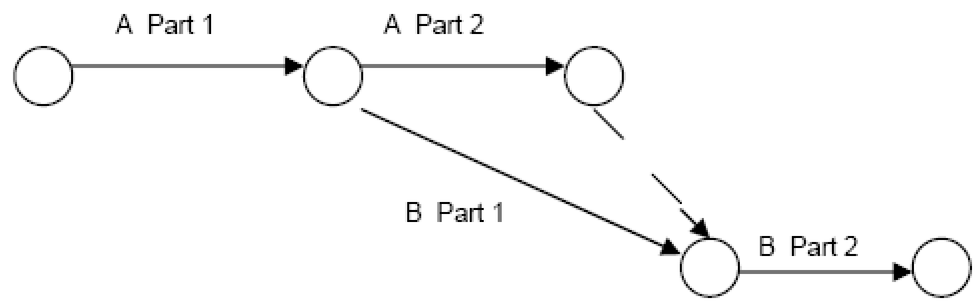


Figure 5.a

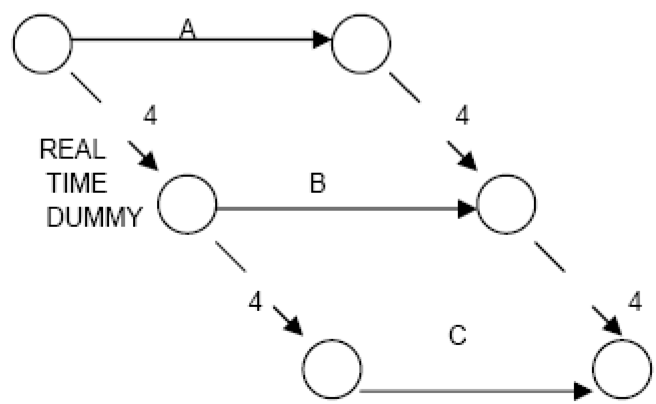


Figure 5.b

Fig. 5.11 Adjustments to arrow networks to produce overlaps between activities

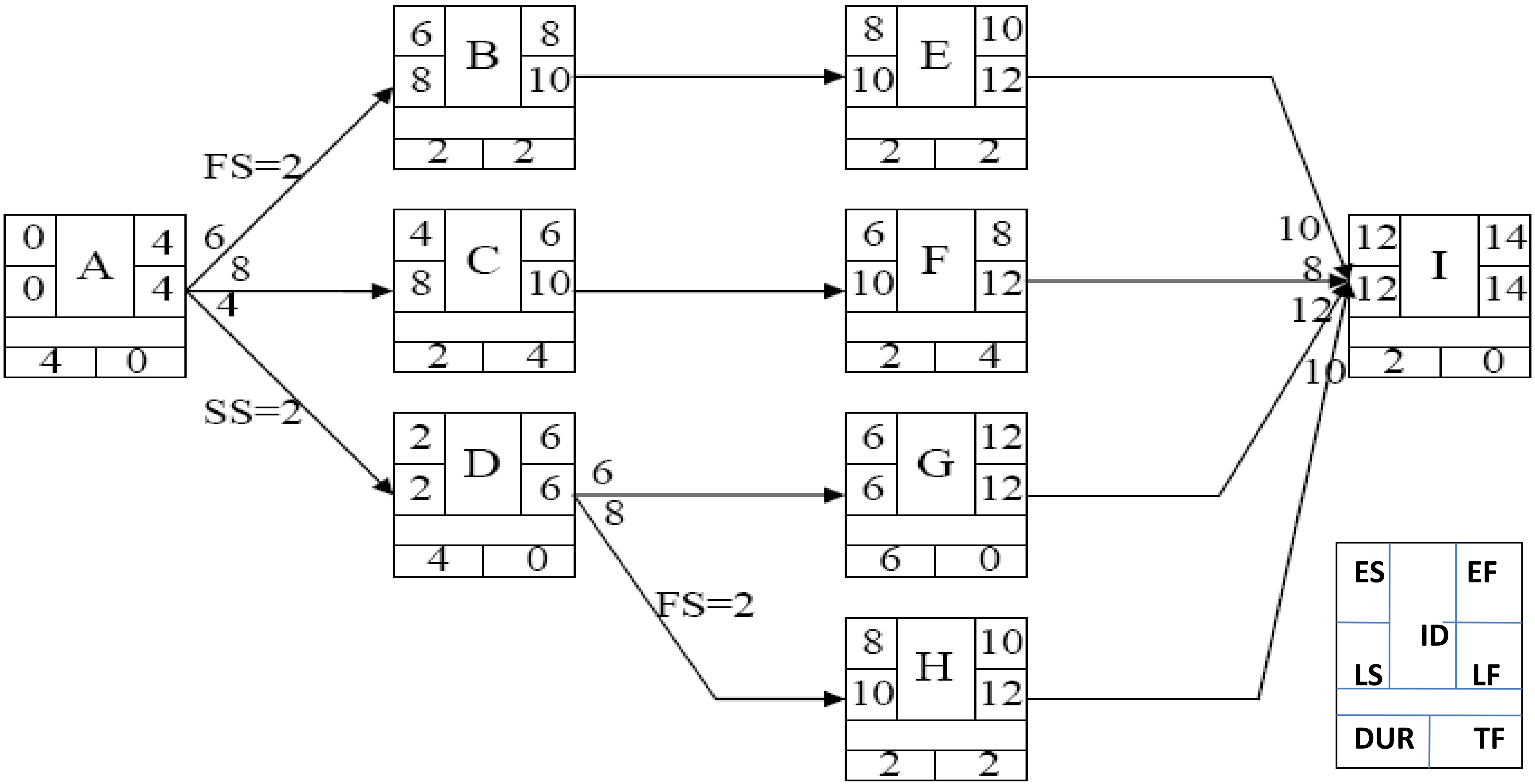
Relationships Between Activities

- In practice use of many different relationships between activities causes the users to confuse their mind and find precedence diagrams complicated.
- Also there is now some evidence that when extensive overlapping of activities is used in planning the project duration tends to be underestimated.
- This results from a zealous use of the overlap facility in order to meet a predetermined target date.
- The main differences between precedence diagrams and activity on the arrows systems are
  - In Precedence Dıagrams node represents activities, whereas in Arrow Diagrams, Arrows represent the activities.
  - precedence diagrams have no dummies,
  - no change of reference number by adding new activities.
  - complex relationships.

Example 5.4

a) Perform resource leveling so that there will be no excessive peaks or troughs in skilled and unskilled labor.

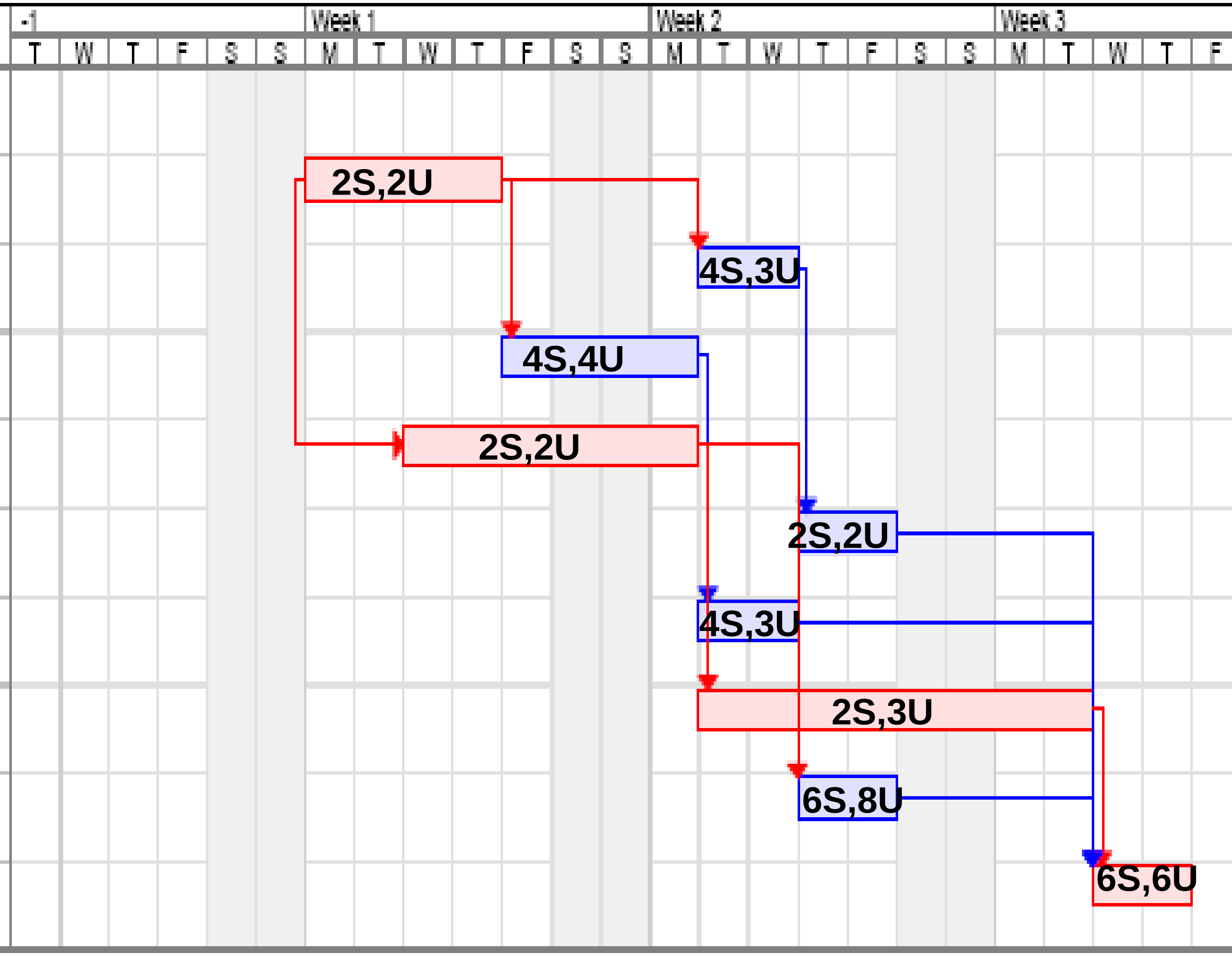
Now we have to draw precedence diagram carry out CPM calculations to find the activities' ES, EF, LS, LF, and TF and also the critical activities.



The critical path is: A – D – G – I

SOLUTION OF EXAMPLE 5.4

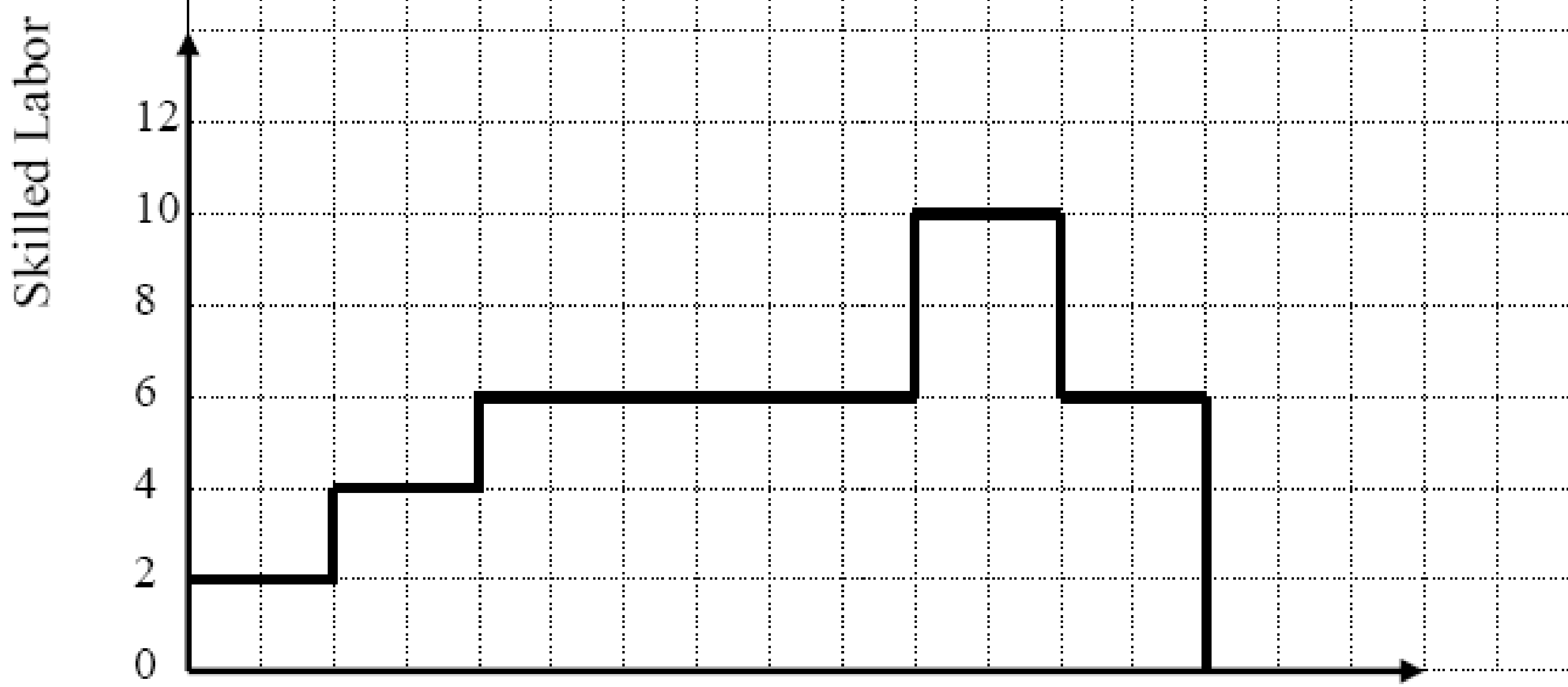
ID	Task Name	Duration	Predecessors	Resource Names
1				
2	A	4 days		2S;2U
3	B	2 days	2FS+2 days	4S;3U
4	C	2 days	2	4S;4U
5	D	4 days	2SS+2 days	2S;2U
6	E	2 days	3	2S;2U
7	F	2 days	4	4S3U
8	G	6 days	5	2S;3U
9	H	2 days	5FS+2 days	6S;8U
10	I	2 days	6;7;8;9	6S;6U



SKILLED LABOR	2	2	4	4	6		6	10	10	10	10		2	2	6	6	
UNSKILLED LABOR	2	2	4	4	6		6	9	9	13	13		3	3	6	6	

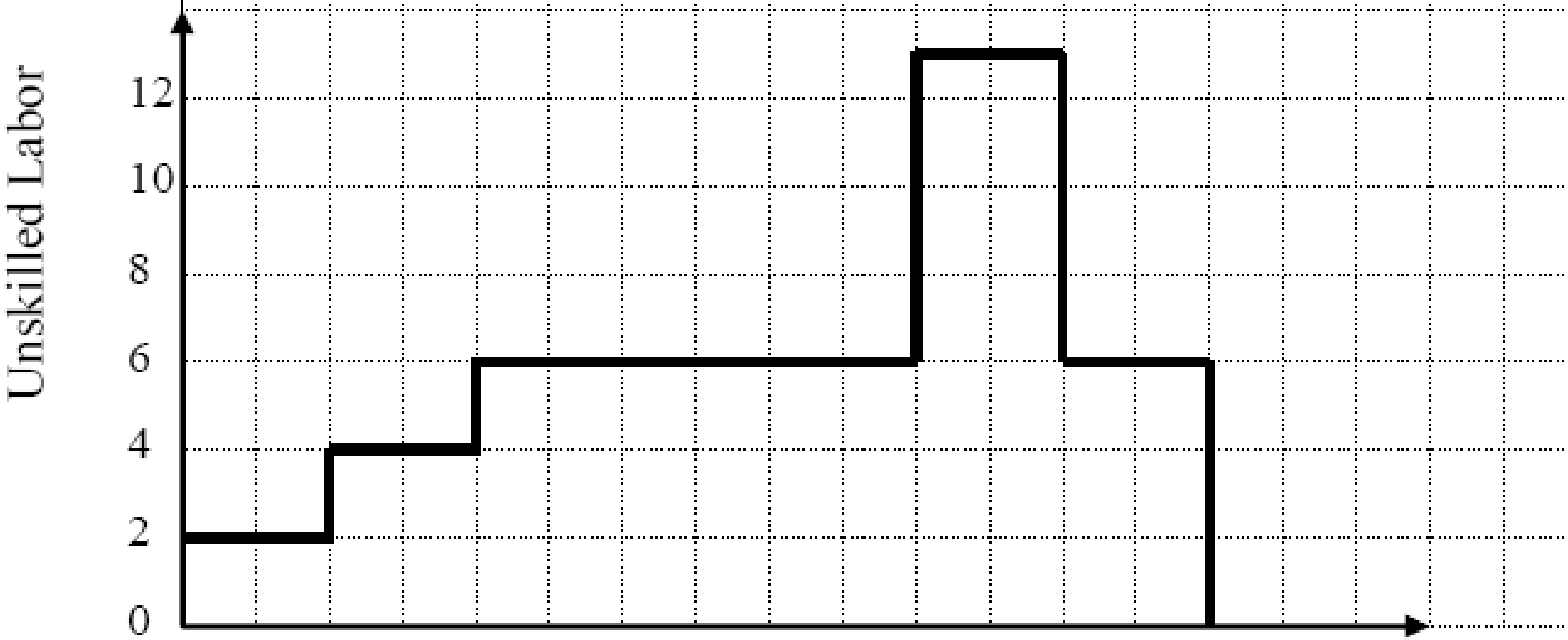
SOLUTION OF EXAMPLE 5.4

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Skilled Labor	2	2	4	4	6	6	6	6	6	6	10	10	6	6					
Unskilled Labor	2	2	4	4	6	6	6	6	6	6	13	13	6	6					



SOLUTION OF EXAMPLE 5.4

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Skilled Labor	2	2	4	4	6	6	6	6	6	6	10	10	6	6					
Unskilled Labor	2	2	4	4	6	6	6	6	6	6	13	13	6	6					



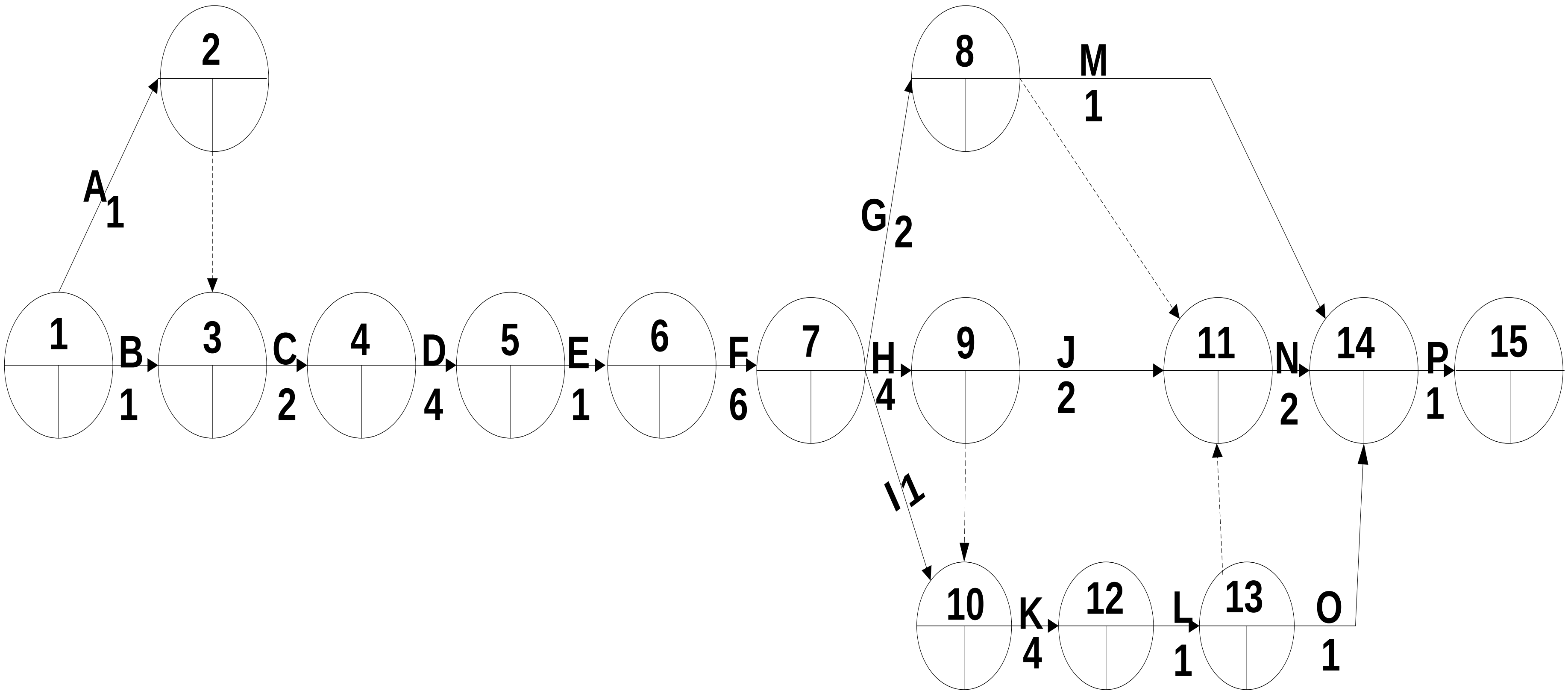
Example 5.5

A Construction Company is awarded a contract. Project activity list and their relationships are given in table below.

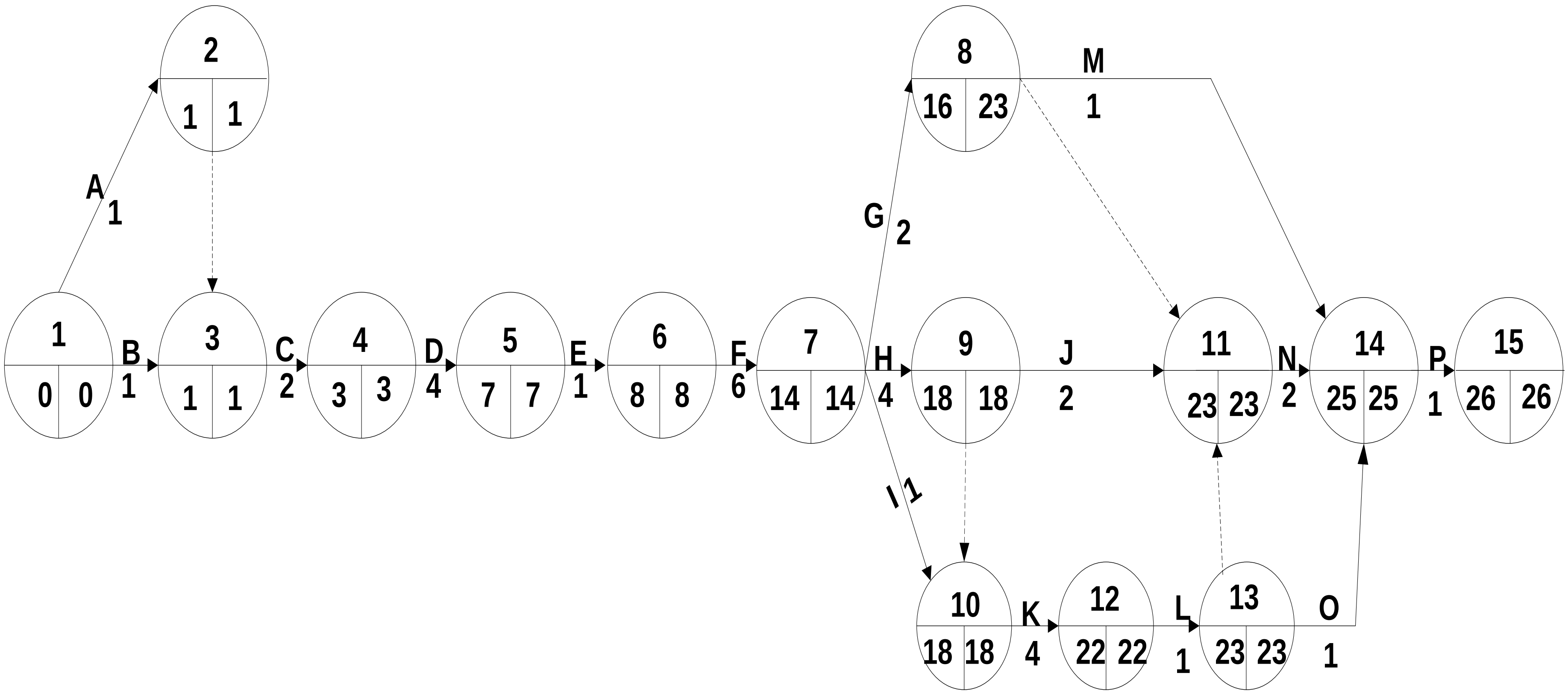
a. Draw arrow diagram and find project completion time
b. Find critical path(s)
c. Calculate activities ES, EF, LS, LF, TF , FF and IF.

ACTIVITY ID	ACTIVITY DESCRIPTION	Duration (weeks)	PRECEEDING
A	Organize	1	-
B	Site layout	1	-
C	Excavation	2	A, B
D	Foundation	4	C
E	Floor slab	1	D
F	Structures	6	E
G	Roof construction	2	F
H	Brick work	4	F
I	Masonary	1	F
J	Plumbing & electrical work	2	H
K	Plastering	4	H,I
L	Door and windows	1	K
M	Roof covering	1	G
N	Painting	2	G,J,L
O	Glazing	1	L
P	Clearing	1	M, N, O

SOLUTION OF EXAMPLE 5.5



SOLUTION OF EXAMPLE 5.5



a) Project completion is 26 weeks

b) Critical paths are : A-C-D-E-F-H-K-L-N-P

: B-C-D-E-F-H-K-L-N-P

c) TABLE 5.5 – ES,EF,LS,LF,TF,AND FF OF EXAMPLE 5.5

ACT ID	Activity Description	Duration (weeks)	ES	EF	LS	LF	TF	FF	IF
A	Organize	1							
B	Site layout	1							
C	Excavation	2							
D	Foundation	4							
E	Floor slab	1							
F	Structures	6							
G	Roof construction	2							
H	Brick work	4							
I	Masonary	1							
J	Plumbing & electrical work	2							
K	Plastering	4							
L	Door and windows	1							
M	Roof covering	1							
N	Painting	2							
O	Glazing	1							
P	Clearing	1							

c) TABLE 5.5 – ES,EF,LS,LF,TF,AND FF OF EXAMPLE 5.5

ACT ID	Activity Description	Duration (weeks)	ES	EF	LS	LF	TF	FF	IF
A	Organize	1	0	1	0	1	0	0	0
B	Site layout	1	0	1	0	1	0	0	0
C	Excavation	2	1	3	1	3	0	0	0
D	Foundation	4	3	7	3	7	0	0	0
E	Floor slab	1	7	8	7	8	0	0	0
F	Structures	6	8	14	8	14	0	0	0
G	Roof construction	2	14	16	21	23	7	0	0
H	Brick work	4	14	18	14	18	0	0	0
I	Masonary	1	14	15	17	18	3	3	3
J	Plumbing & electrical work	2	18	20	21	23	3	3	3
K	Plastering	4	18	22	18	22	0	0	0
L	Door and windows	1	22	23	22	23	0	0	0
M	Roof covering	1	16	17	24	25	8	8	1
N	Painting	2	23	25	23	25	0	0	0
O	Glazing	1	23	24	24	25	1	1	1
P	Clearing	1	25	26	25	26	0	0	0

Example 5.6

Activity list given below are for construction of small industrial building.

a. Draw arrow diagram for the activities listed in table 5.6.

b. Find project duration.

c. Find the critical path(s).

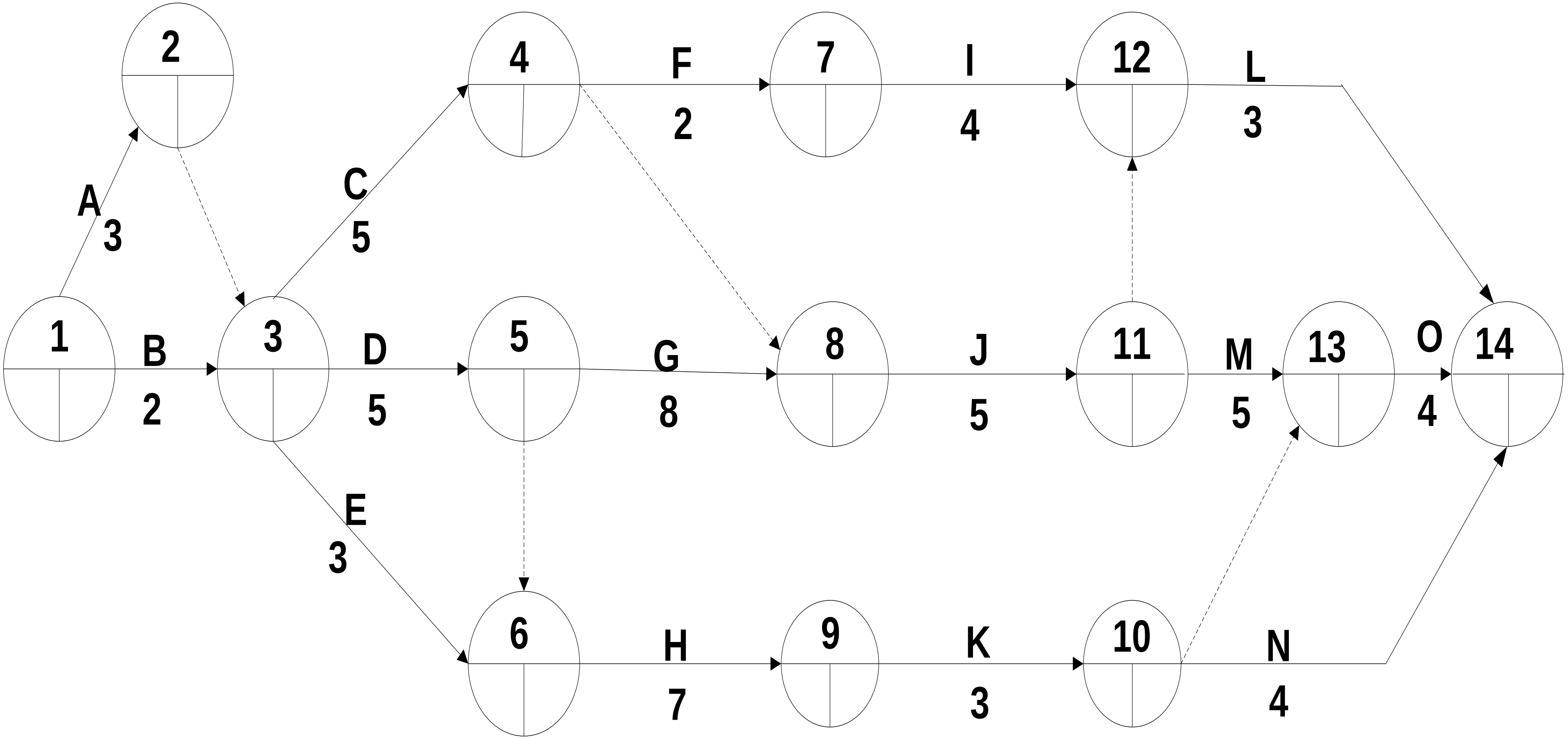
d. Calculate ES, EF, LS, LF ,TF ,FF and IF .

Table 5.6

Activity	Preceding	Duration weeks
A	-	3
B	-	2
C	A, B	5
D	A, B	5
E	A, B	3
F	C	2
G	D	8
H	D, E	7
I	F	4
J	C, G	5
K	H	3
L	I, J	3
M	J	5
N	K	4
O	K, M	4

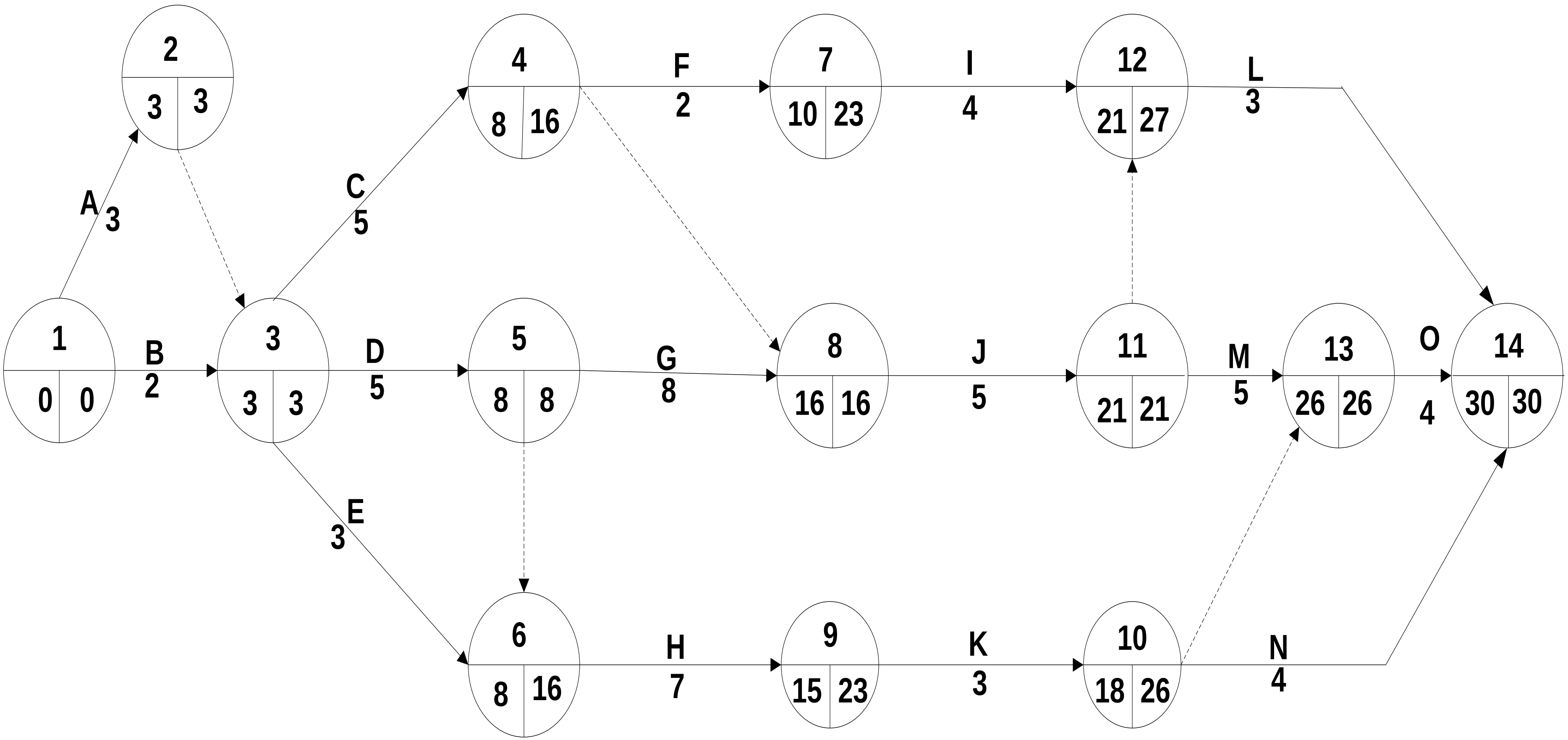
SOLUTION OF EXAMPLE 5.6

a) Arrow Diagram



SOLUTION OF EXAMPLE 5.6

a) Arrow Diagram



b) Project completion time is 30 weeks

c) Critical path (s) is A-D-G-J-M-O

d) TABLE 5.7 – ES,EF,LS,LF,TF,FF OF EXAMPLE 5.6

Act ID	Duration weeks	ES	EF	LS	LF	TF	FF
A	3						
B	2						
C	5						
D	5						
E	3						
F	2						
G	8						
H	7						
I	4						
J	5						
K	3						
L	3						
M	5						
N	4						
O	4						

d) TABLE 5.7 – ES,EF,LS,LF,TF,FF OF EXAMPLE 5.6

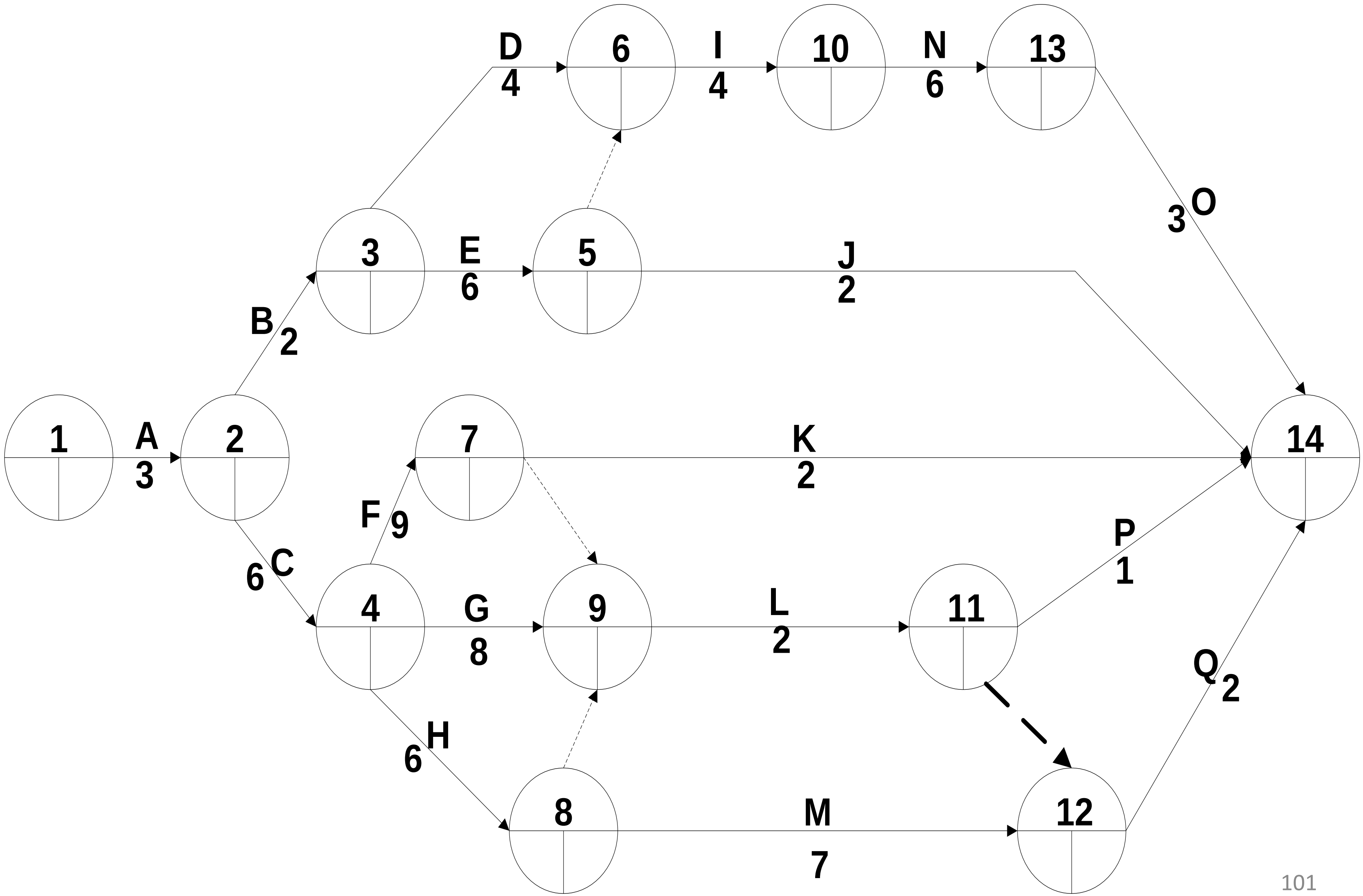
Act ID	Duration weeks	ES	EF	LS	LF	TF	FF
A	3	0	3	0	3	0	0
B	2	0	2	1	3	1	1
C	5	3	8	11	16	8	0
D	5	3	8	3	8	0	0
E	3	3	6	13	16	10	2
F	2	8	10	21	23	13	0
G	8	8	16	8	16	0	0
H	7	8	15	16	23	8	0
I	4	10	14	23	27	13	7
J	5	16	21	16	21	0	0
K	3	15	18	23	26	8	0
L	3	21	24	27	30	6	6
M	5	21	26	21	26	0	0
N	4	18	22	26	30	8	8
O	4	26	30	26	30	0	0

Example 5.7

a. Draw arrow diagram for the activities listed in table below.
b. Find project duration.
c. Find the critical path(s)
d. Calculate ES, EF, LS, LF ,TF, and FF.

Activity	Preceding	Duration
A	-	3
B	A	2
C	A	6
D	B	4
E	B	6
F	C	9
G	C	8
H	C	6
I	D, E	4
J	E	2
K	F	2
L	F, G, H	2
M	H	7
N	I	6
O	N	3
P	L	1
Q	L, M	2

a) Arrow Diagram for Example 5.7



d) ES,EF,LS,LF,TF,FF OF EXAMPLE 5.7

Activity	Duration	ES	EF	LS	LF	TF	FF
A	3						
B	2						
C	6						
D	4						
E	6						
F	9						
G	8						
H	6						
I	4						
J	2						
K	2						
L	2						
M	7						
N	6						
O	3						
P	1						
Q	2						

Example 5.8

a) Draw Precedence diagram.

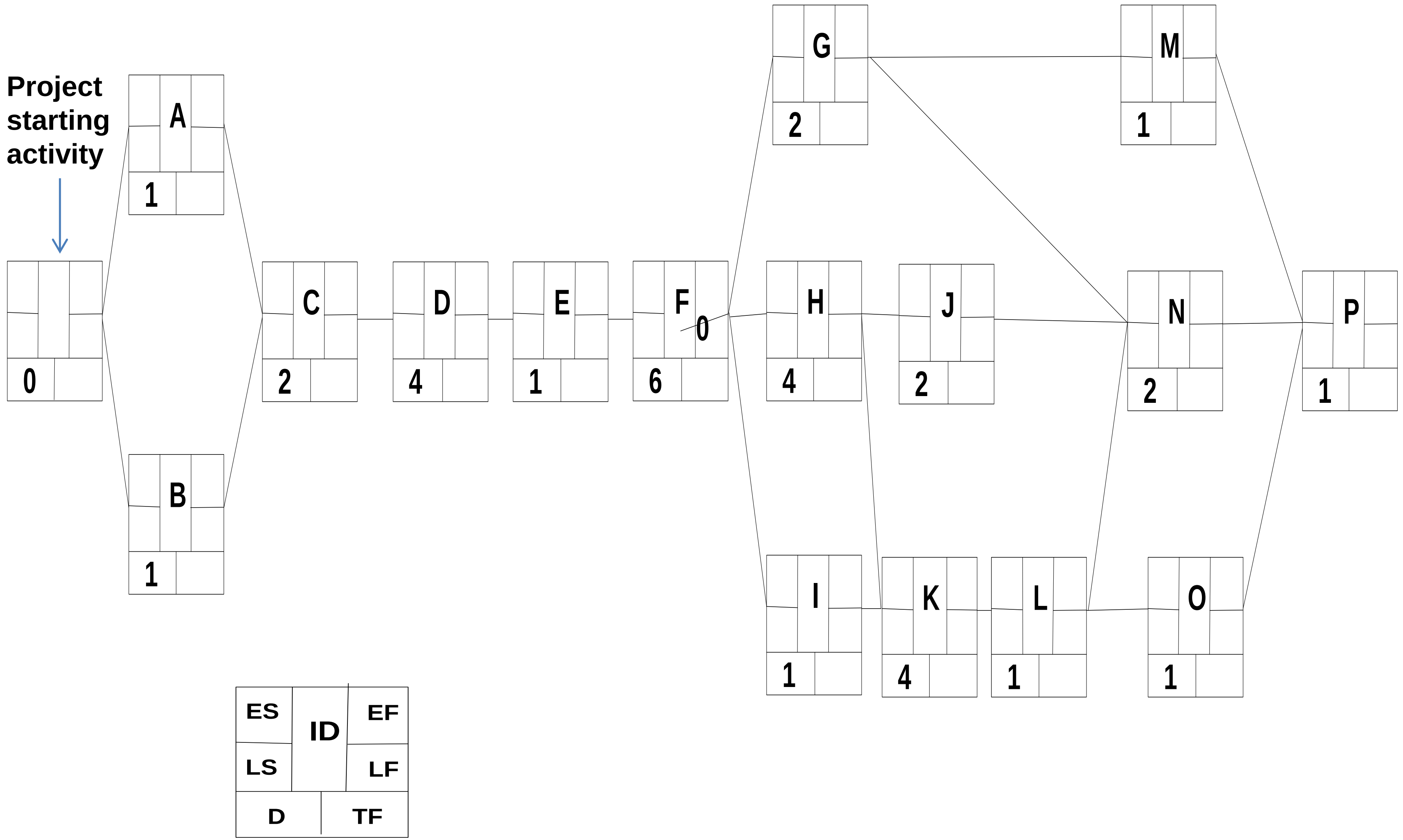
b) Find project completion time

c) Find critical path(s)

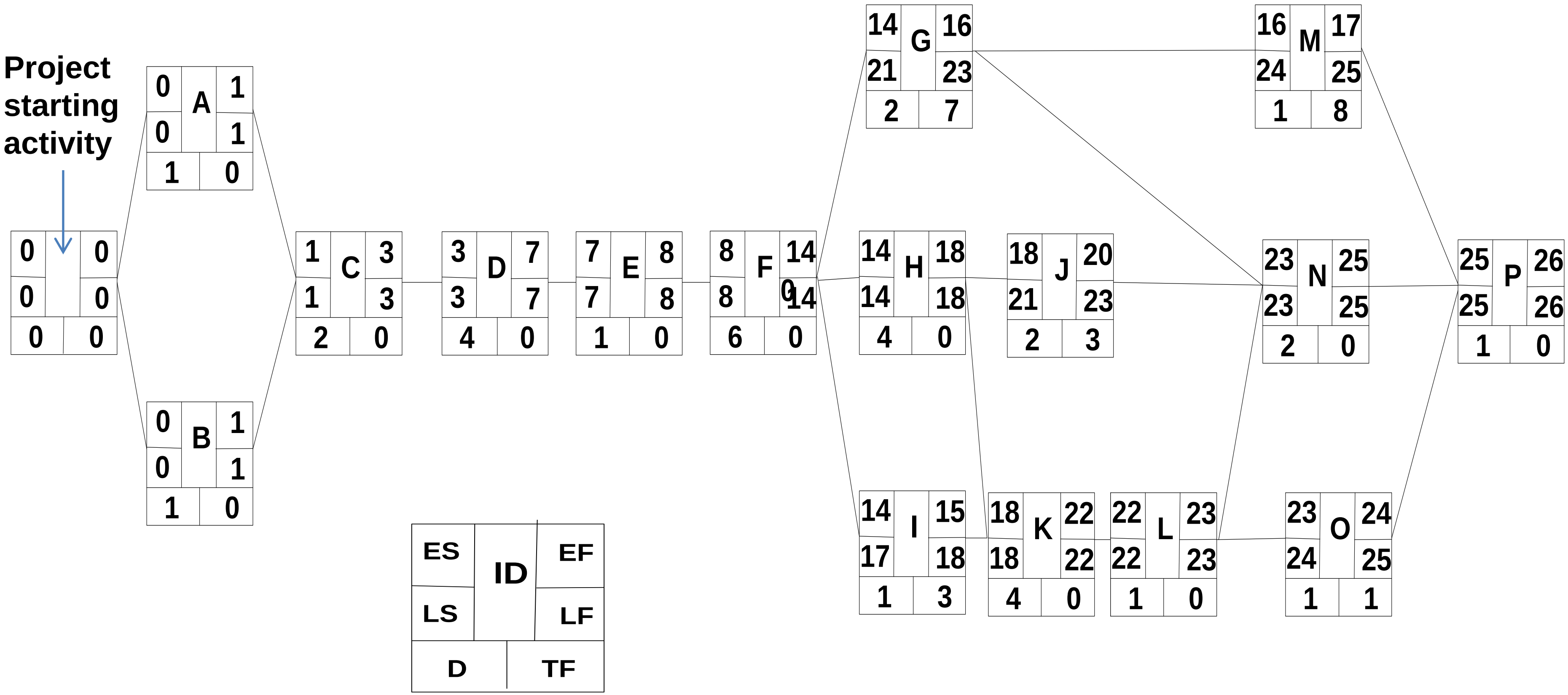
d) Calculate activities ES, EF, LS, LF, TF.

ACTIVITY ID	Activity Description	Duration(week)	PRECEEDING
A	Organize	1	-
B	Site layout	1	-
C	Excavation	2	A, B
D	Foundation	4	C
E	Floor slab	1	D
F	Structures	6	E
G	Roof construction	2	F
H	Brick work	4	F
I	Masonary	1	F
J	Plumbing & elec. work	2	H
K	Plastering	4	H,I
L	Door and windows	1	K
M	Roof covering	1	G
N	Painting	2	G,J,L
O	Glazing	1	L
P	Clearing	1	M, N, O

a) Precedence Diagram for Example 5.8



a) Precedence Diagram for Example 5.8



b) Project completion is 26 weeks

c) Critical paths are : (1) A-C-D-E-F-H-K-L-N-P

: (2) B-C-D-E-F-H-K-L-N-P

d) See the precedence diagram.

Example 5.9

A company is bidding for a work. There are significant liquidated damages if it can not be completed within the scheduled 20 weeks. Activities, durations and relationships are as listed in table below.

a. Draw Precedence diagram.

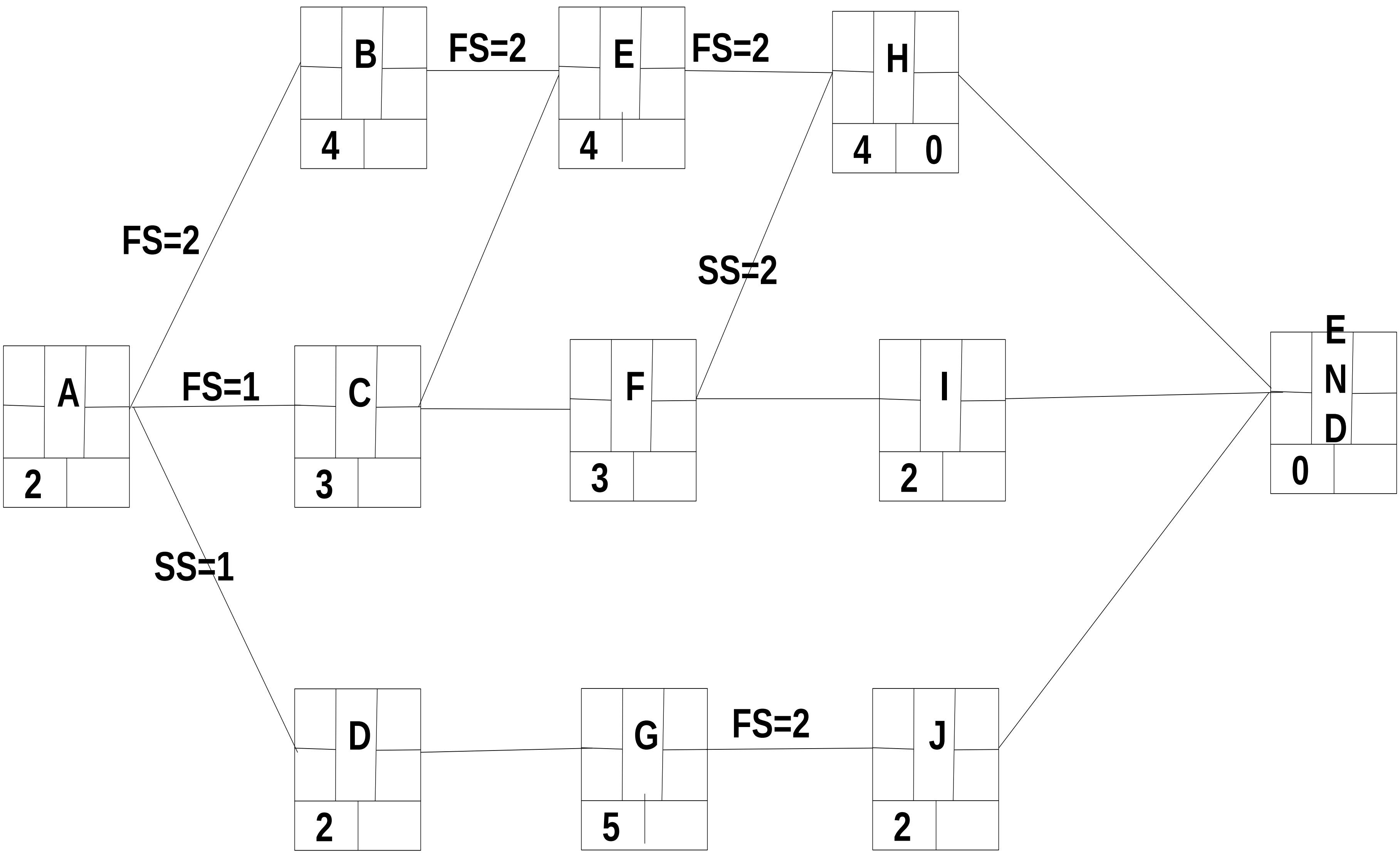
b. Find project completion time.

c. Find the critical path(s).

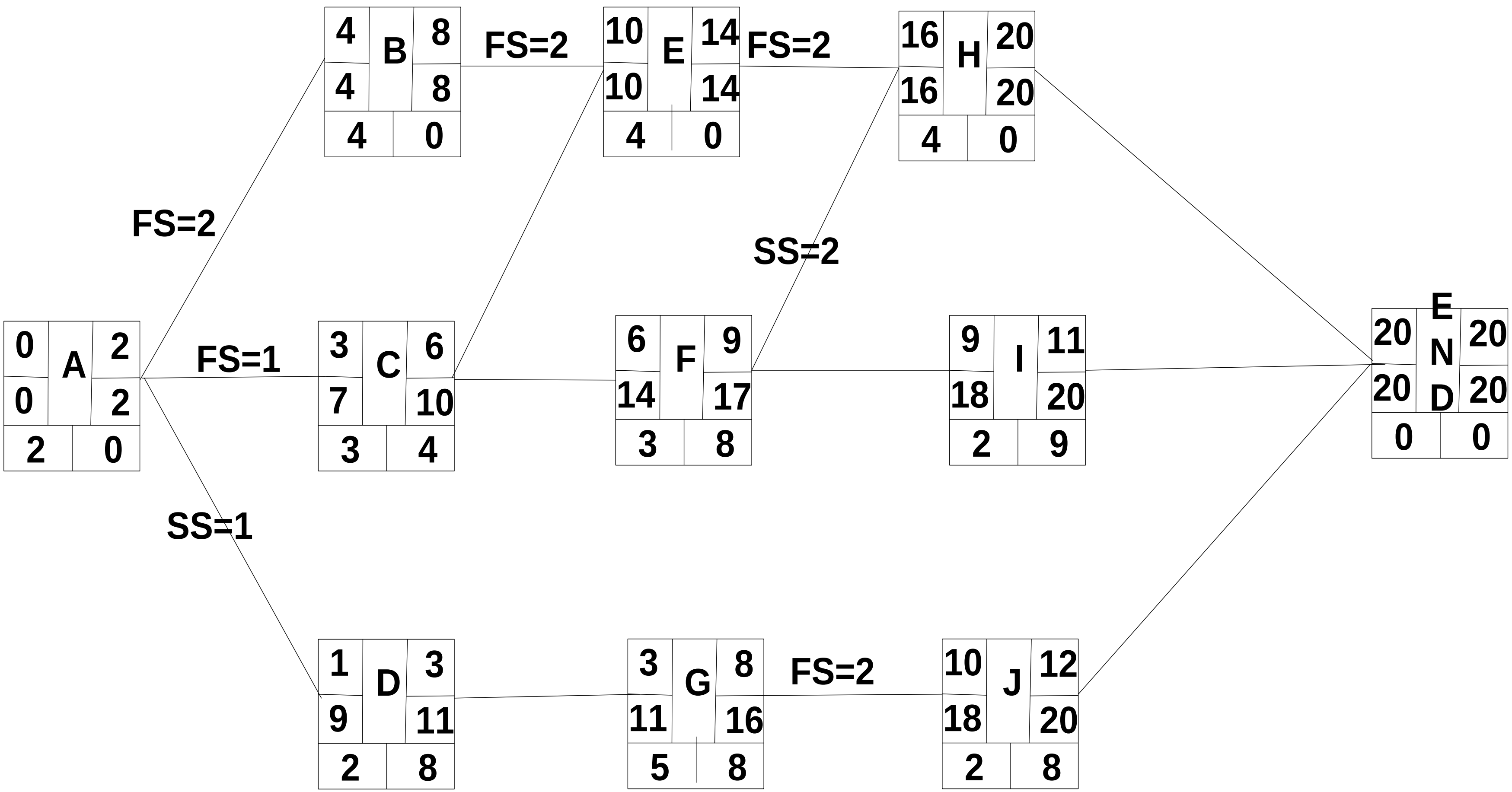
d. Calculate activities ES, EF, LS, LF and TF.

Activity	Preceding	DURATION (weeks)	Relationship	Lag
A	-	2	-	-
B	A	4	FS	2
C	A	3	FS	1
D	A	2	SS	1
E	B, C	4	FS,FS	2 , 0
F	C	3	FS	0
G	D	5	FS	0
H	E, F	4	FS, SS	2, 2
I	F	2	FS	0
J	G	2	FS	2

a) Precedence Diagram for Example 5.9



a) Precedence Diagram for Example 5.9

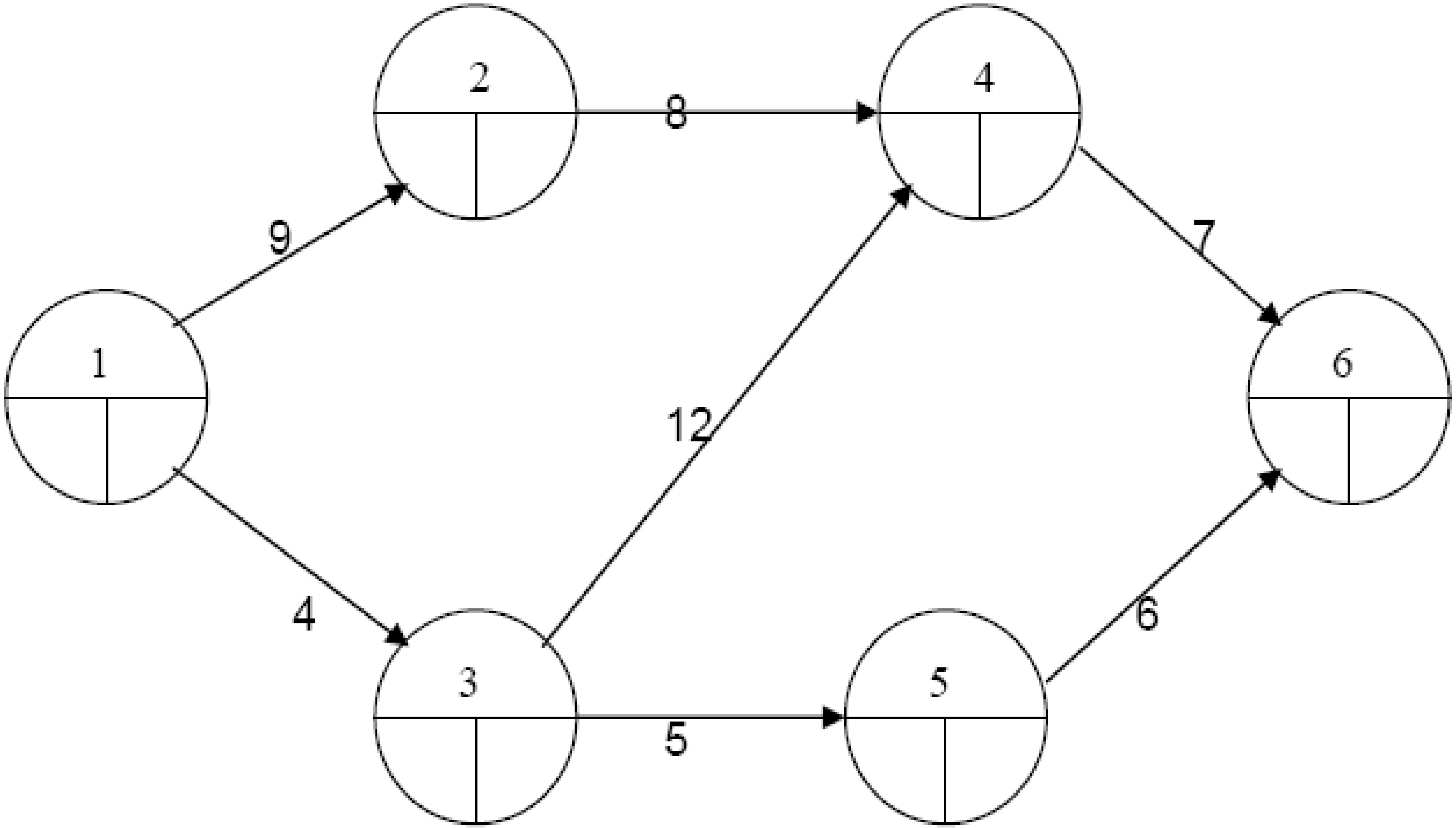


b) Project completion time is 20 weeks

c) Critical path A-B-E-H

d) See the precedence diagram

NETWORK ANALYSIS PROBLEM 1

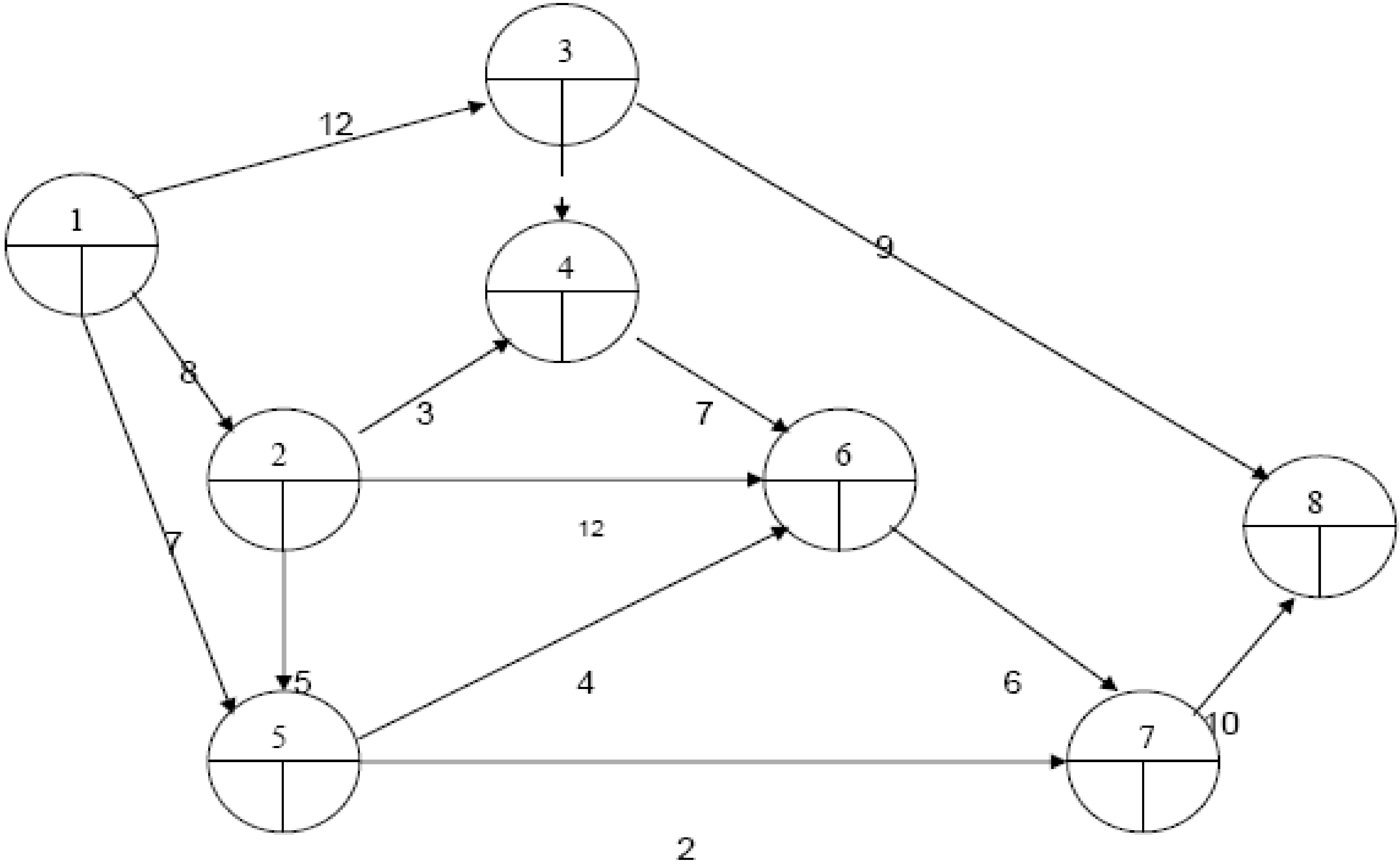


1. CALCULATE THE EARLIEST AND LATEST EVENT TIMES.
2. SHOW THE CRITICAL PATH ON THE NETWORK.
3. CALCULATE THE TOTAL, FREE AND INDEPENDENT FLOAT FOR EACH ACTIVITY IN THE FOLLOWING TABLE.
4. SHOW THE NETWORK IN THE FORM OF A BAR CHART.

SOLUTION OF NETWORK ANALYSIS PROBLEM 1

ACTIVITY EVENT NOS:	DURATION	EARLIEST		LATEST		FLOAT		
		START	FINISH	START	FINISH	TOTAL	FREE	INDEPENDENT
1-2	9							
1-3	4							
2-4	8							
3-4	12							
3-5	5							
4-6	7							
5-6	6							

NETWORK ANALYSIS PROBLEM 2

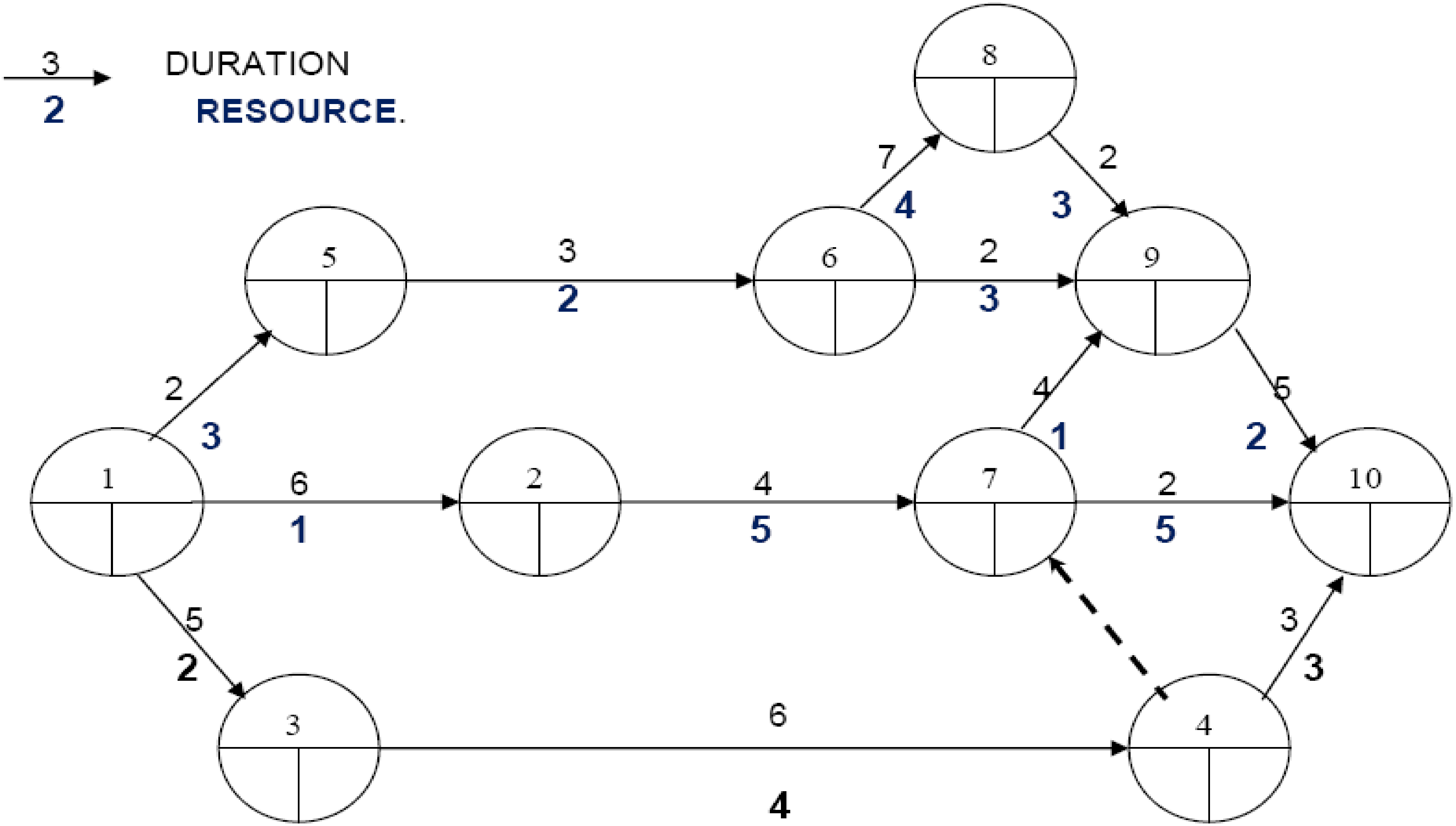


COMPLETE THE BELOW TABLE AND SHOW THE NETWORK IN THE FORM OF A BAR CHART

SOLUTION OF NETWORK ANALYSIS PROBLEM 2

ACTIVITY EVENT NO.	DURATION	EARLIEST		LATEST		FLOAT		
		START	FINISH	START	FINISH	TOTAL	FREE	INDEPENDENT

NETWORK ANALYSIS PROBLEM 3

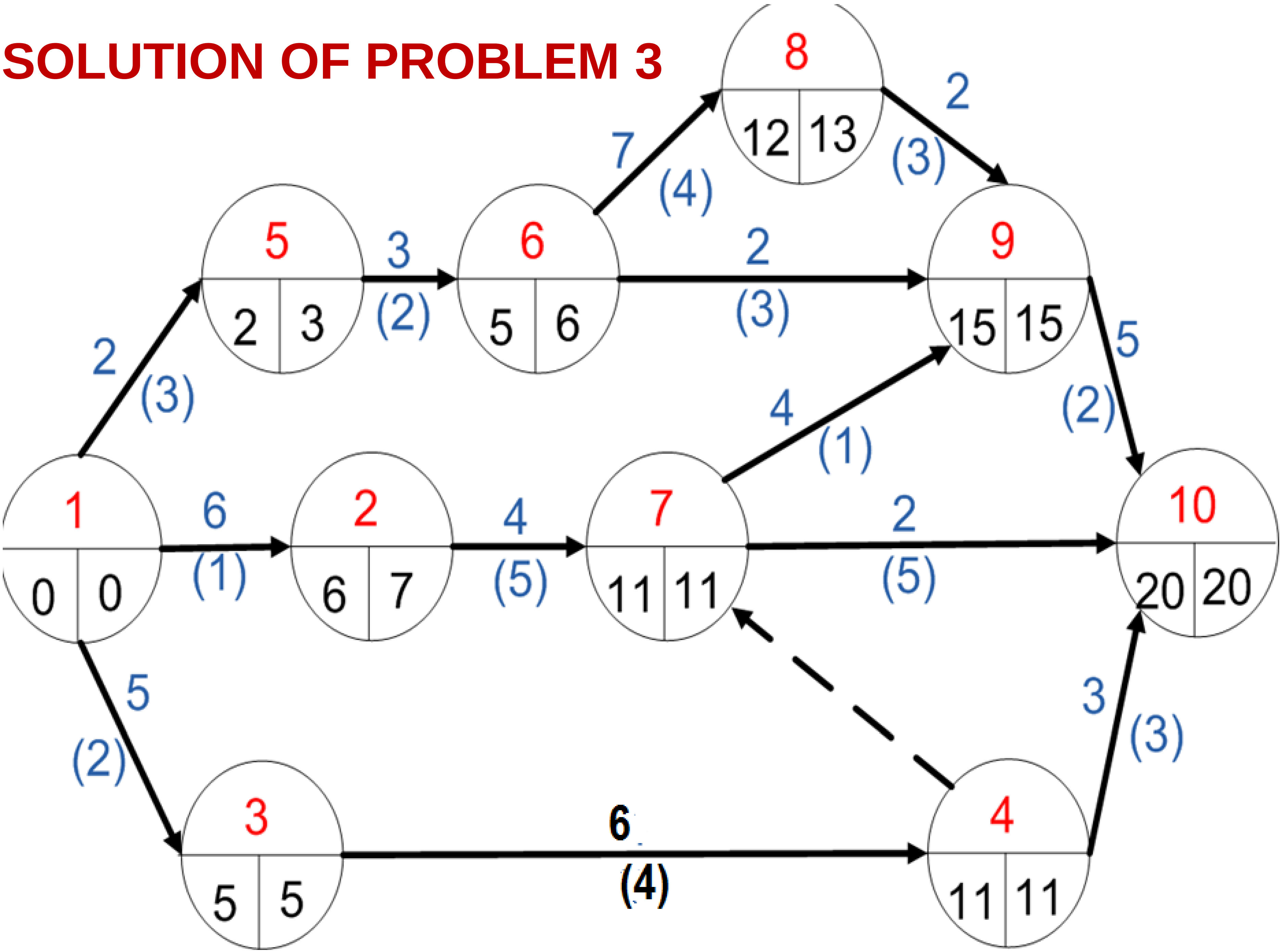


1. ANALYSE THE NETWORK, SHOW THE CRITICAL PATH AND COMPLETE THE TABLE BELOW.
2. DRAW A BAR CHART SHOWING ALL ACTIVITIES AT EARLIEST START DATES.
3. FROM THE BAR CHART SHOW THE RESOURCE REQUIREMENTS IN THE FORM OF A HISTOGRAM.

SOLUTION OF NETWORK ANALYSIS PROBLEM 3

ACTIV. EVENT NOS.	DURATION	EARLIEST		LATEST		FLOAT		
		START	FINISH	START	FINISH	TOTAL	FREE	INDEPENDENT
1-2	6							
1-3	5							
1-5	2							
2-7	4							
3-4	6							
4-7	0							
4-10	3							
5-6	3							
6-8	7							
6-9	2							
7-9	4							
7-10	2							
8-9	2							
9-10	5							

SOLUTION OF PROBLEM 3



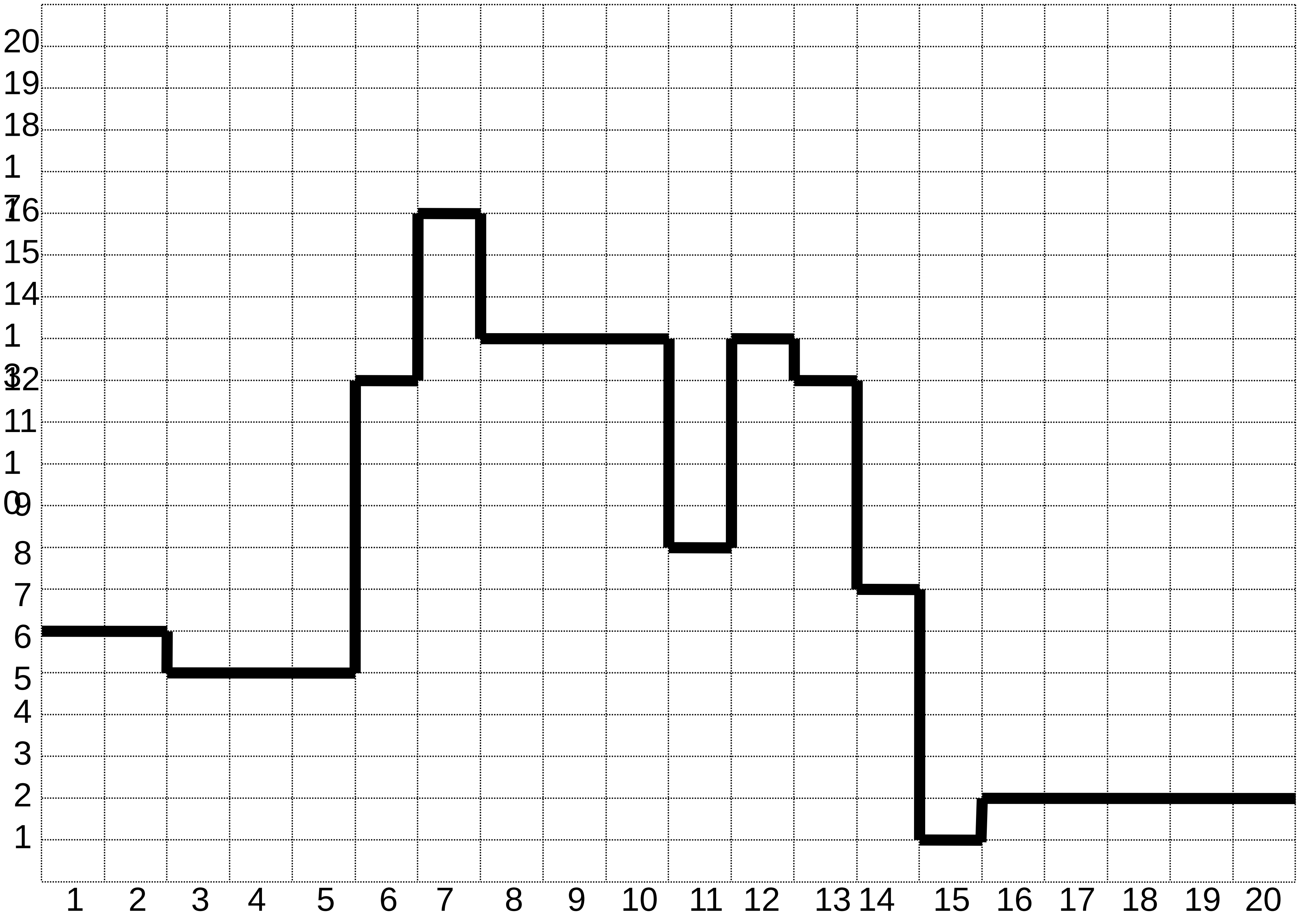
SOLUTION OF PROBLEM 3

ACTIVITY EVENT NOS	DURATION	EARLIEST		LATEST		FLOAT		
		START	FINISH	START	FINISH	TOTAL	FREE	INDEP.
1-2	6	0	6	1	7	1	-	-
1-3	5	0	5	0	5	-	-	-
1-5	2	0	2	1	3	1	-	-
2-7	4	6	10	7	11	1	1	-
3-4	6	5	11	5	11	-	-	-
4-7	0	-	-	-	-	-	-	-
4-10	3	11	14	17	20	6	6	6
5-6	3	2	5	3	6	1	-	-
6-8	7	5	12	6	13	1	-	-
6-9	2	5	7	13	15	8	8	7
7-9	4	11	15	11	15	-	-	-
7-10	2	11	13	18	20	7	7	7
8-9	2	12	14	13	15	1	1	-

SOLUTION OF PROBLEM 3

Activity Event	Duration	Resources	TIME (DAYS)																			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1-2	6	1	1	1	1	1	1	1														
1-3	5	2	2	2	2	2	2															
1-5	2	3	3	3																		
2-7	4	5							5	5	5	5										
3-4	6	4						4	4	4	4	4	4									
4-10	3	3												3	3	3						
5-6	3	2			2	2	2															
6-8	7	4						4	4	4	4	4	4	4								
6-9	2	3						3	3													
7-9	4	1												1	1	1	1					
7-10	2	5												5	5							
8-9	2	3													3	3						
9-10	5	2																2	2	2	2	2
			6	**6**	**5**	**5**	**5**	**12**	**16**	**13**	**13**	**13**	**8**	**13**	**12**	**7**	**1**	**2**	**2**	**2**	**2**	**2**

SOLUTION OF PROBLEM 3



THANKS FOR YOUR ATTENTION