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Analysis of Bullet Train Project Using CPM and PERT

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ABSTRACT: One of the most significant tools for project planning and management is the Critical Path Method (CPM), as well as the Project Evaluation and Review Technique (PERT). When the time required or anticipated to perform specific activities is unclear, PERT is a project management method. CPM is a method for planning activities in which the amount of time required to accomplish the project is presently known. CPM is a step-by-step project management strategy that keeps processes and projects on track by focusing on important tasks. The Critical Route is the shortest approach to finish any project by following one path across all connected operations. The goal of this research is to examine the whole bullet train project, its critical activities and interdependencies, as well as the precedence connection between them. The authors of this research article examine the use of CPM and PERT calculations on bullet train projects. Using CPM we are studying the critical activities which can affect the project completion and using PERT authors are analyzing the estimated time for project completion.

KEYWORDS: Bullet Train, Critical Path Method, Operation Research, Program Evaluation and Review Technique (PERT).

I. INTRODUCTION

The world's first bullet train project was inaugurated in 1964 between Tokyo and Osaka in Japan. The entire project was completed in 1992. In 2017, Indian Government also announced and inaugurated the Bullet train project in India. This research paper studies this project with help of operation research tools like CPM and PERT. Operation research (OR) facilitate with decision making and returns the simplest version of the complex problems using mathematical techniques and tools[1]–[3].

One of the methodologies used in OR for planning, scheduling, and managing big projects is network analysis or network scheduling. These are based on the Project's portrayal as a network of activities [4], [5]. PERT is proper method which is utilized for the undertakings where the time required or expected to finish various exercises are not known. Energetic is significantly applied for planning, association and joining of various assignments inside a task. It gives the outline of task and is productive procedure for project assessment. Energetic is followed the Probability approach[6], [7]. It ascertains the three-time assessment for movement. CPM is a procedure which is utilized for the tasks where the time required for fulfillment of undertaking is now known. It is significantly utilized for deciding the surmised time inside which an undertaking can be finished. Basic way is the biggest way in project the board which generally give least time taken to the end of venture[8]–[10]

II. LITERATURE REVIEW

Ali Göksu and Selma Catovic [11] In order to understand the efficacy and efficiency of the furniture firm "Dallas," they used CPM and PERT in their investigation. The data was collected and study was carried out to learn critical activities and expected project completion time. Karibo Benaiah Bagshaw [12] in his research study discussed the concepts of CPM and PERT. He reviewed both the methods and learnt that CPM is more effective when project ending time is certain whereas if project ending time is uncertain then PERT will be more effective. Muhammad Kholil, et al. [13] in their research study focused on application of CPM and PERT on house construction project. Their objective was to plan the network and obtain the optimal project completion time. According to their calculation they concluded that the project can be completed in 136 days with the prospect 74.54%. Without CPM and PERT, the project would take 173 days. Hence the work shows that the company can save 42 days and can increase their efficiency with the help of these mathematical tools. Wallace Agyei [14] In their case study, they sought to strike a balance between the project's cost and the time it would take to finish it. Angel Estates and Construction Ltd., a construction business situated in Ghana's Ashanti region, provided the information. Analysis was done using CPM and PERT both. Their results concluded that minimum completion time is 40 days instead of 79 days. Their study showed that by proper scheduling of activities, the project can be finished before expected time and it reduces the cost too. Mete MAZLUMa, Ali Fuat GÜNER İb [15] They investigated the use of fuzzy logic, CPM, and PERT in their study. To enhance an online internet branch and plan the project of an online internet branch, fuzzy PERT and fuzzy CPM are utilized. Bodunwa, Oluwatoyin Kikelomo and Makinde, Jamiu Olalekan[1] analyzed the secondary data collected from Samkay

Construction Company using CPM and PERT. They were able to establish the earliest, latest, and slack periods for each activity as a consequence of the research, as well as the critical route using CPM. PERT was used to estimate project completion time (207 days) and the probability (68.8%) that project will be completed within that duration.

III. METHODOLOGY

A. Design

The Critical Path Method (CPM) is a step-by-step project management approach that focuses on critical activities to keep processes and projects on track. The Critical Route is the quickest way to complete any project by taking one path across all of the related activities (PERT). For project completion, CPM employs two methods:

- Critical activity: It is an activity or path which if delayed would delay the whole Project.
- Non-Critical activity: It is an activity which can be delayed.

Basic way is the longest distance between the beginning and the completing of a Project including every one of the undertakings alongside the length. To put it plainly, basic way gives the genuine timetable to the Project. In CPM, the time is deterministic as it is utilized for the Projects which had been developed before in the Project the executives. Along these lines, basic movement is an action with zero float, where float (slack) is how much time that an undertaking can be postponed with creating setback to resulting assignments and Project consummation date. Movement and Events: Some occurrence of time is called an occasion and the one which consumes time is action. Some occurrence of time is called an occasion and the one which consumes time is movement as displayed in Figure 1.

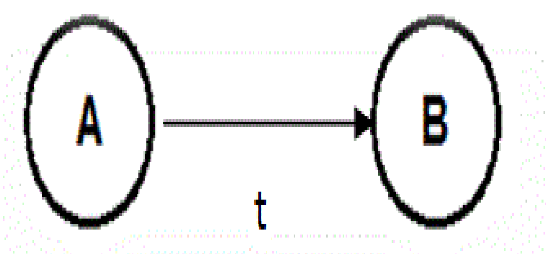

Figure 1: Representation of activity and event, an event is a period of time, while activity is a period of time that uses time.

- ○ denotes event also called as node.
- → denotes activity also called edge.
- 't' is a time taken by activity.

B. Sample

The 'National High-Speed Rail Corporation Limited' is handling this project and has planned total 12 corridors all over India. This research paper is studying only one corridor estimates. The very first construction planned was Mumbai-Ahmedabad high-speed rail corridor which started in 2017 and is expected to finish in 2028 (almost 11 years).

C. Instruments

a. Project Evaluation and Review Technique

PERT (Project Evaluation and Review Technique) is a useful tool for projects when the amount of time required to complete certain tasks is unclear. PERT is a project management tool that is used to organize, plan, and integrate diverse operations. It is a useful tool for project assessment and acts as a template for the project.

b. Critical Path Method

When the time necessary to accomplish a project is already known, the Critical Path Method (CPM) is an approach to use. It's usually used to estimate how long something will take to complete. In project management, the critical route is the most significant path since it assures that the project is finished in the lowest time feasible.

Data Collection

c. CPM Computations

- To achieve the task or Project conveniently; we must compute the following information.
- Total duration to complete Project.
- Classification of critical and non-critical activities.
- Consider the following notations:-
- E_i : Initial occurrence time of an event i.
- L_i : Newest allowable time of event i.
- ES_{ij} : First starting time of an activity (i, j).
- LS_{ij} : Newest starting time of an Activity (i, j).
- EF_{ij} : Initial finishing time of an Activity (i, j).
- LF_{ij} : Newest finishing time of an Activity (i, j).
- t_{ij} : Duration of an Activity (i, j).
- Events are numbered consecutively with integer 1,2,…,n $\ni i < j$; $\forall_{i,j}$ for any two events i as well as j

For the computations of earliest occurrence and latest allowable time, it involves two methods:

- Forward pass: It calculates the first existence time of an event.

Regressive pass: It calculates latest allowable times of an event.

d. Forward Pass

Let the computations starts at node 1 to an end node n.

1. Set $E_1 = 0$ (i.e., Earliest occurrence time of initial event 1).
2. Calculate the ES_{ij} (i.e., Early starting time of event i to j). Here; i=1.
3. ∴ ES_{ij} = Ei, for all activities (i,j) preliminary at event i.
4. Calculate EF_{ij} which is the summation of ES_{ij} and t_{ij}.
5. i.e.$EF_{ij} = ES_{ij} + t_{ij} = E_i + t_{ij}$.
6. Now, proceed to next event say j ; j > i.
7. Calculates E_j , which is maximum of EF_{ij}

8. $E_j = Max\{EF_{ij}\}$
9. $E_j = Max\{E_i + t_{ij}\}$; for all acts that came before it.
10. If , j=n (final node/event) , then earliest occurrence time for the final event say E_n is given by
11. $E_n = Max\{EF_{ij} + t_{ij}\} = Max\{E_{n-1} + t_{ij}\}$; for all terminal activities.

e. Backward Pass

Once completing the forward pass we will start from end node/event n to the node/event 1.

1. Set the earliest occurrence E_i of 'n' event (E_n) equal to the latest occurrence time (L_j) for event 'n' (L_n).
2. i.e., $E_n = L_n$; j=n
3. Calculate LF_{ij} (latest finishing time of event ends at j). This will be equal to the L_n .
4. i.e., $F_{ij} = L_n$, for all activities (i,j) ending at j.
5. Calculate LF_{ij} which is
6. $LF_{ij} = L_j$ and $S_{ij} = LF_{ij} - t_{ij} = L_j - t_{ij}$, for all (i,j) finish at j
7. Proceed backward to the event in sequence.
8. Calculate L_i , which is minimum of LS_{ij} i.e.,
9. $L_i = Min\{LS_{ij}\} = Min\{L_j - t_{ij}\}$; for all immediate succesor activities.
10. If j = 1 , (initial event) , then
11. $L_1 = Min\{LS_{ij}\} = Min\{L_{j-1} - t_{ij}\}$; for all immediate succesor activities

f. Float (Slack)

The float (slack) or available energy is how much time that a non-basic activity or occasion might be postponed or stretched out without causing the general Project consummation timetable to be pushed back.
In short the allowed delay time in Non-critical activities is called float.
Thus float (slack) is denoted by

$$S_{ij} = L_j - E_i - t_{ij}.$$

g. Data Analysis

As PERT is probabilistic, there are three time estimates for PERT.
t_p= Pessimistic time(max)
t_m = Most likely time (normal time)
t_o = optimistic time

For beta distribution , the variance for each activity is calculated by

$$\sigma^2 = \left(\frac{t_p - t_o}{6}\right)^2$$

Thus , the standard deviation for the Project is

$$\sigma_p = \sqrt{\sum \sigma_{CA}^2}$$

where CA is critical activities.
Following are the steps to compute it:
Using t_o , t_p and t_m , are calculated .
To decide the movement length fluctuation in PERT, the standard deviation is expressed as the one-sixth of the range assumed by the variate ,

i.e., standard deviation , $\sigma = \frac{t_p - t_o}{6}$

and variance , $\sigma^2 = \left(\frac{t_p - t_o}{6}\right)^2$

Estimation of Project completion time.
The likelihood appropriation of times for registering an occasion can be approximated by the Normal dissemination .Thus, the likelihood of finishing the Project on the timetable time; t_S is given by:

$Prob\left(Z \leq \frac{t_S - t_E}{\sigma_i}\right)$.

Where, t_E = expected consummation season of Project.
Z = number of standard deviations

IV. RESULTS AND DISCUSSION

A. Rubrics for Constructing a Networks

Every movement is addressed by one and only one bolt.
Each activity must be identified by two distinct end nodes.
Correct precedence relationships consider:
Activities that must immediately precede the current activity.
Activities that follow current one
Activities must occur concurrently (rule 2) with current activity.
Precedence rule: A < B (A is predecessor and B is successor)

B. Precautions to Construct a Network Diagram

Identify the burst element (starting element should not have an incoming arrow).
Identify the merge element (last element should not have an outgoing arrow).
There should be no looping as shown in Figure 2.

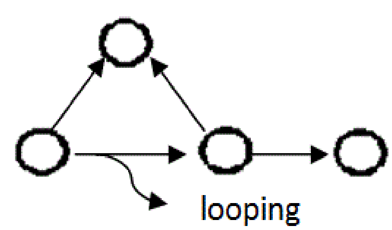

Figure 2: Representation of looping in network diagrams

There should not be any dangling activity as shown in figure 3.

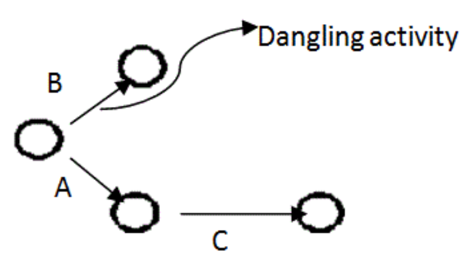

Figure 3: The above Figure Representation of dangling activity

Inserting dummy activity (Figure 4), it is just required to show the Precedence rule of Activities correctly. For eg. A,B<C; A<D

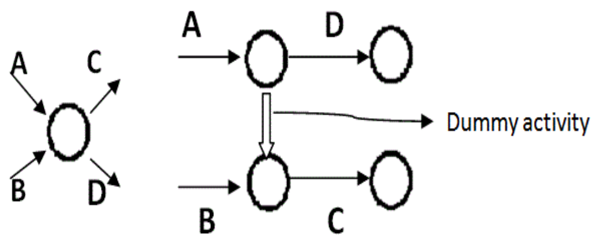

Figure 4: The above figure Representation of dummy activity

The labelling technique used is Fulkerson's rule. Start labelling with the ○ having no head of arrow or incoming arrow. Stop at ○ having no output arrow. Here creators will observe basic way which will tell us the significant exercises and furthermore the absolute undertaking consummation time and likelihood of finishing the development in planned time. A rundown of exercises is given. Ancestors show how subordinate the current movement is on the past exercises. Basic exercises that will postpone the undertaking assuming isn't finished on time will likewise be sorted out. The accompanying Table 1 gives subtleties of the Project and utilizing the CPM technique we can discover the consummation season of the Project.

Table 1: Illustrates the Critical Path Method project activities and duration

No	Activity	Code	Time (Months)	Predecessor(s)
1	Survey	A	9	---
2	Authorization	B	3	A
3	Planning and Designing	C	5	D
4	Area Approval	D	9	B
5	Tender Auction	E	3	B
6	Contract Signing	F	3	C
7	Budget planning and Evaluation	G	6	F
8	Managing Man Power and Resources	H	7	G
9	Importing and Delivery of Materials	I	6	G
10	Construction	J	24	H
11	Electrification	K	6	J
12	Technical Assembly	L	4	J
13	Trials	M	2	K
14	Final Approval	N	2	M
15	Launch	O	1	N

In this undertaking, there are an aggregate of 15 key exercises, every one of which is addressed by an extraordinary code. The movement Survey (A) is the principal action having no ancestor. In light of the table, we will develop an organization outline as displayed in Figure 5.

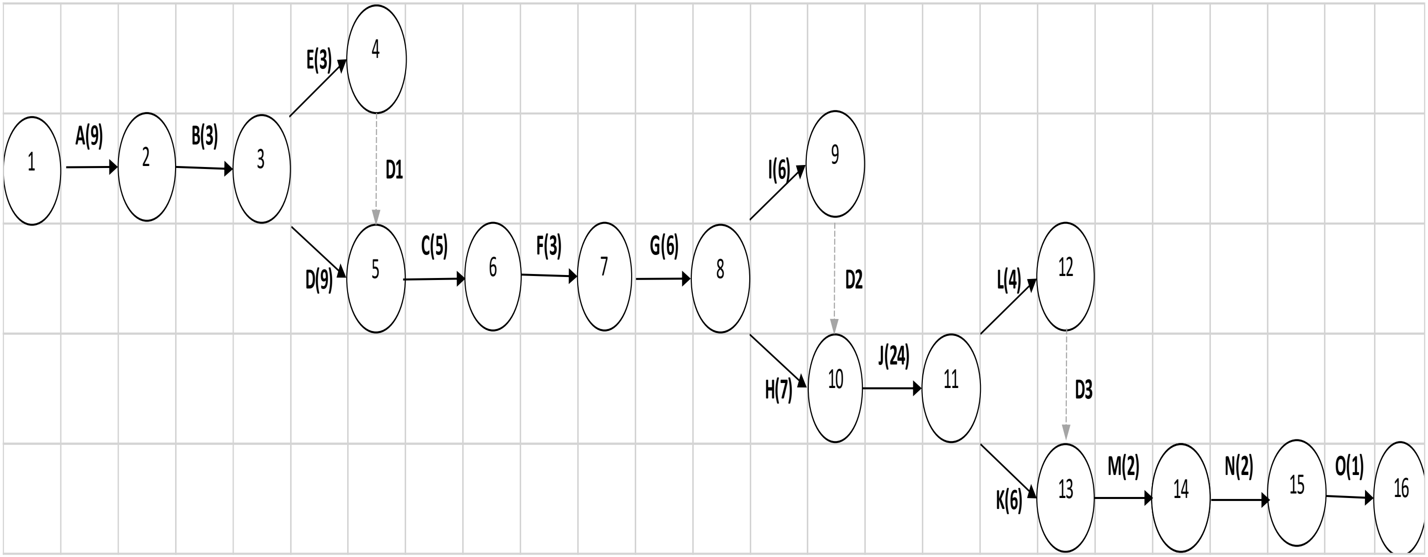

Figure 5. The above Representation of Network Diagram. The circle represents the hub, the bolt indicates the movement code alongside the section which means the given span.

The circle represents the hub, the bolt signifies the movement code alongside the section which indicates the given length. Exercises D1, D2 and D3 are a spurious movement demonstrated by a specked bolt and consume zero-month length.

Forward pass method

Set $E_1 = 0$

$$E_2 = E_1 + t_{1,2} = 0 + 9 = 9$$
$$E_3 = E_2 + t_{2,3} = 9 + 3 = 12$$
$$E_4 = E_3 + t_{3,4} = 12 + 3 = 15$$
$$E_5 = Max\{E_4 + t_{4,5}, E_3 + t_{3,5}\} = Max\{15 + 0, 12 + 9\} = 21$$
$$E_6 = E_5 + t_{5,6} = 21 + 5 = 26$$
$$E_7 = E_6 + t_{6,7} = 26 + 3 = 29$$
$$E_8 = E_7 + t_{7,8} = 29 + 6 = 35$$
$$E_9 = E_8 + t_{8,9} = 35 + 6 = 41$$
$$E_{10} = Max\{E_9 + t_{9,10}, E_8 + t_{8,10}\} = Max\{41 + 0, 35 + 7\} = 42$$
$$E_{11} = E_{10} + t_{10,11} = 42 + 24 = 66$$
$$E_{12} = E_{11} + t_{11,12} = 66 + 4 = 70$$
$$E_{13} = Max\{E_{12} + t_{12,13}, E_{11} + t_{11,13}\} = Max\{70 + 0,66 + 6\} = 72$$
$$E_{14} = E_{13} + t_{13,14} = 72 + 2 = 74$$
$$E_{15} = E_{14} + t_{14,15} = 74 + 4 = 76$$
$$E_{16} = E_{15} + t_{15,16} = 76 + 1 = 77$$

The results have given us $E_{16} = 77$

Now, we will calculate L_j

Backward pass method

Set $L_{16} = E_{16} = 77$

$$L_{15} = L_{16} - t_{16,15} = 76$$
$$L_{14} = L_{15} - t_{15,14} = 74$$
$$L_{13} = L_{14} - t_{14,13} = 72$$
$$L_{12} = L_{13} - t_{13,12} = 72$$
$$L_{11} = L_{13} - t_{13,11} = 66$$
$$L_{10} = L_{11} - t_{11,10} = 42$$
$$L_9 = L_{10} - t_{10,9} = 42$$
$$L_8 = L_{10} - t_{10,8} = 35$$
$$L_7 = L_8 - t_{8,7} = 29$$
$$L_6 = L_7 - t_{7,6} = 26$$
$$L_5 = L_6 - t_{6,5} = 21$$
$$L_4 = L_5 - t_{5,4} = 21$$
$$L_3 = L_5 - t_{5,3} = 12$$
$$L_2 = L_3 - t_{3,2} = 9$$
$$L_1 = Min\{L_j - t_1, j\}; j = 2 = 0$$

Now, we will compute slack time (S_{ij}) for each activities. Thus, $S_{ij} = L_j - E_i - t_{ij}$. For example: - If we calculate $S_{5,6} = L_6 - E_5 - t_{5,6} = 26 - 21 - 5 = 0$. Similarly, we can calculate the slack time for all the activities. Thus, the network diagram with earliest starting time and latest finishing time along with the slack time is shown below Figure 6: -

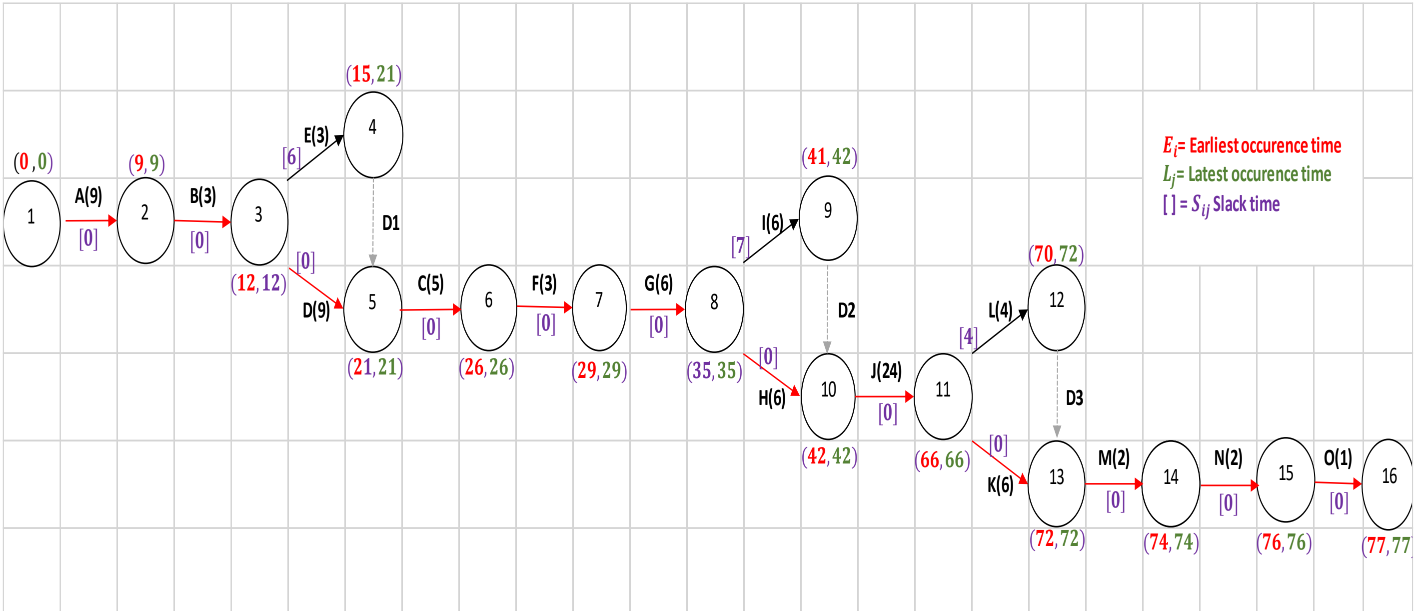

Figure 6: Representation of CPM network diagram with critical path

The critical path of the project is: (1,2) -(2,3) -(3,5) -(5,6) -(6,7) -(7,8) -(8,10) -(10,11) -(11,13) -(13,14) -(14,15) -(15,16). Activities that can run late (activities that have slack time other than 0) are E, I and L. Hence, the completion time for the Project using CPM is 77 months i.e. approximately 6 years and 5 months.

Projects evaluation as well as review Technique (PERT): The three time estimates for the same problem are in the following Table 2 and Table 3:

Table 2: Illustrates the three-time gauges for a similar issue

ACTIVITY	DESCRIPTION	DURATION (days) (t_o , t_m , t_p)
A	Survey	(7,9,10)
B	Authorisation	(2,3,5)
C	Planning, designing and architecture	(4,5,7)
D	Area approval	(8,9,10)
E	Tender auction	(2,3,4)
F	Signing the contract	(1,3,4)
G	Budget planning and evaluation	(5,6,8)
H	Managing man power	(3,7,8)
I	Importing and delivery of materials	(5,6,8)
J	Materialistic construction	(21,24,36)
K	Electrification	(4,6,12)
L	Technical assembly	(3,4,6)
M	Final trials	(1,2,4)
N	Final approval by authorities	(1,2,3)
O	Launch and inauguration	(1,1,2)

Now we compute variance of critical activities by using formula$\sigma^2 = \left(\frac{t_p - t_o}{6}\right)^2$.

Table 3: Illustrates all its computations of three time estimates for the same problem

Activity	t_p	t_o	σ^2
A	10	7	0.25
B	5	2	0.25
C	7	4	0.25
D	10	8	0.1089
F	4	1	0.25
G	8	5	0.25
H	8	3	0.6889
J	36	21	6.25
K	12	4	1.7689
M	4	1	0.25
N	3	1	0.1089
O	2	1	0.0289

Next is the final variance and standard deviation which is obtained as follows:

$$\sigma^2 = \sum \sigma_{CA}^2 = 10.4545$$

$$\boldsymbol{\sigma = \sqrt{10.4545} = 3.23}$$

We know, $t_s(estimated\ time\ ) = 80$ months and $t_e = 77$ months

Then,

$$Prob\left(Z \leq \frac{t_S - t_E}{\sigma_i}\right)$$

$$= Prob\left(Z \leq \frac{80 - 77}{3.23}\right)$$

$$= Prob(Z \leq 0.93) = 0.8238$$

$P_r = 82.38\%$ (from standard normal distribution function where Z= 0.93→ 82.38%).

Thus, the probability of the projects could be finished in given scheduled time is 82.38%.

IV. CONCLUSION

This research report focuses on this project using activity research tools such as the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT). Using numerical processes and apparatuses, activity research works with navigation and returns the simplest adaptation of complex challenges. The author used operation research methods such as CPM and PERT to analyze the bullet train project in this research study. The CPM investigation identified essential activities and paths where delays might have an impact on the overall project completion schedule. Also it calculated estimated project completion time which came out to be 77 months (almost 6 years and 5 months). The PERT investigation uncovers that the Project could in any case be finished in the planned Project length with a likelihood of 82.38% without broadening the booked Project span.

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