

Project Management with Brief Information regarding CPM and PERT Methods

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Abstract — Project Management System keeps an eye on time and investment which will be involved during the development of new projects. It looks for various stages that are involved under entire development work such as analysis, designing, testing and maintenance work. Time and money both are important factor for any organization in the market and therefore they have to keep an exact record of every bit of their investment. This system will keep track of invested time on particular phase and generate reports to make future analysis. A project is an attempt to achieve a goal. In this Paper, different techniques of Project Management have been explained in brief with an example of each method.

Index Terms — Algorithm, Constraints, Era, Perspective, Pessimistic, Stochastic, Timespan

INTRODUCTION

A Project Management is an activity that has some purpose to finish. It is a task that has to be completed within a given time frame. The objectives are clear and the end process is definite. The process followed by Project management are initiating, planning, executing and controlling the Work of a team to achieve specific goals and to meet a Specific Criteria of success at the given specified time.

A project is basically considered as an attempt to achieve a goal i.e. to design and then produce a unique product, service or result with a defined beginning and end to meet its aim. The main objective of project management is to achieve all of the project goals within the given limits (specifically time) and to produce a complete project which complies with the client's objectives. The information related to project is usually discussed in project documentation and it is created at the beginning of the development process itself. The Four main constraints or limits on which the project is managed are scope, time, quality and budget.

Once the client's objectives are clearly established, they should impact on all decisions made by other people involved in the project i.e. the project managers, designers, contractors, sub-contractors, etc.

A key factor that distinguishes project management from just 'management' is that it has this final deliverable and a finite timespan, unlike management which is an ongoing process. Because of this a project professional needs a wide range of

skills; often technical skills, and certainly people management skills and good business awareness.

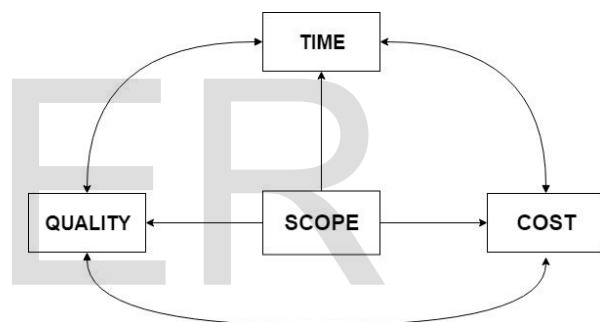


FIGURE: SCOPE OF PROJECT MANAGEMENT

In the year 1900, Civil Engineering projects were mainly managed by different groups or people. Some of them are Creative Architects, Engineers, and Master Builders and Many More.

Some of the famous Engineers of that era who have managed Civil Engineering projects are:

- *Vitruvius (first century BC)*^[1]
- *Christopher Wren (1632–1723)*^[2]
- *Thomas Telford (1757–1834)*^[3]
- *Isambard Kingdom Brunel (1806–1859)*^[4]

In the Era 1950, a group of people or an organization started service for project-management tools and techniques for difficult and complex engineering projects. Thus, project management has been developed from several fields of application including civil construction, engineering, and heavy defense activity.

Two Great Mathematicians of project management are: *Henry Gantt*^[5] known as the father of planning and control techniques, who is famous for his use of the Gantt chart as a project management tool and *Henri Fayol*^[6] for his creation of the five management functions that form the foundation of the body of knowledge associated with project and program management. Both Gantt and Fayol were students of Frederick Winslow Taylor's theories of scientific management.

The late 1950s highlighted the Beginning of the Modern Project Management Era where Core Engineering Fields come together to work as one. After the Year 1950 in the United States, projects were mainly managed by using Gantt charts and many other techniques and tools. At that time, two mathematical project-scheduling models were developed.

The "Critical Path Method" (CPM) was developed as a Joint Project between *DuPont Corporation and Remington Rand Corporation*^[7] for managing plant maintenance projects.

The "Program Evaluation and Review Technique" (PERT), was developed by the *U.S. Navy Special Projects Office in Conjunction with the Lockheed Corporation and Booz Allen Hamilton*^[8] as part of the Polaris missile submarine program.

PERT and CPM are very similar in their perspective but still there are some differences. CPM is used for projects that assume deterministic activity times; the times at which each activity will be carried out are known. PERT, on the other hand, allows for stochastic activity times; the times at which each activity will be carried out are uncertain or varied. Because of this core difference, CPM and PERT are used in different contexts. These mathematical techniques quickly spread into many private enterprises.

In 1969, the Project Management Institute (PMI) was formed in the USA. PMI publishes *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*^[9], which describes project management practices that are common to "most projects, most of the time." PMI also offers a range of certifications.

The Core Components of Project Management are:

- Preparing a Business Case
- Securing Corporate agreement
- Developing and Implementing a management plan for the project
- Leading and Motivating the project delivery team
- Managing the Risks, Issues and changes on the project
- Maintaining communications with stakeholders and the project organization

Project management is essentially aimed at producing an end product that will effect some change for the benefit of the organization.

Investment in effective project management will have a number of benefits, such as:

- providing a greater likelihood of achieving the desired result;
- ensuring efficient and best value use of resources;
- satisfying the differing needs of the project's stakeholders.

Who uses project management?

Projects crop up in almost all industries and businesses, for instance:

- Transport and infrastructure
- IT
- Product manufacture
- Building and construction
- Regulatory changes in finance and law

CRITICAL PATH METHOD

It is an algorithm for scheduling a set of project activities. It is also known as critical path analysis (CPA). It is commonly used with the program evaluation and review technique (PERT).

In the Era 1950s, CPM was developed by the two-great mathematician in Joint Project named Morgan R. Walker of DuPont and James E. Kelley Jr. of Remington Rand.

Critical Path method was developed and taken into practice by DuPont between 1940 and 1943 and thus contributed to the success of the *Manhattan Project*^[10].

Critical path is the sequential activities from start to the end of a project. Although many projects have only one critical path, some projects may have more than one critical paths depending on the flow logic used in the project.

The initial critical path method was used for managing plant maintenance projects. Although the original method was developed for construction work, this method can be used for any project where there are interdependent activities.

Critical Path Analysis can be used with all forms of projects including construction, aerospace, defense, software development, research projects, product development, engineering, and plant maintenance, among many others.

Any project with interdependent activities can apply this method of mathematical analysis.

The Critical Path Method (CPM) can help you keep your projects on track.

The first time CPM was used for major skyscraper such as Twin Towers in New York City.

Critical path schedules will...

- Help you identify the activities that must be completed on time in order to complete the whole project on time.
- Show you which tasks can be delayed and for how long without impacting the overall project schedule.
- Calculate the minimum amount of time it will take to complete the project.
- Tell you the earliest and latest dates each activity can start on in order to maintain the schedule.

The Critical Path Method has four key elements...

- Critical Path Analysis
- Float Determination
- Early Start & Early Finish Calculation
- Late Start & Late Finish Calculation

Using these values, CPM calculates the longest path of planned activities to logical end points or to the end of the project, and the earliest and latest that each activity can start and finish without making the project longer.

This process determines which activities are "critical" (i.e., on the longest path) and which have "total float" (i.e., can be delayed without making the project longer).

In project management, a critical path is the sequence of project network activities which add up to the longest overall duration, regardless if that longest duration has float or not.

This determines the shortest time possible to complete the project.

There can be 'total float' (unused time) within the critical path.

CPM analysis tools allow a user to select a logical end point in a project and quickly identify its longest series of dependent activities (its longest path).

Visualizing Critical Path Schedule-

Let us take an example of the critical path method by consider the following schedule network diagram

QUESTION: The activity durations for a project are given below. Draw the network and identify the critical path. Compute the earliest and latest occurrence time of the events and slack on each event. Perform the forward and backward computations in a tabular form. Durations of the activities are in days.

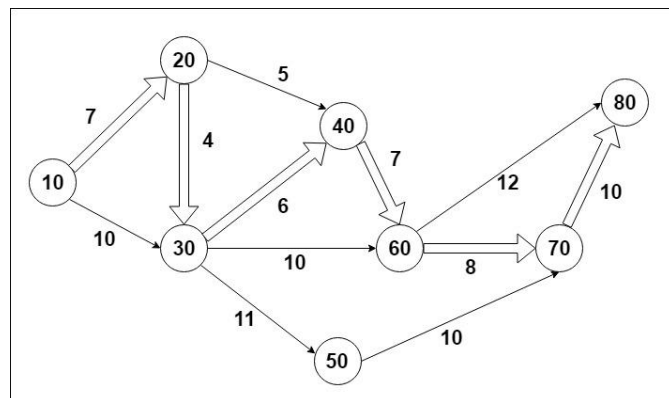
ACTIVITY	DURATION
10 – 20	7
10 – 30	10
20 – 30	4
20 – 40	5
30 – 40	6
30 – 50	11
30 – 60	10
40 – 60	7
50 – 70	10
60 – 70	8
60 – 80	12
70 – 80	10

SOLUTION:

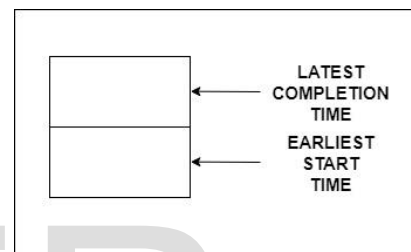
STEP 1: - Create the Network, with the duration of each step. Indicate the Critical path. Critical path of a project network is the longest path in the network. This can be identified by simply listing out all the possible paths from the starting node of the project to the end node of the project and then selecting the path with maximum sum of activity times on that path.

There are two phases to find the critical path –

1. Determine earliest start times (ES) of all the nodes. This is called Forward Pass.
2. Determine the latest completion times (LC) of various nodes. This is called Backward Pass.



Firstly, we need to find the Latest Completion Time and Earliest Start Time for each of the nodes.

Formula to be used for EARLIEST START TIME:

$$ES_j = \text{Max}_i (ES_i + D_{ij})$$

Where, i = starting activity

j = ending activity

D_{ij} = Duration of activity i to j

Earliest start time of 1st node i.e. 10 is always zero.

Therefore, $ES_1 = 0$

For node 2 i.e. 20,

$$ES_2 = 0 + 7 = 7$$

There are 2 possibilities for node 3 i.e. 30, 10 to 30 and 20 to 30

We have to choose the greater value from the above two ranges.

$$\text{For } 10 \text{ to } 30, ES = 0 + 10 = 10$$

$$\text{For } 20 \text{ to } 30, ES = 4 + 7 = 11$$

Thus, choosing the greater value from the above two values, $ES_3 = 11$

$$ES_4 = 11 + 6 = 17$$

$$ES_5 = 11 + 11 = 22$$

$$ES_6 = 17 + 7 = 24$$

$$ES_7 = 24 + 8 = 32$$

$$ES_8 = 32 + 10 = 42$$

LATEST COMPLETION TIME:

We start calculating latest completion time from the last node of the network,

Thus, for last node,

Latest completion time = earliest start time of last node itself

Therefore, $LC_8 = ES_8 = 42$

Formula for calculating Latest completion time is,

$$LC_i = \min_j (LC_j - D_{ij})$$

$$LC_7 = 42 - 10 = 32$$

In case of Node 6, there are again 2 cases arriving, 60 to 70 and 60 to 80

For 60 to 70, $LC = 32 - 8 = 24$

For 60 to 80, $LC = 42 - 12 = 30$

We are going to take the minimum value from the above two ranges, i.e. 24

$$LC_6 = 24$$

$$LC_5 = 32 - 10 = 22$$

$$LC_4 = 24 - 7 = 17$$

$$LC_3 = 17 - 6 = 11$$

$$LC_2 = 11 - 4 = 7$$

$$LC_1 = 7 - 7 = 0$$

Conditions for Analyzing Critical Path are:

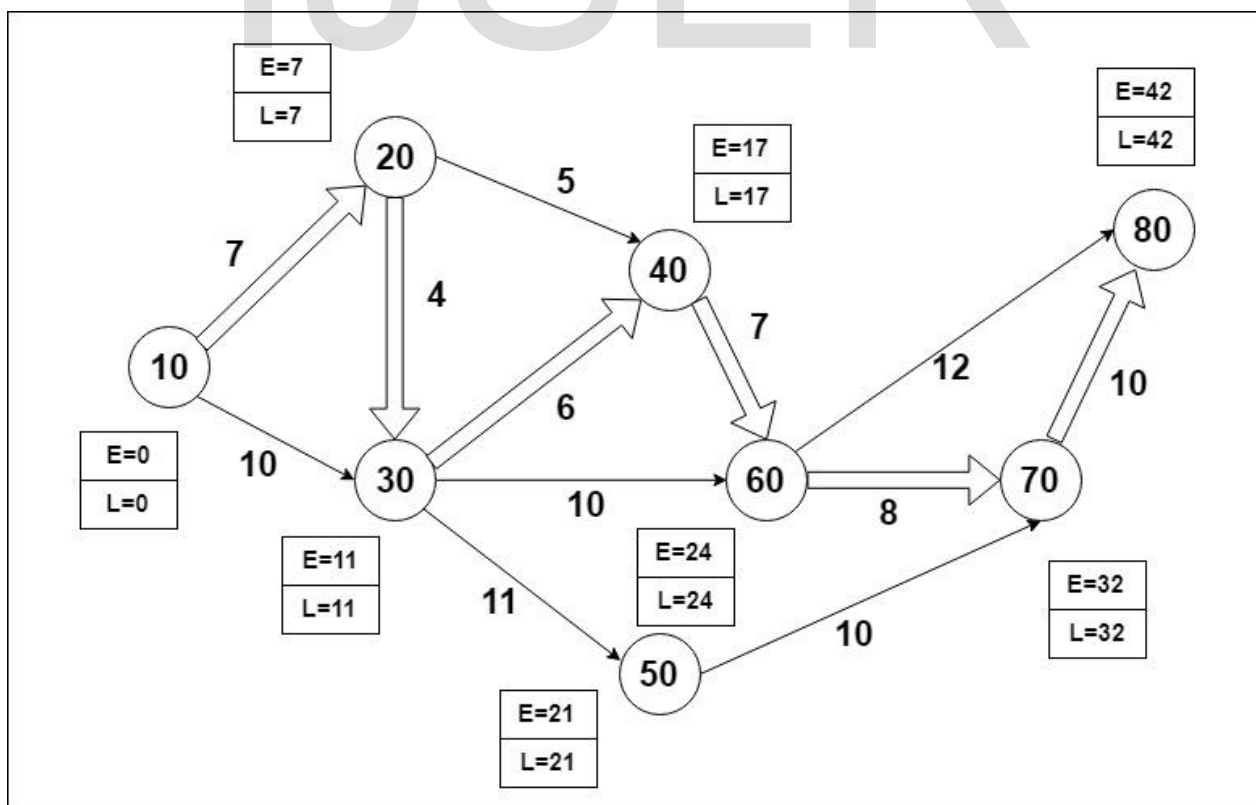
- $ES_i = LC_j$
- $ES_i = LC_j$
- $ES_j - ES_i = LC_j - LC_i = D_{ij}$

Critical Paths are: -

- 10-20-40-60-70-80 = 37
- 10-30-40-60-70-80 = 41
- 10-20-30-40-60-70-80 = 42
- 10-30-50-70-80 = 41
- 10-30-60-70-80 = 38
- 10-30-60-80 = 32

The path which satisfied all the above conditions are- 10-20-30-40-60-70-80 and hence it is the CRITICAL PATH.

From, the above paths the critical path is number 3, I.e. the total duration is 42 days.



ACTIVITY	DURATION	START TIME		FINISH TIME		TOTAL FLOAT
		EARLIEST	LATEST	EARLIEST	LATEST	
10-20	7	0	0	7	7	0
10-30	10	0	1	10	11	1
20-30	4	7	7	11	11	0
20-40	5	7	12	12	17	5
30-40	6	11	11	17	17	0
30-50	11	11	11	22	22	0
30-60	10	11	14	21	24	3
40-60	7	17	17	24	24	0
50-70	10	21	22	31	32	1
60-70	8	24	24	32	32	0
60-80	12	24	30	36	42	6
70-80	10	32	32	42	42	0

STEP 2: - Calculation of Total Float and Free Float for Non-Critical Activities:

Total Floats: it is the amount of time that the completion time of an activity can be delayed without effecting the project t completion time.

$$TF_{ij} = LC_j - ES_i - D_{ij}$$

Where, TF = total float

LC = Latest completion time

ES = earliest start time

D = duration

Hence, Total float for different activities can be calculated as:

$$TF_{10-20} = 7-0-7=0$$

$$TF_{10-30} = 11-0-10 = 1$$

$$TF_{20-30} = 11-7-4=0$$

$$TF_{20-40} = 17-5-7 =5$$

$$TF_{30-40} = 17-11-6=0$$

$$TF_{30-50} = 22-11-11=0$$

$$TF_{30-60} = 24-11-10=3$$

$$TF_{40-60} = 24-17-7=0$$

$$TF_{50-70} = 32-21-10=1$$

$$TF_{60-70} = 32-24-8=0$$

$$TF_{60-80} = 42-24-12=6$$

$$TF_{70-80} = 42-32-10=0$$

FREE FLOATS: It is the amount of time that the activity completion time can be delayed without affecting the earliest start time of immediate success activities in the network.

$$FF_{ij} = ES_j - ES_i - D_{ij}$$

$$FF_{10-20} = 7-0-7=0$$

$$FF_{10-30} = 11-0-10=1$$

$$FF_{20-30} = 11-7-4=0$$

$$FF_{20-40} = 17-7-5=5$$

$$FF_{30-40} = 17-11-6=0$$

$$FF_{30-50} = 22-11-11=0$$

$$FF_{30-60} = 24-11-10=3$$

$$FF_{40-60} = 24-17-7=0$$

$$FF_{50-70} = 32-21-10=1$$

$$FF_{60-70} = 32-24-8=0$$

$$FF_{60-80} = 42-24-12=6$$

Conclusion

Critical Path Analysis reveals network information such as critical path, total float, free float and activity float. Thus, the above calculated data is used for further project execution.

PROGRAM EVALUATION AND REVIEW TECHNIQUE

PERT is a method of analyzing the tasks involved in completing a given project, especially the time and money needed to complete each task. It was developed to simplify the planning and scheduling of large and complex projects. It was first developed by The United States Navy in the late 1950s, it is commonly used in conjunction with the critical path method. It was developed for the U.S. Navy Special Projects Office in 1957 to support the U.S. Navy's Polaris nuclear submarine project. It found applications all over industry.

PERT and CPM are complementary tools, because "CPM employs one time estimate and one cost estimate for each activity; PERT may utilize three-time estimates (optimistic, expected, and pessimistic) and no costs for each activity.

Ten years after the introduction of PERT in 1958 the American librarian Maribeth Brennan published a selected bibliography with about 150 publications on PERT and CPM, which had been published between 1958 and 1968.

In a PERT diagram, the main building block is the event, with connections to its known predecessor events and successor events.

- PERT Event: a point that marks the start or completion of one or more activities. It consumes no time and uses no resources.
- Predecessor Event: an event that immediately precedes some other event without any other events intervening.
- Successor Event: an event that immediately follows some other event without any other intervening events.

PERT has defined four types of time required to accomplish an activity:

- Optimistic Time: the minimum possible time required to accomplish an activity (o) or a path (O), assuming everything proceeds better than is normally expected
- Pessimistic Time: the maximum possible time required to accomplish an activity (p) or a path

(P), assuming everything goes wrong (but excluding major catastrophes).

- Most Likely Time: the best estimate of the time required to accomplish an activity (m) or a path (M), assuming everything proceeds as normal.
- Expected Time: the best estimate of the time required to accomplish an activity (te) or a path (TE), accounting for the fact that things don't always proceed as normal (the implication being that the expected time is the average time the task would require if the task were repeated on a number of occasions over an extended period of time).

$$T_e = (o + 4m + p) \div 6$$

Advantages

- PERT chart explicitly defines and makes visible dependencies (precedence relationships) between the work breakdown structure (commonly WBS) elements.
- PERT facilitates identification of the critical path and makes this visible.
- PERT facilitates identification of early start, late start, and slack for each
- PERT can provide a probability of completing before a given time.

Disadvantages

- There can be potentially hundreds or thousands of activities and individual dependency relationships.
- PERT is not easily scalable for smaller projects.
- The network charts tend to be large and unwieldy requiring several pages to print and requiring specially sized paper.

EXAMPLE-

Consider the following table summarizing the details of the project:

ACTIVITY	PREDECESSOR	DURATIONS (WEEKS)		
		O	m	p
A	-	5	6	7
B	-	1	3	5
C	-	1	4	7
D	A	1	2	3
E	B	1	2	9
F	C	1	5	9
G	C	2	2	8
H	E,F	4	4	10
I	D	2	5	8
J	H,G	2	2	8

- Construct the project network
- Find the expected duration and variance of each activity.
- Find the critical path and expected project completion time.
- What is the probability of completing the project on or before 22 weeks.

SOLUTION:-

Firstly,

O = optimistic time

m = most likely time

p = pessimistic time

FORMULA: for mean duration

$$t_e = \text{expected duration} = (t_o + 4 \times t_m + t_p) / 6$$

Where, t_o = optimistic time

T_m = most likely time

T_p = pessimistic time

$$t_A = (5 + 4 \times 6 + 7) / 6 = 6$$

$$t_B = (1 + 4 \times 3 + 5) / 6 = 3$$

$$t_C = (1 + 4 \times 4 + 7) / 6 = 4$$

$$t_D = (1 + 4 \times 2 + 3) / 6 = 2$$

$$t_E = (1 + 4 \times 2 + 9) / 6 = 3$$

$$t_F = (1 + 4 \times 5 + 9) / 6 = 5$$

$$t_G = (2 + 4 \times 2 + 8) / 6 = 3$$

$$t_H = (4 + 4 \times 4 + 10) / 6 = 5$$

$$t_I = (2 + 4 \times 5 + 8) / 6 = 5$$

$$t_J = (2 + 4 \times 2 + 8) / 6 = 3$$

FORMULA: for Variance: -

$$\text{Variance: } \sigma^2 = [t_p - t_o]^2 / 36$$

Where, t_o = optimistic time

T_p = pessimistic time

Variance for A: 0.111

Variance for B: 0.44

Variance for C: 1.00

Variance for D: 0.11

Variance for E: 1.78

Variance for F: 1.78

Variance for G: 1.00

Variance for H: 1.00

Variance for I: 1.00

Variance for J: 1.00

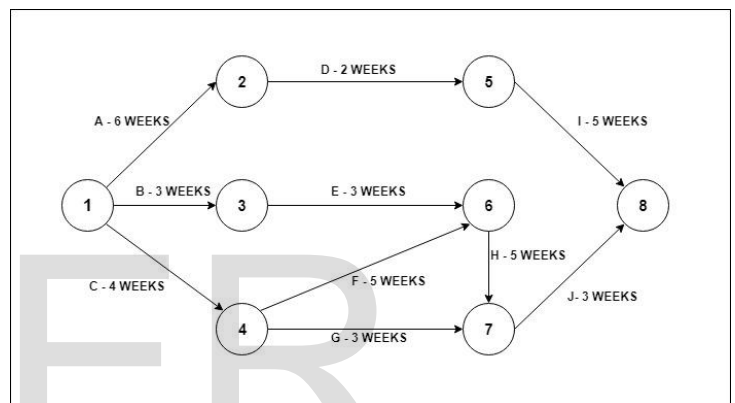


Fig. NETWORK DIAGRAM WITH DURATION

FORMULA: to be used for EARLIEST START TIME:

$$ES_j = \text{Max}_i (ES_i + D_{ij})$$

Where, i = starting activity

j = ending activity

D_{ij} = Duration of activity i to j

Earliest start time of 1st node is always zero.

Therefore, $ES_1 = 0$

LATEST COMPLETION TIME:

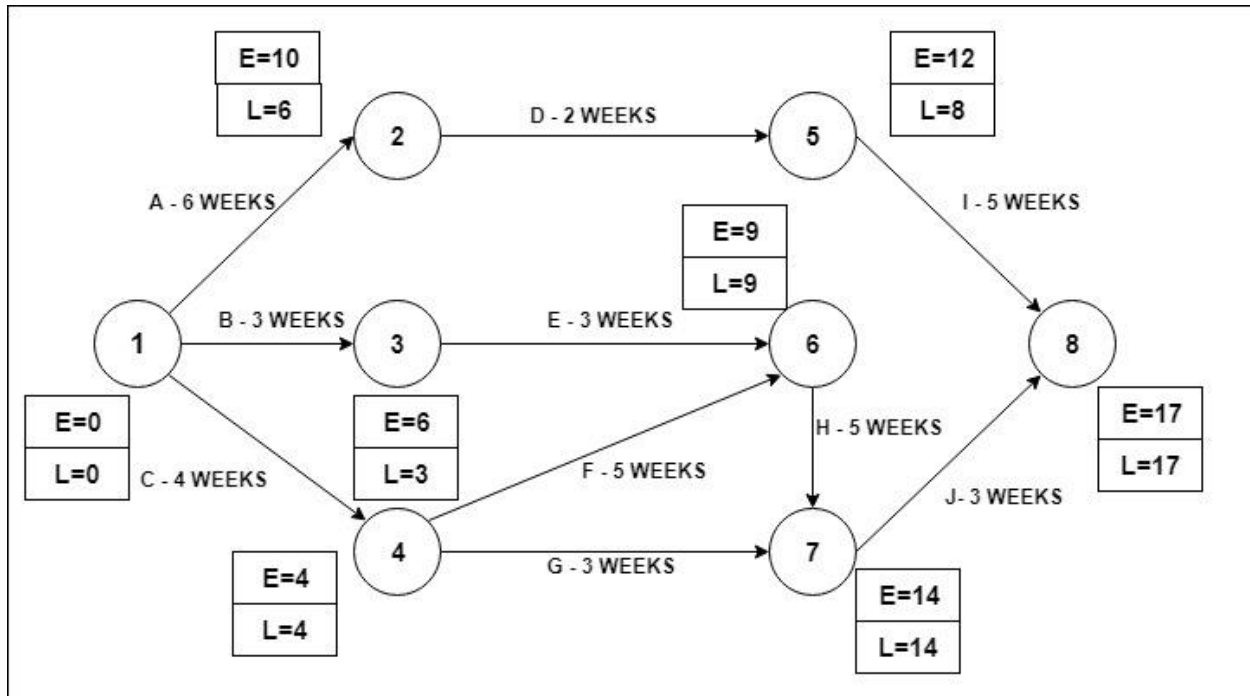
We start calculating latest completion time from the last node of the network,

Thus, for last node,

Latest completion time = earliest start time of last node itself

$$\text{Therefore, } LC_8 = ES_8 = 17$$

NOTE: Method for Calculating Earliest Start Time and Latest Completion Time is same for both CPM and PERT. Hence not shown again.



Conditions for Analyzing Critical Path are:

- $ES_i = LC_j$
- $ES_i = LC_j$
- $ES_j - ES_i = LC_j - LC_i = D_{ij}$

The path which satisfied all the above conditions are- 1-4-6-7-8 and hence it is the CRITICAL PATH. Therefore, expected project completion time is 4+5+5+3 = 17 Weeks

ACTIVITY	MEAN DURATION	VARIANCE
C	4	1.00
F	5	1.78
H	5	1.00
J	3	1.00
	17 WEEKS	4.78

Probability ($x \leq 22$ weeks)

Probability $[(x - \mu) / \sigma]$

Value of sigma: σ : Square Root of 4.78 = 2.19 Weeks

Probability $[(x - \mu) / \sigma] \leq [(22-17)/2.19]$

Therefore, Probability $[z \leq 2.28]$

Now, by the help of standard normal distribution table^[11],

Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9924	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9958	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986

Probability $[z \leq 2.28] = 0.9887$

This value is obtained from standard normal distribution table. Therefore, the probability of completing the project on or before 22 weeks is 0.9887 i.e. 98.87%

COMPARISON BETWEEN PERT & CPM: -

PARAMETERS	PERT	CPM
Full Form	Program Evaluation and Review Technique	Critical Path Method
Meaning	It is a project management technique, used to manage uncertain activities of a project.	It is a statistical technique of project management that manages well defined activities of a project.
Orientation	Event-oriented technique	Activity-oriented technique.
Evolution	Evolved as Research & Development project	Evolved as Construction project
Model	Probabilistic Model	Deterministic Model
Focuses on	Time	Time-cost trade-off
Estimates	Three time estimates	One time estimate
Appropriate for	High precision time estimate	Reasonable time estimate
Nature of Jobs	Non- repetitive nature	Repetitive nature

CONCLUSION

By the help of this paper you should understand the whole process of CRT and PERT, and able to use this process in your daily life.

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