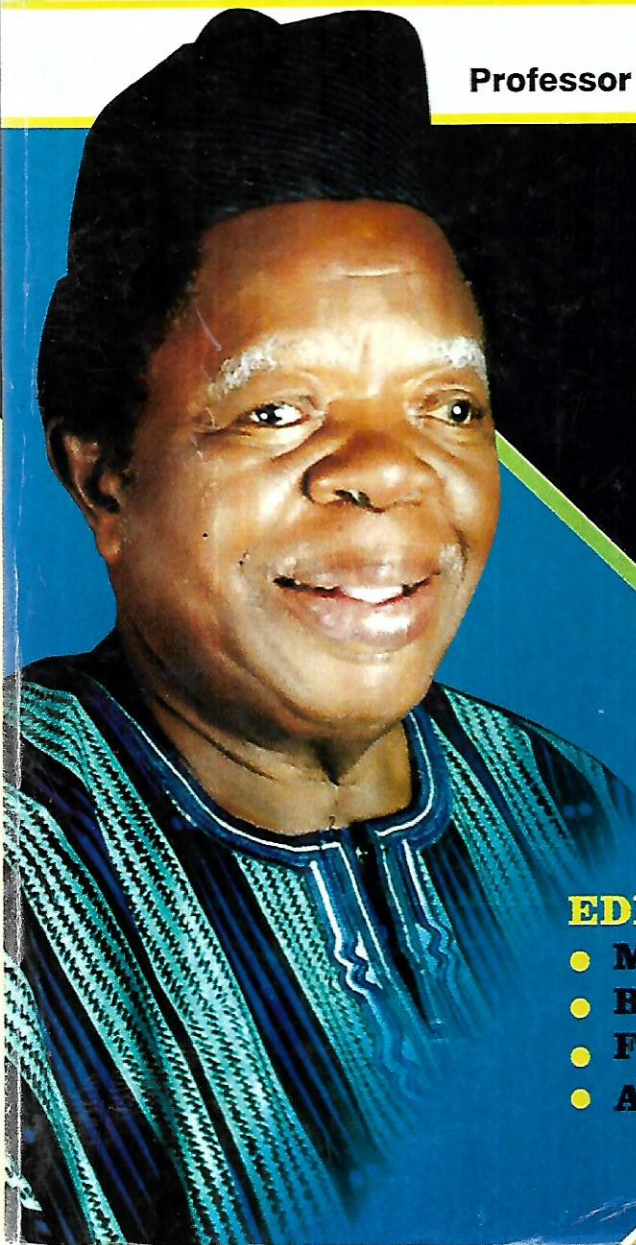


# Theory & Practice

of Education in Nigeria

A Book of Readings in Honour of  
Professor Augustus Adeleke Adeyinka (Mnae, Fhoedson)

Vol. 2



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## Chapter Fifty-Eight

### APPLICATION OF NETWORK ANALYSIS IN EDUCATIONAL PLANNING: AN INTRODUCTION

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#### Introduction

Network analysis is a technique related to sequencing problems, which are concerned with minimizing some measure or performance of the system such as the total completion time of the project, the overall cost and so on (Kothari 1994). Kothari believes that the technique is useful for describing the elements in a complex situation for the purpose of designing, planning, coordinating, controlling and making decision. Kothari (1994) said that network analysis is specially suited to projects, which are not routine and which will be conducted only once or a few times.

Lucey (2001) defined network analysis as a generic term for a family of related techniques developed to plan, manage and control projects. Therefore, network analysis is defined as a general term for a family of related techniques developed to aid management to plan and control projects. These techniques show the inter-relationship of the various jobs or tasks, which make up the overall project and clearly identify the critical parts of the project. They can provide planning and control information on the time, cost and resources aspects of a project. Kothari (1994) stressed that network analysis is likely to be of most value where project are:

- (a) **Complex:** That is, they contain many related and interdependent activities;
- (b) **Large:** i.e. where many types of facilities, high capital investments, and many personnel are involved and stipulated on cost limits; and
- (c) **Where Restrictions Exist** i.e.: where projects have to be completed within stipulated time or cost limits, or where some or all of the resources (material, labour) are limited.

#### Basic Network Terminology

There are some basic terms used in network analysis. These are activity, event, dummy activity and network (Lucey, 2001).

1. **Activity:** This is a task that takes time and resources e.g. build a wall, verify the debtors in a sales ledger, dig foundation of classroom (s) etc, an activity is represented in a network by an arrow thus:



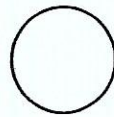
The head of the arrow indicates where the tasks end and the tail where the tasks begin. The arrow points from left to right but is not drawn to scale. An essential preliminary to the use of network analysis is established. The following questions may be asked:

- a. What activities are involved in the project?
- b. What are their logical relationships? (e.g. the activity of building a wall must take place after the activity of dig foundation).

- c. How long will the activity take? (An estimate of the time the activity is expected to take is given).

We should note that the basic time estimate is always necessary but in addition, other estimates of time, cost, resources, probabilities etc may also be required.

2. **Event:** This is a point in time that indicates the start or finish of an activity or activities, e.g. building of a wall, digging foundations etc. An event is represented in a network by a circle or node thus:



It will be noted that the establishment of activities automatically determines events because they are the start and finish of activities and represent the achievement of a specific stage of a project.

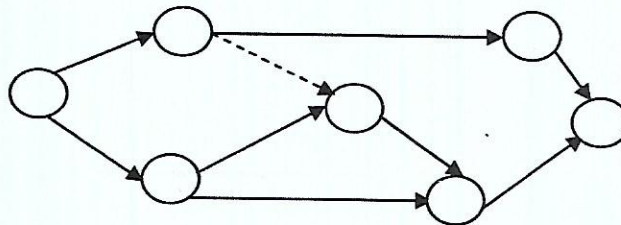
3. **Dummy Activity:** This is an activity that does not consume time or resources. It is used merely to show clear, logical dependencies between activities so as not to violate the rules for drawing network. It is represented on a network by a dotted arrow thus:



Note that dummy activities are not usually listed with the real activities but become necessary as the network is drawn.

4. **Network:** This is the combination of activities, dummy activities and events in logical sequence according to the rules for drawing networks.

Thus a small network might appear as follows:



The other important concepts according to Kothari (1994), are as follows:

1. **Path and Critical Path:** A path is a continuous chain of activities through a network, which connects the first event to the last event. *Critical path* consists of the sequence of those events and connected activities that require the maximum time in the completion of the project. It is that path which takes the longest time. It is known as critical because it

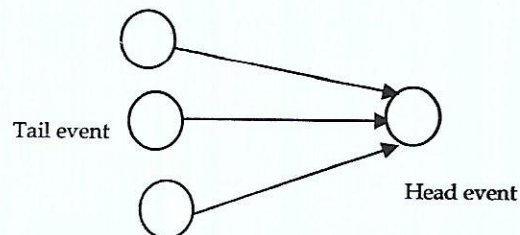
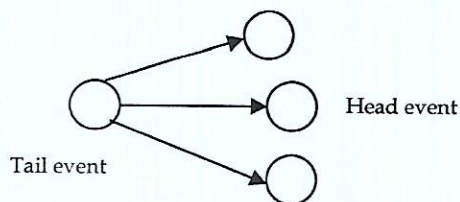
controls the completion date of the project, for the length of this path determines the minimum time in which the project may be completed.

2. **Critical Activities or Bottleneck Activities:** All the activities associated with the critical path are called critical or bottleneck activities. Delay in the completion of one or more of these activities will cause delay in the completion date of the project. Hence, such activities require special attention of the person in charge of the project.
3. **Earlier Star Time (EST):** This is the earliest possible time an activity can begin on the assumption that all activities relating to it started at the earliest possible times.
4. **Earliest Finish Time (EFT):** This is the sum of the earliest start time and the estimated time to perform the activity.
5. **Latest Finish Time (LFT):** This is the latest possible time an activity can finish without delaying the project beyond its deadline on the assumption that all the subsequent activities are performed as planned.
6. **Latest Start Time (LST):** This is the difference between the latest finish time and the estimated time for the activity to be performed.
7. **Float:** This is used in context of network analysis. Float is divided into three:
  - (a) **Total Float:** Is the duration by which an activity can be delayed without delaying the project and can be worked out as either (LST-EST) or (LFT-EFT).
  - (b) **Free Float:** Is that portion of the total float within which on activity can be manipulated without affecting the float of subsequent activities. It is worked out by subtracting the head event from the total float.
  - (c) **Independent Float:** Is that portion of the total float within which an activity can be delayed for start without affecting floats of the preceding activities. It is worked out by subtracting the tail event stock from the free float.
8. **Slack:** The term slack is normally associated with events. It indicates the amount of latitude (or the lee-way) that is available for an event to occur. It is worked out as slack of an event = (Latest occurrence time of the event)-(earliest occurrence time of the event). Simply slack = LT-ET.

### Rules for Drawing Networks

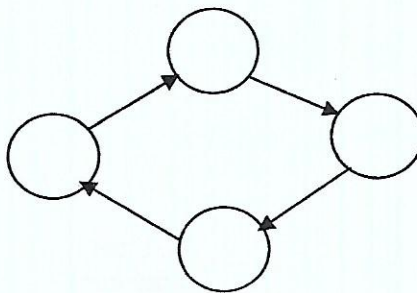
The following rules are all logically based and should be thoroughly learned before attempting to draw networks. According to Lucey (2001), the rules are as follows:

- (a) A complete network should have only one point of entry, i.e a start event and only one point of exit, i.e a finish event.
- (b) Every activity must have one preceding or 'tail' event and one succeeding or 'head' event. Note that many activities may use the same tail event and many may use the head event, e.g.



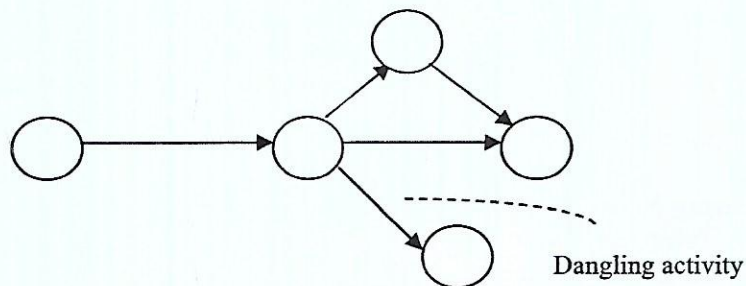
It should be noted that an activity must not share the same tail event and the same head event with any other activities.

- (c) No activity can start until its tail event is reached.
- (d) An event is not complete until all activities leading in to it are complete.
- (e) 'Loops,' i.e a series of activities which lead back to the same event, are not allowed because the essence of network is a progression of activities always moving onward in time.



'Loops' not to be used

- (f) All activities must be tied into the network, i.e they must contribute to the progression or be discarded as irrelevant. Activities which do not link into the overall project are termed 'danglers'.



Dangler not to be used

- (g) Networks proceed from left to right.
- (h) Networks are not drawn to scale, i.e the length of the arrow does not represent time elapsed.
- (i) Arrows need not be drawn in the horizontal plane, but unless it is totally unavoidable they should proceed from left to right.
- (j) Events or nodes should be progressively numbered from left to right. E.g. 1, 2, 3, etc, or numbered at intervals of fives e.g. 5, 10, 15 etc or in tens e.g. 10, 20, 30 etc. this enables

additional activities to be inserted subsequently without affecting the numbering sequence of the whole project.

### Preparation of the Network Diagram

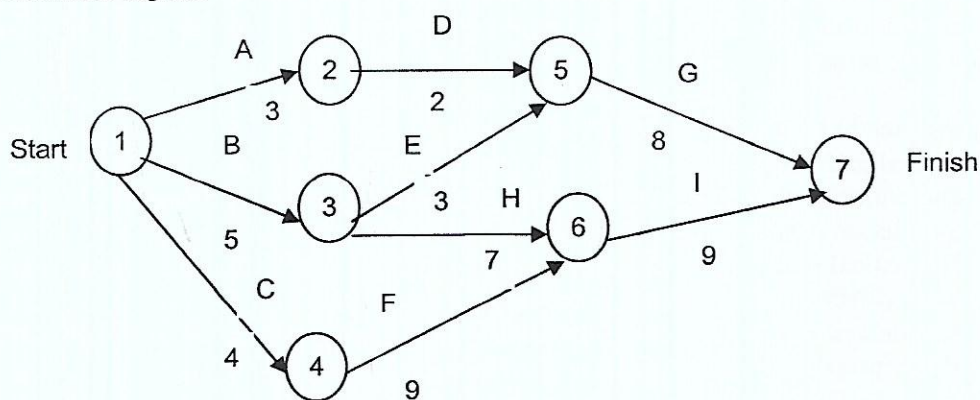
Keeping all what has been stated above in view, the network diagram can easily be prepared by considering the following example

#### Example 1: Prepare A Network Diagram For The Following Information

| Activity |   | Name of the Activity | Pre-requisite Activity | Estimated Time (Weeks) |
|----------|---|----------------------|------------------------|------------------------|
| Event    |   |                      |                        |                        |
| 1        | 2 | A                    | None                   | 3                      |
| 1        | 3 | B                    | None                   | 5                      |
| 1        | 4 | C                    | None                   | 4                      |
| 2        | 5 | D                    | A                      | 2                      |
| 3        | 5 | E                    | B                      | 3                      |
| 3        | 6 | H                    | B                      | 7                      |
| 4        | 6 | F                    | C                      | 9                      |
| 5        | 7 | G                    | D,E                    | 8                      |
| 6        | 7 | I                    | H,F                    | 9                      |

#### Solution 1

Network Diagram



The above is the required network diagram for the given problem. Various circles in it represent various events and the arrows illustrate the activities. The immediate preceding activity of activity D is activity A which means that activity A must be completed before activity D can begin. The arrow from circle 1 to circle 2 indicated that activity A must be completed before activity D can begin. Similarly, activity B must be completed before activities D can begin. Also activity B must be completed before activities E and / or H can begin; activity C must be completed before F can begin; activities H and F must be completed before activity 1 can begin and activities D and E must be completed before

activity G can begin. The estimated time for each activity has been placed just below the arrow representing that activity.

### **Critical Path Method (CPM)**

Critical path method is a graphical technique for planning and scheduling projects. This technique involves the preparation of the network in the form of arrow diagram and its analysis to indicate the critical path. It has the potential for scheduling of a task in minimum time and/or cost in accordance with specified constraints (Kothari, 1994).

After preparing the network diagram and indicating the times for each activity as stated above, we can now mention the various possible paths for determining the critical path under the CPM. The critical path, being the longest path, can easily be found out from the possible paths as the one taking the maximum time in the completion of the project. In example 1 above, network diagrams are in all the four paths viz.

1.  $A \rightarrow D \rightarrow G$  requiring  $3+2+8 = 13$  weeks in completion of the project.
2.  $B \rightarrow E \rightarrow G$  requiring  $5+3+8 = 16$  weeks in completion of the project.
3.  $B \rightarrow H \rightarrow I$  requiring  $5+7+9 = 21$  weeks in completion of the project.
4.  $C \rightarrow F \rightarrow I$  requiring  $4+9+9 = 22$  weeks in completion of the project.

As the path C-F-I takes highest time in completion of the project, it is the critical path in the given case. The activities C, F and I are associated with it and hence they are bottleneck activities. All other activities, viz; A, B, D, E, G, and H are non-critical activities. Non-critical activities have a certain amount of spare time of float available. These activities can be delayed to the extent of the float being available without affecting the overall completion time of the project.

### **Importance of Critical Path Method**

The critical path requires greater attention because of the following reasons (Kothari 1994)

1. The critical path is important as its length determines the minimum time required for the completion of the project.
2. The critical path highlights those activities, which must be performed more rapidly if the total project completion time is to be reduced;
3. Any delays in activities which are on the critical path will produce delays in completion of the project, i.e., will postpone the final completion date of the project. On the other hand, delays in non-critical activities may not actually delay the completion of the project.
4. Advance planning and improvement along the critical path may cause another path to become critical.

In conclusion, the critical path directs management's attention to important facts, spots potential bottlenecks and avoids unnecessary pressure on other paths that will not result in an earlier final completion date of the project.

### **Limitations of CPM**

The following are the important limitations of CPM (Kothari 1994).

1. CPM operates on the assumption that there is a precise known time that each activity in the project will take, but this may not be a true assumption in real life.
2. CPM does not incorporate statistical analysis in determining time estimates.
3. It is difficult to use CPM as controlling device for the simple reason that one must repeat the entire evaluation of the project each time changes are introduced into the network. It may be remembered that CPM was initially developed as a static planning model and not as a dynamic controlling device.

### **Programme Evaluation and Review Technique (PERT)**

PERT may be termed as the approach of multiple time estimates. It deals with the problem of uncertain activity times by the application of statistical analysis to the determination of estimated time for each activity concerning the project. Under CPM we use the precise known time that an activity will take, but such a precise known time approach may not be reliable in real life situations. In order to arrive at a most reliable estimate of time, multiple time estimate approach may be adopted and PERT performs this task. Under PERT, three time estimates are usually employed (Kothari 1994).

These are:

1. The most optimistic time;
2. The most pessimistic time; and
3. The most likely time.

**The Optimistic Time (OT)** is the shortest time possible if everything goes perfectly with no complications, the chance of this optimum actually occurring might be one in a hundred;

**The Pessimistic Time (PT)** is the longest time conceivable. It includes time for unusual delays and thus the chance of its happening might be only one in a hundred;

**The Most Likely Time (MLT)** would be the best estimate of what would normally occur.

The difference in these three times gives a measure of the relative uncertainty involved in the activity. From these three concerning an activity, the Expected Time (ET), which is usually adopted under PERT, can be computed by the following formula:

$$Et = \frac{Qt + Pt + 4MLt}{6}$$

The expected time (ET) provides the time in which there is a 50-50 chance of the activity being completed. This multiple time estimate approach is better since it provides quite often the improved estimates of the expected time to complete an activity and also allows us to consider the variability of the time for completion of an activity. A basic reason to estimate more than one time for an activity is to provide data by which management may determine the probabilities that each activity as well as entire project will be completed by a specified

date. Several formulae are used for this purpose along with the table of probability values for normal distribution.

The following two formulae are important in this context.

1. Standard deviation of the time required to complete an activity, denoted by

$$SD_{(TRCA)} = \sqrt{\frac{Pt - Qt}{6}}$$

2. Standard deviation of the time required to complete the project, denoted by

$$SD_{(TRCA)} = \sqrt{\left(\frac{Pt_1 - Qt_1}{6}\right)^2 + \left(\frac{Pt_2 - Qt_2}{6}\right)^2 + \dots + \left(\frac{Pt_n - Qt_n}{6}\right)^2}$$

Let us explain the use of the above formulae by means of an example:

**Example 2:** A school project is composed of seven activities whose time estimates are given in the following table:

| Activity |       | Name of the Activity | Time Required (Days) |             |             |
|----------|-------|----------------------|----------------------|-------------|-------------|
| Event    | Event |                      | Optimistic           | Most Likely | Pessimistic |
| 1        | 2     | A                    | 6                    | 6           | 24          |
| 1        | 3     | B                    | 6                    | 12          | 18          |
| 1        | 4     | C                    | 12                   | 12          | 30          |
| 2        | 5     | D                    | 6                    | 6           | 6           |
| 3        | 5     | E                    | 12                   | 30          | 48          |
| 4        | 6     | F                    | 12                   | 30          | 42          |
| 5        | 6     | G                    | 18                   | 30          | 54          |

- (a) Find the expected duration for each activity.
- (b) Find the variance for each activity.
- (c) What is the expected project length?
- (d) Calculate the variance and standard deviation of the project length.

**Solution 2**

- (a) Applying the formula for expected time for an activity, using

$$Et = \frac{Qt + Pt + 4MLt}{6}$$

to find the expected duration for each and every activity of the given project.

$$A = \frac{6 + 24 + (4 \times 6)}{6} = \frac{54}{6} = 9 \text{ days}$$

$$B = \frac{6 + 18 + (4 \times 12)}{6} = \frac{72}{6} = 12 \text{ days}$$

$$C = \frac{12 + 30 + (4 \times 12)}{6} = \frac{90}{6} = 15 \text{ days}$$

$$D = \frac{6 + 6 + (4 \times 6)}{6} = \frac{36}{6} = 6 \text{ days}$$

$$E = \frac{12 + 48 + (4 \times 30)}{6} = \frac{180}{6} = 30 \text{ days}$$

$$F = \frac{12 + 42 + (4 \times 30)}{6} = \frac{174}{6} = 29 \text{ days}$$

$$G = \frac{18 + 54 + (4 \times 30)}{6} = \frac{192}{6} = 32 \text{ days}$$

(b) to find the variance for each activity, using variance of an activity =  $\left(\frac{P_t - Q_t}{6}\right)^2$

$$A = \left(\frac{24 - 6}{6}\right)^2 = \left(\frac{18}{6}\right)^2 = 3^2 = 9 \text{ days}$$

$$B = \left(\frac{18 - 6}{6}\right)^2 = \left(\frac{12}{6}\right)^2 = 2^2 = 4 \text{ days}$$

$$C = \left(\frac{30 - 12}{6}\right)^2 = 9 \text{ days}$$

$$D = \left(\frac{6 - 6}{6}\right)^2 = 0 \text{ days}$$

$$E = \left(\frac{48 - 12}{6}\right)^2 = 36 \text{ days}$$

$$F = \left(\frac{42 - 12}{6}\right)^2 = 25 \text{ days}$$

$$G = \left(\frac{54 - 18}{6}\right)^2 = 36 \text{ days}$$

However, to obtain the standard deviation (S.D) for each activity, we find the square root of the obtained variance, i.e S.D. for each activity =

$$\sqrt{\left(\frac{Pt - Qt}{6}\right)^2}$$

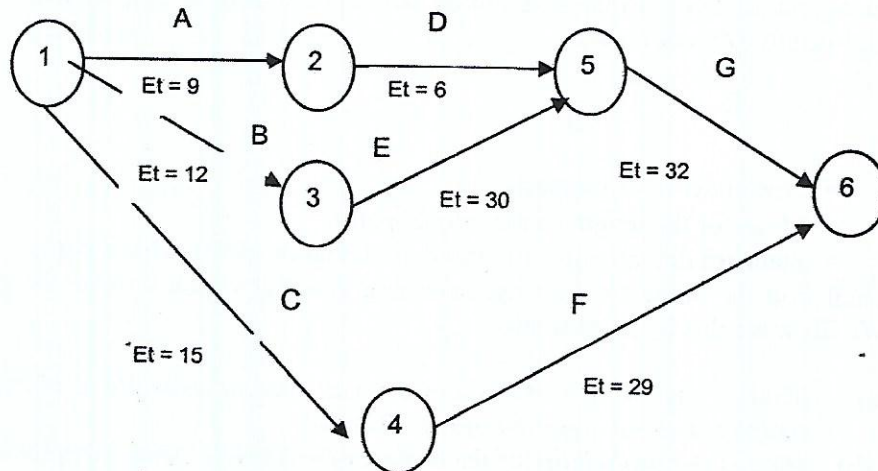
Then for each of the above activities, the S.D's are as follows:-

|   |   |   |
|---|---|---|
| A | = | 3 |
| B | = | 2 |
| C | = | 3 |
| D | = | 0 |
| E | = | 6 |
| F | = | 5 |
| G | = | 6 |

We can list down all these in tabular form as follows:

| Name of the Activity | Expected Time (ET) | Variance | Standard Deviation |
|----------------------|--------------------|----------|--------------------|
| A                    | 9 days             | 9 days   | 3 days             |
| B                    | 12 days            | 4 days   | 2 days             |
| C                    | 15 days            | 9 days   | 3 days             |
| D                    | 6 days             | 0 day    | 0 day              |
| E                    | 30 days            | 36 days  | 6 days             |
| F                    | 29 days            | 25 days  | 5 days             |
| G                    | 32 days            | 36 days  | 6 days             |

- (c) To find the expected project length, we first find out the critical path by drawing the PERT network Est, Eft, Lft, and Lst of various activities and Et and Lt of various events can also be worked out as stated earlier in context of CPM analysis as follows:



Various paths as follows:

- |      |           |           |              |   |         |
|------|-----------|-----------|--------------|---|---------|
| i.   | A - D - G | requiring | 9 + 6 + 32   | = | 47 days |
| ii.  | B - E - G | requiring | 12 + 30 + 32 | = | 74 days |
| iii. | C - F     | requiring | 15 + 29      | = | 44 days |

Thus the critical path B-E-G with an expected length of 74 days. Hence the expected length is 74 days.

If it is assumed that the activity times are independent, then the variance of the time to complete the critical path may be computed as the sum of the variances of the activities on the critical path. We should note that this assumption follows from the fact that the variance of a sum of random variables equals the sum of the variances of each random variable if the variables are independent.

However, our critical path is B-E-G and if we add variance along this path we obtain the variance of the project length (or variance of the critical path) as shown below:-

(d) Variance of project length

$$\begin{aligned}
 (SD_{BEG})^2 &= (SD_B)^2 + (SD_E)^2 + (SD_G)^2 \\
 &= 4 + 36 + 36 \\
 &= 76 \text{ days}
 \end{aligned}$$

Hence the standard deviation of the project length

$$SD_{BEG} = \sqrt{76} = 8.72 \text{ days}$$

### Calculation of Probabilities

If we are interested in finding out the probability of the critical path being completed within a certain time period or the entire project or any of the possible paths being completed within a certain period, then we can make use of the tables of the cumulative normal distribution for the same, assuming that a large number of independent activities operate on the critical path and the distribution of the total time for the path can be taken as normal.

For using cumulative normal distribution tables we will have to first work out the standard normal variate ( $Z$ ) as follows:

$$Z = \frac{X - \bar{X}}{SD}$$

Where  $X$  = time under consideration

$\bar{X}$  = Mean (or the length of the critical path)

S.D = Standard deviation (or the standard deviation of the critical path)

We shall find the value for the corresponding  $Z$  value which will be the required probability. We illustrate this by an example.

- Example 3 (a)** *What is the probability of the critical path of example 2 above being completed within a period of say 80 days?*
- (b) *What is the probability of the project of example 2 being completed within a period of 80 days?*

**Solution 3**

(a) From example 2 solution 2d. Length of the critical path = 74 days

$$\bar{X} = 74$$

Standard deviation of the critical path = 8.72 days

The time under consideration = 80 days

i.e.  $X = 80$  days

therefore,

$$Z = \frac{80 - 74}{8.72} = 0.688 = 0.69 \text{ app.}$$

The value from cumulative normal distribution table when  $Z = 0.69$  is 0.7549. Hence the probability of the critical path being completed within a period of 80 days is 0.7549. This also means that the probability of the critical path not being completed within a period of 80 days is

$$1 - (0.7549) = 0.2451$$

- (b) To find out the probability of the project being completed within a period of 80 days, we must find out the product of the probabilities of the various independent paths in the project, i.e we presume that non-critical paths, especially those which have certain common activities, do not create any problem but in case they tend to create problem, their probabilities should as well as be taken care of while finding out the probability of the project being completed by a certain time period.

Since two paths are independent through the critical path and the path C-F, we will first find out the probabilities of these two paths. The probability of the critical path has already been worked out in example 3(a), hence we will work out the probability of paths C - F being complete within 80 days as follows;

From example 2(b), the variance and S.D. can be worked out as follows:

$$\begin{aligned}\text{Variance} &= (SD_{CF})^2 = (SD_C)^2 + (SD_F)^2 \\ &= 9 + 25 \\ &= 34\end{aligned}$$

$$\begin{aligned}SD &= (SD_{CF}) = \sqrt{(SD_C)^2 + (SD_F)^2} \\ &= \sqrt{34} \\ &= 5.83 \text{ days}\end{aligned}$$

$$\begin{aligned}\text{Length of the path C - F i.e } \bar{X} &= 44 \text{ days} \\ \text{S.D of the path} &= 5.88 \text{ days}\end{aligned}$$

The time under consideration = 80 days, i.e  $X = 80$  days

$$\text{Therefore, } Z = \frac{80 - 44}{5.83} = 6.17$$

The table A value when  $Z = 6.17$  can be taken as much nearer to one which means the probability of path C- F being completed within a period of 80 days is almost equal to one, i.e. it is almost a certainty.

$$\begin{aligned}\text{Hence the probability of the project being completed within a period of 80 days} \\ = 0.7549 \times 1.0000 = 0.7549\end{aligned}$$

### **PERT as a Control Device**

PERT is unique in its emphasis on the control phase of project management because it uses statistical analysis along with probability calculations concerning the project or its path(s) completion by a certain time period. As a result, it is easier under PERT to revise the plan each time changes are introduced into the network. Hence, PERT is equally an important controlling device.

According to Kothari (1994), the information from PERT, the manager is in a better position to know where trouble may occur, where supervision may be needed, and where resources may be shifted to keep the project on schedule. With a PERT network before him, he can easily grasp the interrelationship that exist in the project; and with the network, he can explain clearly to management above and below him just what his objectives are, how the project is progressing, and where difficulty is predicted.

Kothari (1994) outline the advantages and disadvantages of PERT as follows:

### **Advantages of PERT**

1. It forces managers to plan because it is impossible to make a time-event analysis without planning and seeing how the pieces fit together.
2. It forces planning all down the line because each subordinate manager plans the event.
3. It concentrates attention on critical elements that may need correction.

4. It makes possible a kind of feed forward control; a delay will affect succeeding events.
5. It makes possible the pressure for action at the right spot and level in the organization structure at the right time.

#### **Limitations or Disadvantages of PERT**

1. PERT is not practicable for routine planning of recurring events.
2. PERT has been emphasizing on time only and not on costs.
3. The time estimates to perform activities constitute a major limitation of this technique. If the time estimates are unsatisfactory, then the network diagram and the critical path will have little real meaning after the project begins.
4. The calculation of probabilities under PERT approach is done on the assumption that a large number of independent activities operate on critical path and as such the distribution of total time is normal, but this may not be true in real life which reduces the significance of all probability calculations that we often make under PERT.
5. The simple PERT technique does not consider the resources required at various stages of the project. If certain resources are used to perform say activity E and also activity D and if they can only be used for one activity at a time, the Network diagram, which we have drawn, will be infeasible and activity D must not be performed concurrently with activity E.
6. Using PERT for active control of a project requires frequent updating and revising of the PERT calculations and this proves quite a costly affair where, as in the opinion of a few experts, a simple bar-chart of progress to date can provide satisfactory control at relatively much lesser cost.
7. PERT is not a cure-all approach. It will not do the planning although it forces planning. It will not make control automatic although it establishes an environment where sound control principles may be appreciated and used.

#### ***Similarities and Dissimilarities in PERT and CPM Analyses***

Having discussed and illustrated the PERT and CPM Techniques, it is appropriate to point out the similarities and dissimilarities between these two approaches of Network Analysis, as pointed out by Kothari (1994).

##### ***Similarities***

1. PERT as well as CPM are used as decision making aids and tools for analyzing and administering large complex projects to be performed in some technological sequence.
2. PERT and CPM are techniques of Network analysis. In both cases, a project is represented by a diagram or network with each individual activity contributing one element to the diagram.

##### ***Dissimilarities***

1. CPM is used for repetitive jobs whereas PERT is used for non-repetitive jobs. For example, CPM would be used for planning residential construction while PERT could be used to plan the assembly of a space platform.

2. CPM directly introduces the concepts of cost into the analysis, while PERT indirectly accounts for cost if we assume that cost is related to time. As such, CPM is more explicit about cost-time relationship and in addition to the time estimates, cost must be assigned to each activity on the CPM network.

### **Conclusion**

Network analysis as a technique related to sequencing problems associated with projects is concerned with minimizing some measure or performance of the system such as the total completion time of the project, the overall cost and so on. It is useful for describing the elements in a complex situation for the purpose of designing, planning, managing, coordinating, controlling and making decision. These techniques show the inter-relationship of the various jobs or tasks, which make up the overall project and clearly identify the critical parts by providing planning and control information on the time, cost and resources aspects of a project.

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