CONSTRUCTION MANAGEMENT

1- TERMS AND CONCEPTS

Construction is the process of preparing and forming buildings, projects and building systems.

Construction starts with planning, design, and financing and continues until the structure is ready for occupancy.

Construction Management or construction project management is the overall planning, coordination, and control of a construction process from beginning to completion. Construction project management is aimed at meeting a client's requirement in order to produce a functionally and financially viable project.

Project Management: Project management is the application of knowledge, skills, tools, and techniques to project activities in order to meet or exceed stakeholder needs and expectations from a project. Meeting or exceeding stakeholder needs and expectations invariably involves balancing competing demands among:

- Scope, time, cost, and quality.
- Stakeholders with differing needs and expectations.
- Identified requirements (needs) and unidentified requirements (expectations).

Owner's Rep / Project Manager: Company or person planning, organizing and managing the process of design and construction.

Program Manager: Person who manages the components of constructional program; planning organizing and managing design funding and construction process.

The Objectives of Management

This is to ensure that productive efforts undertaken by a company/individual are efficient and effective:

- Less time taken
- Less waste (Lean principles)
- Economic use of resources
- Higher quality products
- More value
- Less accidents and fatalities
- Satisfaction of client / employer
- Products are sustainable e.g. green buildings, low impact design, and passive energy usage.

The project management tools and principles provide the means for:

- project breakdown into tasks and sub-tasks
- finding interdependencies between the tasks
- allocating resources, human and material and smoothing resources
- estimation for total project duration and budget
- monitoring more efficiently project progress.

Project Management activities include:

a) Work Breakdown Structure (WBS): Decomposes project into various levels of detailed tasks

b) Dependency Analysis: Orders the project tasks established by WBS, determining those, which must be done in sequential order, and those, which can go on simultaneously.

c) Network Development: Portrays 'ordered' tasks graphically using a 'network' diagram

d) Resource Commitment / Allocation: Commits the appropriate individual who has the proper skills and expertise to the tasks requiring those skills. Allocates those resources over time to determine the 'build up' and the 'phase out' of the resources over the life of the project

e) Time Estimates: Estimates based on one of several techniques ranging from the forecast method to the quantitative method, the constraint method, or the unit of work method. No matter which method is used, two categories of time are considered:

- Effort: Energy exerted
- Calendar: Elapsed duration

f) Budgeting: Allocates the project development costs spread over the duration of the project

g) Status Reporting: Takes the baselines developed above (schedules, resource loading and budgets) and turns them into a work-in-progress reports which track the plan against the actual.

Figure (1-1) shows the main targets which be desired by the stockholders of any project.

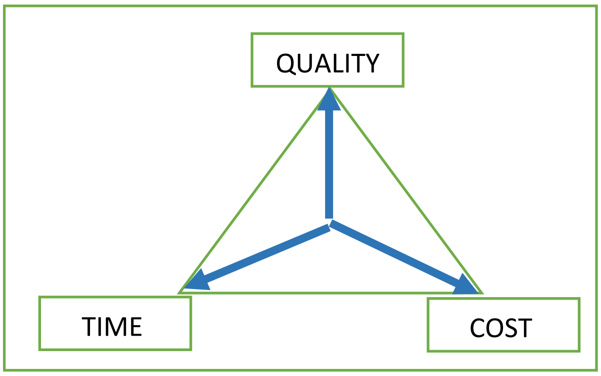


Figure (1-1) the main targets for stockholders for any project

2- PARTIES FOR IMPLEMENTING THE PROJECT (STOCKHOLDERS)

There are different parties involved in construction of project the figure (2-1) shows the major parties who involved in implementing the project.

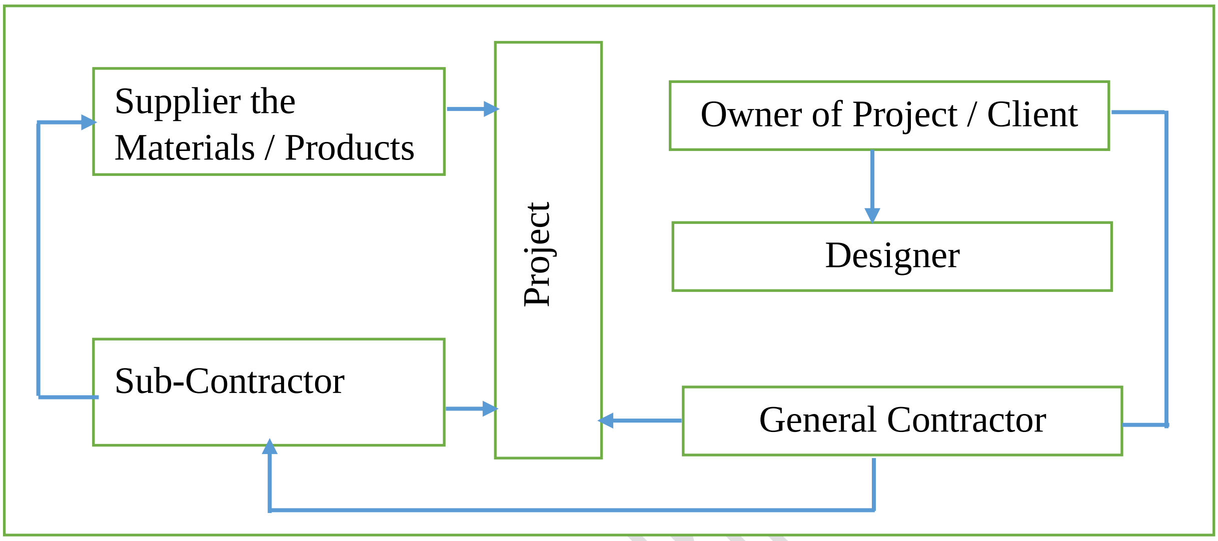


Figure (2-1) the major parties involved in Project

The relationship between the shareholders depends on the type of contract between the owner / client (or his representatives) from the one side and the contractor (or his representative) on the other side. There are different types of contractual relations between these parties and the projects are constructed according to the forms below figures (2-2) - (2-6). These include:

i- Construction employing an owner construction force

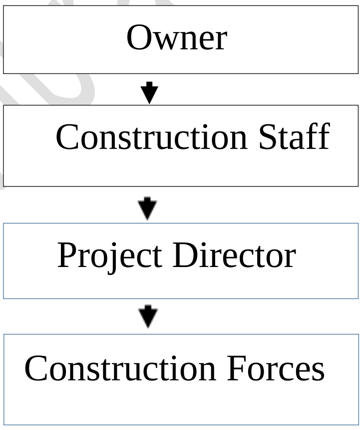


Fig. (2-2) Construction employing an owner construction force ii- Owner Management of Construction

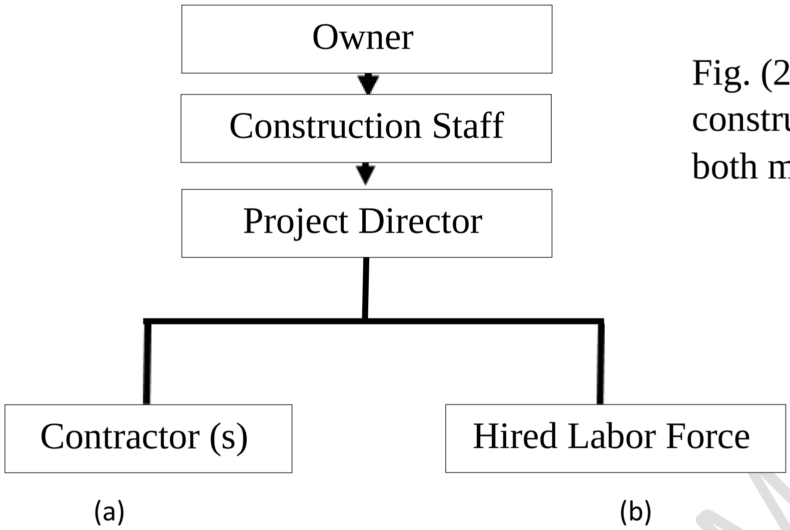


Fig. (2-3) Owner – managed construction. [Either (a) or (b) or both may be employed.]

iii- Construction by a General Contractor

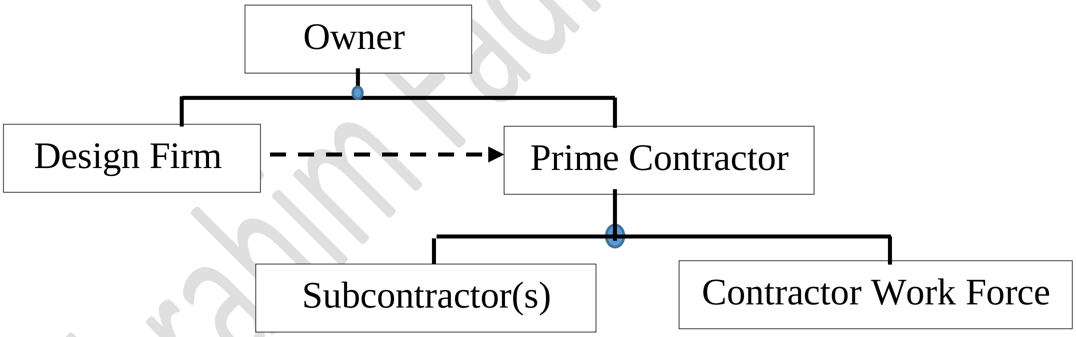


Fig. (2-4) Construction by a General Contractor

iv- Construction Using a Design / Build (Trunkey) Contract.

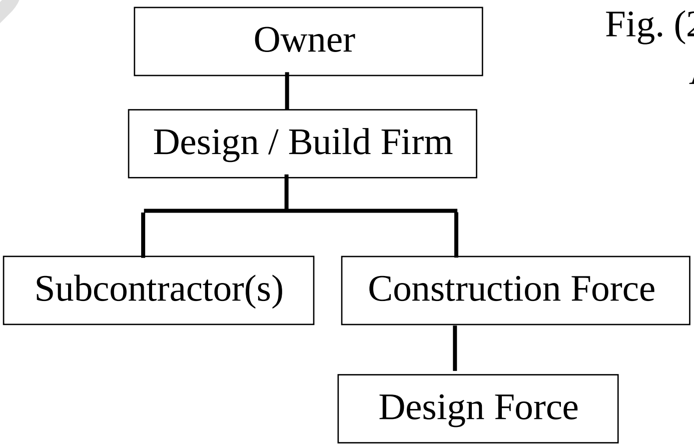


Fig. (2-5) Construction employing A Design / Build Firm

v- <u>Construction Utilizing a Construction Management Contract</u>

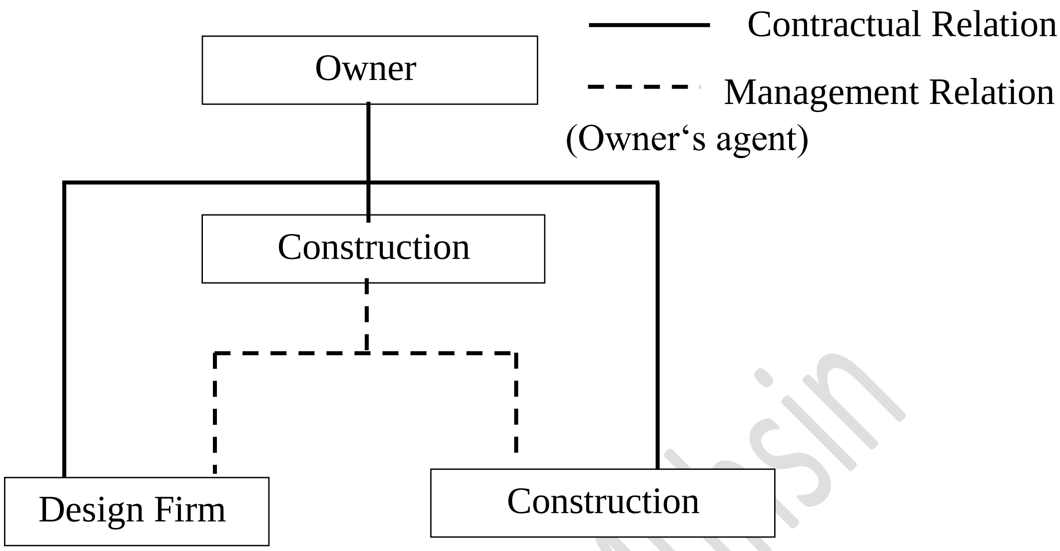


Fig.(2- 6) Construction Utilizing a Construction Management Contract

3- **THE RESOURCES OF PROJECT COMPLETION**:

Something that is required in order to do work. They include: money equipment, people materials, information, skills, knowledge or any other item likely to be in limited supply.

a-**<u>Human Resources:</u>**

Construction Teams can be described as formal group of individuals who work together on a permanent basis to undertake specialist construction, and the essential machines and equipment the team uses.

Construction team members include:

- Designers
- Managers
- Building Team
- Manufacturers
- Production specialists
- Commissioning specialists

b- Money: Financial support is very important for completion the project; it could be calculated the cost of the project activities and control the cost overall of the project, and how to calculate the financial payments of the completion of the project.

c- Equipment and Plant: Which are all the mechanisms, equipment and tools that operate by different types of fuel or without which are necessary for the completion of work and completion, and examples of these mechanisms and equipment:

- Machines used for soil work for slope - Soil slope machines (Grader)
- Tractor
- Bulldozer

- shovel
- Scraper
- Power Shovel
- Excavator - wireline - (Dragline)
- Trucks
- Soil stabilization machines and methods. (Soil compaction)

d- Materials: Which are consumed for the completion of the project (such as the natural materials - raw materials obtained from quarries - or abnormally resulting from a manufacturing or conversion process). Table (3-1) shows the different types of materials

Table (3-1) kinds of Materials

Natural Materials - Raw Materials	Materials manufactured or which converted to their new form
Soil	Cement
Sand	Iron - reinforcing bars
Aggregate	Brick
Rocks	Aluminum
Stones like (lime stone)	Copper
Any materials that can be obtained from quarries	Materials such as glass, plastic, ceramics.... etc.

e- Time: Time is the duration for completing the project. It is scheduled to enable the building / project to be used by a date determined by the client's future plans.

Project Life Cycle: There are several stages to complete the project, each stage from those is depending on the nature, type and size of the project and its importance, in spite of different stages in the cycle life of project, but there is major stages of them could be considered participated in different projects and to be studied as following:

i. **<u>Pre-project phase:</u>**

A construction project begins with an idea, a perceived need, a desire to improve or add to productive capacity or the wish for more efficient provision of some public service.

ii. **<u>Planning and design phase</u>**

The project is fully defined and made ready for contractor selection and deployment during the planning and design phase. It is convenient to divide this phase into three stages.

- The goal of the first stage is to define the project's objectives, consider alternative ways to attain those objectives and ascertain whether the project is financially feasible. In this process of planning and feasibility study, a project brief will be developed, more details will be set forth in a program statement, various sites may be investigated, public input may be sought, a preliminary cost estimate will be prepared, funding sources will be identified and a final decision on whether to proceed with the project will be rendered.

- In the second stage, the design professional will use the results of the planning efforts to develop schematic diagrams showing the relationships among the various project components, followed by detailed design of the structural, electrical and other systems. This latter activity is the classical hard core engineering familiar to students in the design professions, in which various engineering principles are used to estimate loads and other requirements, select materials, determine component sizes and configurations and assure that each element is proper in relation to other elements.
- The output from this design development effort is used in the final stage, wherein contract documents are prepared for use in contractor selection and installation work at the construction site. The design professional prepares not only the detailed construction drawings but also written contract conditions containing legal requirements, technical specifications stipulating the materials and the manner in which they shall be installed and a set of other documents related to the process of selecting the contractor and finalizing the contract with the successful tenderer.

iii. <u>Contractor selection phase</u>

In anticipation of selecting a contractor, the owner must decide whether an open invitation will be issued to all possible tenderers or whether only certain contractors will be invited to submit offers and whether any sort of pre-qualification process will be invoked to limit the number of tenders.

iv. <u>Project Mobilization phase</u>

After the contractor is selected, a number of activities must be completed before installation work can begin at the project site. Various bonds, licenses and insurances must be secured. A detailed program for the construction activities must be prepared. The cost estimate must be converted to a project budget and the system for tracking actual project costs must be established. The worksite must be organized, with provisions for temporary buildings and services, access and delivery, storage areas and site security. The process of obtaining materials and equipment to be incorporated into the project must be initiated and arrangements for labor, the other essential resource, must be organized. With the completion of this phase, it is finally time to begin the actual field construction.

v. Project operations (Execution) phase

In presenting the contractor's activities on the construction site, we will suggest, perhaps too simply, that the responsibilities involve three basic areas: monitoring and control, resource management and documentation and communication. Five aspects of monitoring and controlling the work are important. Actual schedule progress must be compared against the project program to determine whether the project is on schedule; if it is not, actions must be undertaken to try to bring the program back into conformance. Likewise, the cost status must be checked to establish how actual performance compares with the budget. An equally important part of monitoring and control is quality management, to assure that the work complies with the technical requirements set forth in the contract documents. In addition, the contractor has an important role to play in managing the work safely and in a way that minimizes adverse environmental impacts.

vi. Project closeout and termination phase

Finally, as the project nears completion, a number of special activities must take place before the contractor's responsibilities can be considered complete. There are the various testing and startup tasks, the final cleanup, various inspections and remedial work that may result from them and the process of closing the construction office and terminating the staff's employment. In addition, a myriad of special paperwork is required, including approvals and certifications that allow the contractor to receive final payment, a set of as-built drawings that include all changes made to the original design, operating manuals, warranties and a final report. The contractor will also be responsible for transferring and archiving project records and will conduct some sort of project critique and evaluation; operator training may also be part of the contractor's contractual responsibilities.

vii. Operation and Maintenance (O&M) phase

After the completion of previous phases, the operation and maintenance (O & M) the pilot operation of project begin at this phase. The operation may be followed according to the procedures in the contract and should be documented properly in technical record and meet all environmental and health requirements. Command from the contractor also requires that will prepare all documents operation and efficient appliances provide the courses training to owner representatives, these training courses consist of how devices, equipment and in the project are running. Contractor shall be responsible for all the failures that occur during the maintenance period, which are generally extended to one year after the completion of the project and taking over by the owner.

4- PLANNING AND SCHEDULING

4-1 BAR CHART

Schemes invented by Henry Gant (1865-1915) in 1910, a project planning tool that can be used to represent the timing of events required to complete the project. Because Gantt charts are simple to understand and easy to build, they are used by most project managers for all but not used in more complex projects.

In the Gantt chart, each activity takes time and is listed respectively with the rest of the events.

How to prepare the Gantt chart?

1- List all needed information for the project

2- Install dates along the top of days, weeks or months, depending on the total length of the project .

3- The expected time of each activity is indicated by the right part, which represents the expected start of this activity and continues with the expected duration of the implementation of this event, which coincides with the expected completion date. Events may be drawn on a chart that was run sequentially, in parallel, or overlapping

4- As the project progresses, the chart is updated by filling in the cells along a length commensurate with the part of the work done at the event. In this way, one can get a quick reading of the progress of the project by drawing a vertical line through the graph in the current date. Completed events lie at the left of the line and are fully filled. Current events traverse the line and beyond the schedule and may indicate the progress or delay of implementation of the project

5- Determine the Schedule time for each activity in the top of each row, and explain the actual work which is completed or the work currently is being done.

Figure (4-1) shows the Bar Chart for a small project.

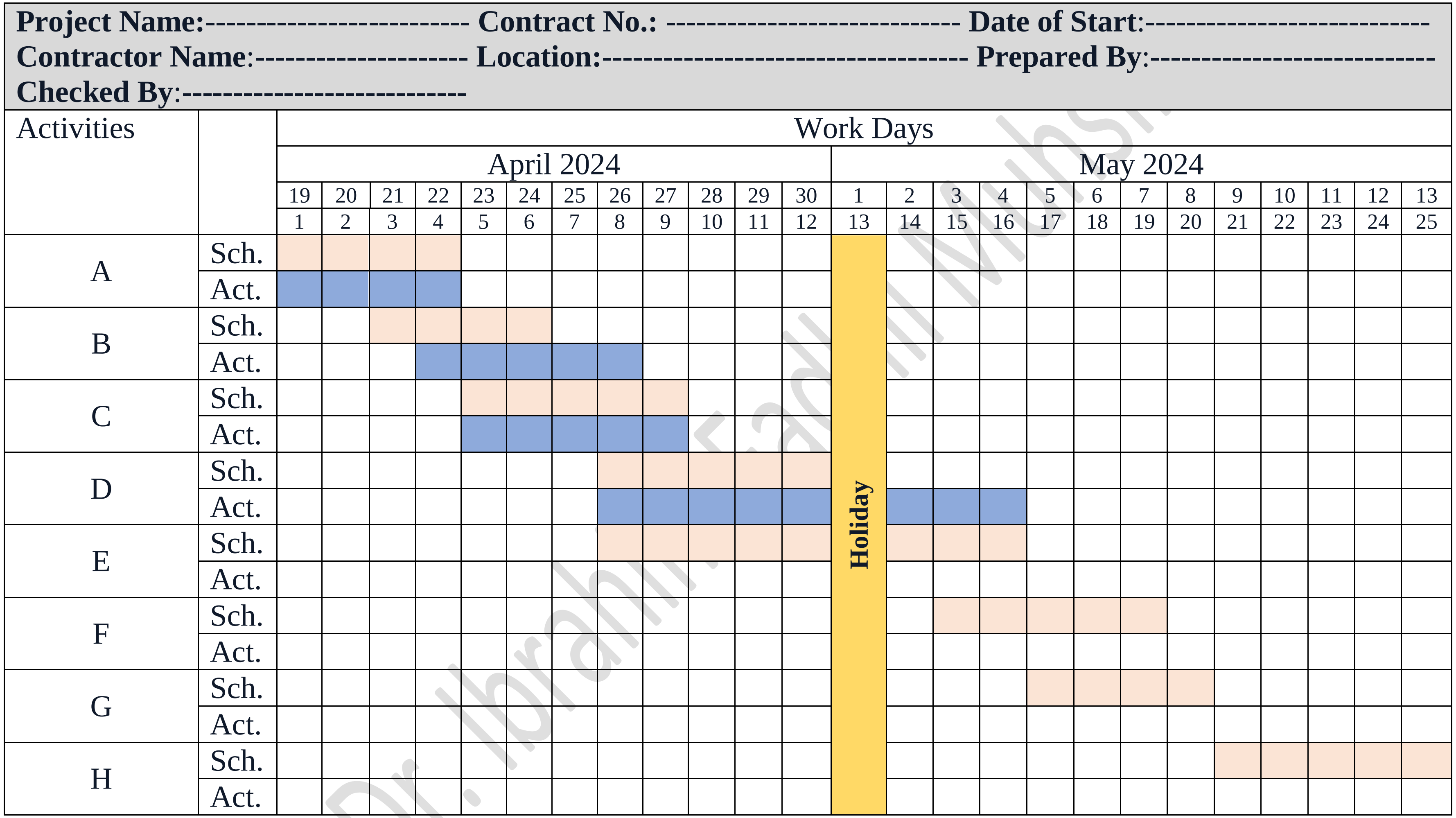


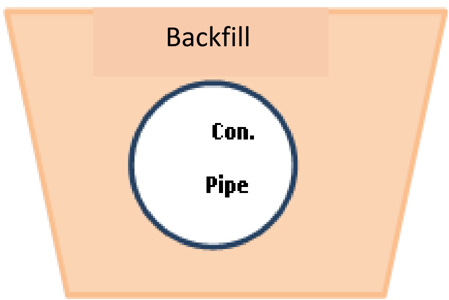
Fig. (4-1) Typical of Gantt Chart

Example (4-1):

A project for execution with a 400 m of an irrigation canal (as shown in Figure - cross section of the canal). The work includes three main process, Excavation, Laying the Precast pipe and Backfill, the productivity of the work as follows:

1- Excavation the trench of the canal 100 L .M / day.
2- Laying the precast concrete pipe 200 M / day.
3- Backfill the trench (canal path) 50 M / day

There is a working condition that involves required for waiting for three days after laying the pipe laying by the supervising authority prior to the re-burial of the trench. Prepare a timetable (Schedule work) for the work activities?



Solution:-

Project Name: Irrigation Canal	Contract No.: I / C 203						Date of Start: 4Dec. 2023									
Contractor Name: Baghdad Co.	Location: Baghdad – Iraq															
Prepared By: Eng. Steve Nelson	Checked By: Eng. Richard William															
Activities		Work Days														
		December 2024														
		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A Excavation	Sch.															
	Act.															
B Laying the Concrete Pipe	Sch.															
	Act.															
C Backfill	Sch.															
	Act.															

Example (4-2):

There is a Contract for implementing an irrigation canal with a length of 1,500 m, with a section as in the attached figure, the contract includes several activities for the construction this irrigation canal. However, the certain activities have been listed below to calculate the project duration

1- The excavation process, the contractor decided to use the excavating machines 2 two excavators, the productivity for each excavator is 750 m^3 per day, these excavators will use on the total length of the canal.
2- Spreading a layer of sub base on the canal floor (only) and make compaction on the canal floor (only) with a thickness not less than 30 cm and the contractor will implement the sub base layer and compaction with the limit is 500 m^2 daily.
3- One of the contract condition is that the soil density test and degree of compaction is by 5 tests per day for an area of 750 m^2.
4- The contractor ability for placing the frame and the reinforced concrete with B.R.C on the canal floor and the shoulders (two sides) with a thickness of 10 cm covering 750 m^2 per day.

Try to prepare the Gantt Bar chart and calculate the estimated duration of the mentioned paragraphs (only) to complete this irrigation channel project? The attached charts can be used figure (4-2)?

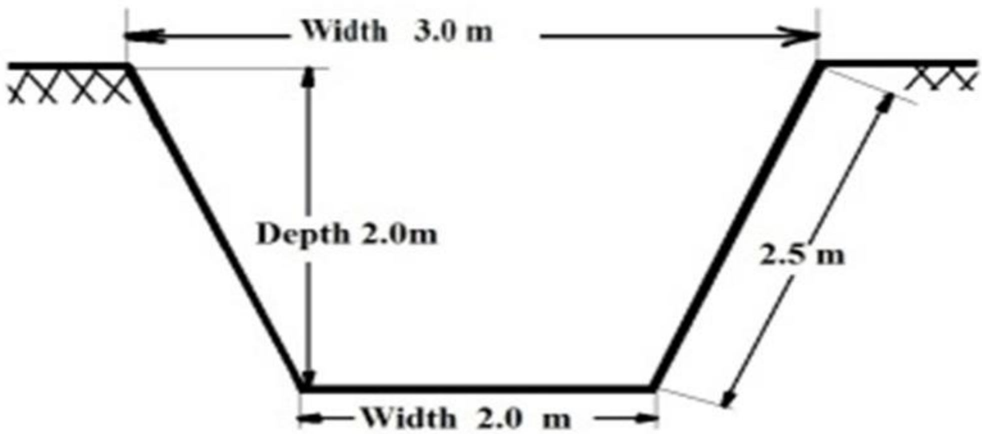


Figure (4-2) Channel Excavation Diagram - (Note: The chart without scale)

Solution:

Before starting with the Gantt Chart, it is necessary to know the length of time required for the activities to be drawn on the chart, which is only four activities (as mentioned in the question). Each activity will be addressed and how to calculate the time required to accomplish in detail as follows:

1. The activity of excavation the irrigation canal, we must calculate the total amount of drilling of the canal (i.e. the volume of the soil to be drilled), if we know that the irrigation canal length 1500 m and the area of the section of the canal can be easily calculated it represents a shape of trapezoid.

A= $\frac{1}{2}x\ (b_1 + b_2)xh$

A= $\frac{1}{2}x\ (2\ +3)x2$ = 5 m^2

The volume of excavation = the area of canal section x length of canal
= $5\ m^2 x\ 1{,}500 = 7{,}500\ m^3$

As the contractor uses two excavators and each excavator with 750 m^3 / day, the productivity of the two excavators will be 1500 m^3 / day, and thus it will take 5 days to complete the excavation efficiency according to the following equation:

Number of days of excavation $=\frac{\text{the total excavation quantity}}{\text{production for one day}} = \frac{7{,}500\ m^3}{1{,}500\ m^3} = 5\ days$

As the activity of excavation is the first one, it will be launched from the beginning of the first day of work (the first day of the Gantt scheme) and will be for five days.

2. The second activity is spreading of sub-base layer and the necessary the compaction. calculate the area of the canal floor (canal bottom) only as shown in the question, which is equal to
= the width of the canal floor × canal length = $2\ m\ x\ 1{,}500\ m =\ 3{,}000\ m^2$
and where the contractor's productivity as in question $500\ m^2$ can calculate the number of days for this activity as it comes:

Number of days of the spreading the sub base layer and compaction =

$$\frac{\text{Total area of canal floor}}{\text{The contractor productivity for one day}} = \frac{3{,}000\ m^2}{500\frac{m^2}{day}}$$ = 6 days

It is not possible to start this activity with the excavation at one time, it is necessary to provide the area to be furnished with sub base layer after the excavation and the contractor had drilled at the end of the first day 1500 m3 and this means that the drilling of the canal length of 300 m or digging area of the canal ($2m\ x\ 300\ m =\ 600\ m^2$), and therefore it is possible to start activity the sub base after the end of the first day i.e. the start of the second day (as shown in the diagram).

3. Activity of the density (compaction) test which covering the area equal to ($750\ m^2/day$) and using the same area as the previous activity.

There is no need to refer to the number of tests per day, but attention only to what is accomplished in one day (which is mentioned in the question) and will be the number of days of density test is equal to =

$$\frac{\text{The total area of canal floor}}{\text{The area that can be examined in one day (m}^2\text{)}} =$$

$$\frac{3{,}000\ m^2}{750\ m^2/day} = 4\ days$$

This activity cannot be started at the beginning of the third or fourth day as the contractor will not be able to perform the tests because the work is still continuing to achieve the previous activity, so it can be started at the end of fourth day.

4. In order to calculate the area of placing the molds and the casting of the concrete, it is necessary to refer to the area covered by this activity, the bottom of the channel with the shoulders (the tilted sides of the channel), the lengths of the sides of the channel are given in the question which is 2.5 m on each side, the total width of canal is equal to =
($2.5\ m + 2\ m + 2.5\ m = 7\ m$); and the total area =
($7{,}500\ m\ x\ 7\ m = 10{,}500\ m^2$).
The contractor's productivity is ($750\ m^2/day$). The number of days required for this activity can be calculated as follows:

The number of days of placing the frame and casting concrete

$$= \frac{\text{The Area of canal floor and two sides}}{\text{The Area that can be placed by conrete m}^2\text{/day}}$$

$$= \frac{10{,}500\ m^2}{750\ \text{m}^2/\text{day}} = 14\ days$$

Beginning at the end of fifth day. The work site will be ready for this activity and ends at the end of the 19th day. Thus, the total time required to complete these activities is only 19 days, as is clear in the chart below.

Project Name: **Irrigation Canal** Contract No.: **I / C 2000** Date of Start: **7 November 2023**
Contractor Name: **Construction Co**. Location: **Babylon Government** Prepared By: **Engineer / Gorge Neville**
Checked By: **Engineer / Vector Michael**

Activities		Work Days																								
		November 2023																								
		7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A (excavation)	Sch.																									
	Act.																									
B (Sub base layer)	Sch.																									
	Act.																									
C (Compaction Test)	Sch.																									
	Act.																									
D (Concrete Layer)	Sch.																									
	Act.																									

5- ESTIMATION

5-1 Earthworks:

Excavations may be carried out for the purpose of removing the upper surface layer of the natural land, which may be has the waste, grass and organic materials. The contractor is required to drill to a suitable depth according to the contract the amount of excavation measuring by m^3.

- Excavation: is usually done in specific depth according to maps and with predefined dimensions, and the contractor uses heavy machines such as Shovel, Bulldozer ... etc.
- Excavations are not limited to the limits of the workspace only according to the scheme of the project, but there is a need for additional external distances outside the boundaries of the project area by 1 m to 1.5 m for general purposes.
- After the completion of the earthworks may be needed there is a need for backfill and must be geometrically defined, which is characterized by the following:

❖ Backfill layers shall be placed in the form of horizontal layers from (20~30) cm in thickness.

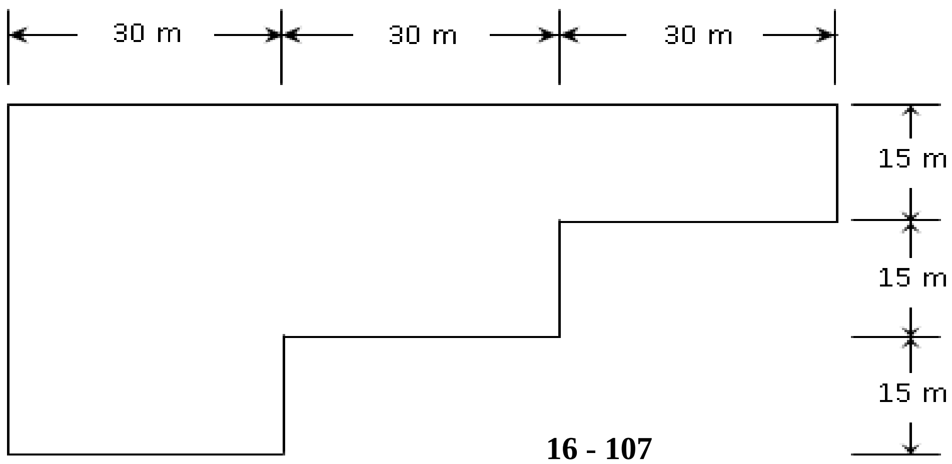
❖ The layers shall be have with a moisture content with percentage (10-15%).

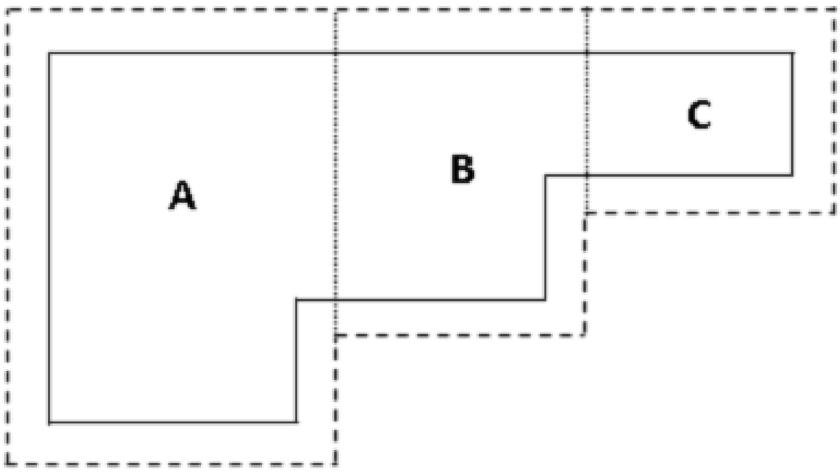
❖ A test shall be taken as a specimen for each 500 m^2 and which shall be at least 95%.]

Example 5-1

Estimating the amount of earthmoving necessary for the construction of a concrete foundation under the building below, note that the excavation areas are 1.5 m from all sides and the depth of the excavation 0.8 m.

Solution: We draw the outer boundary of the required excavation in the form of a dashed line 1.5 m away from all sides, and then divide the total area into secondary areas as shown in the figure below, and then calculate the size of the earthworks.





The Depth (D) of excavation = 0.8 m

Calculation of Excavation (m^3)

Sec.	L_1 (m)	L_2 (m)	Area=L_1*L_2 (m^2)	Vol.=Area*D (m^3)
A	33	48	1548	1267.2
B	30	33	990	792
C	30	18	540	432

5-2 Concrete Works

Concrete is a mixture of three main materials: cement, sand and gravel. If these three materials are mixed with water, the mixture will loses about a third of its size. These materials are usually mixed on a volume basis and in specific proportions, among these ratios are the following:

The most common proportions

Gravel	Sand	Cement
3	1.5	1
4	2	1
6	3	1
8	4	1
10	5	1

To estimate the quantities involved in 1 m3 of concrete, the following approximate equation can be used:

Vol. = 0.67 (C+S+G)

Where:

Vol. = Volume of concrete after adding water to its components

C = cement size, S = size of sand, G = size of gravel

The figure of 0.67 refers to shrinkage in the size of the concrete components after adding water. This shrinkage is one-third of the volume, i.e. 0.33, so the net size after deflation is two-thirds of the total size before deflation, or about 0.67 of the total volume before deflation.

If the cement, sand and gravel were mixed with a mixture of 1: 2: 4, and one cubic meter ($1m^3$) of concrete was obtained, the quantity of materials included in the installation of this volume can be estimated as follows:

$$1\ m^3 = 0.67\ (C + 2C + 4C)$$

C = 0.21 m3 Cement size

S = 2C = 0.42 m3 the size of the sand

G = 4C = 0.84 m3 the size of the gravel

Cement mass = 1400 * 0.21 = 300 kg

Standard package block for cement bag is 50 kg

The number of bags = Density of cement = 1400 kg / m3 = 6 bags

For the purposes of work, an approximation is adopted as follows:

Cement quantity = 300 kg or 6 bags,

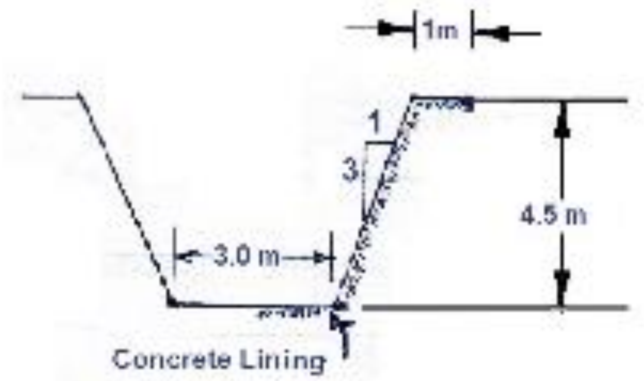
The size of the sand = 0.5 m3

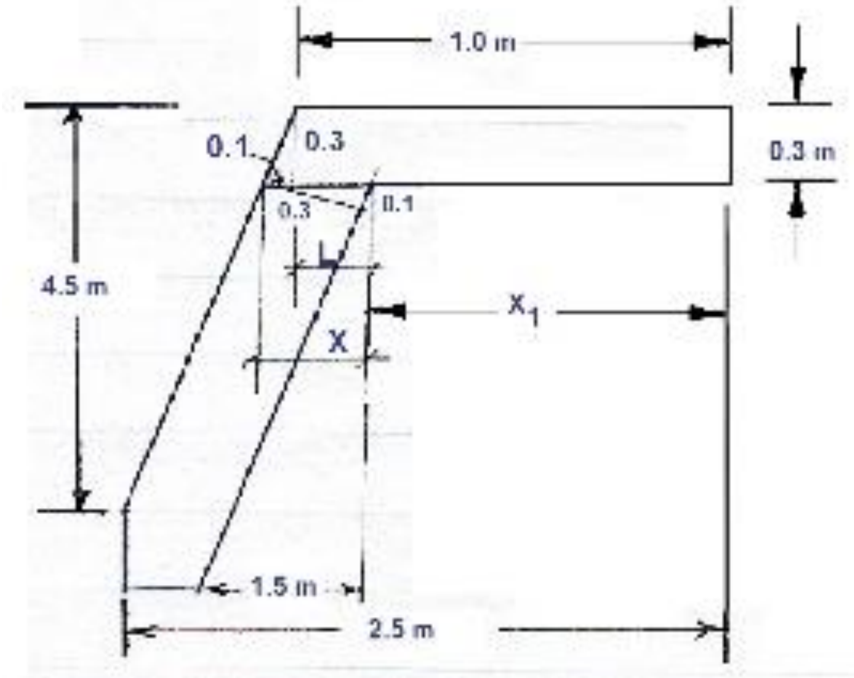
The size of gravel = 1 m3

This approximation only depends for the mixture ratio 1: 2: 4 for the easily of calculations

Example 5-2

Estimate the amount of construction material required for the lining of the canal, which has cross section shown in figure below and the thickness of lined layer is 30cm of concrete, the length of the canal is 3 km and the mixing ratio for concrete is 1: 2: 4.





$x = \sqrt{0.3^2 + 0.1^2} = 0.316 \; m$

$L = x - 0.1 = 0.216 \; m$

$x_1 = 1 - L = 1 - 0.216 = 0.784 \; m$

$$A = 0.3 * 2.5 + \frac{2.5 + 1}{2} * 4.5 - \frac{1.5 + 2 * 0.784}{2} * 4.5 = 1.722 \; m^2$$

$Total \;\; A = 1.722 * 2 + 0.3 * 3 = 4.344 \; m^2$ *

$Vol. = 4.344 * 3000 = 13032 \; m^3$

Cement = $\frac{13032 * 300}{1000} = 3909.6 \; ton$

Sand = 0.5*13032 = 6516 m^3

Gravel = 1*13032 = 13032 m^3

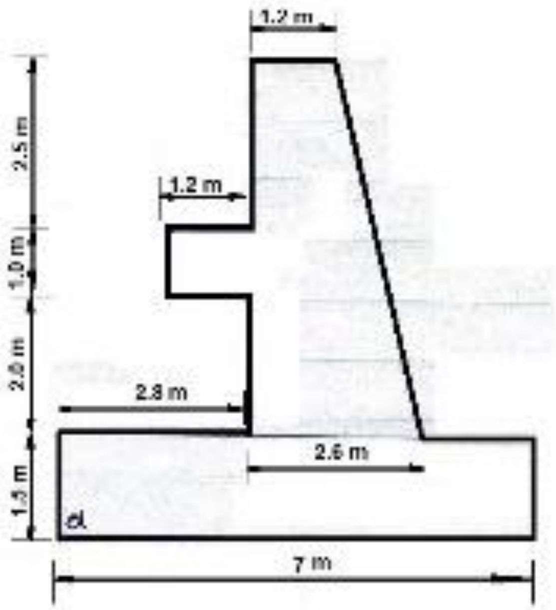
The method of calculation the area is very accurate but it is long and complex and there is another way:

$$A = \left(3 + 1 * 2 + 2 * \sqrt{4.5^2 + 1.5^2}\right) * 0.3 = 4.346 \quad m^2$$

$$\therefore error = \frac{0.002}{4.344} * 100 = 0.046 \; \% \quad very \quad little$$

Example (5-3)

Estimate the quantities of materials required to cast the retaining wall shown in the figure, if the length of the wall is 22 m and the mixture ratio is 1: 1.5: 3?



$$A = 7 * 1.5 + \frac{2.6 + 1.2}{2} * 5.5 + 1.2 * 1 = 22.15 \; m^2$$

$$Vol. = 22.15 * 22 = 487.3 \; m^3$$

$$487.3 = 0.67\left(C + 1.5C + 3C\right), \; \therefore C = 132.239 \quad m^3$$

$$cement = \frac{132.239 * 1400}{1000} = 185.134 \quad ton$$

$$sand = 1.5C = 198.3 \; m^3$$

$$gravel = 3C = 396.7 \; m^3$$

487.3 = 0.67C + 1.005C+2.01C 487.3 = 3.685 C $C = \frac{487.3}{3.685} = 132.239 \; m^3$

6- TYPES OF CONTRACTS

Below the Famous Types of Contracts in Iraq for the Construction Projects:

a- Design and Construction Contract: In this contract the employer presents a general view or a identification of project for the performance requirements, design and specifications standards by the drawings.

b- Turn Key Contract: In this contract the owner provides generally the requirements and invite the contractor will provides the details of Turn Key for the whole project activities.

c- The Management Contract: In this contract the contractor with highly experience shall be invited to execute the projects or the multiple activities after being entrusted to sub-contractors and the contractor shall manage these contracts.

d- Cost compensation contracts: This type of contract includes the following:

d-1 Contracts Cost plus a percentage of wages;

d-2 Cost contracts plus fixed wages

d-3 Cost contracts plus variable wages according to the working paragraphs

e- Contracts for the total cost of completion of the project

f- Measurement or measurement contracts

f-1 Contract Quantities - BILL OF QUANTITIES (B.O.Q)

f-2 Contract according to progress rates or scheduling work.

6-1 BILL OF QUANTITIES (B.O.Q) ?

The Preparing of the Bill of Quantities is an important thing and as it is one of the contract documents between the Contractor and the Employer (Project Owner) and must be prepared well to avoid any confusion or ambiguity as this will effect on the contractual form between the two parties (Contractor and Employer - Project Owner)

The Bill of quantities shall be prepared by preparing tables including work paragraphs and for each activity, whether civil, mechanical or electrical.

Bills of Quantities is considered as one of the most common contractual formulas in Iraq and widely adopted of contracts between the two contracting parties (contractor and employer - project owner).

For preparing a Bill of Quantities for implementing an irrigation canal in previous example, the works may include only the works of civil activities. Table (5-1) describe the major topic should be mentioned in the Bill of Quantities.

Table (5-1) Simple of Bill of Quantities

Item No.	Description of Item	Unit	Qty.	Price in figure and writing	Total Item Amount in figure and writing
Total of schedule.					

Example (6-1)

A project to build a main Line of Sewage Water, the length is 0.8 Km, the trench section is 0.75 m depth x 0.75 m width. Prepare a Bill Of Quantities ((B.O.Q), and calculate the total cost for the following major activities below.

Note: Ignore the manholes and inspection rooms and slope of pipe.

Solution

Item No.	Description of Item	Unit	Qty.	Price ($)	Total Item Amount ($)
1	Moving to the work site, conducting the necessary investigations, leveling the land of the site, determining the bench marks and preparing the site management.	Sum total		2,000	2,000
2	The preparation of materials, tools and equipment and the work of digging the trench path using the 2 excavators at least with manpower if necessary	M^3	450	15	6,750
3	The preparation of materials, tools and equipment and spreading the sub base layer not less than 25 cm on the trench line.	M^2	600	10	6,000

4	Preparing the materials, tools, and equipment to perform the 10 tests per 200 square meters for the soil density (compaction).	No.	30	5	150
Item No.	**Description of Item**	**Unit**	**Qty.**	**Price ($)**	**Total Item Amount ($)**
5	Preparing the pre-cast pipes with a length of 5 meters to the site and preparing the materials, tools and equipment and extending the pipes in the trench along the course of the ditch with good shape.	L.M	800	20	1,6000
6	Preparing the materials, tools and equipment and backfill of the trench and around the pipe.	M^3	245	10	2,450
7	Preparing the materials, tools and equipment for leveling and cleaning the site.	Sum total		1,000	1,000
Total of schedule. (Thirty four thousand and three hundred and fifty dollars).					34,350

7- <u>PENALTY OF DELAY</u>

If the contractor fails to complete the work or its a part within the specified period, there is a penalty to be imposed on the contractor.

It is important for each party in the contract to pay attention to the issue of penalty of delay. It represents a power of the employer to influence the contractor and urged him to continue work without delay and provide the requirements of work, and its continuation in the best way, because the project represents to the employer one of the forms of investment that invest for profit, and on the other hand, the delay penalties represent additional costs may be added by the project owner.

The instructions for the implementation of government contracts for 2014 issued by the Ministry of Planning in Chapter Eight - Article IX - Paragraph IV - A. The delay penalties shall be determined by the Contracting Party at a rate not less than 10% and not more than 25%, the contractual side has to determine of that percentage of penalty of delay in contractual terms in tender documents and instructions to bidders .

The following equation shall be applied when calculating the value of penalty.

Penalty / day =

$$\frac{\text{Total contract amount (original amount} \mp \text{any change in amount)}}{\text{Total duration of Contract (Original duration} \mp \text{any change in duration)}} \text{x}(10\% \sim 25\%)$$

Example (6-1)

A contract was hold with a contractor for a project at a cost of 250 million Iraqi dinars, with a completion period of 110 days. However, there have been changes in the work which led to an increase in the cost of the project to 300 million Iraqi dinars and the period of completion to 120 days. But the contractor was unable to complete the work during the duration of the contract and the additional period and the project was completed with a period of 130 days, and the contractor had a delay penalty set by the employer to be 10%. What will the total amount of the total delay that the contractor has to paid?

Total Cost = Original Cost + Additional Cost

= 250,000,000 + 50,000,000 = 300,000,000 Iraqi Dinars

Total contract period = original duration + additional period

= 110 + 10 = 120 days

Duration of Delay = Actual Project Duration - Contract Duration = 130-120 = 10 days

The Penalty / day = $\frac{300,000,000}{120} \text{x}(10\%)$= I.D 250,000 / day

The total Penalty = 250,000 x 10 days = I.D 2,500,000

8- METHODS OF MEASURING THE WORK PROGRESS:

There is a need to study progress of the work from time to time. There are several ways that can give an image of the progress of work by calculating the percentage of achievement and to calculate the percentage of work completion and work progress must be the standard .

The most important methods to measure the percentage of progress of the work are as follows:

a. Method of measuring the work actually performed and "comparing it with the previously estimated quantity" in the charts.
The percentage of the completion of the operation (%)

$$= \frac{\textbf{The amount of work which actually performed}}{\textbf{The Total quantity of work which previously estimated}} \ \mathbf{x\ 100\%}$$

The advantages of this method are: Accuracy (i.e. dealing with clear data), while the disadvantages: Long time to complete the required results, because we need information.

b. Method of Percentage of time elapsed from the period allocated for the operation

$$= \frac{\textbf{The time elapsed}}{\textbf{The Time allocated in planning}} \ \mathbf{x\ 100\%}$$

Or in other formula

$$= \mathbf{1} - \frac{\textbf{The required time for completion the activity}}{\textbf{The total estimated time to complete the activity}} \ \mathbf{x\ 100\%}$$

For example, assuming a six-day process and two days after the process, we consider the completion ratio (2 / 6 = 0.33) the advantageous: the time required to complete the process is less than the measurement of the work. The disadvantages of this method are: the accuracy is lower than the previous method, and its assumption is a linear relationship between time and work performed (the work increases steadily over time).

c. Method of resources ratio used to resources allocated to the operation:

Percentage of completion of operation

$$= \frac{\textbf{Amount of resources used}}{\textbf{The estimated amount of resources}} \ \mathbf{X\ 100\%}$$

It is a good method to calculate the ratio of completion of work and the disadvantages of this method multiplied the proportion of completion by the multiplicity of resources, and give a percentage of completion is greater than expected when there is waste.

d. Method of cost paid to the total cost of the process:

Percentage of completion of the process

$$= \frac{\textbf{Cost of work performed}}{\textbf{Original budget}} \ \mathbf{x\ 100\%}$$

This is the most widely used method, since cost is the tool that is fully monitored by any project to provide cost-related information. The disadvantages of this method are: to give a significant percentage of the reality when introducing non-direct costs (e.g. Salaries, (A list of the quantities of work required in the project). And depend on the accuracy of the cost representation of the real work.

e. The engineer needs to schedule the progress of the work and know standard ratio for each activity, so that he can know the percentage of completion of the project and know the amount of deviation in the project can be next treated.

In following is a simple example for this subject.

Example (7-1)

A small project is assigned by the contractor for one year to complete it, and its activities were listed below in a simplified manner, and determining their costs and their duration of completion as follows. Find the Standard Ratio and the Percentage Standard for each activity in the project?

Item No.	Description of Item	Unit	Total amount ($)	Duration (Months)
1	Foundation	M^3	1,000	1
2	Bricks building works	M^3	3,000	2
3	Concrete Placing works	M^3	9,000	3
4	Finishing (plastering, painting, etc.)	M^2	1,000	2
5	Sanitary and Electrical works	No.	1,000	2
6	Roofing and Fences works	M^2	1,000	2
Total			16,000	12

$$\textbf{Standard Ratio for each activity} = \textbf{Financial Amount x Durtion}$$

Solution

Table below describes the Financial Standard, Duration Standard, Standard weight and the Percentage Standard for each activity

Item No.	Description of Item	(3) Financial Standard $x10^3$	(4) Duration Standard	(5) The Standard Of activity = (3) x (4)	(6) The Standard for each activity = (5) / 0.208306	(7) Percentage Standard (%) for each Activity = (6) x 100
1	Foundation	1/16= 0.0625	1/12=0.0833	0.005206	0.025	2.5
2	Bricks building works	3/16= 0.1875	2/12=0.1666	0.031238	0.15	15
3	Concrete Placing works	9/16= 0.5625	3/12=0.25	0.140625	0.675	67.5
4	Finishing (plastering, painting, etc.)	1/16= 0.0625	2/12=0.1666	0.010413	0.05	5
5	Sanitary and Electrical works	1/16=0.0625	2/12=0.1666	0.010413	0.05	5
6	Roofing and Fences works	1/16= 0.0625	2/12=0.1666	0.010413	0.05	5
Total		1	1	0.208306	1	100 %

f. In order to find the weights of the activities of the project there are several methods:-

i- The method of weighing the time scales of the project activities: In this method will adopt the time required to complete each activity of the project as a criterion for determining the weight of this activity, which represents its share of the total estimated period of the project works.

$$The\ weight\ of\ the\ activity = \frac{The\ estimated\ duration\ for\ activity}{The\ total\ estimated\ durations\ for\ completion\ of\ the\ project\ activities}\ x100\%$$

ii- Method of weight of cost of the project activities: The direct cost estimates are adopted for completing the project activities as follows:

$$The\ weight\ of\ the\ activity = \frac{The\ direct\ cost\ of\ activity}{The\ total\ direct\ cost\ of\ the\ project}\ x100\%$$

iii- The Standard weights for project activities: The total cost (Direct and Indirect) is adopted as a criterion for finding the standard weight of the activity as follows:

$$\text{The standard weight of the activity} = \frac{\text{Direct cost of activity} + \text{Indirect cost of project}}{\text{The total cost of the project}}\ x\ \frac{\text{the time for completion the activity}}{\text{the Sum of total durations of implementation of project activities}}$$

Example 7-2

Find the standard weight of implementing the concrete structure for execution the culvert project on the river, use the following information:

1- The estimated time for this activity is 3 months
2- The total estimated duration for the project is 8 months
3- The estimated direct cost for this activity is 4 M dollars
4- The estimated indirect cost for the project is 8 M dollars.
5- The estimated direct cost for other activities = 10 M dollars.

$$\text{The standard weight of the activity} = \frac{\$4\ \text{M} + \$\ 8\ M}{\$\ 4\ \text{M} + \$\ 8\ M + \$\ 10\ M}\ x\ \frac{3}{8} = .2045$$

9- THE CRITICAL PATH METHOD

During recent years the critical path method of planning, analyzing, and controlling a construction project has become a useful tool for engineers, architects, contractor, and others who are associated with construction' many government and. private agencies require the preparation and use this method when planning the construction of a project.

In order to analyze a project by using the critical path method it necessary to divide the project into activities. The number of units of work required to complete each activity, should be determined' Then the time required to complete each activity, considering available equipment and labor, should be estimated in appropriate units, such as days, weeks, or months. Also, it is necessary to determine the time sequence in which the activities should be constructed. For example, concrete for a beam cannot be placed until the forms have been erected and the reinforcing steel has been placed.

Each activity should be identified by a symbol or an appropriate description or both, and then listed in column form, with the duration of the activity, together with the activities which immediately precede and follow it, given. Then the interrelationship of the activities can be indicated by a network or arrow diagram, in which each arrow represents an activity

Example (8-1)

Figure 8-1 illustrates an arrow diagram for a simple project involving five activities, designated by the letters, A, B, C, D, and E, for which the durations are estimated to be 4, 5,3,6, and 8 days, respectively'

Activities A and B can be started at the same time. Activities C and D cannot be started until A is completed. Activity E cannot be started until B and C are completed. An examination of Figure (8-1)

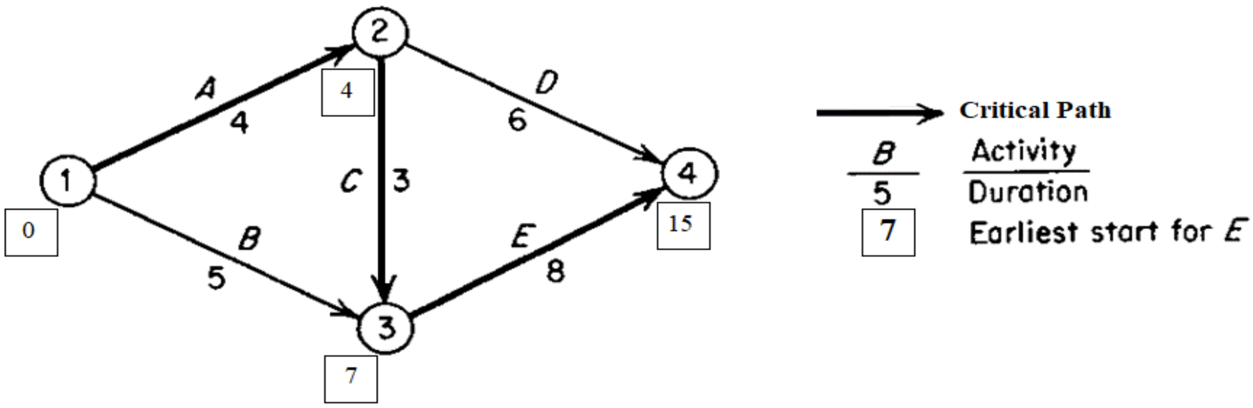


Fig. (8-1) Arrow diagram for determining the Earliest Start for each activity

In the next figure (8-2) illustrates how to determine the Earliest Latest Start (ES and LS) also the Earliest and Latest Finish (EF and LF).

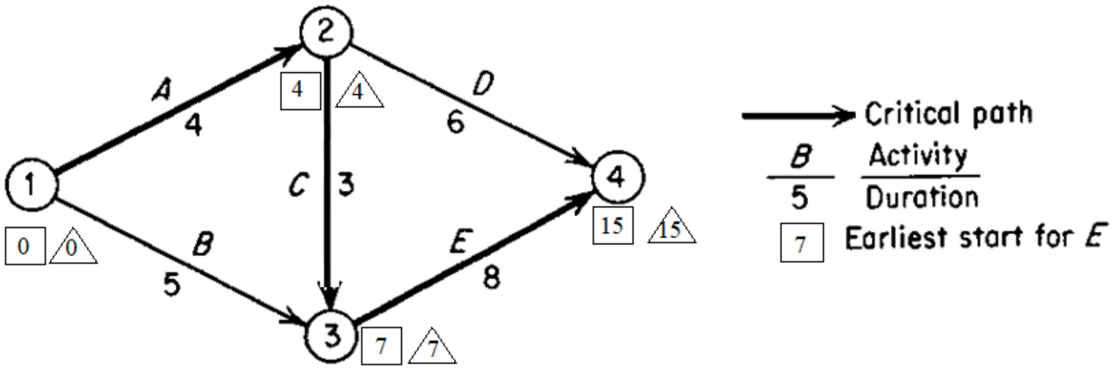


Fig. (8-2) illustrates the (ES, EF, LS, and LF)

Reveals that the minimum total time required to complete the project is the sum of the durations of activities A, c, and. E, which is equal to 15 days. This is the critical path for the network. If the project illustrated in Figure (8-3) is modified by eliminating activity C, with the condition that activity E cannot be started until activities A and B are completed, a method must be used to indicate this requirement in the network. Since activity c does not appear in the network, it must be replaced with a dummy arrow, as illustrated in Figure (8-3).A dummy is not a true activity, and it requires no time for completion. The critical path now lies along activities B and E.

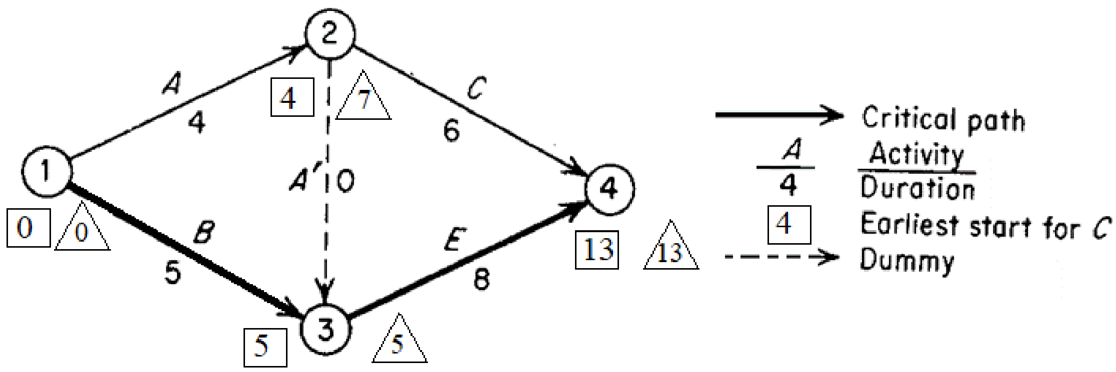


Fig. (8-3) Arrow diagram with dummy activity

Definitions of Terms and Symbols

Because terms and symbols are used in analyzing a project and constructing the arrow diagram it is necessary to define these items. *Activity*: An activity is the performance of a specific task, such as placing reinforcing steel. It requires time to perform an activity.

Event: An event represents the completion of an activity. It requires no time in itself. It is usually indicated on the arrow diagram by a number enclosed in a circle.

Arrow: An arrow is drawn to represent each activity included in the network for a project, joining two events. An arrow is designated by two number one at the tail and one at the head, with the number at the head always larger than the number at the tail.

The length of the arrow has no relation to the duration of the activity which it represents.

Network: This is an arrow diagram drawn to represent the relations of the activities and events. It is common practice to start time and the first arrow or arrows at the left end of the network and to proceed to the right.

Dummy: A dummy is an artificial activity, represented on the arrow diagram by a dotted line, which indicates that an activity following the dummy cannot be started until the activity or activities preceding the dummy are completed. A dummy activity does not require any time.

Duration: This is the estimated time, expressed in any desired unit, required to perform an activity.

Earliest Start: ES: This is the earliest time that an activity can be started.

Earliest Finish: EF: This is the earliest time that an activity can be finished. It is the earliest starting time plus the duration of an activity: EF= ES + D.

Latest start: LS: This is the latest time that an activity may be started without delaying the completion of a project: LS= LF-D.

Latest finish: LF: This is the latest time that an activity can be finished without delaying the completion of a project: LF= LS+D.

Total float: TF: This is the amount of time that the start or finish of an activity can be delaying the completion of project: TF = LF - EF = LS - Es. In Fig. 2-1 the earliest time for event 3 is the sum of the durations for activities A and C = 4 + 3= 7 days. Because activity B has a duration of only 5 days, it can be completed 2 days prior to event B. Thus its total float is 7 – 5 = 2 days. If the start or finish of activity B is delayed 2 days, it will not delay the completion of the project.

Free Float: FF: This is the amount of time that the finish of an activity can be delayed without delaying the earliest starting time for a following activity. FF - ES (following activity) - EF (of this activity).

Critical Path: The critical path is the series of interconnected activities through the network for which each activity has zero float time.

The critical path determines the minimum time required to complete a project.

The uses of these terms and symbols are illustrated more fully in the examples which appear below.

Persons who wish more comprehensive information on this subject may obtain such information from books devoted to the treatment of the critical path method.

Steps in Critical Path Scheduling

For persons who wish to apply the critical path method of scheduling the construction of a project it is suggested that the following steps be used.

1- Prepare a list of activities for the project.
2- Estimate the duration of each activity
3- Determine which activity or activities immediately precede each activity.
4- Determine which activity or activities immediately follow each activity.
5- Draw a network with the activities and events properly interconnected.
6- Assign numbers to the events, being sure that the number at the head of each arrow is larger than the number at the tail of the arrow.
7- Prepare a chart with vertical columns and horizontal lines on which to list each activity with an appropriate designation: duration, earliest start, earliest finish, latest start, latest finish, and total float. A column for free float may be included, if this information is desired.
8- Determine which activities lie on the critical path.

The following example illustrates a method of scheduling a project by the critical path method. Table (8-1) illustrates a form that can be used to tabulate the activities, together with the estimated durations, and the activities that immediately precede and follow each activity. Although the activities are designated by letters in this example, it is desirable in actual practice to designate each activity by appropriate descriptive words. Thus this example is intended to demonstrate how an arrow diagram and the related information are developed. This table provides the information specified in steps 1 through 4 of the preceding section.

Steps 5 and 6 are illustrated by Figure (8-4). In this figure it will be noted that there are four dummies. The dummies C' and D' indicate that activities C and D respectively, must be completed before activity G can be started. If activity G is drawn directly from event 4, without dummy C', it will be necessary to draw dummy D' from event 5 to event 4. This then will indicate that activity F cannot be started until Activity D is completed, which is not true. Thus the two dummies O′, and O" are required for the same reasons.

Example (8-2)

The project for build a new dam consists of different activities (21 activities) listed in table below with their estimated durations and the relationships between them:-

1- Draw the arrow network for the project activities
2- Find the amount of ES, EF, LS, LF, TF, and the FF for each activity in this project.

Table (9-1) List of activities, durations, and precedence

Activity	*Duration*	*Activities which immediately precede*	*Activities which immediately follow*
A	3	None	*B, C, D*
B	5	*A*	*E*
C	4	*A*	*F, G*
D	6	*A*	*G, H*
E	4	*B*	*I*
F	5	*C*	*J*
G	3	*C, D*	*K*
H	6	*D*	*L*
I	5	*E*	*N*
J	7	*F*	*O*
K	4	*G*	*P*
L	5	*H*	*M, Q*
M	3	*L*	*P*
N	4	*I*	*S*
O	5	*J*	*S, T*
P	6	*K, M*	*T*
Q	4	*L*	*R*
R	4	*Q*	*T*
S	5	*N, O*	*U*
T	4	*O, P, R*	*U*
U	3	*S, T*	None

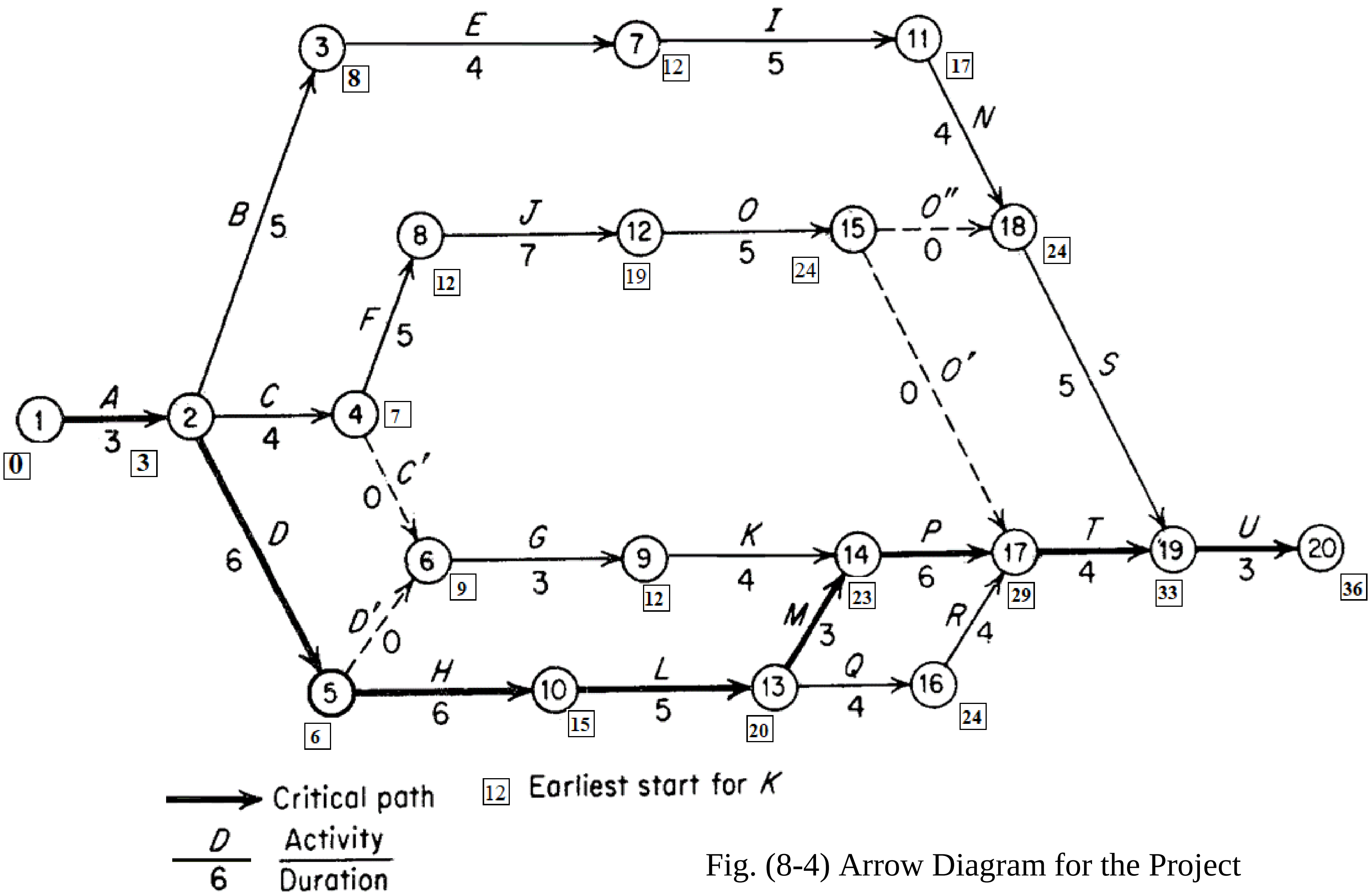


Fig. (8-4) Arrow Diagram for the Project

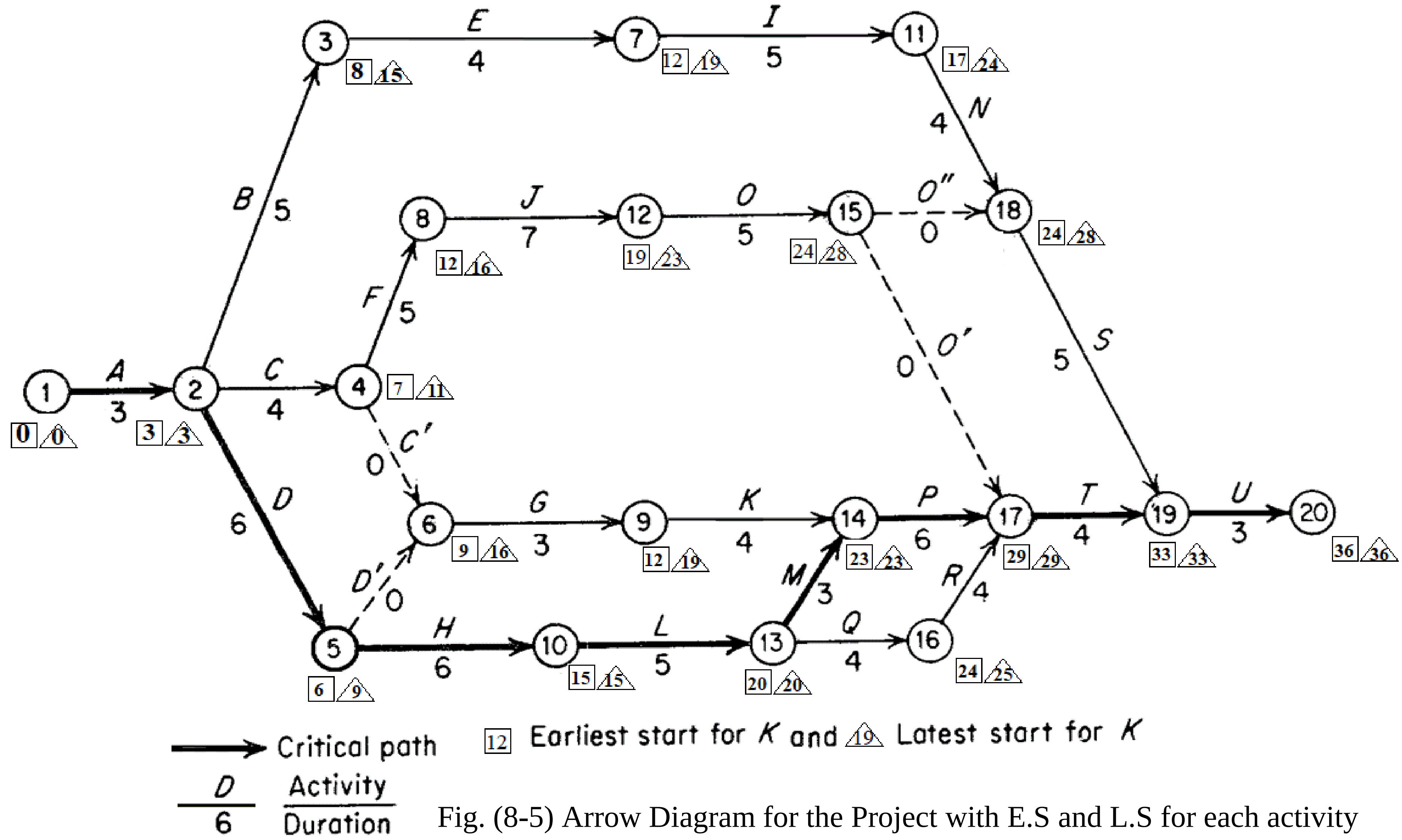


Fig. (8-5) Arrow Diagram for the Project with E.S and L.S for each activity

In the figure the heavy lines representing activities *A, D, H, L, M, P, T*, and *U* lie on the critical path. The estimated time *required to complete the project is 36 working days.*

Table 8-2 lists the activities, events, durations, starts, finishes, total floats, and free floats. Numbers appearing in the events columns should be taken from the arrow diagram after it is completed and the events numbered thereon.

Perhaps the easiest method of completing this table is to determine and record the earliest start time and finish time for each activity, including the dummies. The earliest start time for an activity is the controlling earliest finish time for the one or more immediately preceding activities. If two preceding activities have earliest finish times of 12 and 16 days, respectively, the 16 days will determine the earliest start time for the following activity.

After the minimum time required to construct the project is determined 36 , days for this project, the latest finish times for each activity can be determined by working backward from the 36 days. For example, the latest, finish times for activities *S* and *T* are determined by subtracting the duration of activity *U*, namely 3 days, from 36 to give 33 days. The latest start time for activity *S* is its latest finish time minus the duration of *S*, namely 5 days, to give a value of 28 days. This procedure is applied along each path of activities.

The symbol *19* appearing under event 12 in Fig. 8-4 indicates that 19 days is the earliest finish time for activity *J* and the earliest start time for activity *O*. The symbol 23 appearing above event 12 indicates that 23 days is the latest finish time for activity *J* and the latest start time for activity *O*.

Determining Total Float

The total float of an activity is the number of days or other appropriate units of time that the start or finish of an activity may be delayed without delaying the completion time for the overall project. Referring to Figure 8-4 it will be noted that the earliest finish date for activity *B* is the end of the eighth day, while the latest finish time is the end of the fifteenth day. Thus there is a leeway of 15 - 8 = 7 days for completing activity *B*. This is the total float designated in Table 8-2. The total float of 7days may be allocated to any one of the activities along the path *B, E, I, N*, or it may be allocated in parts to more than one activity, provided the total delays do not exceed 7 days.

Determining Free Float.

This is the number of days that the finish of an activity may be delayed without delaying the earliest start for a following activity. Referring to Fig. 8-4 and Table 8-2, it will be noted that activity *B* can be finished at the end of the eighth day and that activity E, which follows, can be started as early as the end of the same day, which is the beginning of the ninth day. Thus activity B has no free float.

Activity *O* is followed by activities *S* and *T* whose earliest start dates are the end of the twenty-fourth and the and of the twenty-ninth days, respectively.
Because the earliest of the early starts of the following activities determines the free float, which in this instance is activity *S*, activity *O* has zero free float.
Activity *K* may be completed as early as the end of the sixteenth day, but the following activity cannot be started until the end of the twenty- third day. Thus activity *K* has a free float of 23- 16 = 7 days.

Table 9 - 2 List of activities and related information

Activity	*Events*		*D*	*ES*	*EF*	*LS*	*LF*	*TF*	*FF*
*A**	1	2	3	0	3	0	3	0	0
B	2	3	5	3	8	10	15	7	0
C	2	4	4	3	7	7	11	4	0
C′	4	6	0	7	7	16	16	9	2
*D**	2	5	6	3	9	3	9	0	0
D′	5	6	0	9	9	16	16	7	0
E	3	7	4	8	12	15	19	7	0
F	4	8	5	7	12	11	16	4	0
G	6	9	3	9	12	16	19	7	0
*H**	5	10	6	9	15	9	15	0	0
I	7	11	5	12	17	19	24	7	0
J	8	12	7	12	19	16	23	4	0
K	9	14	4	12	16	19	23	7	7
*L**	10	13	5	15	20	15	20	0	0
*M**	13	14	3	20	23	20	23	0	0
N	11	18	4	17	21	24	28	7	3
O	12	15	5	19	24	23	28	4	0
O′	15	17	0	24	24	29	29	5	0
O″	15	18	0	24	24	28	28	4	0
*P**	14	17	6	23	29	23	29	0	0
Q	13	16	4	20	24	21	25	1	0
R	16	17	4	24	28	25	29	1	1
S	18	19	5	24	29	28	33	4	4
*T**	17	19	4	29	33	29	33	0	0
*U**	19	20	3	33	36	33	36	0	0

* These activities are on the critical path.
NOTE: All days shown are the ends of days.

Example:

There is a small project consists of several activities shown in the table below with their estimated durations. The requirements:

1- Draw the arrow network diagram
2- List in table the values of ES,EF, LS, LF TF and FF

Table (9-3) Activities for Project

Activities	Est. duration
1—2	4
2—3	4
2—4	7
2—5	4
3—6	0
3—10	15
4—6	0
4—8	7
5—8	0
5—10	10
6—7	6
7—8	0
7—9	14
8—9	7
9—10	14

Solution

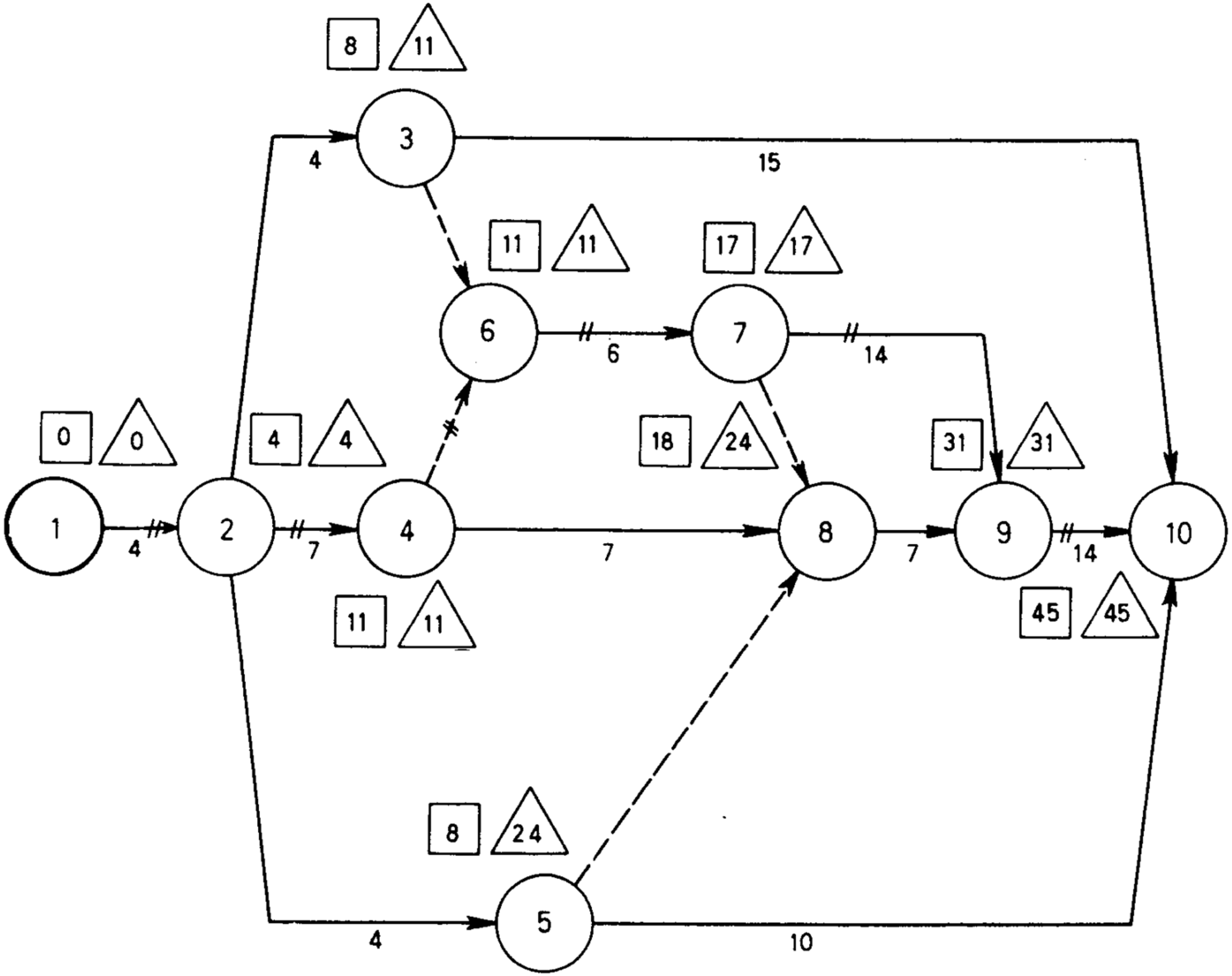

8
11
3
4
15
11
11
17
17
6
7
6
14
0
0
4
4
18
24
31
31
1
2
4
8
9
10
4
7
7
7
14
11
11
45
45
8
24
5
4
10

Table (9-4) Activities and ES, EF, LS, LF, TF, and FF

Activities	Est. duration	Early Start	Early Finish	Late Start	Late Finish	Float Total	Float Free	CP
1–2	4	0	4	0	4	0	0	*
2–3	4	4	8	7	11	3	0	
2–4	7	4	11	4	11	0	0	*
2–5	4	4	8	20	24	16	0	
3–6	0	8	8	11	11	3	3	
3–10	15	8	23	30	45	22	22	
4–6	0	11	11	11	11	0	0	*
4–8	7	11	18	17	24	6	0	
5–8	0	8	8	24	24	16	10	
5–10	10	8	18	35	45	27	27	
6–7	6	11	17	11	17	0	0	*
7–8	0	17	17	24	24	7	1	
7–9	14	17	31	17	31	0	0	*
8–9	7	18	25	24	31	6	6	
9–10	14	31	45	31	45	0	0	*

10-THE TIME – GRID DIAGRAM METHOD

Whereas the lengths of arrows in Fig. 9-4 do not indicate the durations of the activities the lengths of the arrows in the time-grid diagram of this method are drawn to indicate the durations of the activities which they represent, as illustrated in Fig. 10-1. In preparing a time-grid diagram all arrows representing and float are drawn horizontally, with each arrow tail starting at the head of the arrow for the immediately preceding activity and then continuing to the right through a path of interrelated activities.

In The diagram vertical lines don't indicate any elapsed time. They simply indicate the precedence of the activities. For example, the broken vertical line from the head of activity A to the tail of activity B indicates that activity A must be completed before activity B can be started.

Because the float times are represented by broken horizontal lines, whose lengths indicate time, it is relatively easy to determine the float time for any activity by an inspection of the diagram. An examination of the diagram might indicate that activities C, F, J, and O have float time of 5 days. However, because activity, S cannot be started until activity O is completed, O has the same float time as activity S, namely 4 days.

Because the arrows are drawn to a time scale it is possible to show the calendar dates for the activities, which an arrow diagram does not show. Space in the time schedule is provided for working days only. Saturdays, Sundays, and holidays should be excluded unless work will be performed on these days.

Prior to drawing the time-grid diagram, steps l, 2, 3, 4, and 7 appearing on page 20 should be completed. Step 7 will provide a table which indicates those activities lying on the critical path, that is, those with zero float time. Then, when drawing the diagram, the critical path can be drawn through or near the middle of the diagram, which is usually desirable.

If the name of each activity is written along its arrow and the dates are shown along the bottom of the diagram, the diagram can be a very useful reference during the period of construction.

The diagram in figure (10-1) is based on the information listed in Tables 9-1

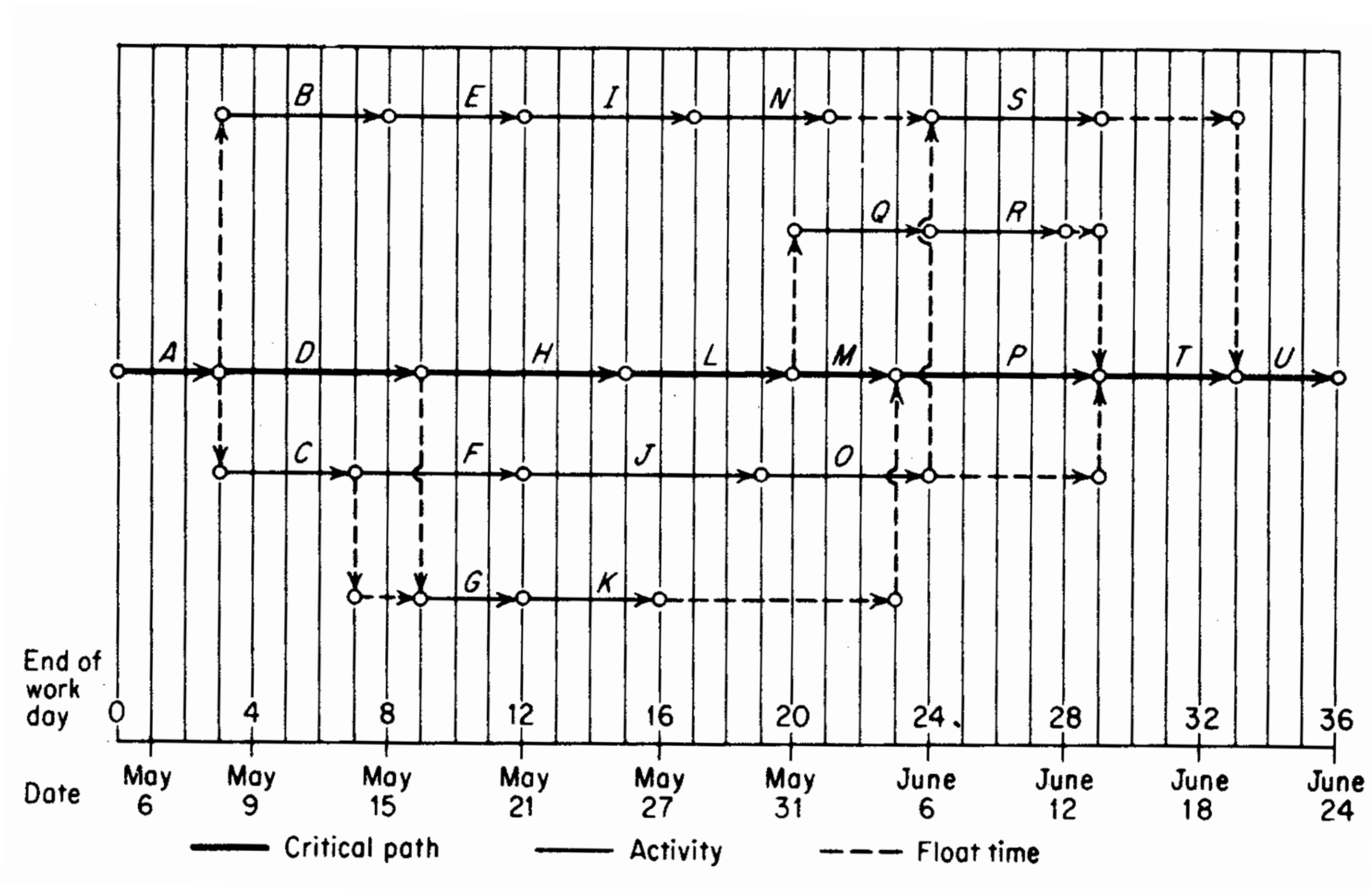


Figure (10-1) Time Grid Diagram

ADVANTAGES OF THE TIME_GRID DIAGRAM

Because this diagram shows a time relationship between possible by a visual inspection to determine the desirability of shifting the construction schedules for some activities to obtain a better distribution of materials, labor, or equipment, or for other reasons. For example, if activities J and K, which are shown in Fig. 10-1 to be operated simultaneously, both require carpenters, it will be necessary to provide two crews for a short duration. However, an examination of the diagram reveals that the start of activity K can be delayed for 7 days, until activity J is finished, without delaying activity P.

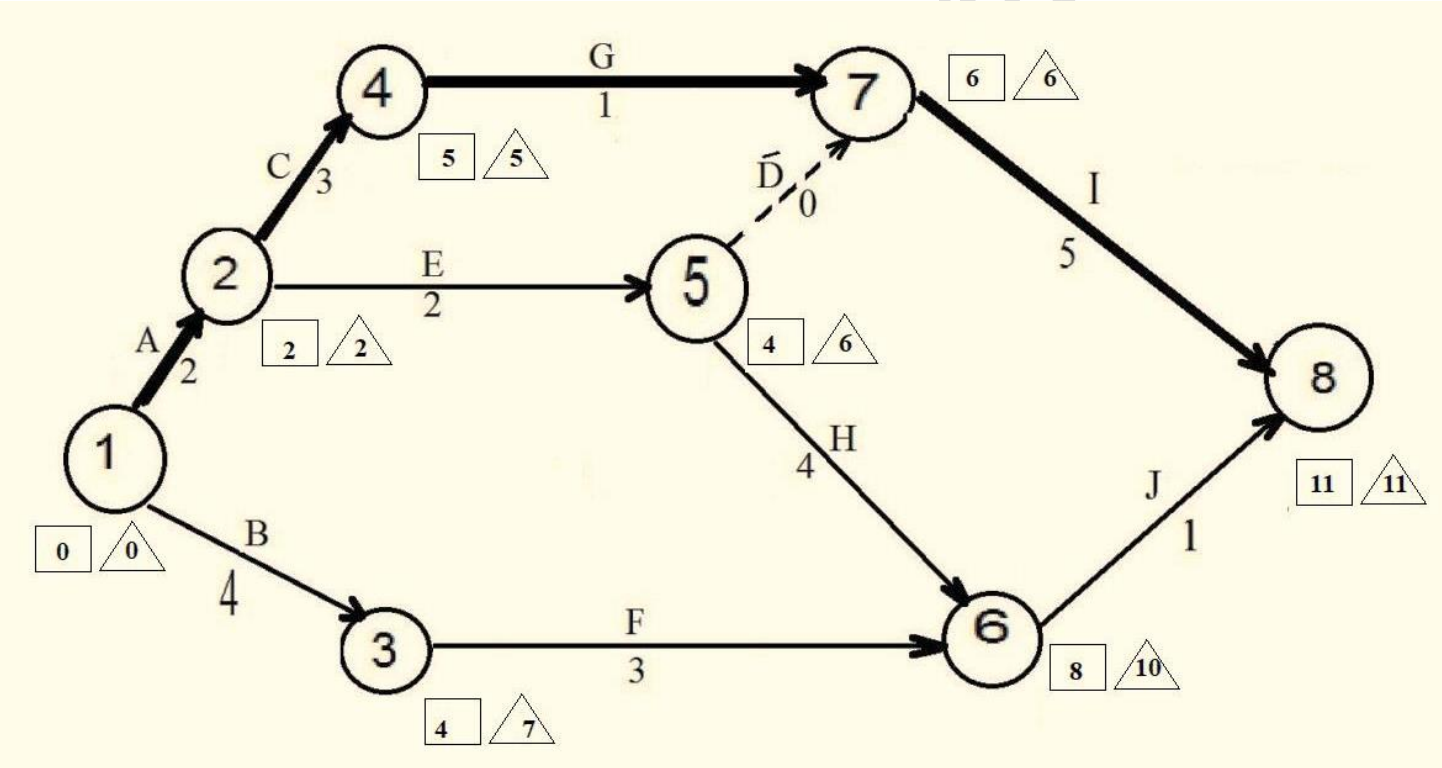
Then the carpenters from activity J can be assigned K. This is referred to as labor leveling because it permits the use of fewer men for greater periods of time without delaying the completion of the project.

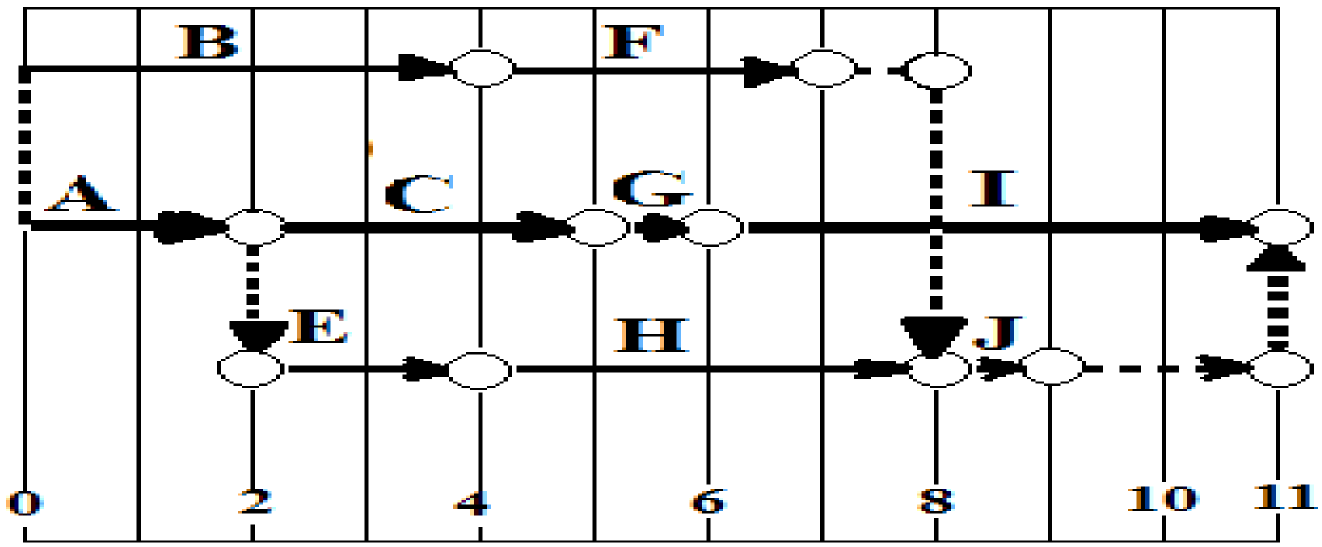
In a similar manner it is possible that altering the schedules for activities, within the periods permitted by float time, may eliminate the need for providing additional equipment on a project for short periods of time only.

Example 10-1

Below is the information on a small project, which is required to calculate the time required to complete the project, as well as drawing the project arrow diagram with the early and late start and the early and late completion of each activity. Try to draw the Time Grid Diagram.

Activity	Preceded by	Duration	Activity	Preceded by	Duration
A	---------	2	**C**	A	3
B	--------	4	**E**	A	2
F	B	3	**G**	C	1
J	F,H	1	**D′**	------	0
I	G,E	5			
H	E	4			




B
F
A
C
G
I
E
H
J
0
2
4
6
8
10
11

11- PERT (Program Evaluation and Review Technique)

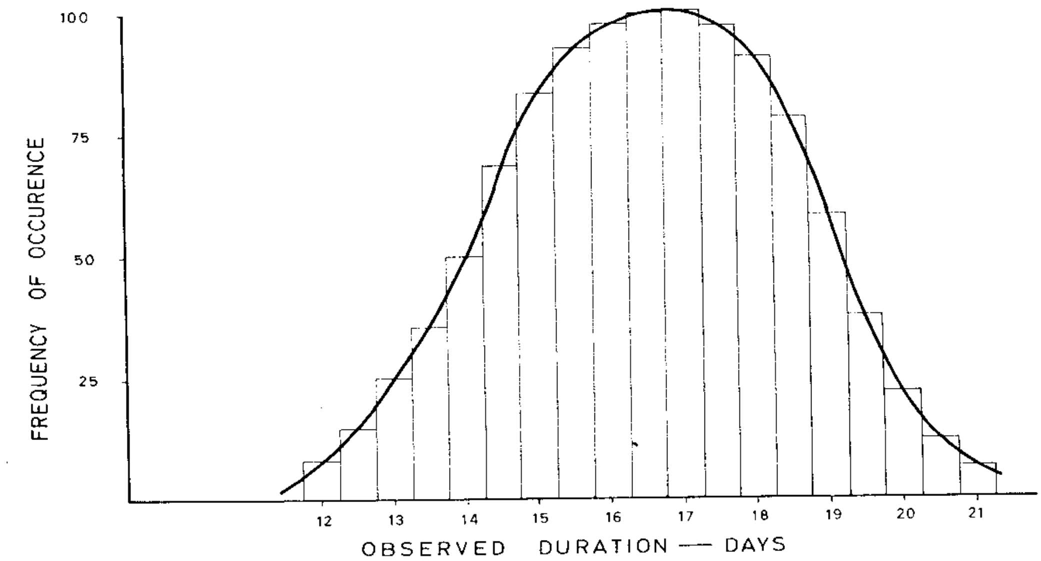
The PERT method of drawing and computing with network analysis was devised to take account of the difficulty of estimating the durations of activities which cannot be established conclusively from past experience. In the case of construction work, excavation, for example, has been carried out under many varied conditions and in all types of soil. The experience of conducting this operation is, therefore, very broad, and, in estimating durations for carrying out future work, there is little doubt about the estimated normal durations if the facts about the excavation conditions are known.

Where it is necessary to estimate the possible duration of such work as research or development, or work that is being carried out for the first time, then the basis for estimation is by no means as sound as that for construction works. It is for this type of worh0hat"lhe PERT statistical approach was developed. Statisticians have relatively simple means for the determination of uncertainty in quantitative terms and such methods, though they have been challenged in this context, are the basis for the PERT approach to network analysis.

PERT methods do take account of the activity which is likely to have a wide range of durations. An activity in CPM may be estimated to have a most likely duration of ten days. It may be that, due to the nature of the operations, the possible range of the duration could be from two to eighteen days or, fog a different operation, it could be from eight to fifteen days. No distinction between these two types of activity is made in CPM; the duration is stated to be l0 days and the probable uncertainty is not considered at all.

Other than the different approach to estimating the durations of activities, PERT is known as *an event-orientated* method. In the PERT method, certain events are selected throughout the program to act as milestones for the program. These are events which are important in the overall program and against which progress in general can be measured. These milestones are labelled with a specific title, for example, *Completion of all foundation work.* With CPM, the tendency is to refer to the activity and not to the event. When a number of events or milestones in the PERT network has been established, these are linked together by arrows in the same way as the CPM network. The expenditure of resource is assumed to occur on the activity arrow in PERT and in CPM.

The method of estimating durations in the PERT technique uses elementary probability theory to measure the probability of each event being achieved as predicted. In simple terms, probability theory is a means of putting a figure to such statements as *most likely, very probable, unlikely, etc*. The scale against which probability is measured is one that runs from 0 to 1. At the lower end of the scale we have the situation which is impossible and 1 represents a situation which is definite. In between are the various degrees of probability.



One commonly sees frequency distributions of various topics representing the results of surveys which have been made in specific fields. Such a frequency distribution is reproduced in Fig. 9.13. The distribution represents the spread of times which a well-defined activity has taken in the past. This might be something which is carried out fairly frequently in a maintenance procedure or a factory workshop, for example. On the vertical axis of the graph is shown the frequency of occurrence for any duration and on the horizontal scale the actual duration time as it was observed. From Fig.9.l3 it will be seen that the activity took seventeen days for an observed number of times of 100. Other numbers of occurrences for other durations are plotted. If the interval between the activity duration is reduced and the number of plots will tend to a smooth curve, an example of which has been superimposed upon the figure in 9.13. Such a frequency distribution was assumed by the originator of PERT and in this case he assumed that the plots of durations of the activities almost fitted a *beta distribution* curve, a curve the characteristics of which are well known to statisticians. Having assumed that the beta distribution was a satisfactory model for the estimation of duration time, it was then possible to develop the equation

$$t_e = \frac{t_o + 4t_m + t_p}{6}$$

Where:

t_m = the most likely duration of the activity
t_o= the optimistic time, that is the shortest time which could be anticipated for the activity
t_p= the pessimistic estimate of the time, that is, the duration of the activity assuming that everything goes at its worst.
Let's assume that a 20,000 –square- slab foot on grade is to be cast in place. For scheduling purposes, the project superintendent is asked for estimates of the three durations above (i.e., most pessimistic, optimistic and likely) rather than for a single constant duration. The three estimates are used to calculate an *expected* activity duration. The calculations are loosely based on concepts from mathematical probability.
The expected duration t_e is assumed to be the average value of a probability distribution defined by the three –estimate set. The expected duration, t_e of each activity with variable characteristics is given as:

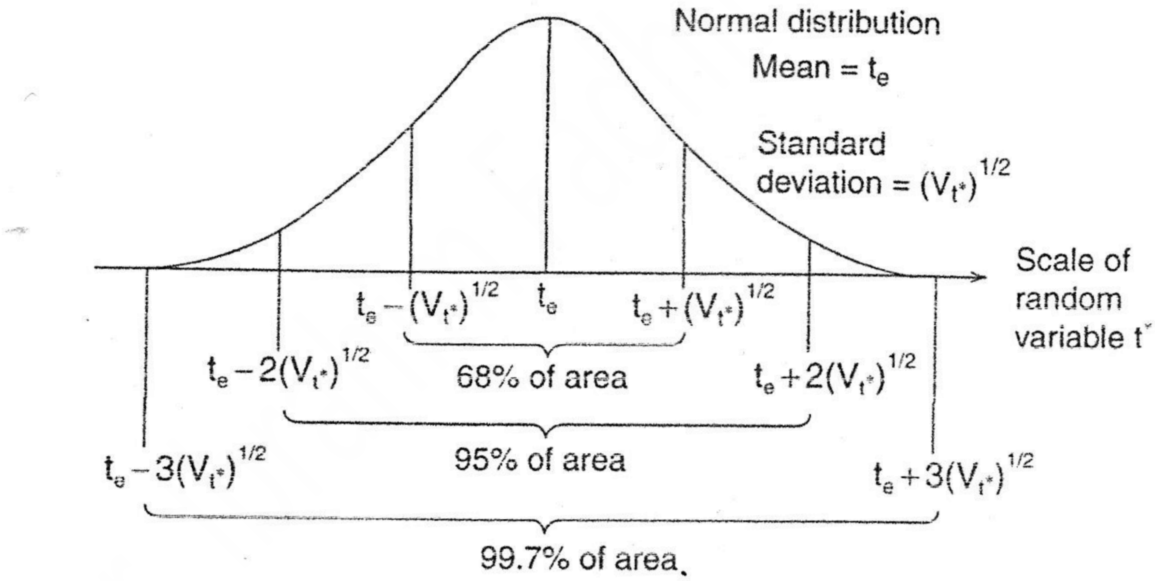


Figure (8-2) Selected area under the normal distribution curve

$t_e = \{t_o + 4t_m + t_p\} / 6$

For instance, if for the slab pour, the three estimates from the superintendent are:

$t_o = 5\ days$

$t_m = 8\ days$

$t_p = 12\ days$

The expected activity duration is calculated as:

$t_e = \{5 + 4(8) + 12\}/6 = 49/6 = 8.17\ days, say\ 9\ working\ days.$

The expected value for each activity with a constant value is $t_e =$ constant. Once the t_e values for each variable duration activity have been calculated, the longest path and project duration are determined using the same methods used by CPM. The probability of completing the project within a predetermined time duration is calculated by assuming that the probability distribution of the total project duration is normally distributed with the longest path of t_e values as a mean value of the normal distribution.

The normal distribution is defined by its mean value χ (i.e., in this case the value of the longest path through the network) and the value,σ which is the so-called *standard deviation* (σ) of the distribution. The standard deviation is a measure of how widely about the mean value the actual observed values are spread or distributed. Another parameter called the variance is the square of the standard deviation. i.e.,(σ^2). It can be shown mathematically that 99.7 % of the values of normally distributed variables will lie in a range defined by three standard deviations below the mean and three standard deviations above the mean (see Figure 8.2).

In PERT, the standard deviation (σ) of the normal distribution for the total project duration is calculated using the variance of each activity on the critical path. The variance (σ) for each PERT activity is defined as:

$\sigma^2 = [(t_p - t_o) / 6]^2$

Where the expression inside the brackets approximates the standard deviation of the activity being considered. If the variance of each activity on the longest (i.e., critical) path is summed, that value is assumed to be the variance of the normal distribution of the entire project duration values.

The fact that the normal distribution is used to represent the probability distribution of the possible total project durations is based on a basic concept from probability theory called the Central Limit Theorem.

Theorem

Suppose m independent tasks are to be performed in order; (one might think of these as the m tasks that lie on the critical path of a network). Let $t_1^*, t_2^*, \dots . t_m^*$ be the times at which these tasks are actually completed:

$Note\ that\ these\ are\ random\ variables\ with\ true\ means\ t_1^*, t_2^*, \dots . t_m^*\ and$ $true\ variance\ V_{t1}^*, V_{t2}^*, \dots\dots . . V_{tm}^*, and\ actual\ times\ are\ unknown\ untile$ $the\ sespecific\ tasks\ are\ actually\ performed.\ Now\ define\ T^*\ to\ be$ $the\ sum$:

$$T^* = t_1^* + t_2^* + \cdots \dots \dots + t_m^*$$

$And\ note\ that\ T^*\ is\ also\ a\ random\ variable\ and\ thus\ has\ a\ distribution. The$

Central Limit Theorem states that if m is large, say four or more, the distribution of T^* is approximately normal with mean T and variance VT^* given by

$$T = t_1 + t_2 + \cdots \ldots . + t_m$$
$$V_T^* = V_{t1}^* + V_{t2}^* + \cdots \ldots \ldots + V_{tm}^*$$

That is, the mean of the sum, is the sum of the means; the variance of the sum is the sum of the variances; and the distribution of the sum of activity times will be normmal regardless of the shape of the distribution of actual activity performance times.

Example 8-1

A small project consists of several activities as shown in table below, due to uncertain information about the duration for completing each activity there are three expected times for them:

Activity	Preceded by	t_m	t_o	t_p	Activity	Preceded by	t_m	t_o	t_p
A	--------	3	1	5	F	B and E	9	8	16
B	--------	6	3	9	G	B and E	7	4	13
C	--------	13	10	19	H	D	6	3	9
D	A	9	3	12	I	C and G	3	1	8
E	A	3	1	8					

The t_e values shown for each activity are calculated using the formula:

$t_e = \{t_o + 4t_m + t_p\} / 6$

For instance, the t_e for activity G is:

$t_e = (4 + 7x4 + 13)/6 = 45/6 = 7.5,$ and the same steps for the other activities.

The variance for each activity is approximated by the equation:

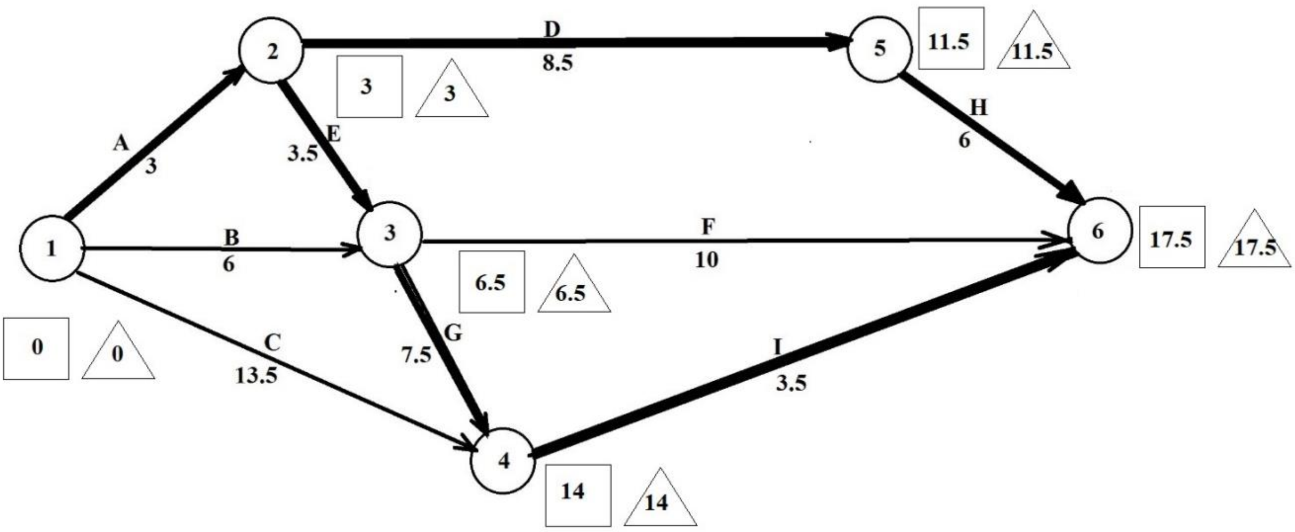
$V = [(t_p - t_o)/6]^2$

For Activity G, the variance is:

$V_G = [(13 - 4)/6]^2 = 2.25$

Using the forward and backward pass methods described previously

Activity	Preceded by	t_m	t_o	t_p	t_e	Variance	Activity	Preceded by	t_m	t_o	t_p	t_e	Variance
A	-----	3	1	5	3	0.44	F	B and E	9	8	16	10	1.23
B	-----	6	3	9	6	1.00	G	B and E	7	4	13	7.5	2.25
C	-----	13	10	19	13.5	2.25	H	D	6	3	9	6	1.00
D	A	9	3	12	8.5	2.25	I	C and G	3	1	8	3.5	1.36
E	A	3	1	8	3.5	1.36							



There are two paths have an expected duration of 17.5 days. These paths are shown below:

Critical Path	Duration	Variance
Path 1 (A, D, and H)	3+ 8.5+ 6 = 17.5	0.444+2.25+ 1.0 = 3.694
Path 2 (A, E, G, and I)	3+ 3.5+ 7.5+3.5 = 17.5	0.444+ 1.361+2.25+1.361=5.41

The mean of the normal distribution is therefore assume is to be 17.5 days. The variances of the two longest paths are calculated by adding variances of the individual activities in each path. The variance of path two {5.416} is greater than that of path one {3.694}. Because this means a greater spread of the probable total project durations, the variance of path two is selected as the variance to be used for further PERT calculation.

The PERT normal distribution for total project duration is shown in Figure 8.3.

The normal distribution is symmetrical about the mean. The standard deviation will be:

$$\sigma = SQRT\ (0.5416) = 2.327.$$

PERT answers the question: "What is the probability (given the veritable duration of the activities) that the project can be completed in N days?" The probability of completing the project is given by the area under the normal distribution to the left of the value N selected for investigation. Because we know that 99.7% of the area (representing probability) under the normal distribution is in the range of 3σ below the mean and 3σ above the mean, we can say that there is a better than 99.7% chance that the project can be completed in $[x + 3\sigma]$ or $[17.5 + 3\ (2.327)\ ]$ = 24.5 days or less. That is, at least 99.7% of the area under the normal curve is to the left of the value 24.5 days in figure 8.3. In other word, we can be almost 100% sure that the project can be completed in 25 days or less.

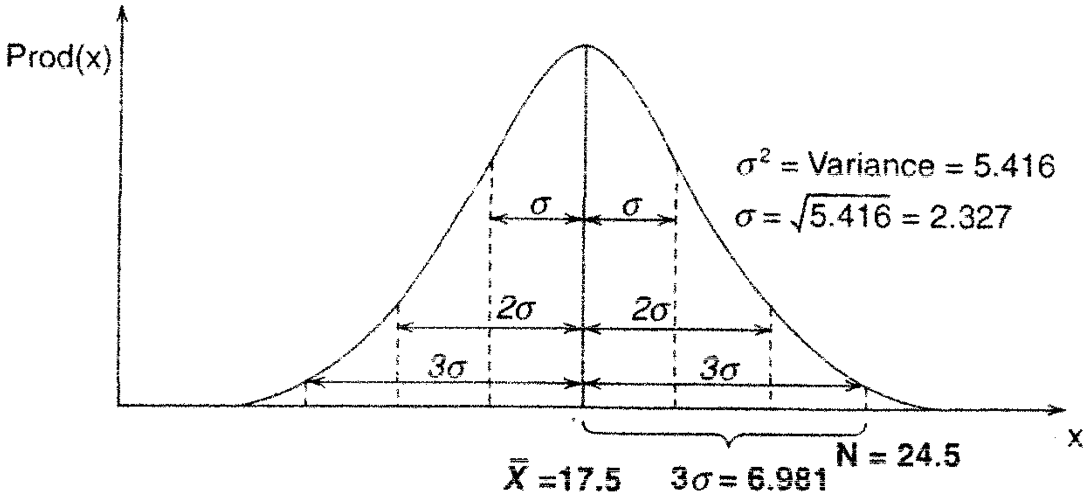


Figure (8-3) Normal distribution of total project durations for small PERT network

What if we want to know the probability of completing in 19 days? Given the values of the mean and the variance, we can use a cumulative normal distribution function table such as shown in the table at the end of these papers to calculate the area under the curve left of the value 19. First, we must calculate the Z value which for a given value *x* (e.g., 19):

$$Z = \frac{Mean - x}{\sqrt{Variance}}\ or\ Z = \frac{(\bar{x} - x)}{\sigma}$$

Where σ is the standard deviation of the cumulative normal distribution in our case.

$$Z = \left|\frac{17.5 - 19}{\sqrt{5.416}}\right| = \frac{1.5}{2.327} = 0.644$$

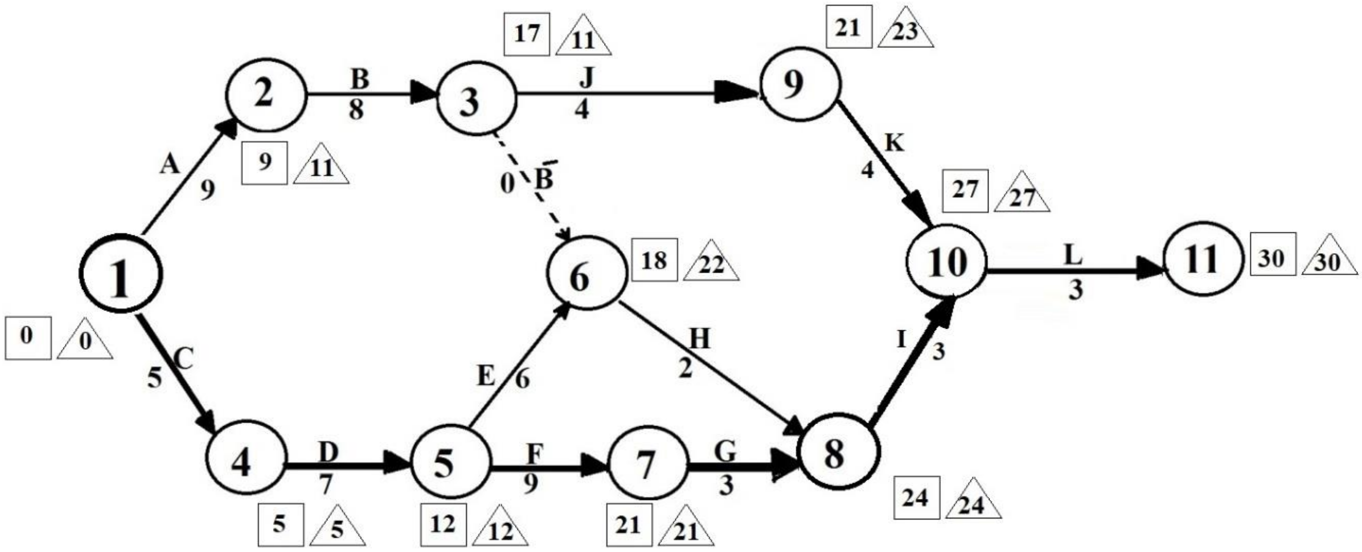
Consulting the cumulative normal distribution function table given in the papers (at the end of this text book), with a Z value of 0.644, yields a value of 0.7389 or 73.89% probability of completing the project in 19 days. What would be the probability of completing the project in 16 days?.

Example 8-2 Because of the uncertain nature of the program for construction of specific project it decided to draw and analyze the arrow the network for the following activities by using three estimating of duration for each activity. What is the probability that the program will be completed in 33 weeks?

Solution

Activity	Duration (week)			Depend on
	to	tm	tp	
A	6	9	12	-
B	6	8	10	A
C	2	5	8	-
D	4	7	10	C
E	4	6	8	D
F	5	9	13	D
G	2	3	4	F
H	1	2	3	B,E
I	2	3	4	G,H
J	2	4	6	B
K	3	4	5	J
L	2	3	4	K, I

Activity	**to**	**tm**	**tp**	**te**	**δ**	**ES**	**EF**	**LS**	**LF**	**TF**
A	6	9	12	9	1	0	9	2	11	2
B	6	8	10	8	2/3	9	17	11	19	2
C*	2	5	8	5	1	0	5	0	5	0
D*	4	7	10	7	1	5	12	5	12	0
E	4	6	8	6	2/3	12	18	16	22	4
F*	5	9	13	9	4/3	12	21	12	21	0
G*	2	3	4	3	1/3	21	24	21	24	0
H	1	2	3	2	1/3	18	20	22	24	4
I*	2	3	4	3	1/3	24	27	24	27	0
J	2	4	6	4	2/3	17	21	19	23	2
K	3	4	5	4	1/3	21	25	23	27	2
L*	2	3	4	3	1/3	27	30	27	30	0



The activities on critical path are C-D-F-G-I-L= 30 weeks

$$\delta_{C.P} = \sqrt{\sum \; 1^2 + 1^2 + (\tfrac{4}{3})^2 + (\tfrac{1}{3})^2 + (\tfrac{1}{3})^2 + (\tfrac{1}{3})^2} = 2.03$$

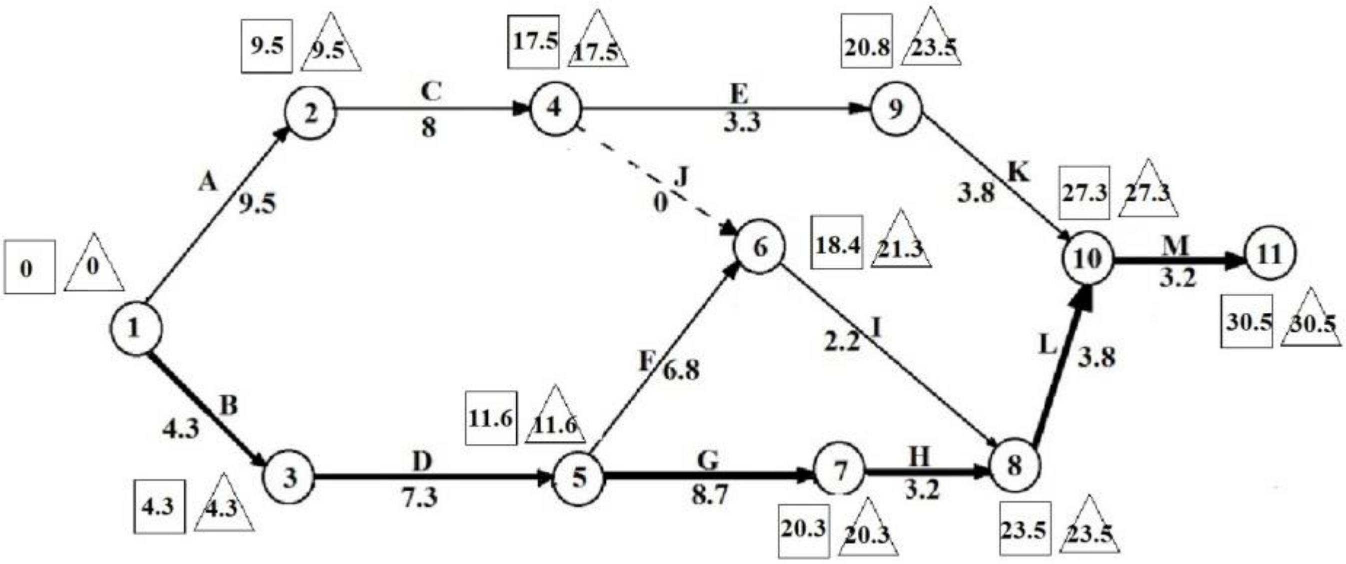
$$Z = \frac{T_S - T_e}{\sigma_{c.p}} = \frac{33-30}{2.03} = 1.48$$

The corresponding value of Z = 1.48 equals = 0.93, which means that the probability of completion of the project with a period of (33) weeks is 93% and this is a high probability.

Example 8-3 Construct the PERT Network representing the activities and DATA shown below, and determine the expected finish date and the probability the finishing work in 25 months? What's the probability in 33 months finish the work?

<u>Solution.</u>

Activity	Events	Duration (Months)			t_e	δ	$δ^2$
		t_p	t_m	t_o			
A	1-2	15	9	6	9.5	1.5	2.25
B*	1-3	8	4	2	4.3	1.0	1.0
C	2-4	10	8	6	8.0	0.67	0.45
D*	3-5	12	7	4	7.3	1.33	1.77
E	4-9	6	3	2	3.3	0.67	0.45
F	5-6	9	7	4	6.8	0.83	0.69
G*	5-7	11	9	5	8.7	1.0	1.0
H*	7-8	5	3	2	3.2	0.5	0.25
I	6-8	4	2	1	2.2	0.5	0.25
J	4-6	0	0	0	0	0	0
K	9-10	6	4	1	3.8	0.83	0.69
L*	8-10	5	4	2	3.8	0.5	0.25
M*	10-11	5	3	2	3.2	0.5	0.25



The activities on critical path are B-D-G-H-L-M= 30.5 weeks = Te

$$\sigma_{c.p} = \sqrt{(1.0)^2 + (1.33)^2 + (1.0)^2 + (0.5)^2 + (0.5)^2 + (0.5)^2} = 2.125$$

$$Z = \frac{25-30.5}{2.125} = -2.588$$

From the table the area under the curve equal to = 0.004940

The probability to complete the project in 25 weeks = 0.49%

$$Z = \frac{33 - 30.5}{2.125} = 1.176$$

From the table the area under the curve equal to= 0.878999

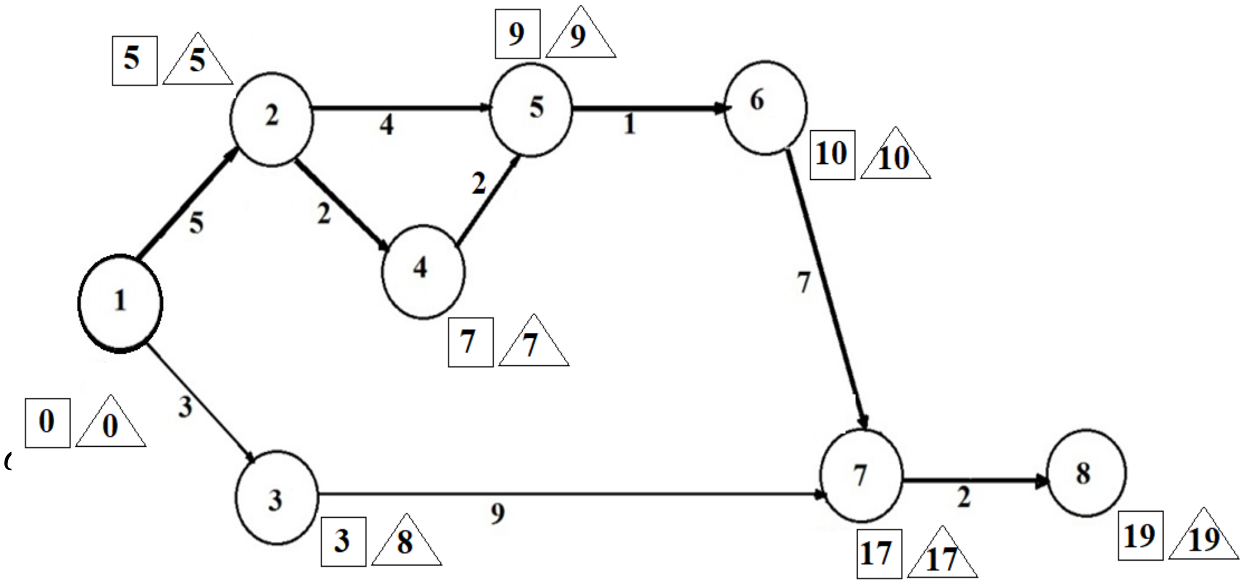
The probability to complete the project in 33 weeks= 87.9%

Example 8-4: The Project manager requested the consultants for providing the estimated times of the project activities, consultant group suggested the following durations for each activity. Find the

1- The project construction duration at probability 4%
2- The project construction duration at probability 81%

Activity	Duration (week)		
	to	tm	tp
1-2	4	5	6
1-3	1	3	5
2-4	2	2	2
2-5	3	4	5
3-7	7	8	15
4-5	1	2	3
5-6	1	1	1
6-7	6	6	12
7-8	1	2	3

Activity	Duration (week)				δ	ES	EF	LS	LF	TF	CP
	to	tm	tp	te							
1-2	4	5	6	5	1/3	0	5	0	5	0	*
1-3	1	3	5	3	2/3	0	3	5	8	5	
2-4	2	2	2	2	0	5	7	5	7	0	*
2-5	3	4	5	4	1/3	5	9	5	9	0	*
3-7	7	8	15	9	4/3	3	12	8	17	5	
4-5	1	2	3	2	1/3	7	9	7	9	0	*
5-6	1	1	1	1	0	9	10	9	10	0	*
6-7	6	6	12	7	1	10	17	10	17	0	*
7-8	1	2	3	2	1/3	17	19	17	19	0	*



For probability 4% ⟶ from table Z= -1.7

$$Z = \frac{Ts - Te}{\delta C.p} \quad -1.75 = \frac{Ts - 19}{1.15} \qquad Ts = 19 - 2 = 17 \text{ Weeks}$$

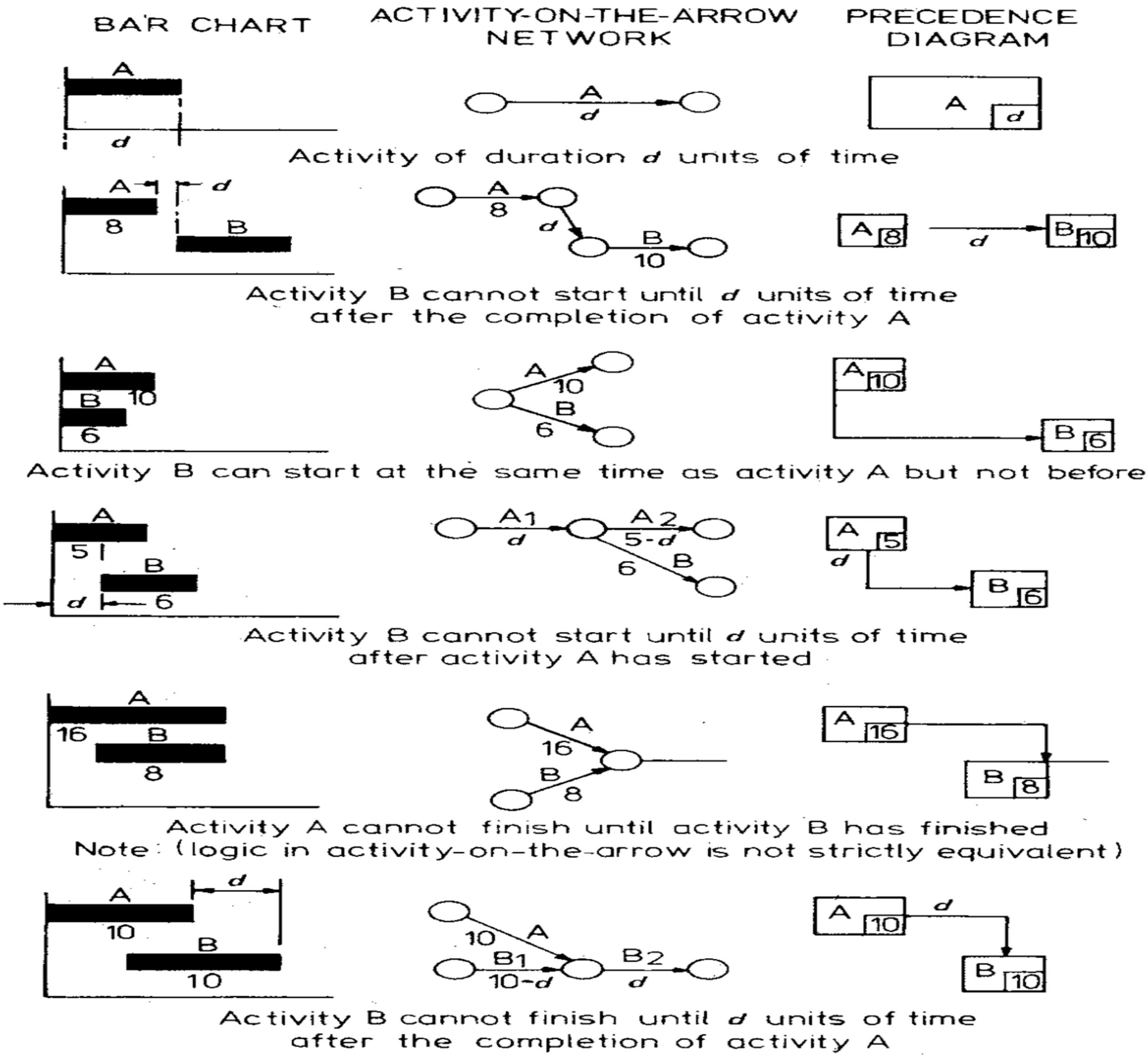
For probability 81% ⟶ from table Z= 0.88

$$Z = \frac{Ts - Te}{\delta C.p} \qquad 0.88 = \frac{Ts - 19}{1.15} \qquad Ts \cong 20 \text{ Weeks}$$

9- ACTIVITY –ON- NODE DIAGRAM (PRECEDENCE DIAGRAM)

As stated earlier, there are two principal formats used in drawing network diagrams. The activity-on-arrow format has been used up to this point. The second format is the activity on-node format. This technique uses the same general principles of network logic and time calculations as does the activity-on-arrow technique. However, the activity-on-node network diagram looks somewhat different from the activity-on-arrow diagram because the node (which represented an event in the activity-on-arrow method) is now used to represent an activity. A simple form of the activity-on-node diagram is the circle diagram or circle notation, in which each activity is represented by a circle containing the activity description, an identifying number, and the activity duration.

9-1 The Differences between the other Planning Schedules



As shown in above, the shape of the square, rectangle, or circle can be used to draw the Precedence activities. The figure (9-1) illustrates the activity drawn by activity on node with the relation information for each activity. This activity was represented by square shape.

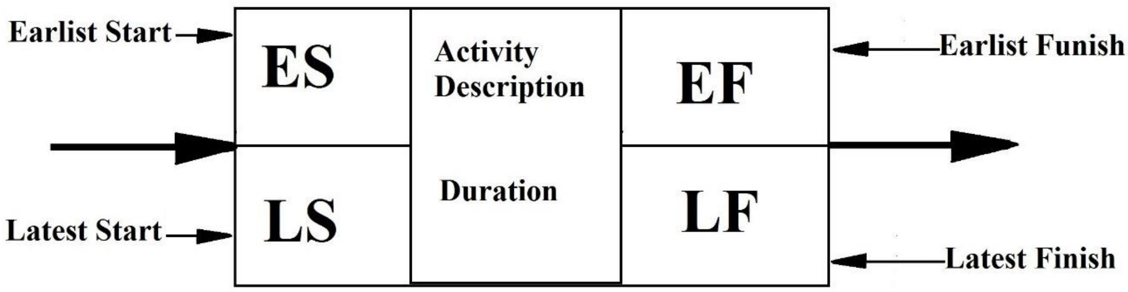


Figure (9-1) Activity –on-Node Square Shape

As for the representation in circular form, which will be relied upon in the scheme of precedence, it will be as follows:

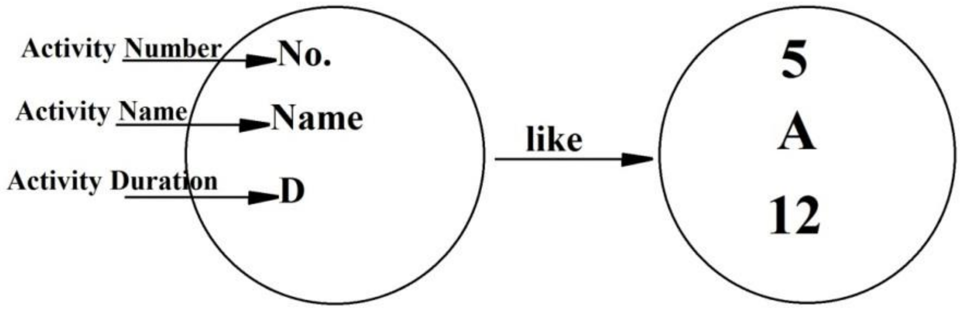
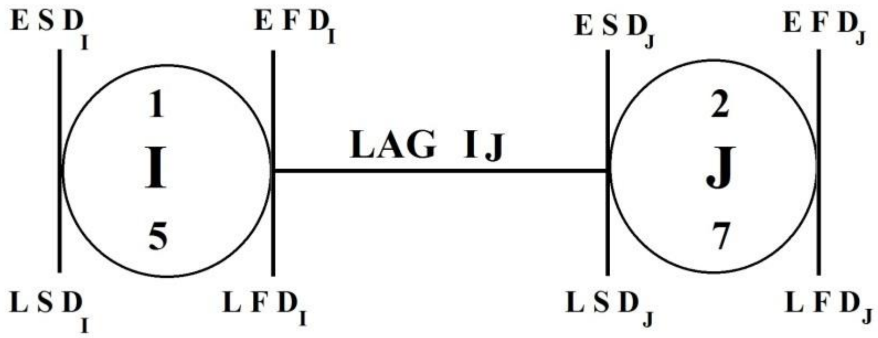


Figure (9-2) Activity in Node as Circle



$LAG\ IJ = ESD_J - EFD_I$

$ESD_J = Max.\ EFD_I$

$EFD_I = ESD_I + T_I\ (D)$

$LFD_I = Min.\ LSD_J$

$LSD_I = LFD_I - TI\ (D)$

$F.F_I = Min\ [ESD_J - EFD_I]$

$= Min.\ LAG\ IJ$

$TFI = LFD_I - EFD_I$

$= LSD_I - ESD_I$

$= Min. [LAG\ IJ + TFJ]$

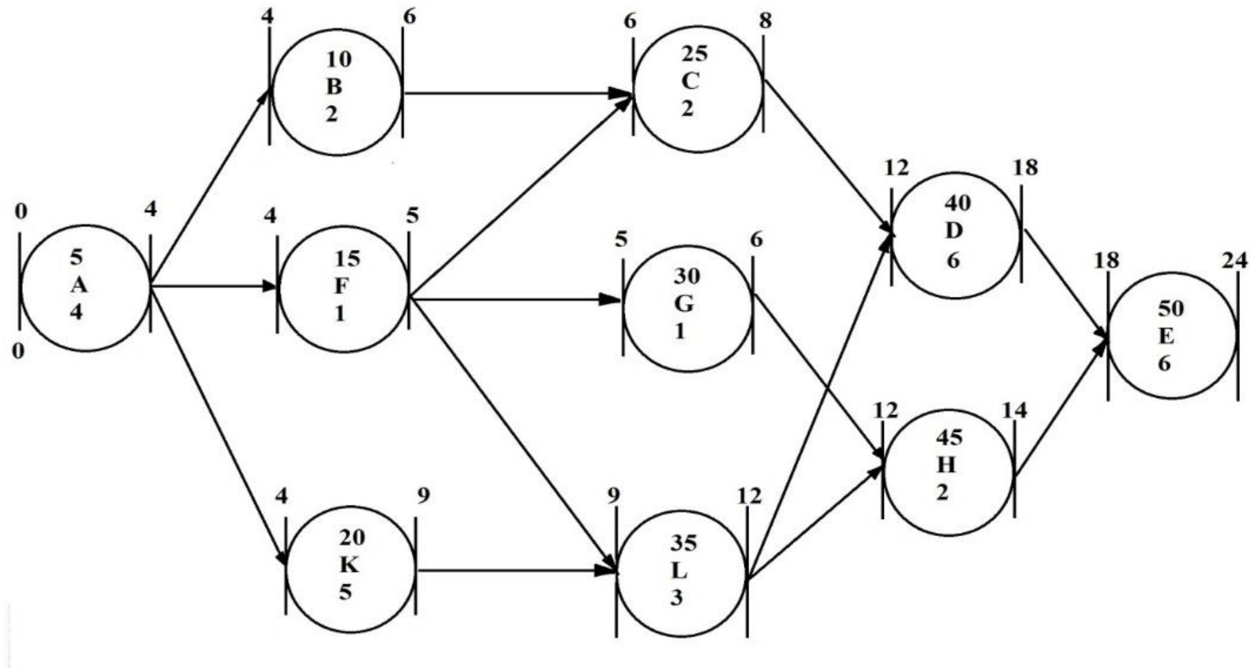
Example 10-1

Setup a table and compute the early start, early finish, latest start, latest finish dates and indicate the critical path on the network for the activities of the project, its relationships are given below?

Activity	T (Duration)	Depended on		Activity	T (Duration)	Depended on
A	4	-----------		F	1	A
B	2	A		G	1	F
C	2	B,F		H	2	G,L
D	6	C,L		K	5	A
E	6	D,H				
L	3	F,K				

Solution

The first stage to assign Activity on Node Diagram as shown below the Early Start and Early Finish:



The second stage for determining the latest start and latest finish

Then calculate the Total Float and Free Float for each activity as describe in

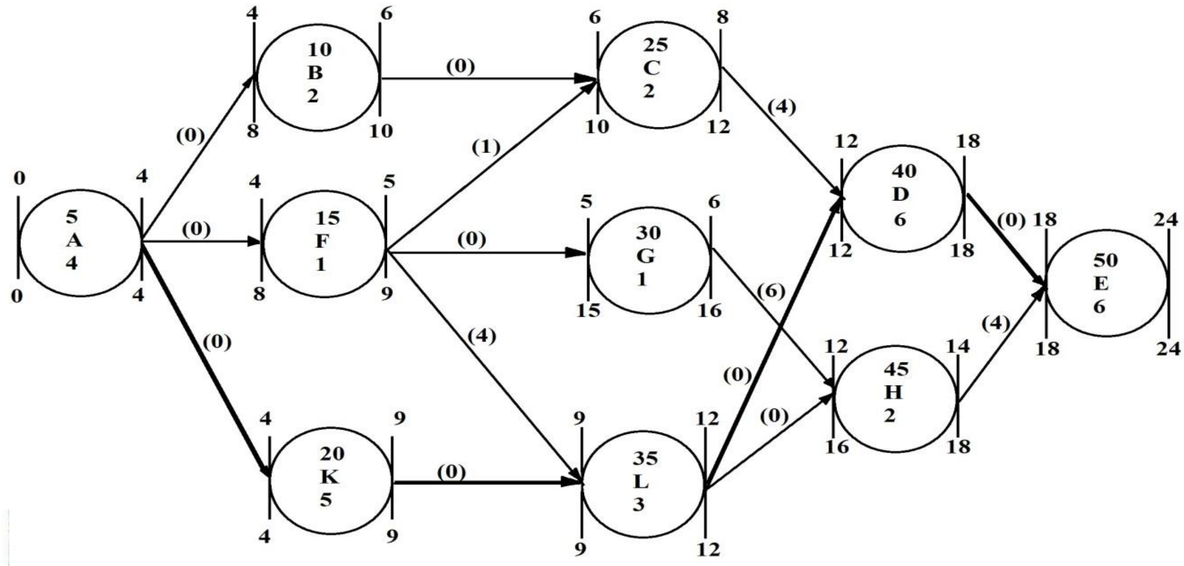


table below:

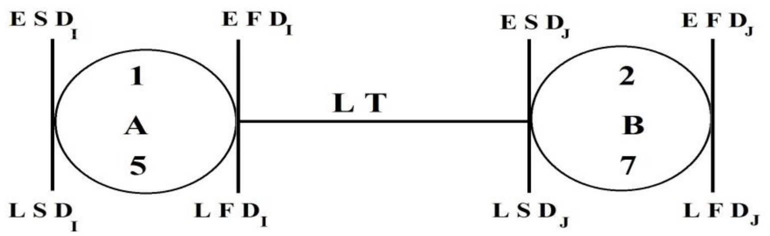
Activity	T (Duration)	Depended on	TF	FF
A	4	-----------	0	0
B	2	A	4	0
C	2	B,F	4	4
D	6	C,L	0	0
E	6	D,H	0	0
F	1	A	4	0
G	1	F	10	6
H	2	G,L	4	4
K	5	A	0	0
L	3	F,K	0	0

For assign the critical path is shown in bold lines (A, K, L, D and E)

Overlapped and the Precedence Network Techniques

There is a feature in the precedence schemes, which is the overlap and correlation between the events of the scheme of precedence and there are types of this interdependence. This correlation is governed by the actual working conditions on the site.

a- **The term LT- Lead Time**; which means the lead time or the time of waiting, Precedent and subsequent effectiveness to achieve the requirements of this interdependence which is as follows:

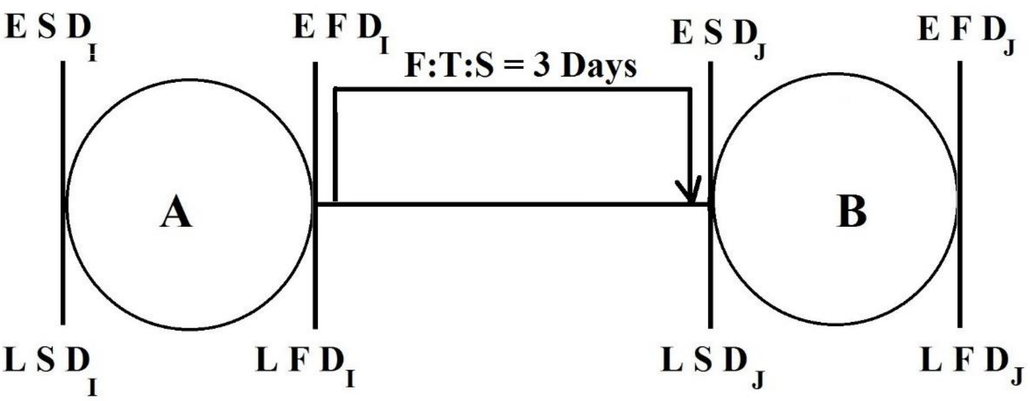


Activity (B) depends on the end of Activity (A). This is a beginning-after-end relationship. Here, Lead Time is the previous activity time to finish and then the subsequent activity begins. Lead Time may be a specific time period (B) after activity (A), lead time.

b- Finish to Start (F:T:S)

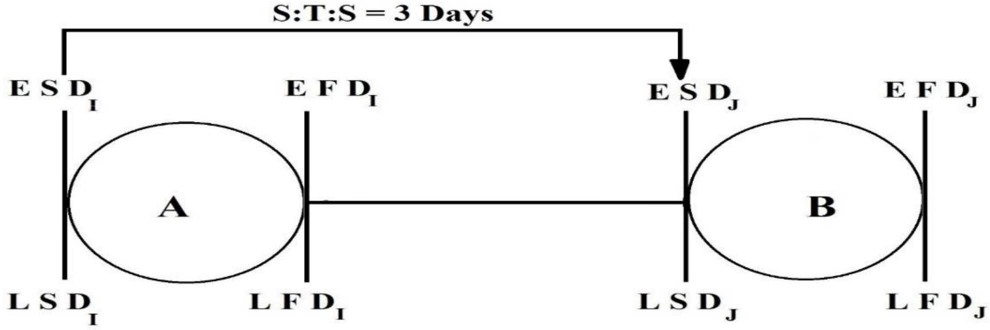
In this case the next activity will not be start unless the previous activity be completed, the beginning of the subsequent activity is determined by completion of previous activity (directly or with specific duration).

The subsequent activity B can only begin if 3 days have elapsed after the previous activity A has ended

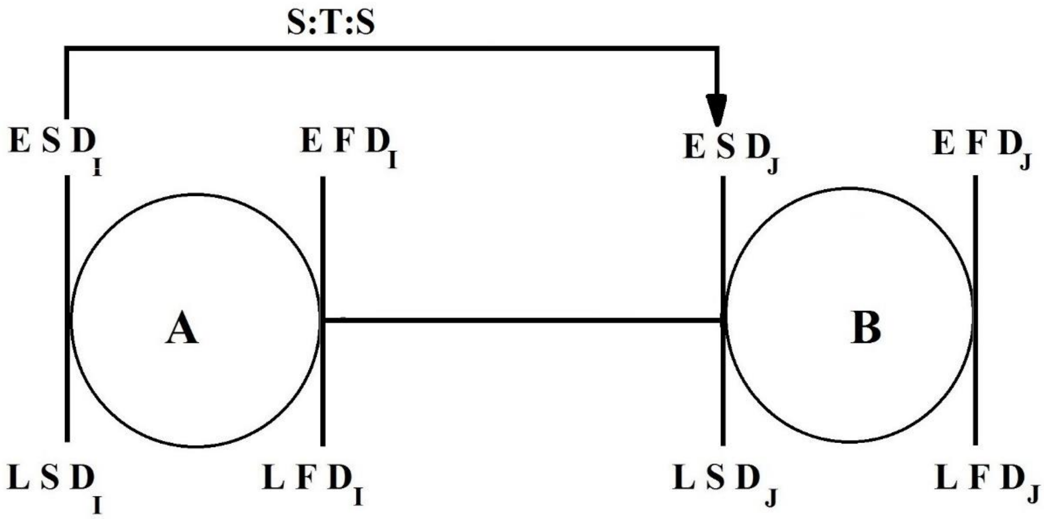


c- Start to Start (S:T:S)

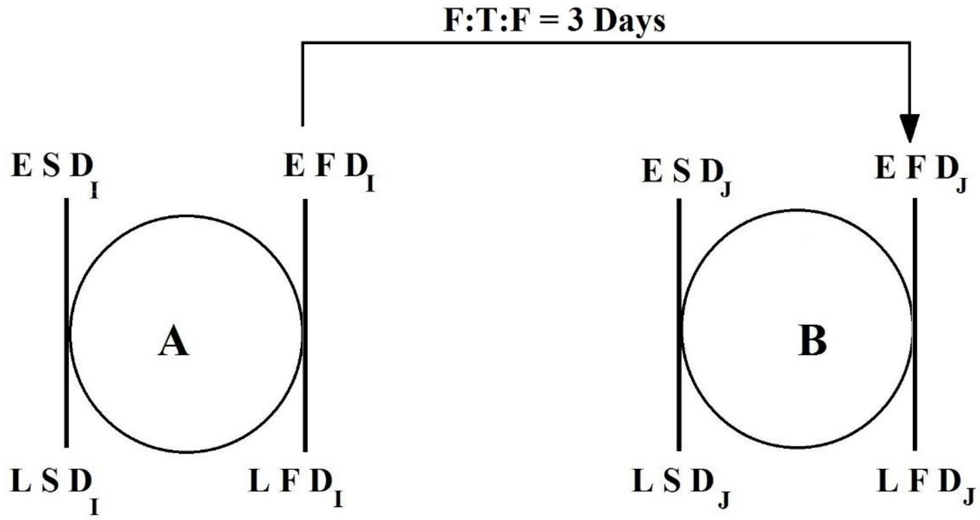
Activity B can be started after 3 days of starting the previous activity A



While the other case in below the activity B will start together with activity A.

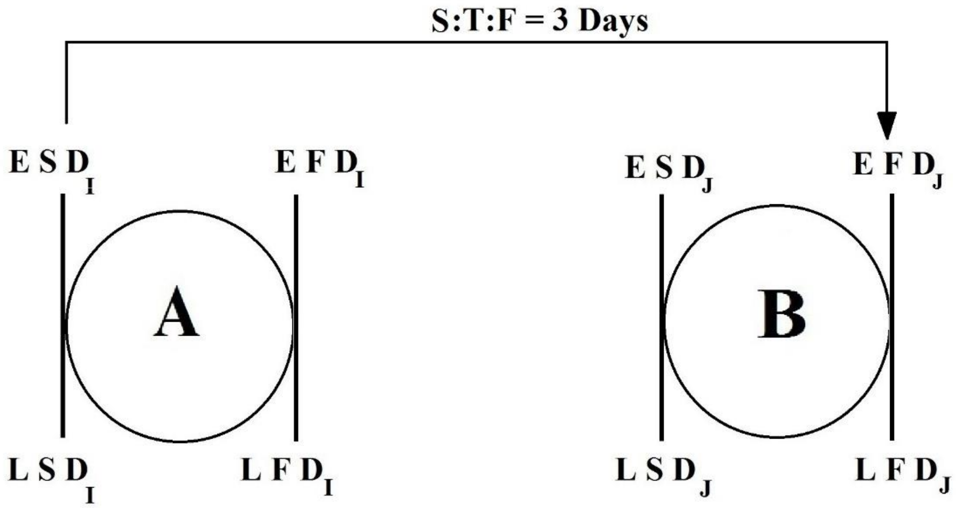


d- <u>Finish to Finish (F:T:F)</u>



Activity B will complete with completion of activity A after 3 days.

e- Start to Finish (S:T:F)

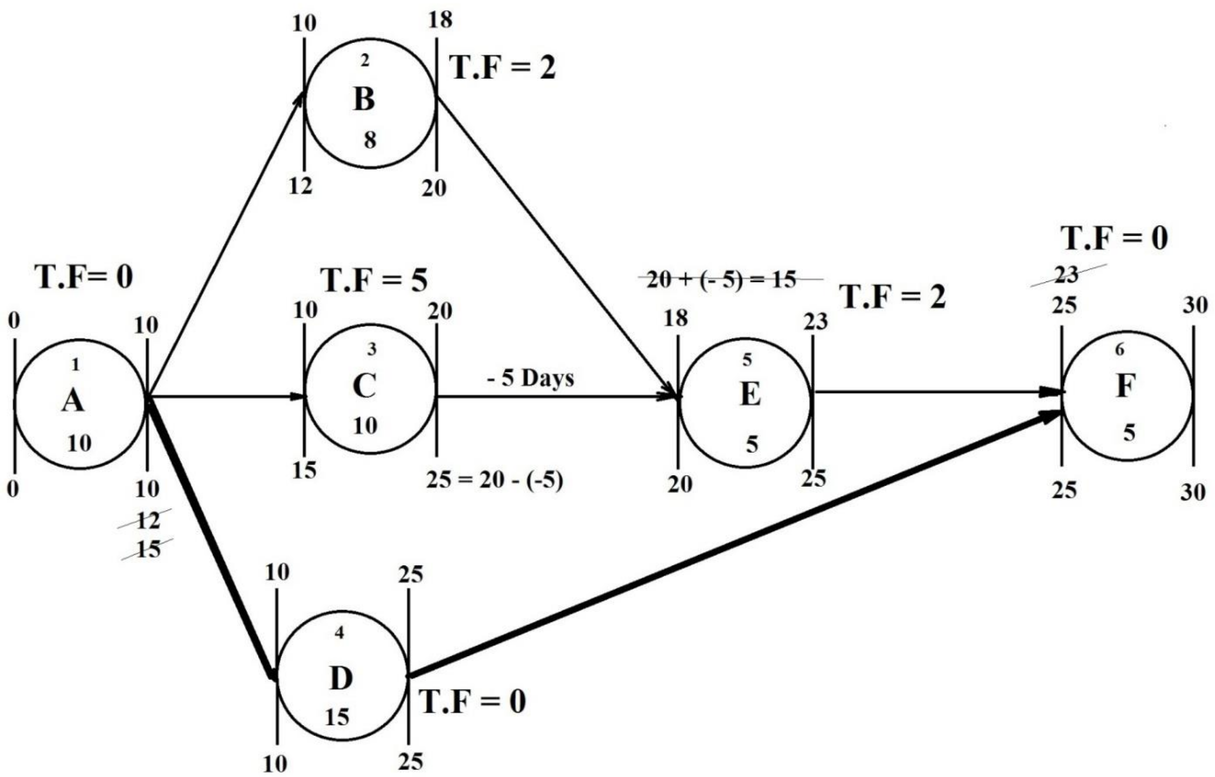


Activity B will finish after 3 days of starting of the activity A.

Examples

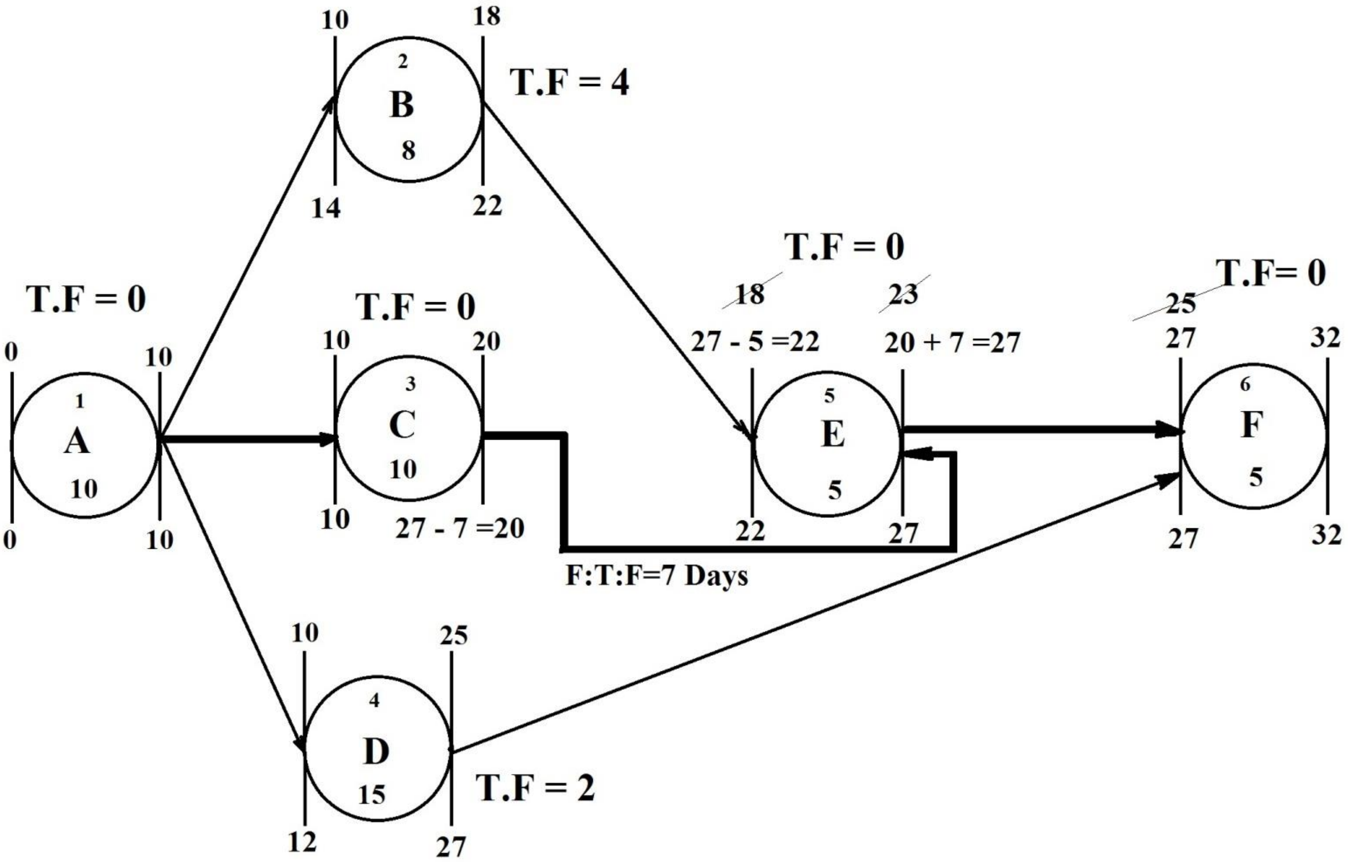
Example 1:- For information the following table, prepare an Activity On Node (A-O-N) network and state the critical path and T.F?

Activity	Duration	Preceded by	Additional Relationship
A	10	-------	
B	8	A	
C	10	A	
D	15	A	
E	5	B and C	C- E = F:T:S= -5 Days
F	5	D and E	



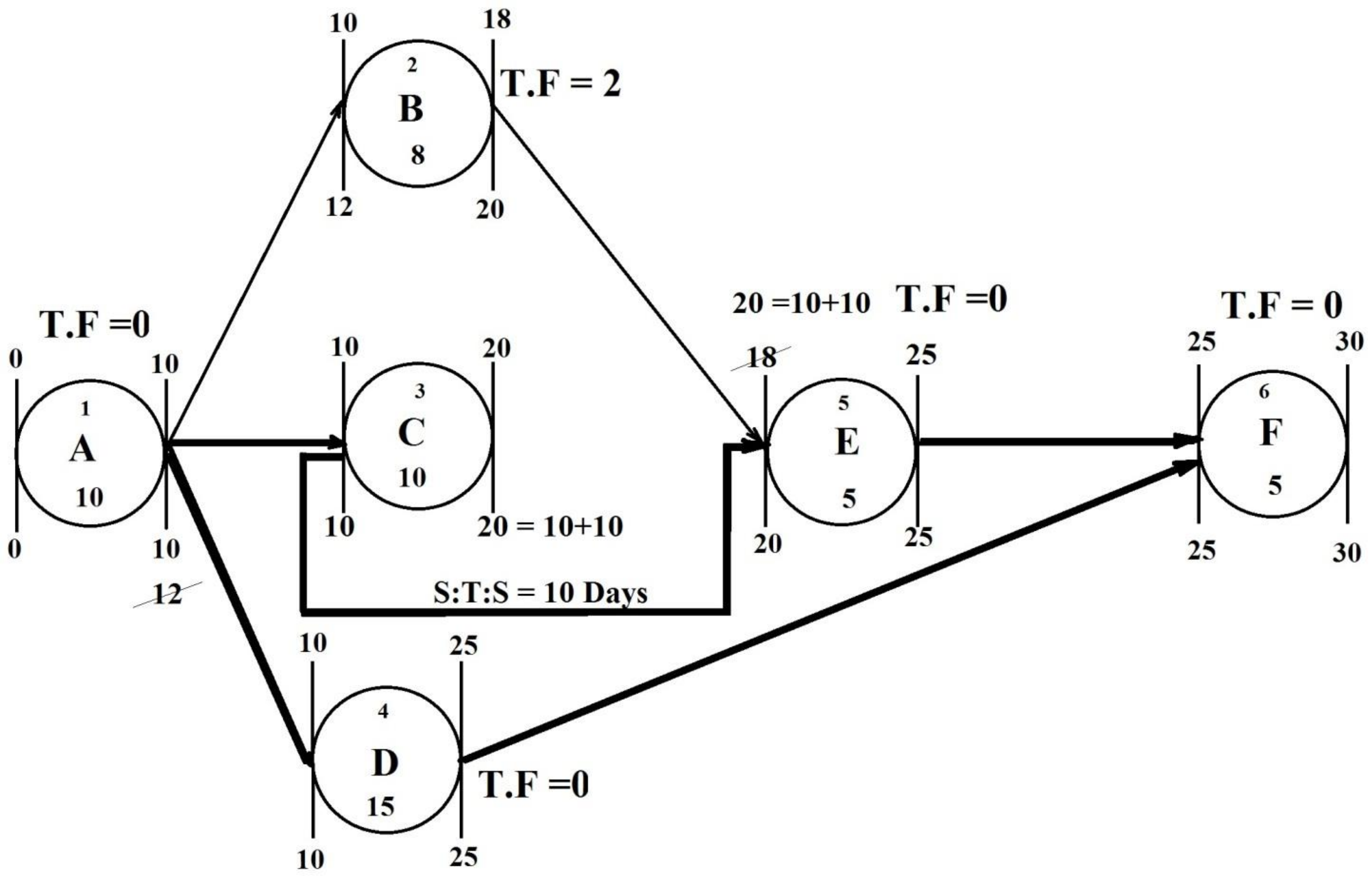
Example 2:- The same previous example but there is a different relationship as shown in table below

Activity	Duration	Preceded by	Additional Relationship
A	10	-------	
B	8	A	
C	10	A	
D	15	A	
E	5	B and C	C- E = F:T:F= 7 Days
F	5	D and E	



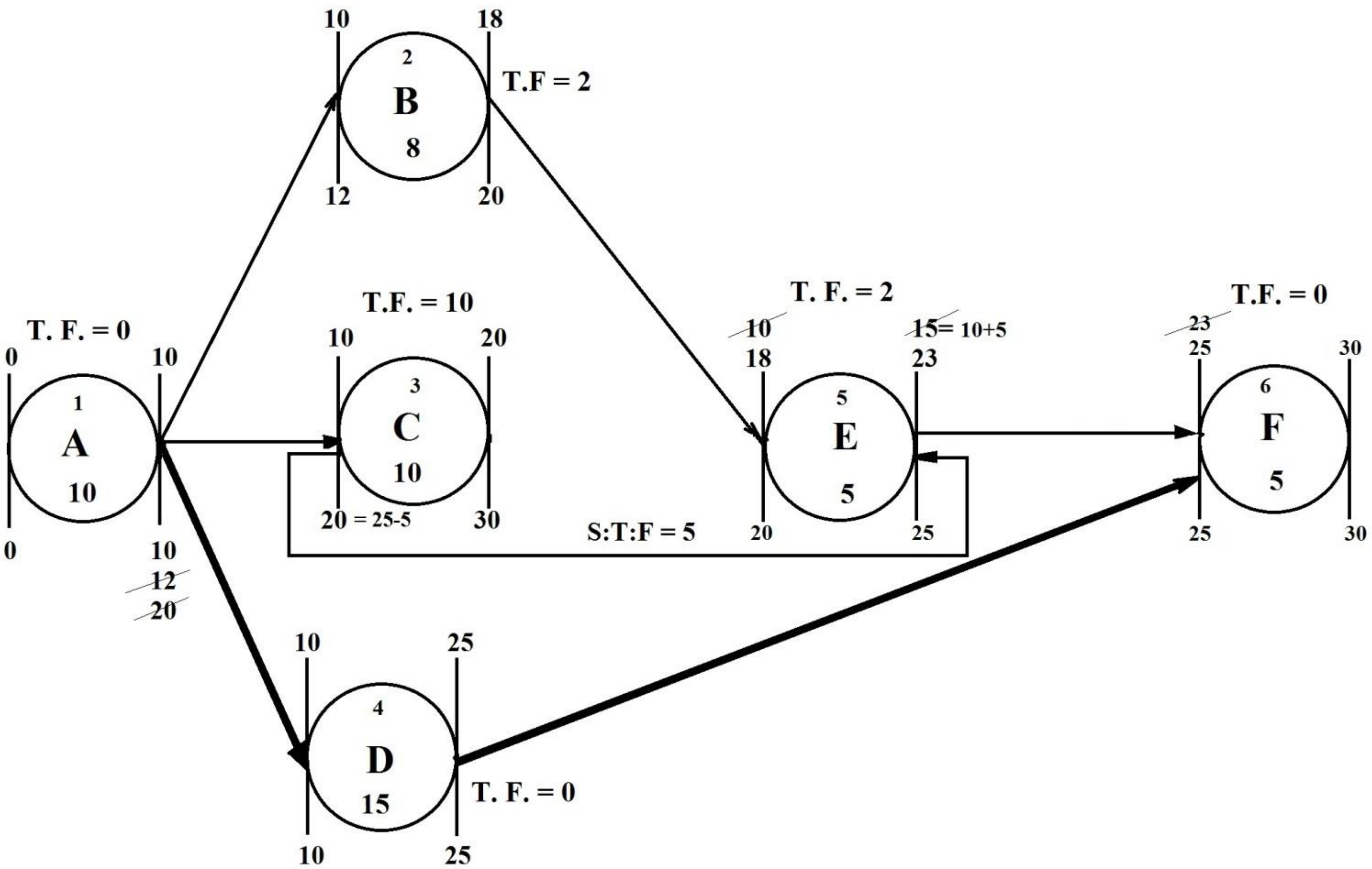
Example 3:- The same previous example but there is a different relationship as shown in table below:

Activity	Duration	Preceded by	Additional Relationship
A	10	--------	
B	8	A	
C	10	A	
D	15	A	
E	5	B and C	C- E = S:T:S= 10 Days
F	5	D and E	



Example 4:- The same previous example but there is a different relationship as shown in table below

Activity	Duration	Preceded by	Additional Relationship
A	10	-------	
B	8	A	
C	10	A	
D	15	A	
E	5	B and C	C- E = S:T:F= 5 Days
F	5	D and E	



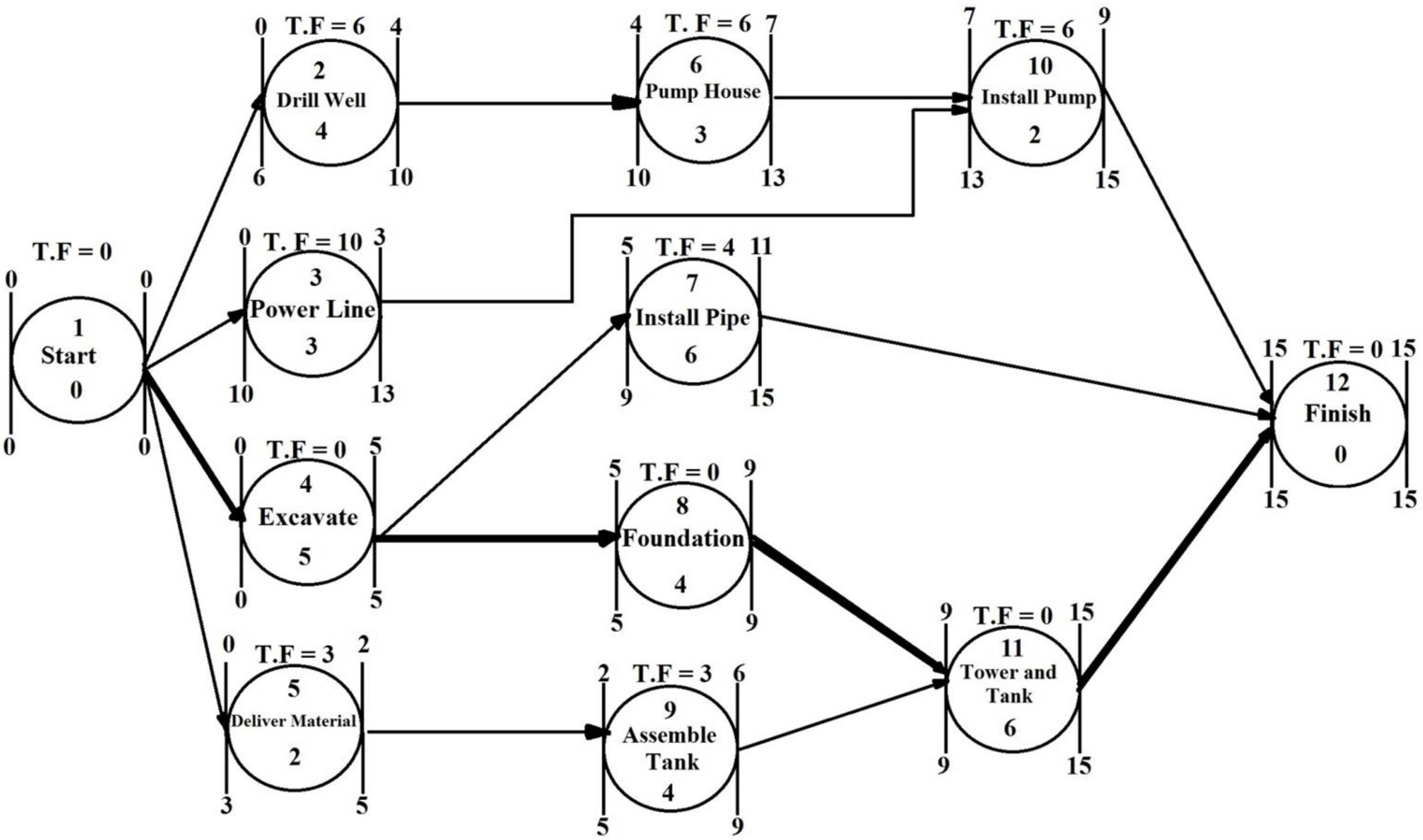
Example 5 A small project consists of number of activities listed in the table below the diagram will be prepared as finish to start relationship and no lag times are used. Try to prepare a work program arrow according to the precedence program.

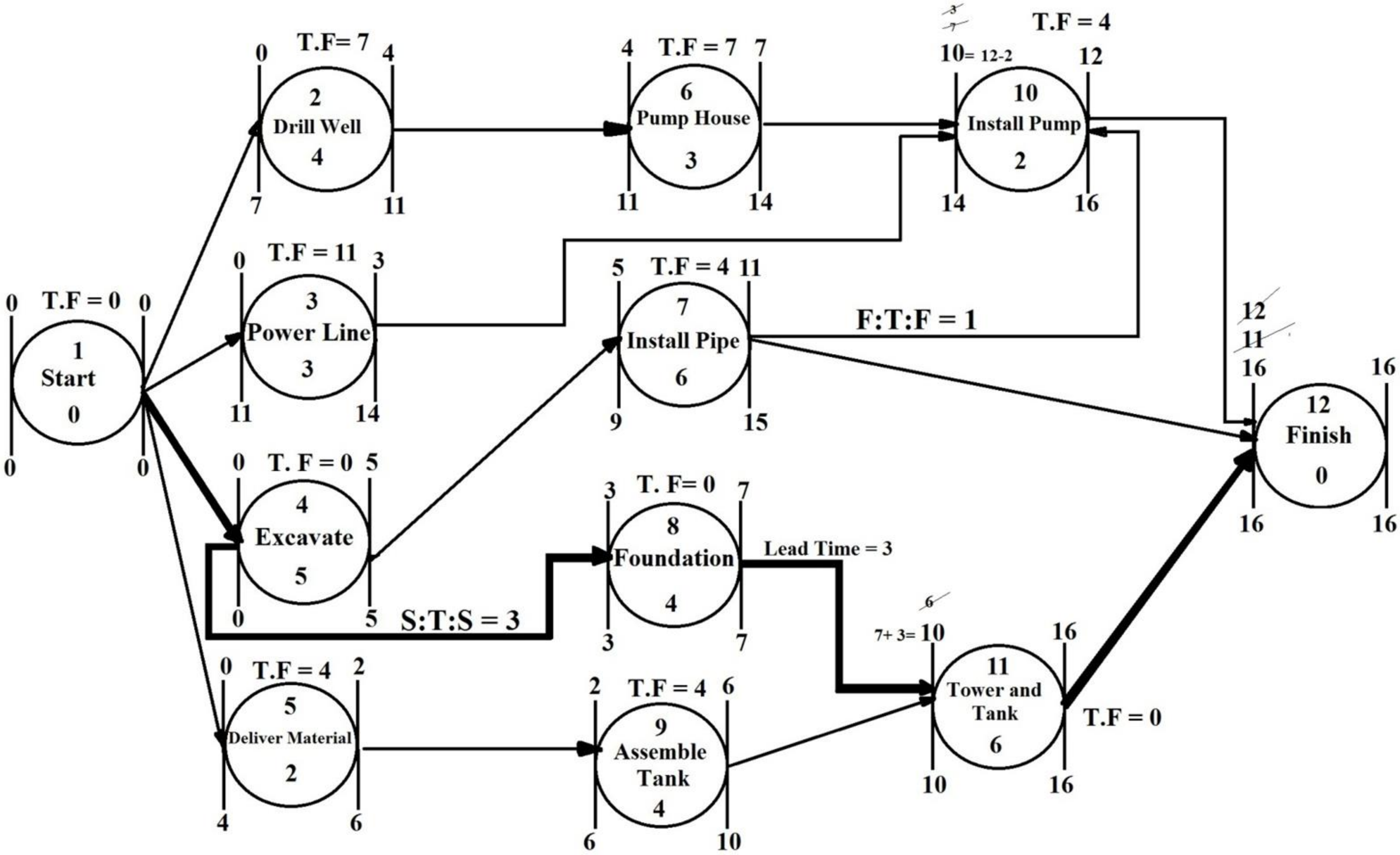
No.	Activity	Duration	Preceded by
1	Start	0	-------
2	Drill well	4	1
3	Power line	3	1
4	Excavate	5	1
5	Deliver material	2	1
6	Pump house	3	2
7	Install pipe	6	4
8	Foundation	4	4
9	Assemble tank	4	5
10	Install Pump	2	3 and 6
11	Tower and Tank	6	8 and 9
12	Finish	0	7, 10 and 11

The solution is shown in the next page:

Now; suppose that the new following logic constraints are added to some activities in this project as following:-

1- The activity (Erection of the Tower and Tank - 11) can not start until 3 d after completion of the foundation (Activity 8)
2- Installation of Pump (Activity 10) cannot be completed until 1 d after completion of Pipe Installation (Activity 7)
3- The Foundation (Activity 8) can start 3 d after start of Excavation (Activity 4).


T.F = 0
1
Start
0
T.F = 6
2
Drill Well
4
T. F = 10
3
Power Line
3
T.F = 0
4
Excavate
5
T.F = 3
5
Deliver Material
2
T. F = 6
6
Pump House
3
T.F = 4
7
Install Pipe
6
T.F = 0
8
Foundation
4
T.F = 3
9
Assemble Tank
4
T.F = 6
10
Install Pump
2
T.F = 0
11
Tower and Tank
6
T.F = 0
12
Finish
0

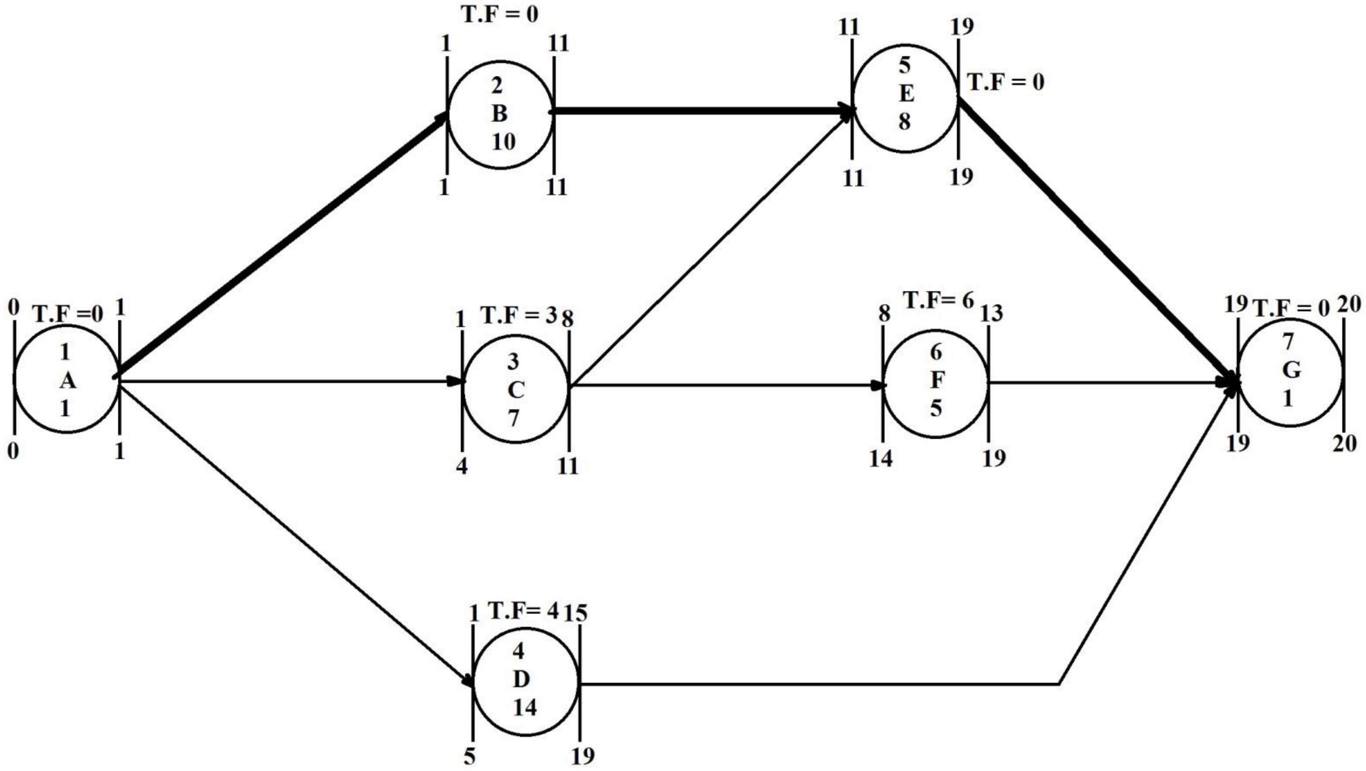

T.F = 0
1
Start
0
T.F= 7
2
Drill Well
4
T.F = 11
3
Power Line
3
T. F = 0
4
Excavate
5
T.F = 4
5
Deliver Material
2
T.F = 7
6
Pump House
3
T.F = 4
7
Install Pipe
6
T. F= 0
8
Foundation
4
T.F = 4
9
Assemble Tank
4
T.F = 4
10= 12-2
10
Install Pump
2
11
Tower and Tank
6
T.F = 0
7+ 3= 10
12
Finish
0
F:T:F = 1
S:T:S = 3
Lead Time = 3

Example 6: The figure below shows the small precedence diagram. It contains seven activities linked by traditional relationships:

The constraints are added to the project activities as following:

A – B as S: T: S = 2

B – E as F: T: S= 3 and F: T: F= 12



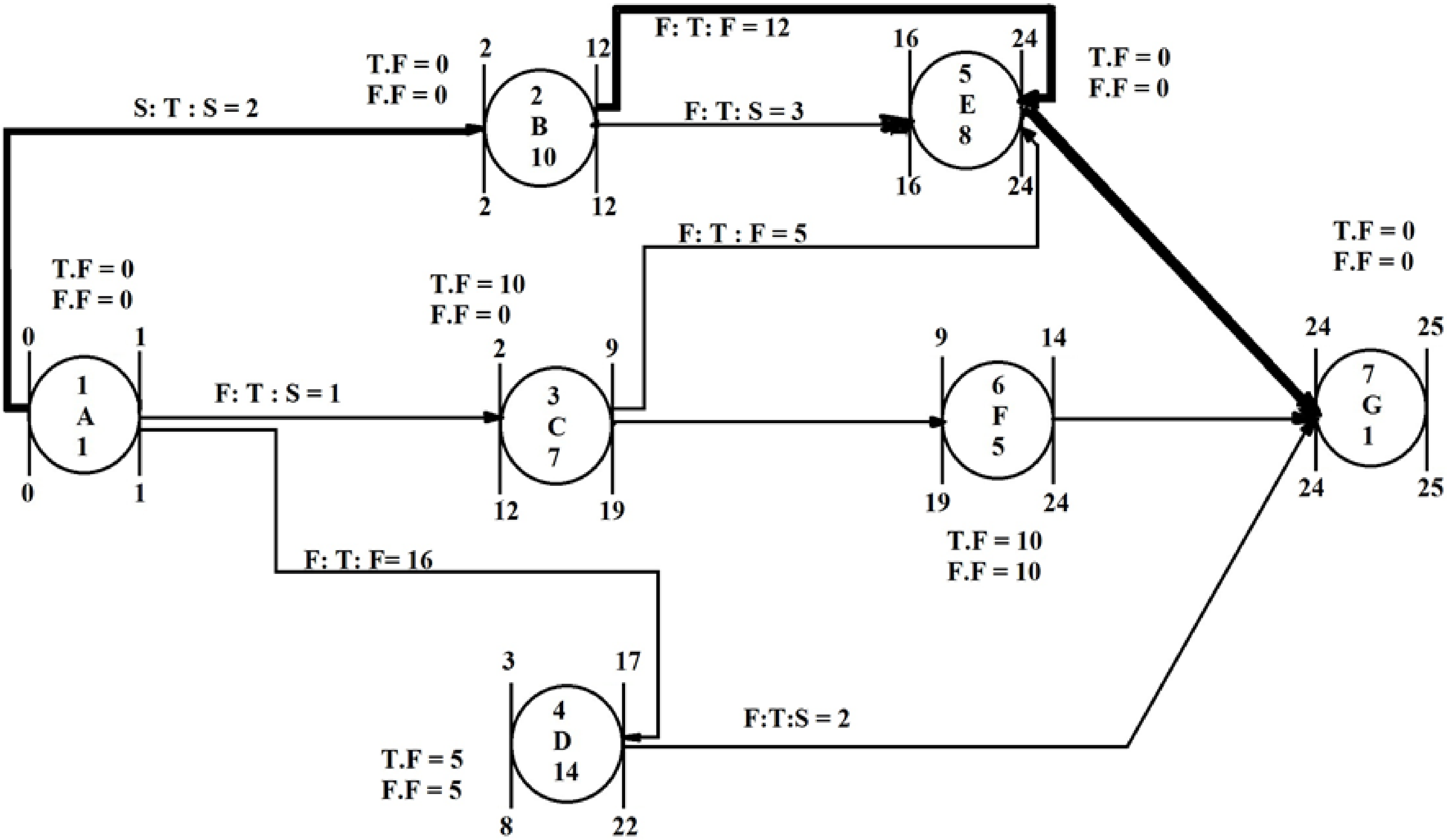
A- C as F:T:S =1

A-D as F: T: F = 16

C-E as F: T: F=5

D-G as F: T: S = 2

Draw the Precedence diagram and state the ESD, EFD, LSD, LFD, T.F, F.F and the Critical Path for this project?


S: T : S = 2
T.F = 0
F.F = 0
2
12
2
B
10
2
12
F: T: F = 12
F: T: S = 3
16
24
5
E
8
16
24
T.F = 0
F.F = 0
F: T : F = 5
T.F = 0
F.F = 0
T.F = 0
F.F = 0
0
1
1
A
1
0
1
T.F = 10
F.F = 0
2
9
3
C
7
12
19
F: T : S = 1
9
14
6
F
5
19
24
T.F = 10
F.F = 10
24
25
7
G
1
24
25
F: T: F= 16
3
17
4
D
14
8
22
T.F = 5
F.F = 5
F:T:S = 2

H.W: A small project consists of 9 activities as shown in table below. State the Earliest Start Date, Earliest Finish Date, Latest Start Date, Latest Finish Date, T.F, F.F and the Critical Path?

Activity	**Preceded by**	**Duration**	**Relationship**
A	--------	2	
B	A	3	A- B S:T:S = 2
C	A	4	C-A F:T:F = 4
D	B and C	5	C-D S:T:S = 8 and C-D F:T:F= 3
E	B and C	4	B- E F:T:F = 4
F	C	3	F-G F:T:F = 6
G	D, E , and F	6	D-G Lead Time = 3
H	E and F	4	
I	G and H	2	I-H S:T:S= 3

10- TIME COST RELATIONSHIP

In the previous lectures, we identified the methods of calculating the total time of the project by calculating the time for each project activity and the critical time of the project (through the critical path). The methods of calculating the time were identified in different forms.

In this lecture we will identify the simple relationship between the cost of the project (or the cost of the activity for each project) with time or change at the time of the project.

There are three different terms that refer to one meaning:

Time Cost Adjustment

Time Cost Relationship

Time Cost Trade off

The above terms indicate the time change and the impact of that change on the cost of the project.

When the project manager sets the implementation plan for the project assigned to him, he puts in his accounts to maintain the time and not to exceed the time scheduled for implementation as well as the case of cost accounts will be parallel to the plan and not to exceed the cost of discretion is the same goal desired by the employer.

Sometimes there is a need to accelerate the pace of work and reduce the duration of completion.

We have to identify, even if only slightly, the costs that are calculated in the completion of the project.

CRASH (COMPRESS) THE PROJECT TIME

After completion of project scheduling and knowing the total time to complete the project, there is sometimes an urgent need to shorten the project time for the following reasons:

1- The owner sometimes imposes on the contractor the completion of the project in less than the estimated duration at the scheduling stage or else the contractor will be subject to the payment of delay penalties.

2- Sometimes the owner asks the contractor during the execution of the project to complete the rest of the project so that the project completion time is less than the time stipulated by the contract before, and ask the contractor to introduce new prices to shorten the project time.
3- Sometimes the contractor wants to finish the project in less time to avoid any of unexpected adverse climatic conditions ahead.
4- Sometimes the contractor is forced to terminate the project in less time, in order to devote another project or before the end of the financial year to receive his dues quickly.
5- Sometimes the contractor resort to reduce the period of completion of the project to get incentives from the owner.
6- The contractor shall have to crash the project time in the event of several delays throughout the project and there is an urgent need for recovery the time for such delays before the end of the project.
7- The Contractor shall have to compress the project time in order to deliver parts of the project at specified times.

The profit achieved by the contractor through the contracting contract shall be the result of the difference in the price of the contract concluded with the employer for the actual costs that he spends on the project according to the following equation:

Max. Gain = Bid Price-Total Cost -- (1)

Whereas-:

Max. Gain: The highest profit (or expected profit) of the contractor.

Bid Price: The amount of the contract concluded between the employer and the contractor.

Total Cost: All actual costs incurred by the Contractor during the project completion period

The total cost is equal to:

Total Cost = Direct Cost + Indirect Cost ----------------------------------- (2)

What do Direct Cost and Indirect Cost mean? Direct Cost refers to the following (for example) - :

The cost of the raw materials used for the completion of the project - cement, iron, sand, bricks, gravel, wood, etc.

Wages of workers to complete the project

Fees or costs of machinery and equipment used during the completion of the project (Excavators - Mechanical shavings - Material transport trucks to the site –

Indirect Cost refers to the following (for example)- :

1- Main administrative costs (Main Office Cost)

2- Costs for supervisors (supervision) or other costs for workers such as guarding.
3- Costs of logistical support such as electricity, communications and water.
4- Fuel costs for operating machinery and equipment

There is a relationship between the resources used and the time needed to complete the project or achieve any project activity as well as the size of the project or the size of the activity.

Method of shorten (reducing) the project time

When project time is compressed in order to decrease the project completion time, focus should be placed on shortening the critical path length of the project. If you want to end a specific activity at an earlier time, focus on shortening the longest path in the network leading to this activity from the start of the project.

it is noted that the successive pressure of the project time leads to decrease in the float (total float) in periods of activity and then to the lack of it, which in turn leads to create the new critical paths in the network, and when appeared any new critical path in additional to the original critical path, the new one will be in consideration of the following stages of the process of shortening the project time.

The relationship between time and cost must be studied well, especially when gained the time and the cost is sacrificed. There are two concepts that need to be known: Normal Time: the time when work is done in its usual or natural form, and the concept of Normal Cost is accompanied. If it is thought to reduce or reduce the estimated time or time to complete the activity, so there is the Crash Time, faced by the compressed cost or the (Crash Cost). Some project activities may be of a nature in which the normal time does not vary with the compressed time, so that the time for achieving the activity cannot be reduced.

It should be noted that there is a relationship between the time of completion of the project and the direct costs or indirect costs that relationship can be written as follows:

For the Direct cost;

$$\text{Time} \propto \frac{1}{Direct\ Cost}$$

For the indirect cost, the relationship is simply as follows:

$$Time \quad \propto Indirect\ Cost$$

The Direct costs or other direct resources will increase when the time to be completed is reduced and vice versa for indirect costs (the increase in indirect costs will be a continuous increase with increasing time and less reduction). The following diagram illustrates the relationship between normal time and its reduction with cost separately.

The figure above showing the relationship between natural project time and its natural cost.

While the following figure represents the relationship between the reduced time (Crash Time) and the cost that will increase accordingly.

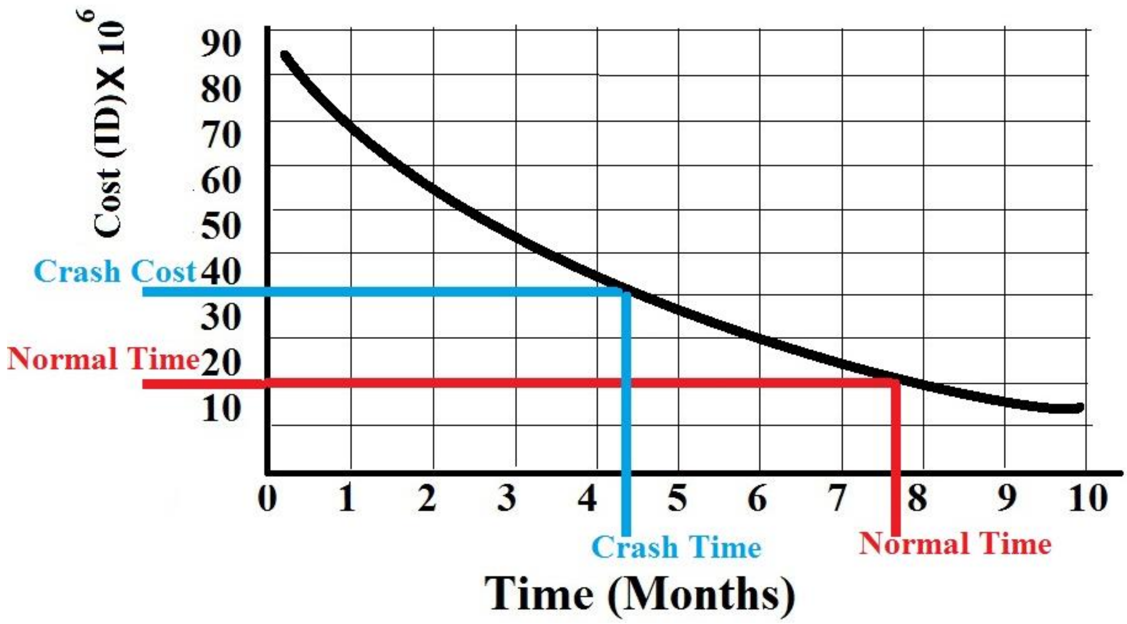
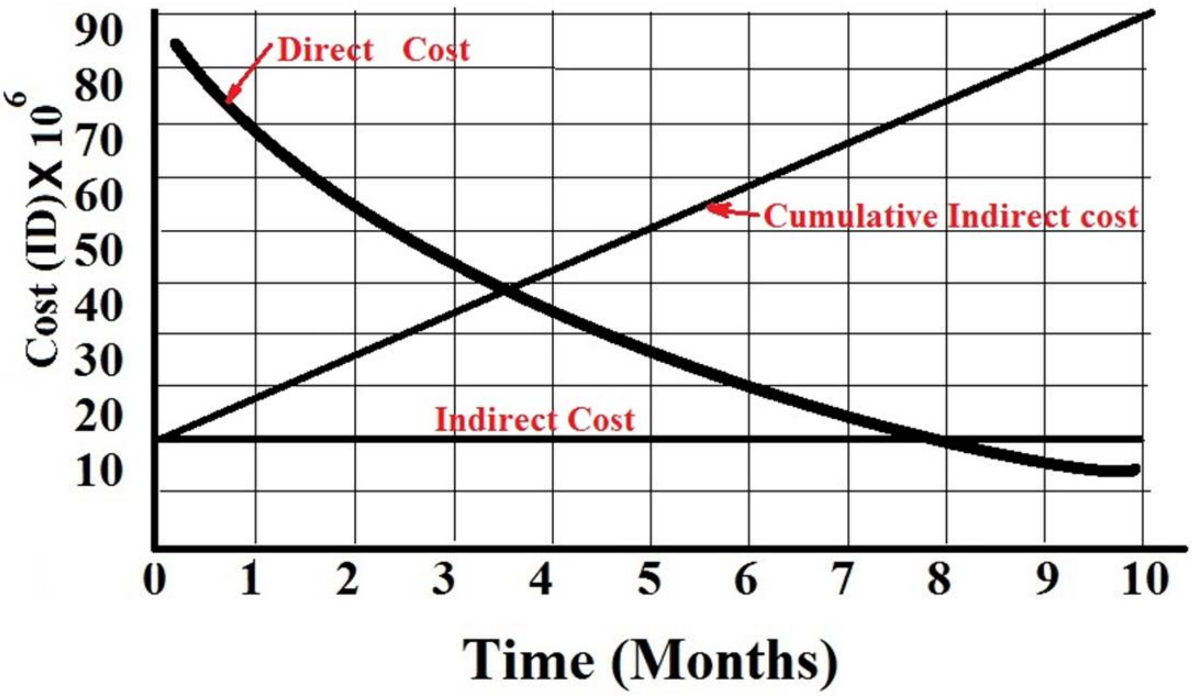


Figure above showing the relationship between the time that has been reduced and the cost required by that reduction.

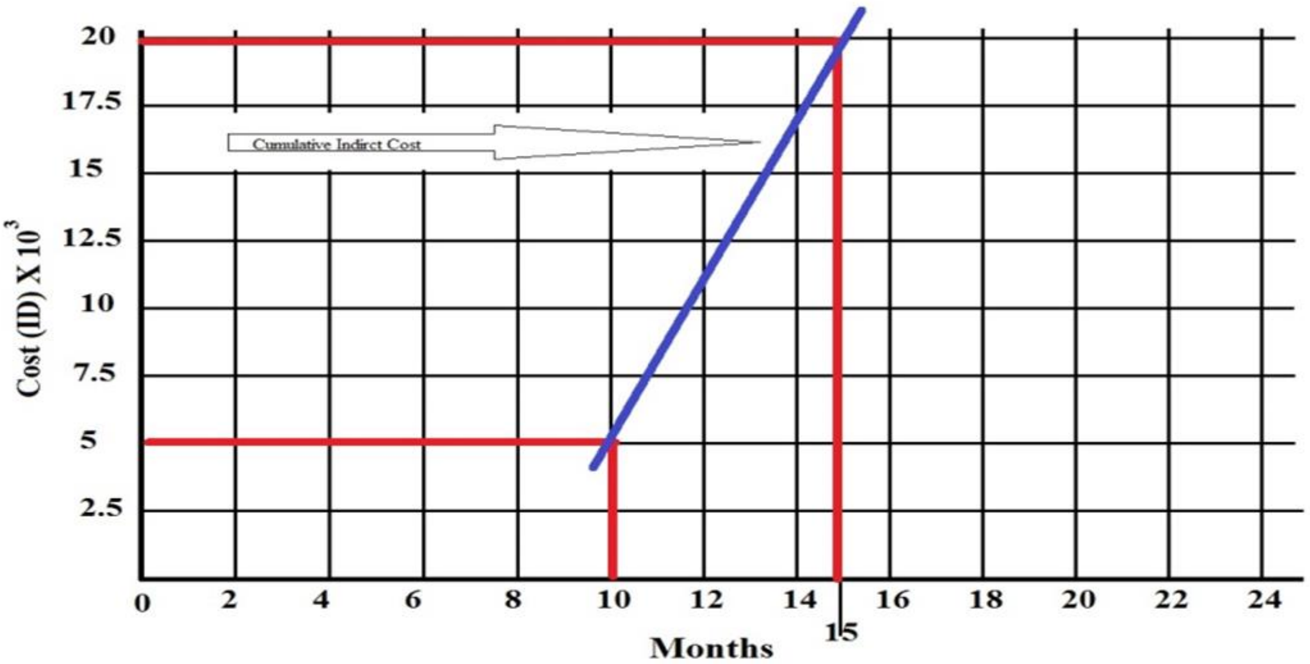


Example 1

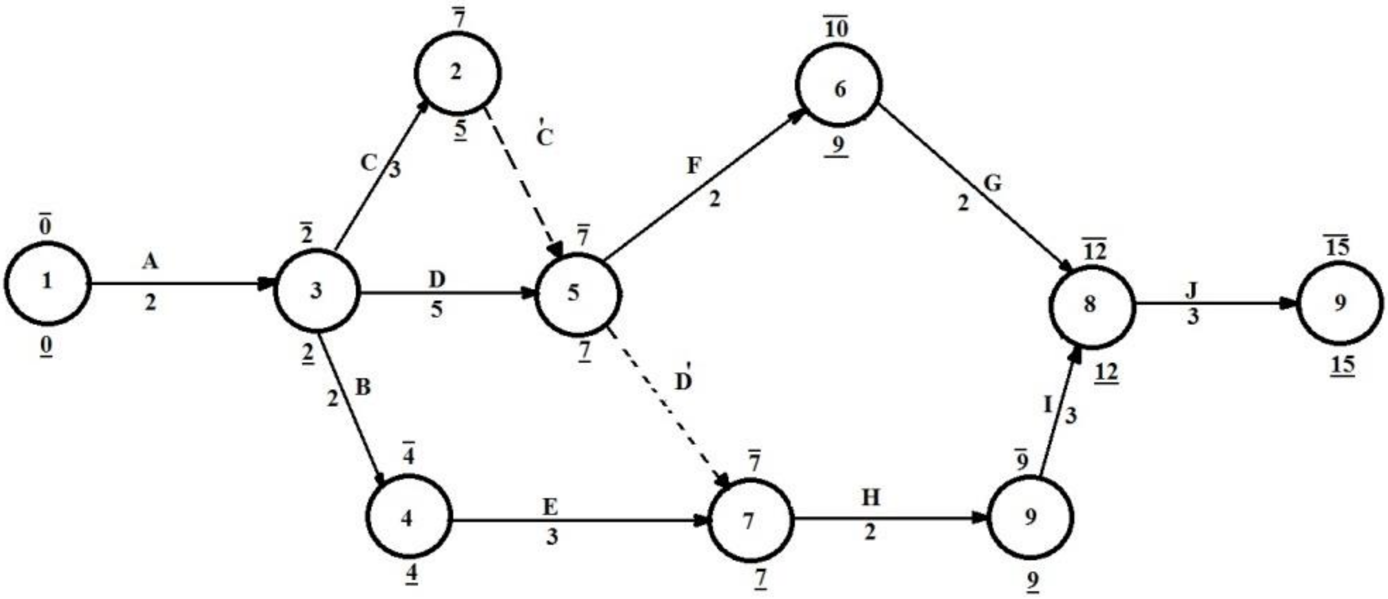
A small project consists of several activities as shown in table below.
The contractor wants to reduce the Total project duration and the plan aims to achieve the optimum cost against to the minimum of the executing time?
The cost slope also described in the figure below and all the other information also provided.

Activity	Duration	Preceded by
A	2	--------
B	2	A
C	3	A
D	5	A
E	3	B
F	2	C and D
G	2	F
H	2	D and E
I	3	H
J	3	G and I

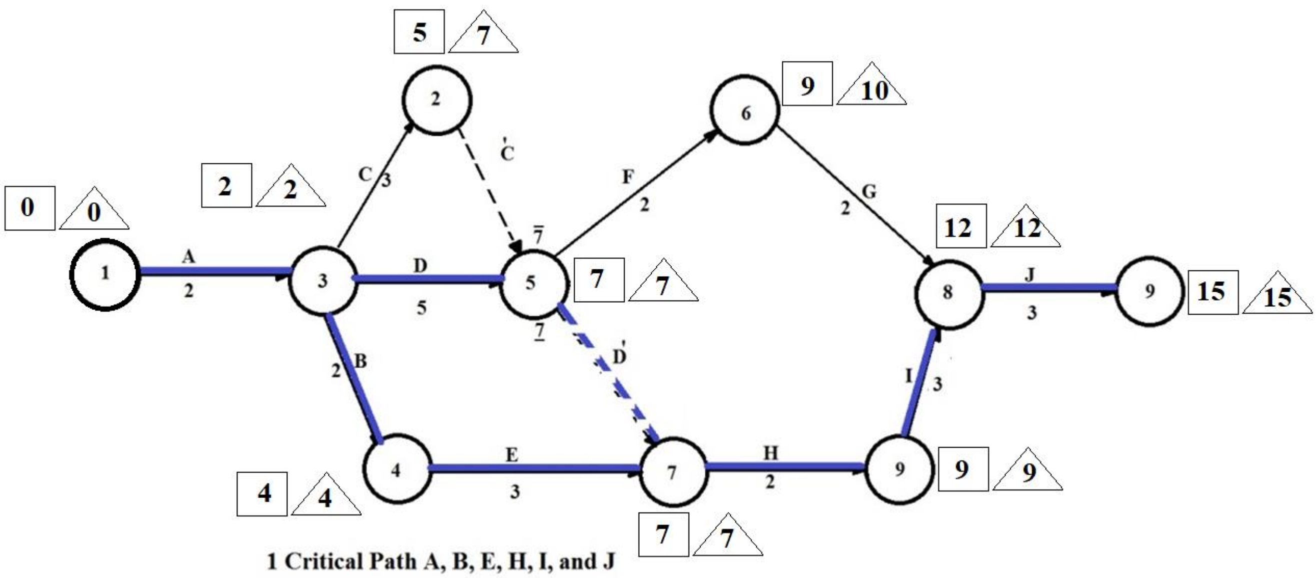
Activity	Duration Month		Direct Cost $ $x\ 10^3$		Rate	Freq.
	Normal	Crash	Normal	Crash		
A	2	2	10	10	--------------	
B	2	2	15	15	--------------	
C	3	1	12	13	13-12=1 /2=0.5	
D	5	2	10	13	13-10= 3 / 3=1	2,3
E	3	1	14	16	16-14=2 / 2=1	2,3
F	2	1	11	13	13-11=2 / 1=2	4
G	2	1	16	19	19-16=3 / 1=3	
H	2	1	13	16	16-13=3 / 1=3	4
I	3	2	18	19	19-18=1 / 1=1	1
J	3	2	11	17	17-11=6 / 1=6	5
Total	27	15	130			



1. Draw the project (Network) diagram and determine the date of start for each activity depending on the duration of its specified time.



2. Define the critical path of the project. We may see more than one critical path sometimes and then calculate the indirect cost of the project.



1 Critical Path A, B, E, H, I, and J

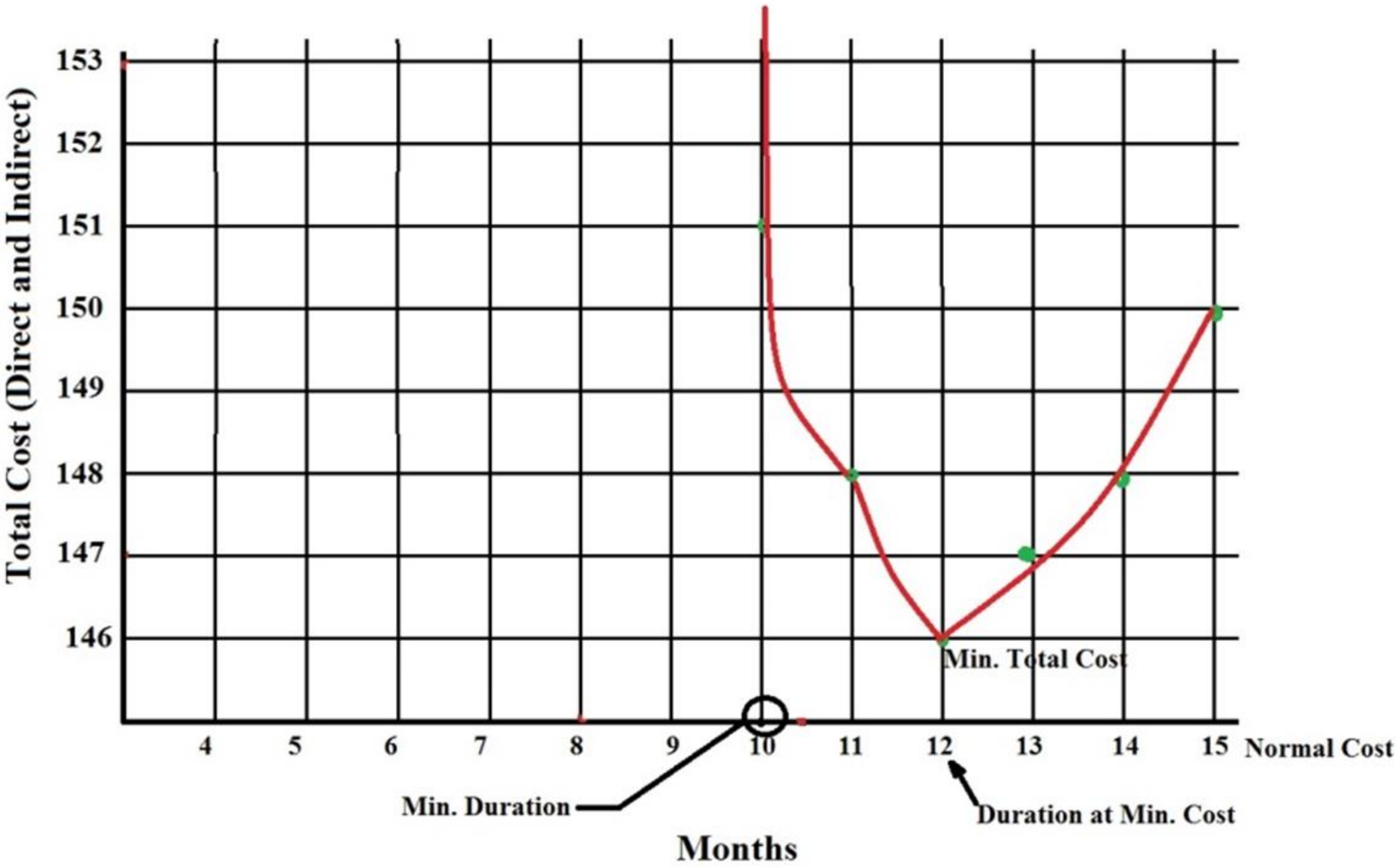
2 Critical Path A, D, D', H, I, and J

3. The total indirect cost of the project is $ $10x10^3$ and because the project is completed within 15 months, the cost of one month are:

   Indirect cost / month $=\frac{20,000-5,000}{15-10} = \$\ 3,000$
4. Activities on the critical path are those whose time can be reduced durations
5. Look for activity that can reduce the duration.
6. Look at the lowest-cost activities on the critical path.
7. There are critical activities and need to reduce or activities need to reduce, we look for cheapest one and reduce the time.
8. The total project duration is calculated as (15) days and according to the above:
9. Starting with activity (I), because it is located between the two critical paths, and it is cheapest than the rest of the activities and is reduced for one day (the period allowed) as stated in the previous table and then we calculate the total period of completion of the project which became after this reduction (14) days.
10. Look; then at which activity can be reduced at the same time at a lower cost. We then reduce the duration of both the activities (D and E) together because they have a single cost impact.
11. Then; go back and look at which activities can be reduced at a lower cost then go again and reduce the duration of both (D and E) because they have one cost effect, as in the previous paragraph.
12. Then go back and look at which activities can be reduced at a lower cost and then decrease the duration of both (F and H) because they have one cost effect, as in the previous paragraph.
13. Then go back and look at which activities can be reduced time and cost less, then we reduce the duration of the activity (J) because it is only left, although the proportion of the impact on the cost is equal to 6.
14. Each step in our procedures we try to note the cost and time and the impact of this change in time on the direct and indirect cost.
15. We note that after the activity reduction (J), the total time required to complete the project is 10 days and the total cost (direct and indirect) is $ $151x\ 10^3$. If another attempt is made, it is not useful and the cost will increase at the same time.
16. The following table shows the reduction ratios for the activities in the critical path with their cost.

Action	Duration (Normal)	Direct Cost $	Indirect Cost $	Total Cost $
Normal Start	15	130,000	20,000	150,000
I	14	131,000	17,000	148,000
D and E	13	133,000	14,000	147,000
D and E	12	135,000	11,000	146,000
F and H	11	140,000	8,000	148,000
J	10	146,000	5,000	151,000
All Crash	10	153,000	5,000	158,000

Activity C = 2x 500 = 1,000
Activity D = 1x1, 000 = 1,000
Activity F= 1x2, 000 =2,000
Activity G= 1X3, 000 =3,000
And the same process for the other activities which reduced their durations:

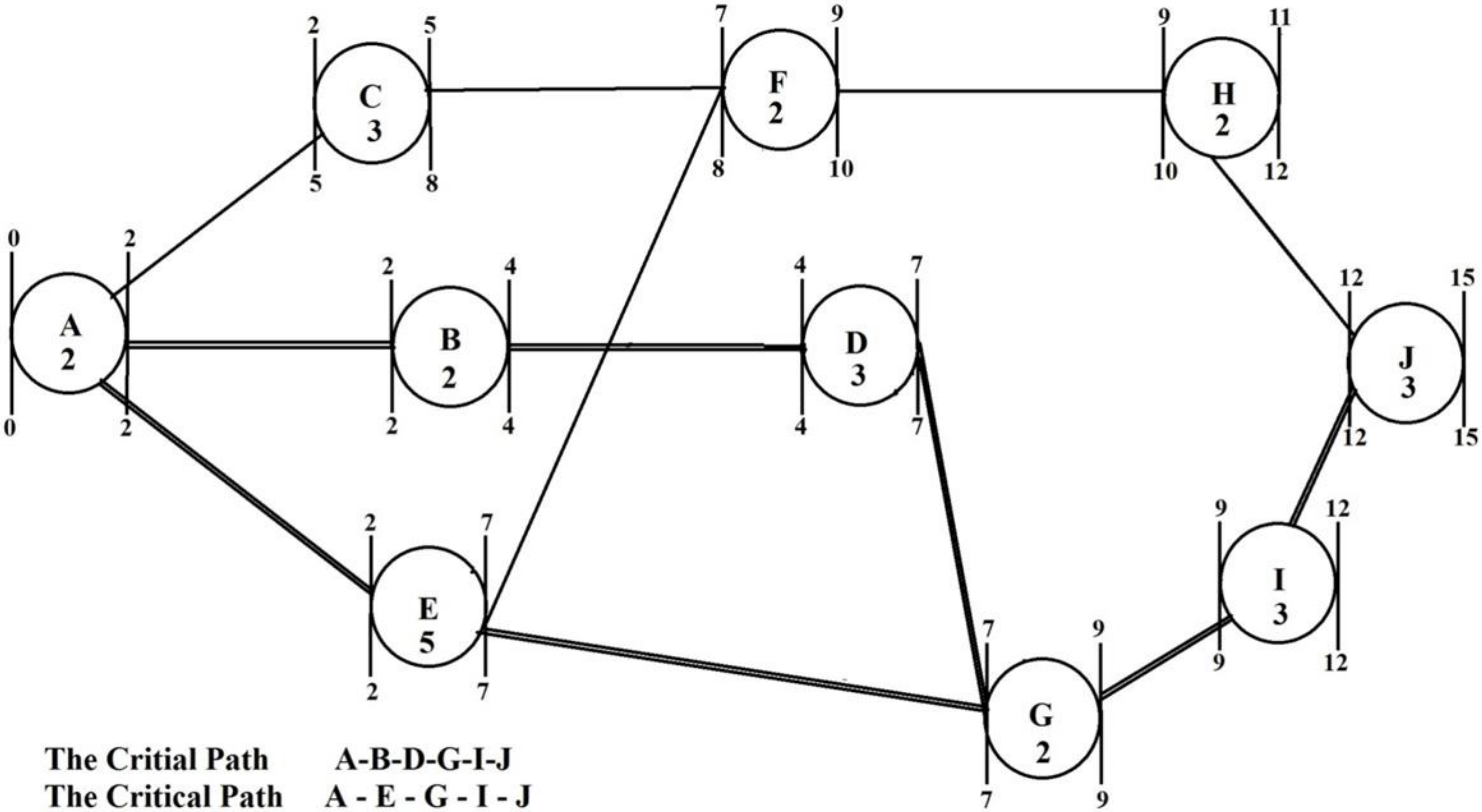


Example 2: The time and cost analysis is required for planning of a small project in precedence diagram. Draw the total cost curve showing the relationship between the total cost and project duration. Determine the minimum total cost if the management decided to finish the project with the minimum possible duration the follow are data available for your analysis.

Activity	Duration	Preceded by
A	2	--------
B	2	A
C	3	A
D	3	B
E	5	A
F	2	C and E
G	2	D and E
H	2	F
I	3	G
J	3	H and I

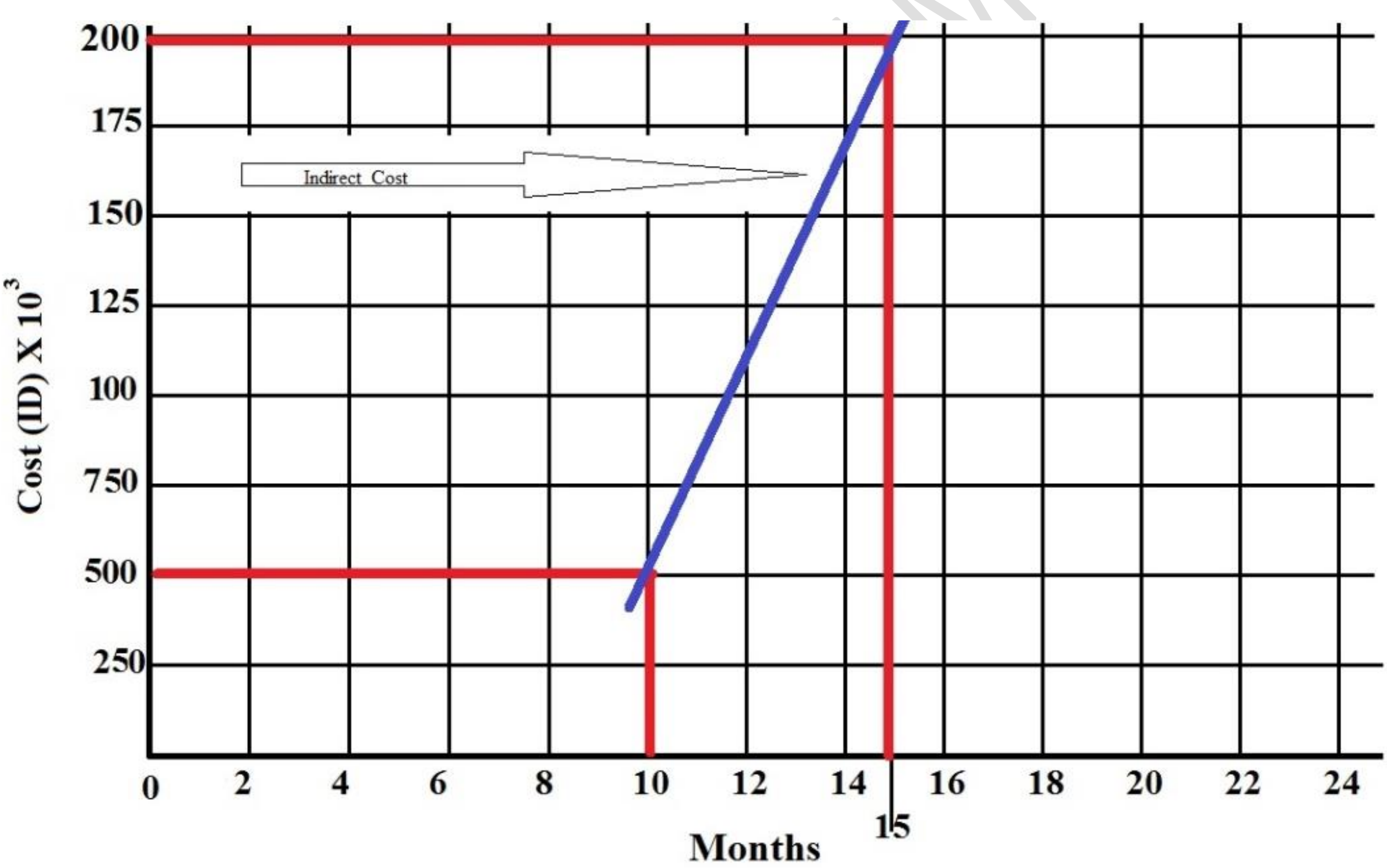
Solution

The first step to draw the Node network diagram; see the following diagram



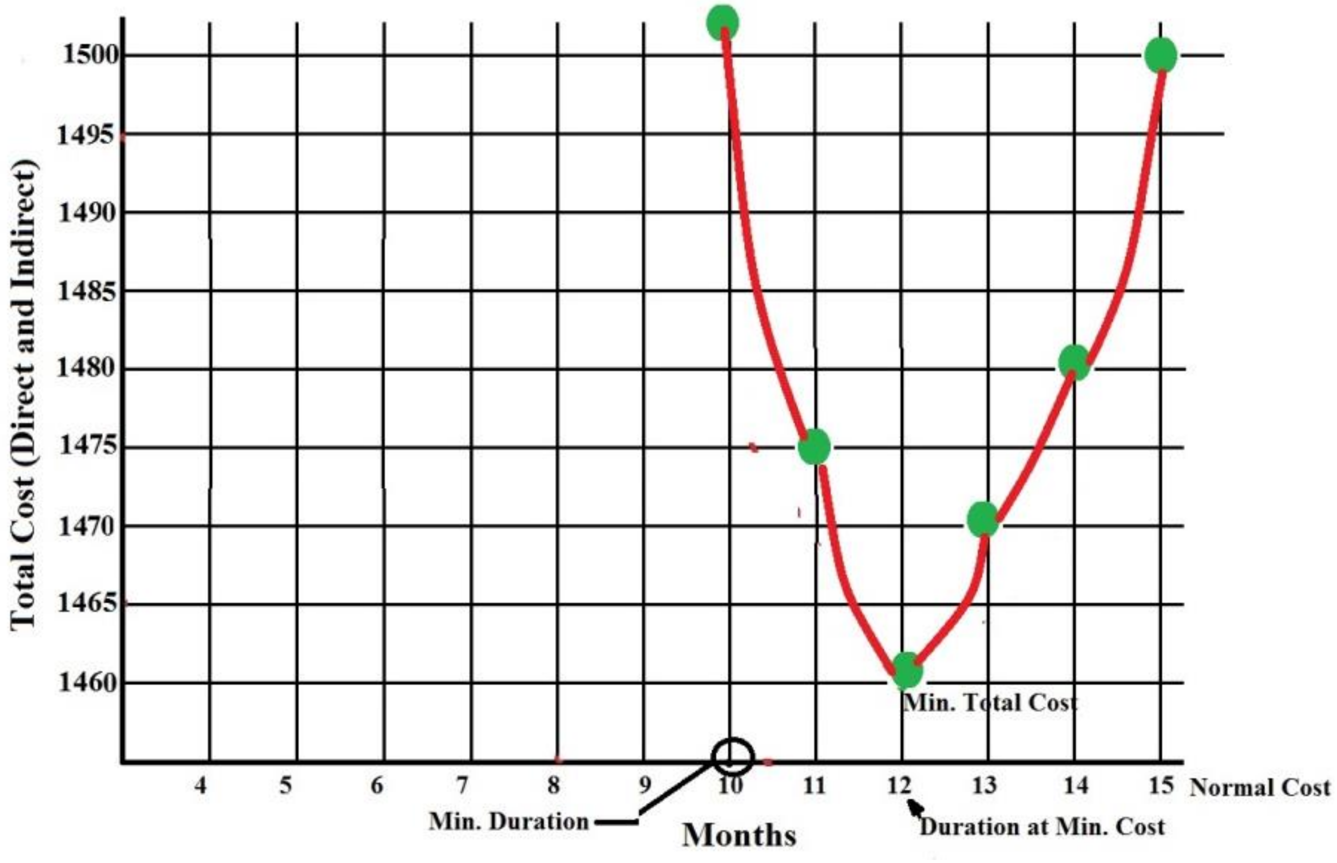
The Critial Path A-B-D-G-I-J
The Critical Path A - E - G - I - J

Activity	Duration Month		Direct Cost $		Rate	Freq.
	Normal	Crash	Normal	Crash		
A	2	2	100	100	--------------	
B	2	2	150	150	--------------	
C	3	1	120	130	130-120=10/2 =5	
D	3	1	140	160	160-140=20/2=10	
E	5	2	100	130	130-100=30/3=10	
F	2	1	110	130	130-110=20/1=20	
G	2	1	130	160	160-130=30/1=30	
H	2	1	160	180	180-160=20/1=20	
I	3	2	180	190	190-180=10/1=10	
J	3	2	110	170	170-110=60/1=60	
Total		15	1300			



Indirect Cost for each month= $\frac{(200-50)x1000}{15-10} = \frac{150,000}{5} = \$\ 30,000$

Action	Duration (Months)	Direct Cost $	Indirect Cost $ x10^3	Total Cost $ x10^3
Normal Start	15	1300	200	1500
Reduce time of Activity I	14	1310	170	1480
Reduce time of Activity D and E	13	1330	140	1470
Reduce time of Activity D and E	12	1350	110	1460
Reduce time of Activity C, E and G	11	1395	80	1475
Reduce time of Activity J	10	1455	50	1505
Reduce time of Activity C, F and J	10	1500	50	1550



11- Planning for Construction the allocation of resources

Introduction

So far in the preceding chapters, network analysis has been considered using one resource only, that is, it has been a time-only network. The resource or money has entered into the consideration of the network only in so far as the duration has to be optimized or costs have been collected. The assumption which is implicit in the use of a time-only network, is that all the resources required to carry out the job are available as and when required. Such an assumption implies, for example, that on a construction site, not only will all the labor be available as required but that it will be available in each category of skill required at any one specific time in the program. It implies that the necessary plant will be available as required. A time-only network, for instance, may assume that three large mechanical excavators will be on the site for two or three weeks, only to send them away for three weeks and bring them back again for another short period subsequently. This is obviously uneconomic and some consideration must be given to the high utilization of the available resources in planning a project.

On any contract it is undesirable that there should be peaks of labor employment at a number of different points in the contract. Not only is it bad for the morale of the labor force that there should be sackings one week and additional men taken on a few weeks later, but the very action of getting rid of labor and re-engaging them is an expensive one. In addition, new men are bound to be less efficient during the period in which they are becoming accustomed to their new surroundings, and their supervisors need time in order to assess their capabilities. Contracts offering security of employment for long periods have a distinct advantage when attracting labor which may be in short supply.

From the above points of view it is desirable that there should be as even as possible demand for labor over the whole of the contract period with a smooth increase in the numbers required at the beginning of the contract and a smooth tailing-off at the end. This becomes the first problem of resource allocation that of smoothing or levelling the demand for labor within the specified project time. The smoothing or levelling that will be achieved will almost never be perfect, but a solution is sought as near the optimum as possible.

The nature of the other problem that can be tackled in resource allocation is that of optimizing the project duration, knowing that there are certain restraints as to the quantity of resources that will be available during the project. A very critical situation of this nature arises more often in the factory type of production, where casual labor is not employed to such a great extent as in construction work, and perhaps in a maintenance group there will be a more or less fixed number of key tradesmen. Such a situation might well occur, however, in construction work in, for example, an under-developed country where the key labor has to be imported from far afield. If, for example, twelve carpenters are brought in to do a particular job, the project must be scheduled on the basis that a maximum of twelve will be available, since it may take some weeks to obtain additional men at the site.

There are many sophisticated resource allocation computer programs available and the use of a computer is the only rational way in which to tackle such a problem to any depth. Even by the use of a computer there must always be the element of human judgment in the end, since a computer will never be able to smooth to the last degree or to work within resource restraints on every occasion, giving always an acceptable program schedule. Even without computer programs, there are many methods of allocating resources with different degrees of sophistication, from the brief visual check to some form of systematic tabular approach to the problem.

Resource aggregation

Resource aggregation is simply a summation on a time-period basis, for example, day to day or week to week, of the resources which are used in order to carry out the program. Figure **(11.1)** below illustrates a simple bar chart to which has been added the total labor requirements on a weekly basis for each individual operation. Along the bottom of the bar chart the totals are added up, forming a resource aggregation. These totals may be plotted in graphic form as indicated below the bar chart. The variable demand for labor will be seen by the fluctuating level of the chart and, obviously, some attention needs to be given to the program if this is to be smoothed or levelled satisfactorily. In comparing this bar chart with a network diagram, it becomes clear that the former is an attempt in precise terms to set the activities between fixed dates. This is not the case with a network diagram where only the critical activities are tied to performance at fixed times and the remaining activities in the network have float and thus can be varied in time. It will be appreciated therefore, that, whereas the bar chart as it is shown lends itself to the formation of a unique resource aggregation graph the network diagram has a certain amount of flexibility. For instance, if the bar for the floors in the bar chart, which may have float in the network, can be moved to weeks 5 and 6, this is obviously going to affect the smoothness of the resource aggregation.

For a program represented by a network diagram there will be a number of resource aggregation graphs, depending where in time the activities with float are actually carried out" Nevertheless, having carried out a network analysis for a project and having arrived at an optimal duration in the view of limited resources or alternatively having settled on a fixed program duration, the resources can then be aggregated to advantage. Making a further visual inspection of the bar chart in Figure **(11.1)** below, clearly, with the peak of labor as it is in the second week,

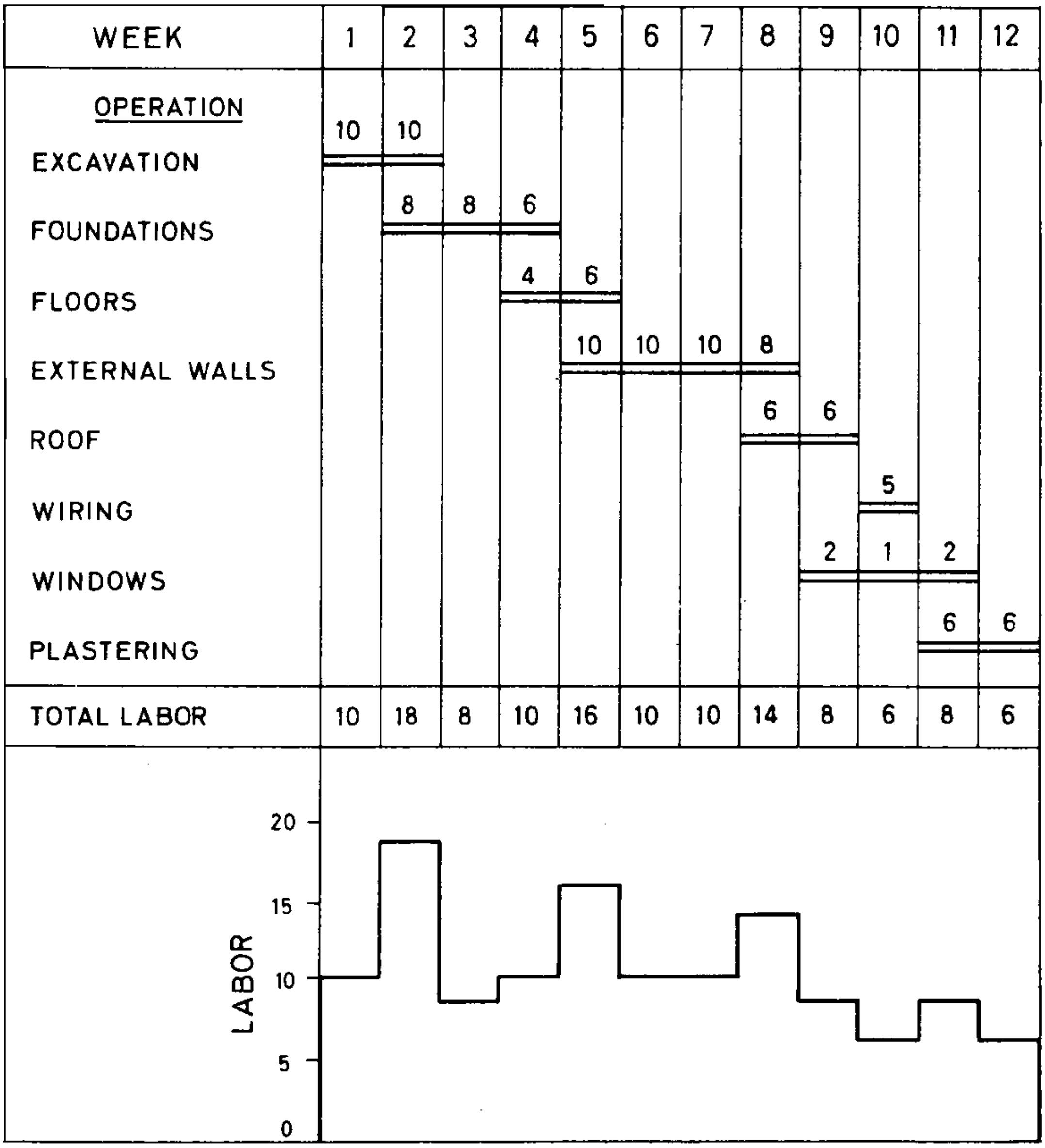


Figure (11.1) a simple bar chart to which has been added the total labor requirements on a weekly basis for each individual operation

it is desirable either to extend the excavation into week 3 and reduce the labor demand over the three weeks or to delay the commencement of the work on the foundations for a few days in order to reduce the immediate demand of labor for this work. Alternatively, it is possible to make a combination of both these adjustments in order to get rid of the peak of eighteen men in week number 2. Similarly, in weeks 5 and 8 it is desirable to make some adjustment to the program to smooth resource demand at these points. This is a simple program and the smoothing and levelling can be carried out by eye and manual calculation.

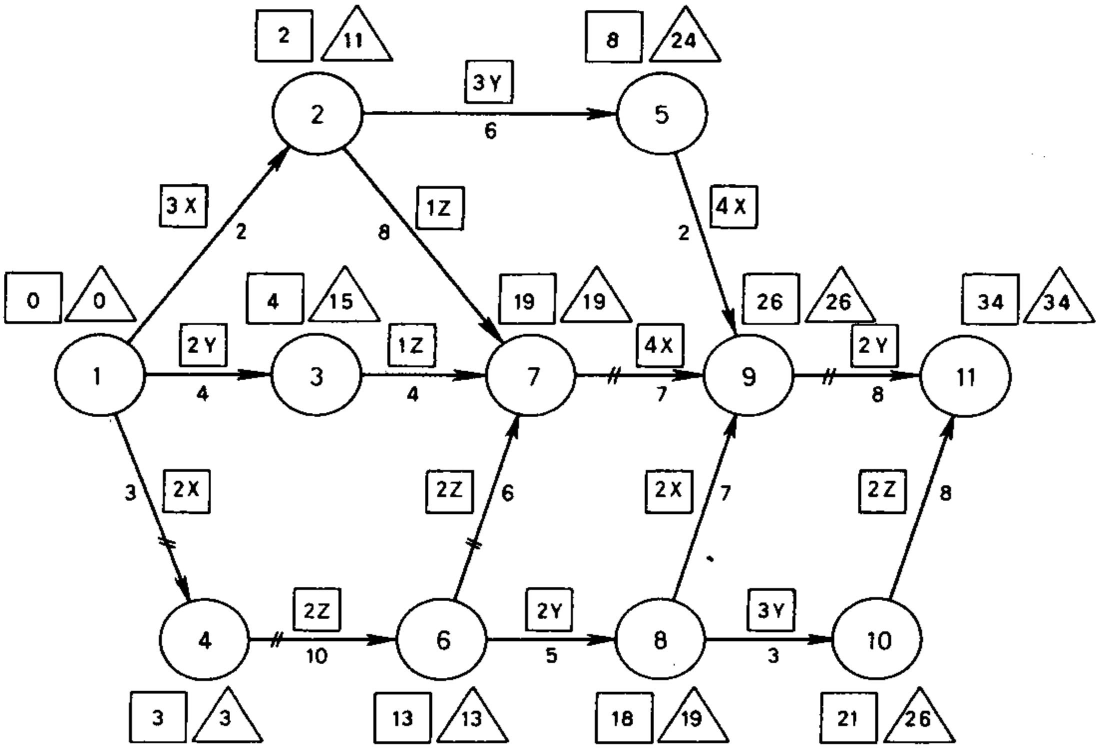


Figure (11.2) a simple example network

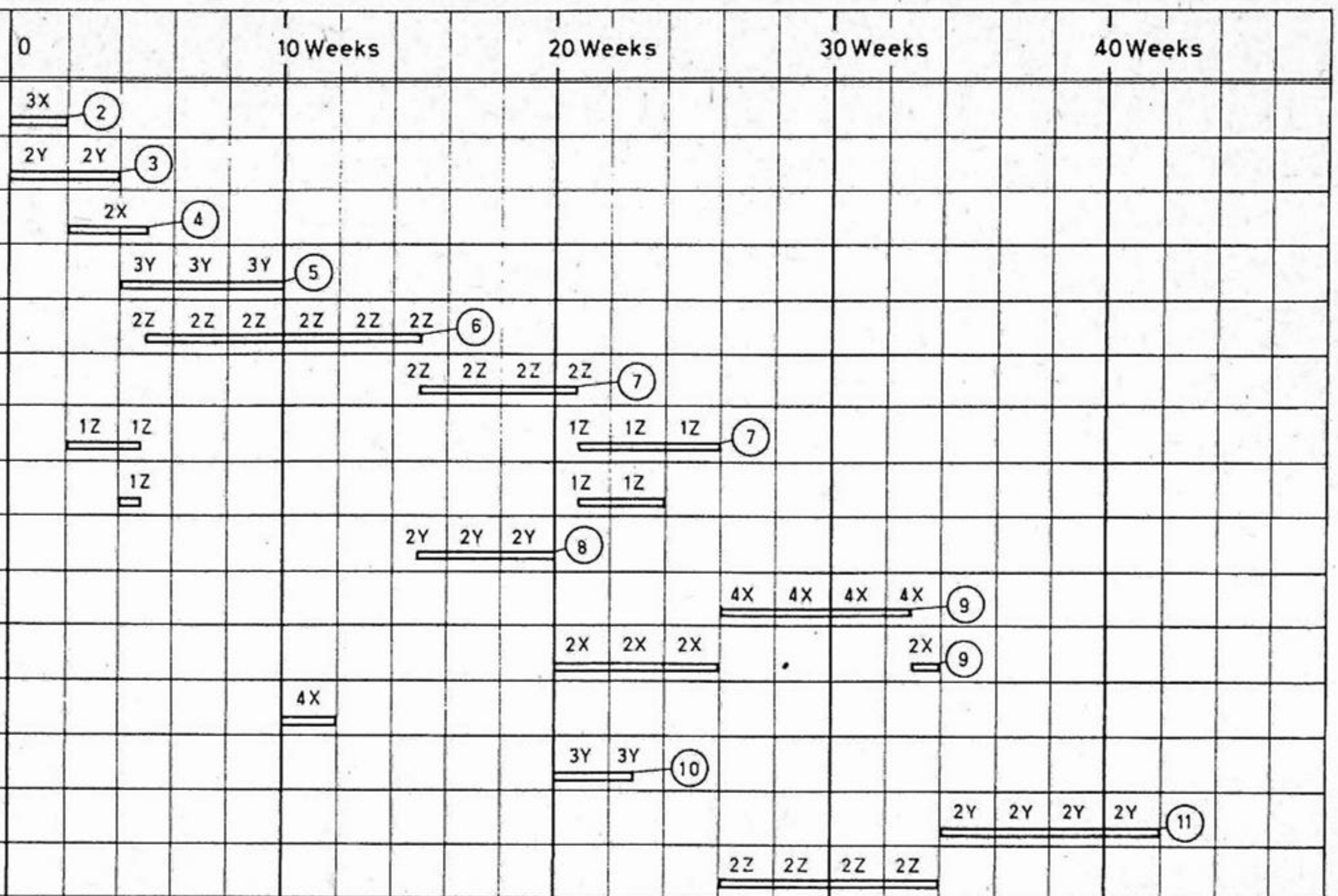
Priorities and sorts

Figure **(11.2)** shows a simple example network comprising eleven events and fifteen activities. The network has been numbered in serial fashion from left to right and the duration in weeks of each activity has been placed against the arrows. The forward and backward passes have been carried out and the duration of the program is established at thirty-four weeks. Against each arrow in a box is shown the resource requirement of each activity. This requirement is the minimum amount of resource required to do the work. For example, against activity l-2 is shown 3X, which means that 3 units of resource X are required throughout the duration of the activity 1-2. For simplicity X has been chosen to represent a particular type of tradesman. Of the three types of resource required, X, Y and Z, it is assumed that not more than four, three,4fld two units respectively of the resource are available at any one time. It is required to establish a program for carrying out the project represented by the network in such a way that demand for these resources will never be exceeded during the project duration.

First of all, the activities making up the network must be listed in order of their priority of resource allocation so that there must be some means of sorting the initial sequence. One thing which has been established by the network diagram- is the logical sequence of activities, giving a clear indication of those activities which must precede others. The order in which the activities are listed must, if they are to be dealt with from the top of the list to the bottom, reflect the dependency of some activities on the preceding

completion of others. The process of arranging the activities in a list to certain specified rules and conditions is known as a sort.
Figure **(11.3)** shows the activities of the diagram of Figure **(11.2).** sorted in order of the activity 7-numbers. Activity l-2 therefore commences at the head of the list, followed by l-3 and l-4. It will be noted that this does not necessarily result in a list arranged with i-numbers ascending in numerical order.
Sorting in this fashion illustrates one of the reasons for using a serial numbering system. If the number at the head of an activity arrow is always greater than that of the tail and the activities are sorted in the order of precedence as indicated on the left-hand side of Figure **(11.3)** by ascending numerical order of the 7-number, it means that the list will have the important property that those activities above any particular activity will always be those of preceding activities. Conversely, those below the particular activity will always be the activities succeeding that chosen. Thus, in the case of activity 6-8, all those activities below it in the list can be carried on independently or in succession to activity 6-8. The sort of the table also ensures that all those activities, upon which the start of 6-8 depends, will appear in the list above activity 6-8.
If this sorting of activities is examined more closely, it becomes apparent that it is by no means a unique listing of the activities and depends to a large extent on the way in which the network diagram is numbered. For example, in Figure **(11.2)** the logic of the diagram would not have been disturbed if, instead of placing a 4 where it is on the diagram, it had been placed where now appears event number 2 or 3. This would have necessarily meant that a different order of precedence of activities would have been established in the sort. Attention is drawn to this feature, since, if the resource allocation is a particularly critical or difficult one, it may be advisable to renumber the network and carry through a process of resource allocation again in order to see if a better solution can be obtained.
The sort so far has been carried out on the basis of an ascending numerical order of the *j-number*. Where an event is a merge event there will be more than one activity bearing the same *j-number*, as in Fig. 12.3 there are activities 2-7, 3-7 and 6-7 .It is necessary, therefore, to have a secondary rule whereby an order of precedence is given to activities which cannot be sorted conclusively using the first rule. The primary rule for sorting is known as the *major sort* and, the secondary rule is known as the *minor sort*. In this example, the *minor sort* has been made in accordance with the magnitude of total float, an activity having a small total float taking precedence over one with a larger total float. If one is going to consider each activity in accordance with the order in which it appears in the sorted list, this means that priority of resource allocation is being given to an activity of low total float. The reason for this will be apparent.

i — j	DURATION	TOTAL FLOAT	RESOURCE X	RESOURCE Y	RESOURCE Z
1 — 2	2	9	3	—	—
1 — 3	4	11	—	2	—
1 — 4	3	0	2	—	—
2 — 5	6	16	—	3	—
4 — 6	10	0	—	—	2
6 — 7	6	0	—	—	2
2 — 7	8	9	—	—	1
3 — 7	4	11	—	—	1
6 — 8	5	1	—	2	—
7 — 9	7	0	4	—	—
8 — 9	7	1	2	—	—
5 — 9	2	16	4	—	—
8 — 10	3	5	—	3	—
9 — 11	8	0	—	2	—
10 — 11	8	5	—	—	2



TOTALS																																										
X	3	3	2	2	2	-	-	-	-	-	4	4	-	-	-	-	-	-	-	-	2	2	2	2	2	2	4	4	4	4	4	4	4	2	-	-	-	-	-	-	-	-
Y	2	2	2	2	3	3	3	3	3	3	-	-	-	-	-	2	2	2	2	2	3	3	3	-	-	-	-	-	-	-	-	-	-	-	2	2	2	2	2	2	2	2
Z			1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2								
TOTAL	5	5	5	5	7	5	5	5	5	5	6	6	2	2	2	4	4	4	4	4	7	7	7	4	3	3	6	6	6	6	6	6	6	4	2	2	2	2	2	2	2	2

Figure (11.3) a simple example network

Sorting can be carried out on the basis of many priorities related to the network diagram. The activities can be sorted in order of ascending numerical order of i-number or j-number and the minor sort can be in terms of duration, total float, free float, resource requirement, and many others.

The resource requirements for each activity are stated against the activities in Figure (11.2) and the resources can then be allocated manually to each activity in turn within the restraints imposed. A bar chart can be drawn out as the allocation proceeds and a note made at the time of the allocation of each resource. In Fig. 12.3 the first activity to be dealt with is l-2 with duration of two weeks and this is filled in as a bar two weeks long, showing a demand for resource 3X during each of those weeks. The next activity to be dealt with is 1-3, which has a duration of four weeks and uses a resource of 2Y for each of these weeks. It is useful at this stage, for quick identification subsequently, to make a note of the *j-number* at the end of each bar as it is drawn. In the two activities so far plotted, these are 2 and 3 respectively.

Since no activity can proceed unless its preceding event or its *i-number* event has been achieved, care must be taken in the allocation process to ensure that no bar is plotted before it may proceed in accordance with the logic of the original network diagram of Figure **(11.2).** When activity 1-4 is considered, it too can start at zero date in accordance with the logic of the original network diagram of Fig. 11.2, but its demand of resource type X is for two units and three units have already been allocated for the first two weeks to activity l-2. It is therefore necessary to delay activity 1-4 until the resource becomes available from the maximum number of 4. Activity l-4 cannot be scheduled to commence until the beginning of week number 3. This means that since it takes three weeks to complete that activity,4-6 cannot start now until the beginning of the sixth week. Clearly this is a case where human judgment can be used to improve the allocation since activity 1-4 is critical and it would have been better to deal with this before activity 1-2 which has nine days total float.

When activity 2-7 is considered, an important decision has to be made. This activity can follow on from activity l-2, bengthe sole activity upon which it depends. One unit of resource Z is available at this time but, due to the prior allocation of resources to activities 4-6 and 6-7 to the full extent of their availability, activity 2-7 can proceed for only three weeks in the first instance.

The decision has to be taken whether activity 2-7 is a *splittable* activity, in other words, whether its operation can be divided over two or more periods of time. In construction work there are many activities which cannot be treated in this way. For example, a large pour of concrete in a foundation, which is specified as a continuous pour and may be programmed in terms of hours on a detailed program, is a non-splittable activity. Other jobs in construction, such as the spreading of topsoil on the verges of roadways, tend to become the sort of jobs which are used to fill in gaps in the times between the full employment of the labor elsewhere. Under these conditions they can be considered as splittable jobs. The chart in Figure **(11.3)** has been prepared on the basis that, where necessary, activities can be split.

The process is carried out by working through the list of activities in the order of precedence, and a final date is now achieved, showing an overall program of forty-two weeks to carry out the work. This extension of the program over the thirty-four weeks shown by the network is a direct result of having to work within the restraints on the number of available resources and the sorting of the activities in the list in accordance with the initial priority rules.

In carrying out the resource allocation, a new total restraint has been put on the project which does not appear in a time-only network of the type shown in Figure. The concept of float has been completely removed from the network and, under the conditions previously stated, each activity now has a clearly defined time within which it must be carried out in order that it does not produce conflicting resource demands. It is important to realize that activities no longer have float of any description, if one is to comply with the allocation of resources in a network.

The resources may now be aggregated as in Figure **(11.3)** under the various categories in which they are listed.

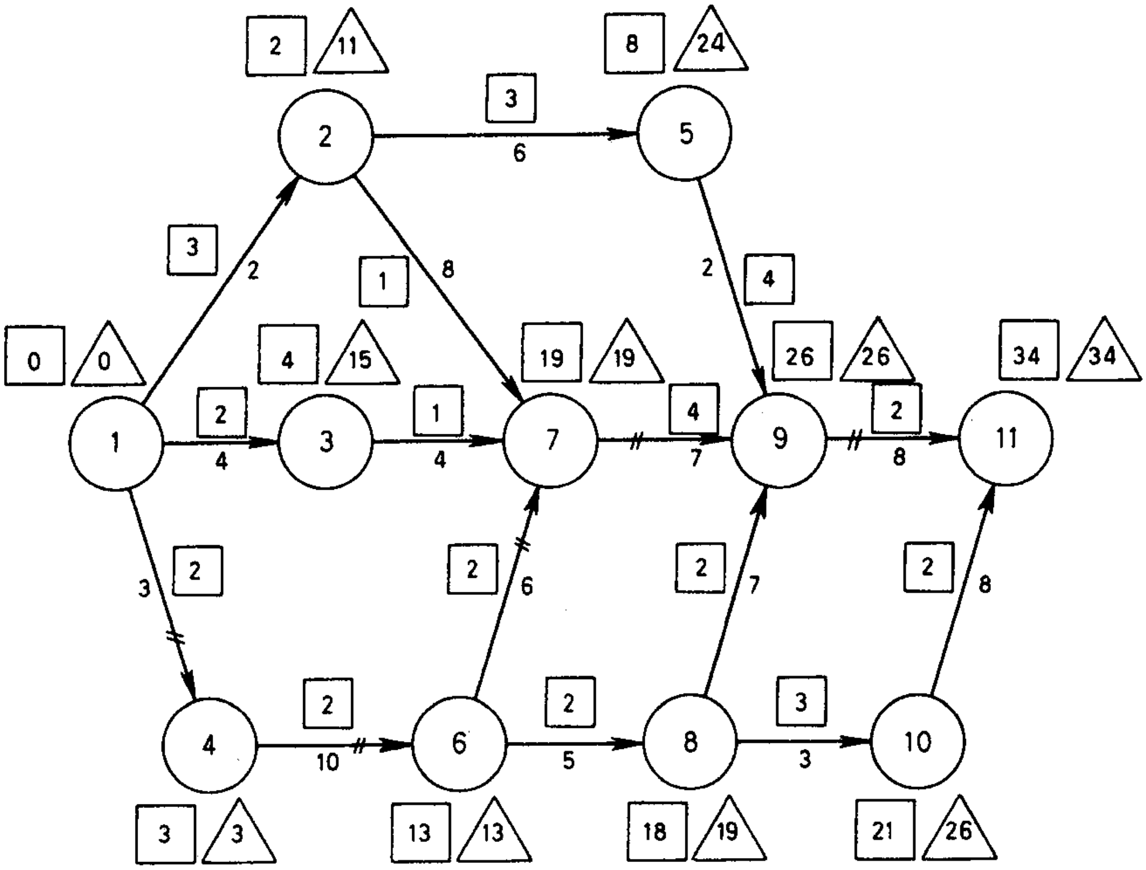


Figure (11.4)

Early start or late start?

Figure **(11.4)** above is a similar diagram to Figure **(11.2)** having similar activity durations and similar resource demands, with the exception that no distinction is made between any of the types of resource. They are all assumed to be units of one man of a similar skill. Table **(11.1)** has been drawn up from the information contained in Figure **(11.4)** and the activities have been listed by a major sort of early start time and a minor sort of total float. Early start is the earliest time by which an activity may be commenced. By comparing the column under early start with

Table (11.1)

Activity	Duration	Early start	Total float	Resource units
1—4	3	0	0	2
1—2	2	0	9	3
1—3	4	0	11	2
2—7	8	2	9	1
2—5	6	2	16	3
4—6	10	3	0	2
3—7	4	4	11	1
5—9	2	8	16	4
6—7	6	13	0	2
6—8	5	13	1	2
8—9	7	18	1	2
8—10	3	18	5	3
7—9	7	19	0	4
10—11	8	21	5	2
9—11	8	26	0	2

the figures in the square boxes against each event in Fig. **(11.4)**, it will be appreciated that the early start information can readily be obtainable from the network diagram, after the backward and forward passes have been completed.

Where two activities have equal early starts, such as 2-7 and 2-5, then total float is used as the secondary sort and priority is given to the activity of lower total float. Total float and the number of units of resource which are to be used me also included in Table **(11.1)** above.

On the basis of the early start data, a resource aggregation can now be made, and this is plotted in the upper graph of Figure **(11.5)**.

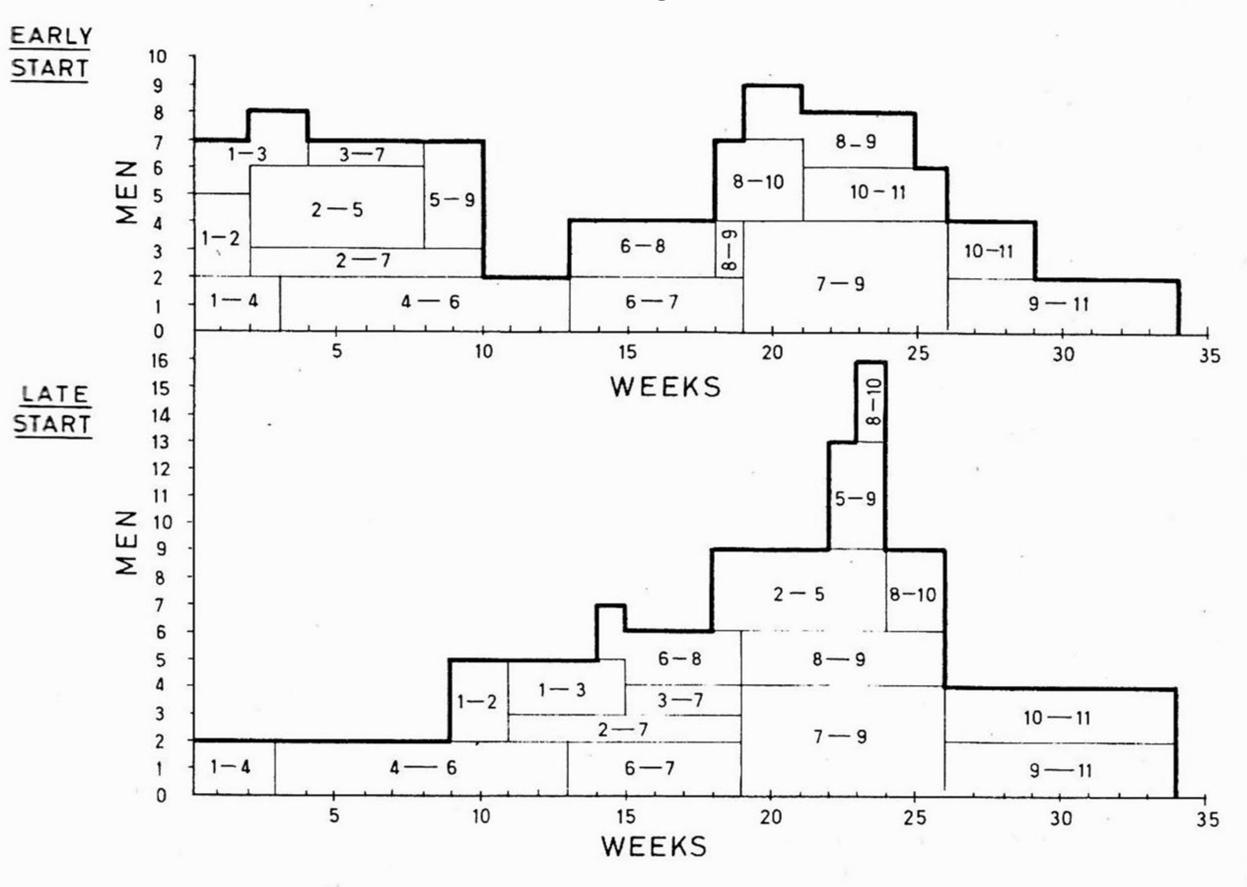


Figure (11.5)

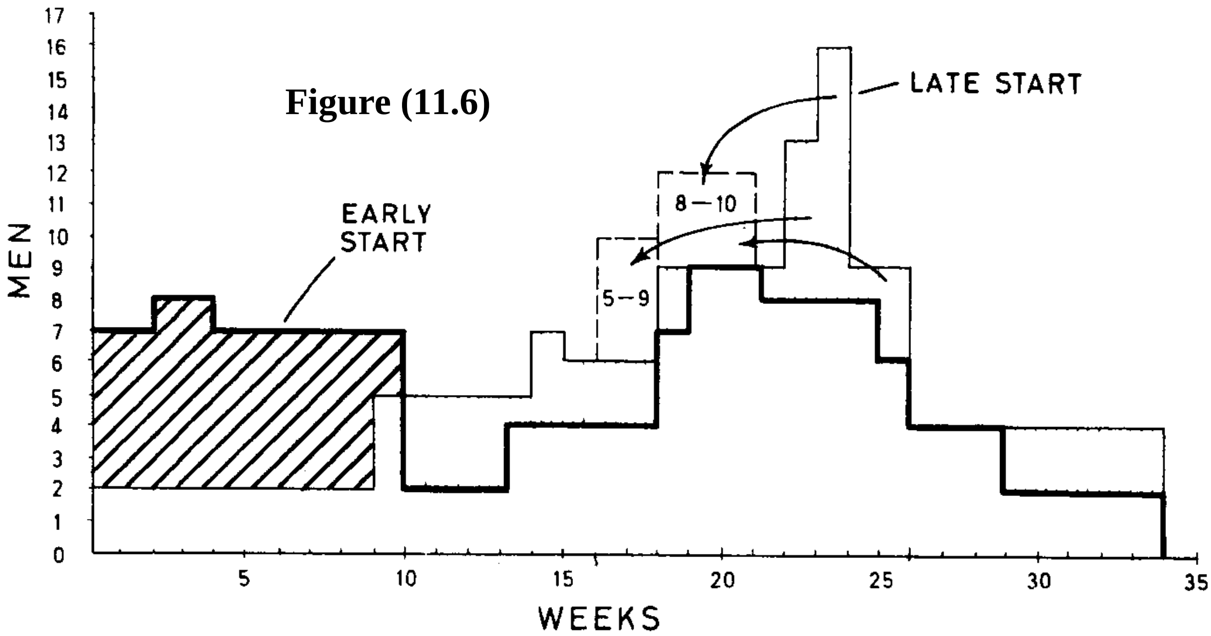
Table (11.2)

Activity	Duration	Late start	Total float	Resource units
1—4	3	0	0	2
4—6	10	3	0	2
1—2	2	9	9	3
2—7	8	11	9	1
1—3	4	11	11	2
6—7	6	13	0	2
6—8	5	14	1	2
3—7	4	15	11	1
2—5	6	18	16	3
7—9	7	19	0	4
8—9	7	19	1	2
5—9	2	22	16	4
8—10	3	23	5	3
9—11	8	26	0	2
10—11	8	26	5	2

Table **(11.2)** above now shows a listing of activities for the same network, but the major sort has been made by late start and the minor sort again is by total float.

The diagram in the lower part of Figure **(11.5)** now represents the resource aggregation based on late start and the precedence of activities listed in Table **(11.2)** above. It will be noted from the two diagrams that there is considerable variation in the demand for resources, depending upon whether the activities are sorted by late start or by early start. Neither of the resource aggregation curves gives an ideal or even near-ideal situation. In the case of early start, there are two predominant peaks but the major demand for resource does not exceed nine men, whereas, in the diagram for the late start, there is a single peak but it will be noted that the maximum demand rises to sixteen in the extreme case.

These two resource aggregation diagrams represent two extremes, inasmuch as the early start aggregation represents the requirements of resource for a situation in which every activity in the project commenced at its earliest possible date. If the logic and timing of the network diagram is not to be upset, any smoothing process must take place between the two extremes already plotted. Figure **(11.6)** below is a diagram which is a modification of both early start and late start resource aggregation curves. Part of the area is common to both curves, but the area which is cross-hatched is the excess of the early start over the late start resource aggregation, and the vertical hatching denotes the excess of the late start over the early start aggregation. Since the areas under the curves are representative of man weeks, the area of the cross-hatched portion must equal the sum of the areas of the vertical-lined portion since the durations and the resource requirements are the same in both cases. If smoothing is to be carried out within the overall duration of thirty-four weeks, it must be carried out in an area between the two extremes as plotted. In carrying out any smoothing or levelling operation, care must be taken not to upset the logic of the original network diagram. An inspection of the combined diagram shows that the peak



activity, nothing can be done about it without affecting the end date of the program. Activity 5-9, however, has a total float of sixteen days and may therefore be moved in such a way that it helps to fill the gap between the two peaks. It will be seen that the manipulation of the diagrams becomes easier if the resource demands for the critical activities are kept to the lower part of the chart, since, unless the contract duration is to be extended, these cannot be adjusted. The peak of the late start diagram can be removed by bringing forward activity 5-9 to commence at week 16 and also bringing forward activity 8- l0 to its earliest start date. Neither of these changes affects the logic or the overall duration of the original network. Figure **(11.6)** shows the new positions of activities 5-9 and 8-10 by a broken outline and when considered in conjunction with the late start diagram results in a curve with but one major peak. This is just one solution to the problem, as there must be a great many solutions between the limits of early and late start. It is often desirable to tend towards the resource aggregation curve illustrated by early start, since this means that, if there are to be labor difficulties to be overcome, they will occur in the early part of the contract, leaving as long a time possible for the difficulties to be resolved. Leaving peaks of resource requirement until late in the contract does mean that, should something go wrong at this stage when there are heavy demands on the resource, unless they can be righted immediately there will be a permanent effect on the contract duration.

Allocation within resource restraints

The previous method of aggregating resources has been carried out within a fixed project duration, the prime object being to total the amount of resource used at any particular period of the project but doing this so as to maintain the given

Table (11.3)

Activity	Duration	Late start	Total float	Resource	Units of resource
1—4	3	0	0	X	2
4—6	10	3	0	Z	2
1—2	2	9	9	X	3
2—7	8	11	9	Z	1
1—3	4	11	11	Y	2
6—7	6	13	0	Z	2
6—8	5	14	1	Y	2
3—7	4	15	11	Z	1
2—5	6	18	16	Y	3
7—9	7	19	0	X	4
8—9	7	19	1	X	2
5—9	2	22	16	X	4
8—10	3	23	5	Y	3
9—11	8	26	0	Y	2
10—11	8	26	5	Z	2

duration. The next method to be described is one for the allocation of resources within known limitations of availability. Such a method may result in a project duration which is longer than the minimum.

Use is made of Fig. 12.2 with three types of resource, X, Y, and Z. Two levels of resource restraint will be used - a normal level of availability at four units of X, three of Y, and two of Z, and a maximum level of resource availability. The latter will be of X, five units, of Y, five units, and of Z, three units. The activities are again sorted by late start as the major sort and by total float as the minor sort and the requirement of units and type of resource are shown at the right-hand side of the Table **(11.3)**. In addition it is necessary to compile a list of events showing the earliest date by which they will be achieved, and a column headed ***Scheduled date***. The list for this example is shown in Table **(11.4).**

The only scheduled date known at the beginning of the analysis is for Event l. This is zero. No specific sorting method need be used on the event

Table (11.4)

Event number	Earliest date	Scheduled date
1	0	0
2	2	5
3	4	4
4	3	3
5	8	11
6	13	13
7	19	19
8	18	18
9	26	33
10	21	21
11	34	41

numbers and they can be listed in ascending numerical order, since the only facility that is required of them is that they should be easily found at the time of calculation.

To facilitate the allocation of resources during the procedure it is compile a loading chart for each category of resource. Three loading charts are shown in Figure **(11.7)** below. The lower of the thick horizontal lines shows the normal availability of resource, and the horizontal line immediately above this indicates the maximum possible availability of resource. For the purpose of this example, it will be assumed that no activity can be split for its operation but must be performed as a continuous operation.

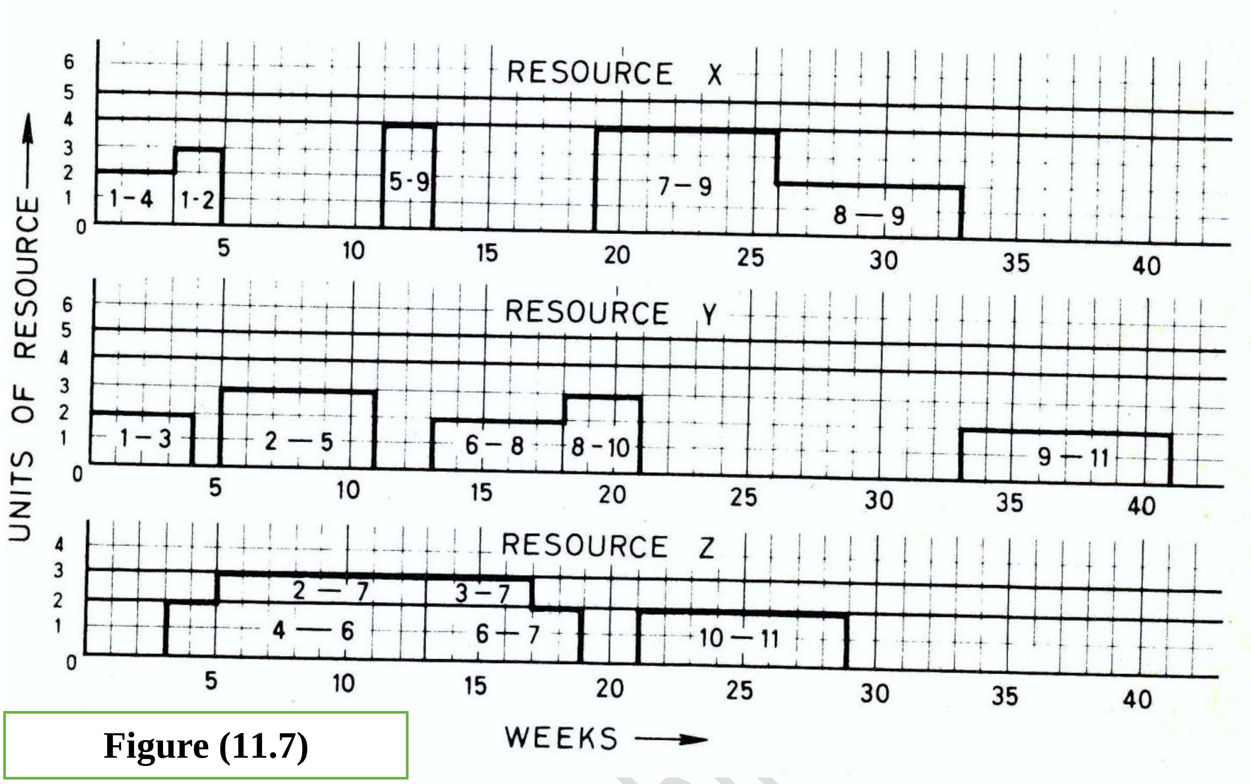


Figure (11.7)

The first on the list in Table 11.3 is activity l-4 requiring two units of resource X for a duration of three weeks, commencing at day zero. This resource demand is then loaded into the chart, occupying an area of two units of resource by three weeks, commencing at an earliest date of zero, the figure, for the scheduled date on the event list. Since the resource requirement is less than the availability of the resource, this demand can be satisfied. If the activity is carried out at this point, event 4, as far as can be seen at the time of calculation, will be reached at the end of the third week. The scheduled date in the event list against the event number 4 should therefore be listed as 3.

The next activity on the list of Table **(11.3)** is 4-6. The earliest date for event 4, the *i-event* of activity 4-6, is 3 and the scheduled date is 3. Therefore, the activity demand for resource of two units of Z for a duration of ten weeks is loaded into the resource loading chart of z to cover this demand and the time required. There is no difficulty with loading this particular resource and since it does not overload the availability, the scheduled date for event 6 is noted as being 13 and added to the event list. It is important to remember in this systematic procedure that, having successfully loaded a demand for resource in a loading chart, a note must be made of the time at which the end event will be achieved for this particular activity. This is necessary in order to maintain the logic of the diagram. It can be seen that even after loading activity 4-6, event 6 will not be achieved until at least the end of the thirteenth week. There may be other activities running into event 6 which have not yet been considered, but so far no activity with an *i-number* of 6 can commence before this scheduled date.

Activity l-2 can be loaded with no difficulty. When activity 2-7 is considered, having a demand of one unit of resource Z for eight days, and a scheduled date of 5, it will be seen that the demand for resource, when added to that for activity 4-6, exceeds the normal availability. It is necessary to make a decision at this point as to whether the normal availability can be exceeded or whether the project's duration will be extended to keep the resource demand within the normal. In this case it has been decided that the normal can be exceeded, so the resource demand for activity 2-7 is loaded and the scheduled date of the end of week 13 is recorded.

Having decided that, in the case of resource Z, the upper limit will be used, then on proceeding through the table, activity 3-7 can be loaded in this manner. No further difficulties are experienced until the activity 8-9 is considered with a demand for two units of resource X for a period of seven weeks. The scheduled date for event number 8 is the eighteenth week and, if the resource demand is to be loaded on the loading chart commencing at this point, the maximum availability of resource of five units will be exceeded by one over most of this period of time. The decision to be made now is whether the maximum availability can be exceeded by some means or other, or whether one must comply with the resource restraint and the duration of the project as a whole must be extended. In this case, it is decided that, since there is no more of that resource available, the project duration must be extended as necessary. The earliest point at which the resource requirement of activity 8-9 can be loaded is immediately following that of activity 7-9 in the resource loading chart for unit X The completion time for activity 8-9 and the accomplishment of event number 9 is at the end of the thirty-third week and the scheduled date for the event list must therefore be 33.

The next activity on the list, 5-9, has an earliest date of 8 and a scheduled date of I I and can readily be loaded into the loading chart for resource X, beginning at the scheduled date of 11. Activity 8-10 can be dealt with in normal circumstances, but activity 9-11 will take the completion of the program beyond the duration already calculated at thirty-four weeks. The new duration for the project is forty-one weeks. Activity 10-11 with its demand for two units of resource Z can readily be fitted in to the resource loading chart for resource Z, beginning at the earliest date as shown on the event list.

The effect of the restraint on the quantity of resource which is available is again shown, inasmuch as a maximum number of five units of resource X is insufficient to cope with the peak demand for that resource. It is necessary to lengthen the duration of the project unless an additional unit of resource X can be found over a period of six weeks during the course of the project. It is as well to remember at this point that this is just one solution of the resource allocation problem and, by considering now a table ranked in order of early start as the major sort and a minor sort of total float with the resource requirements as indicated in Table **(11.5)**, a different solution is obtained.

The allocation procedure is carried out as before and results in resource loading charts of Figure **(11.8)** below, together with an event list as Table **(11.6)**. By using this alternative method of sorting, the overall duration of the project is reduced by one week and, amongst other things, now dictates a slightly different sequence in which the activities must be carried out. This latter variation may be desirable in certain circumstances since, if there is a choice as to when a particularly critical operation can be carried out, it should be done so at the earliest possible moment on the premise that has already been stated.

Table (11.5)

Activity	Duration	Early start	Total float	Resource	Units of resource
1—4	3	0	0	X	2
1—2	2	0	9	X	3
1—3	4	0	11	Y	2
2—7	8	2	9	Z	1
2—5	6	2	16	Y	3
4—6	10	3	0	Z	2
3—7	4	4	11	Z	1
5—9	2	8	16	X	4
6—7	6	13	0	Z	2
6—8	5	13	1	Y	2
8—9	7	18	1	X	2
8—10	3	18	5	Y	3
7—9	7	19	0	X	4
10—11	8	21	5	Z	2
9—11	8	26	0	Y	2

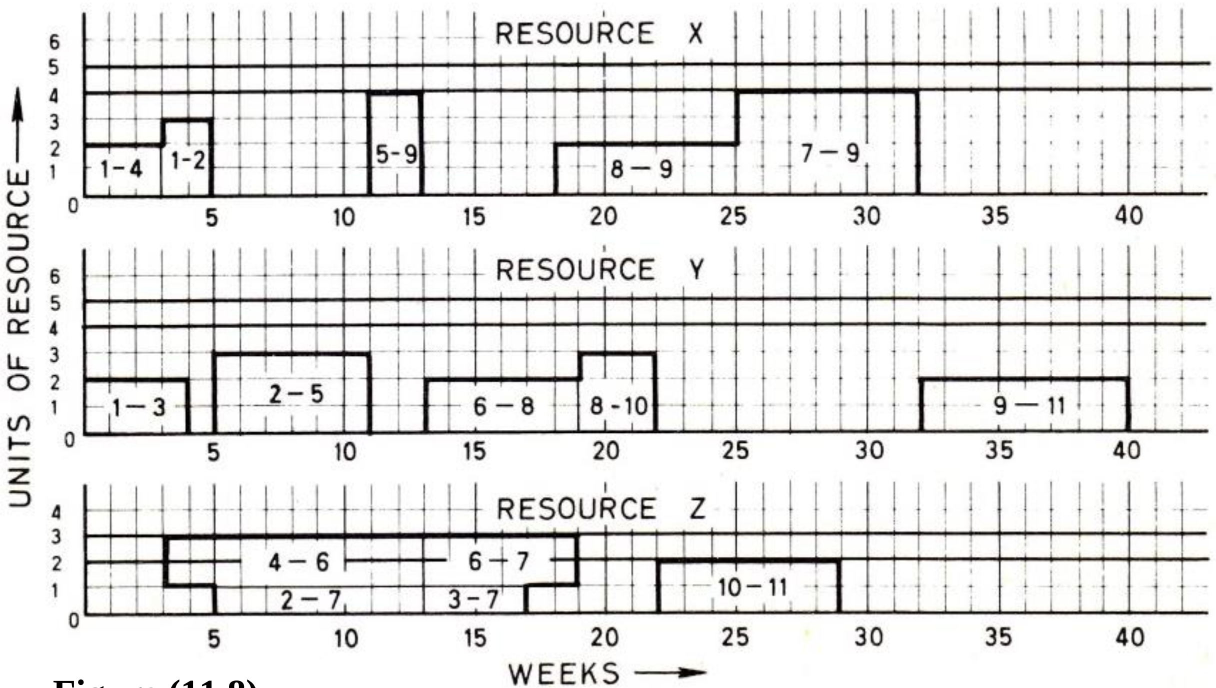


Figure (11.8)

Table (11.6)

Event number	Latest date	Scheduled date
1	0	3
2	11	5
3	15	4
4	3	3
5	24	11
6	13	13
7	19	19
8	19	18
9	26	32
10	36	21
11	34	40

The above is an example of the serial method of the allocation of resources. In such a method, the general principle is that the activities are sorted into a list so that any activity in the list has those preceding it above it and those succeeding it below it. The principle of allocation is such that one activity is dealt with at a time, working in sequence down the list. As the activity is considered an allocation of resource is made to it, and so on until each activity in the list has received its respective allocation. From the method of working it will be seen that the method can easily be used for more than one project using common resources simply by listing all the activities properly sorted.

There is a further general approach to the problem of resource allocation and it is termed the *parallel method* of allocation. In the parallel method, each period of time is considered in turn rather than each activity. The available resources in any one time period are allocated on the basis of some criteria which set up priorities. For example, it may be that, if two or three or more activities compete for the available resources, the resource will be allocated to that activity with the least total float, the total float being used as a measure of the criticality of any activity. Having allocated, in the parallel method, the resources which are available for a particular time period, allocation moves forward to the next time period and the activities which perhaps have not previously received an allocation of resource are then considered. Due to the fact that consideration is made on one time period later in the program, the criticality of those activities, which have already been considered but rejected in the light of other more critical competition for the resources, has increased. For example, if an activity cannot obtain an allocation of resource that has a total float of ten weeks at one particular time period, then, in considering the next time period of one week, the total float of the activity brought forward will be nine weeks and so on, until it is in such a position that its total float enables it to obtain priority over all other activities which are brought forward. In such a system a situation may arise where three critical activities are competing for the resources which are sufficient only to satisfy two this case one of the critical activities will have to be put back for consideration In in the next time period and inevitably, since the activity is critical, the overall duration of the project will be extended.

Judgment and resource allocation

As has been shown in the above examples, it is necessary to adopt some sort of priority rules in the allocation of resources. This is necessary in order to tackle the resource allocation problem in a systematic manner and, at the same time, to give priority to activities on a rational basis, especially when there is competition for limited resource. It has been illustrated that the choice of priority will give different results for similar examples and, therefore, the decision as to which priority rules will be used must be one of judgment based upon experience. Not only is the choice of priority rule a matter, of judgment but, having levelled and allocated the resources for any project in a systematic manner, it is then a question of judgment as to how the results of the process can be moulded to suit the situation in hand. No systematic process of resource allocation, whether carried out manually or by the use of computer, will necessarily give the optimum solution for the levelling of resources. It ii a combination of the judgment of the planner with the experienced and intelligent use of a computer which can combine to give the best solution, The above examples have been used to illustrate some of the principles of resource allocation and have involved the use of manual methods, only. When problems are only slightly more complicated than those illustrated, the manual allocation of resources becomes out of the question. It is a tedious and complicated process which will lead to mistakes on the part of the allocator. It is in this field that the computer comes into its own; use of its facility to calculate quickly enables a quick review to be made not only of allocation in accordance with a specific priority rule, but also, if satisfactory results are not obtained, of taking a look at the allocation in the light of several different priority rules.

Computers and resource allocation

Most of the large computer manufacturers and workers in the field have written many programs in the critical path and resource allocation areas. As time goes by, these tend to become more and more sophisticated and lead to the ability to deal with larger and larger networks in more detail. Programs allow for such diverse requirements as whether or not to split an activity ,to work within resource restraints or within a project duration restraint, to produce aggregation summaries within trades or total aggregation figures, and many other variations.

The advantages and disadvantages of critical path methods

One of the prime advantages that critical path methods have had, particularly in the construction field or the field of the one-off project, is that for the first time there has had to be some logical thinking about the sequence of events which must take place on a site. The bar chart or the Gantt chart does not require the discipline of thought that is required by the construction of a network with its inter-dependency of one activity on others. It could well be that this particular advantage is the most important of them all. On the other hand, it must not be thought that the man who implements the use of critical path techniques has the solution to all his problems, since the critical path method can be used only as a tool to assist in making decisions - it will not make decisions by itself. Critical path methods not only set up a discipli.ne in the planning and scheduling of a project but they also enable the control of a project to be carried out within strictly defined limits. In addition, they encourage the preparation of long-term plans for projects where the use of traditional planning methods have been somewhat woolly in their application. The logic of the network cannot be neglected in the situation where it is desirable to reduce a project duration. For example, if it is required to reduce the duration of a project by four weeks, this can be done only by considering the critical activities first followed by the sub-critical activities. If the logic of the diagram is accepted as being correct, the saving in overall time must come about by a saving on individual activities. It is not possible to overlap activities in the network. With the bar chart such a discipline is not apparent, since the only thing that has to be done in order to plan a job and to make a bar chart conform to a reduced project duration is to squeeze up the bars and make them overlap a little more. This is an easy enough operation and does not require any consideration of the interdependency of one activity with another, so far as the drawing and presentation of the bar chart is concerned.

Management by exception can be practiced when using network analysis as a control tool. The use enables the attention to be focused on a few critical activities which arc likely to have the most effect upon the overall duration of the project. The remaining activities, so long as they all carry float, can be ignored as far as the top manager is concerned in looking at the general overall picture. It is only when such activities tend to become critical, or near critical, that attention must be concentrated on them. One of the original reasons for developing network analysis was in order to harness the speed and accuracy of computation by electronic means. Certainly this is one of the advantages of using such methods on a large scale, since revisions to the plan and periodic updating can be carried out with the use of a computer in an extremely short space of time.

The attention to planning in construction is usually placed on the contractor's part in the scheme of operation. With the use of network analysis techniques, there is no reason why the architect and/or the engineer, and even the client, should not allow the operations coming within their control to be scheduled on the network diagram together with those of the contractor. Certain milestones should be agreed between the client and the contractor, such as the issue of key drawings, and these should be recorded within the network so that the contractor and the client both have a clear understanding of what is required of the other. The network diagram, therefore, becomes a clear and certain means of communication and co-ordination between all the parties bound together by a contract to carry out work. The subsequent use of the network diagram as a basis for contract sum adjustments by either the contractor or the client is a fair and equitable one. If the contractor's work has been held up by the non-issue of certain essential drawings and he has incurred additional expense by the delay, it is only right and proper that he should be recompensed. The use of a network diagram can show conclusively what the effect is of non-delivery of items such as drawings on the whole of the project duration. The responsibility for delays of this kind can be recorded and pinpointed with great clarity. The very process of drawing a network diagram can itself be a profitable procedure for the site manager. He is not required, and should not be required, to keep the network diagram up to date as the work proceeds, but, if he draws a simple network for the whole of the project before it commences, he will have in mind a general idea of the sequence of events and the relationship of one activity with another.

There are disadvantages of using such techniques but these are similar to the disadvantages that occur when any new technique is used. There is scope in such a situation for empires to be built and a lot of paper to be produced which will be ineffective and, in fact, will have a negative effect on the progress of events. There is a tendency for such methods to be looked upon as the panacea for all the ills which have gone before; but let us repeat - this is a tool to be used in combination with personal judgment and it will not in itself resolve difficulties or make decisions. The use of critical path methods, generally speaking, is a more expensive process of planning than the use of conventional methods. It is not easy to evaluate the benefits of its use in terms of money. There is, however, the assurance that, if a diagram has been completed, the project has been planned. There is no similar assurance from using traditional methods of planning. This aspect of critical path planning may well have its effect through a planning organization, because it will surely expose the man who has ostensibly been planning for many years but, in fact, has been quickly and lightly sketching the bars of a chart to arrive at a likely figure for the overall duration of the project. Many people who have used critical path methods find it to have definite advantages over other types of planning. It is necessary, however, in using such methods to train all the personnel who will come in contact with the diagram as a means of communication and control. With more sophisticated methods, extensions, and derivatives of the basic critical path method, more and more use will be made of such techniques in the construction industry.