Analysis Of Nagpur Metro Rail Project Using CPM, PERT And Crashing

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Abstract

Network analytical tools like CPM/PERT are used for project scheduling and to determine the optimum project completion time. A network diagram is the first thing to sketch an arrow diagram which shows inter-dependencies and the precedence relationship among activities of the project. In most of the situation the duration of the project can be reduced by assigning more resources to many of the activities. The additional resources or even labor, increase the cost of the project. Crashing method is used to analyze the balance between the time duration and the project cost.

In Nagpur, the second capital city of Maharashtra state, India, its mega project of Metro rail is a new mass rapid transport system (MRTS) and also a hub for various sectors. The objective of this research is to identify the major activities associated with the Nagpur Metro rail project and arrange them in a proper sequence. The research study also provides the comparative analysis by using the traditional network planning methods of CPM and PERT. To optimize the time-cost tradeoff the Crashing method is used.

Keywords: *Network Planning, Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), Crashing*

1 Introduction:

The Metro rail project work in Nagpur is one of the mega project associated with different departments of government sector and private sector. The coordination between these sectors includes various activities, starting from planning, execution, along with supervision. For this Metro rail project, scheduling is important to set the various activities in a proper sequence and also to estimate the time duration. The sequence of different stages, the relation between the activities and dependencies form the network scheduling model. The main reason for project scheduling is to ensure that the deadline can be achieved.

The Operation Research techniques used for planning, scheduling and controlling large and complex projects are often referred to as network analysis. Now-a-days we use a technical tool for planning, scheduling and controlling stages of the projects known as Critical Path Method (CPM) and Program Evaluation & Review Technique (PERT). CPM is deterministic approach based on activities whereas PERT is a probabilistic approach based on nodes. CPM calculates the duration in terms of the longest path called as the critical path. The non critical path activities provide the slack time without delaying the successor activity or the actual project completion time. On the other hand given by three different cases of time viz.- optimistic time, the pessimistic time and most likely time, the expected time is calculated and considered to find the expected project duration time. The probabilistic approach provides the scope for optimizing the project completion duration using the crashing approach. The crashing involves four parameters - Normal Time, Normal Cost and Crash Time and Crash Cost. An additional parameter called as the indirect cost play a significant role while analyzing the optimization of project completion time. The total project cost analysis also provides the scope for saving the cost related to the crashing of the activities.

The analysis of all the three approaches legitimates the official authorities and the citizen towards the fulfillment of this mega project. This research work can also be a platform for planning and implementing the network scheduling for any of the future metro rail project.

2 Literature Review:

This section is divided into parts. The first part is related to the concept of network scheduling and their applications as to understand the influences of the findings and the end results. The second part is about the various case studies related to metro rail projects, as to identify the parameters associated with the network scheduling. The available literature supports to solve the problem statement for the Nagpur Metro rail project.

Aliyu A.M. has resolved a Nigerian pragmatic study using CPM and the Floats associated with the various activities. He simulated the problem by using the TORA software [1]. Paritosh Tamrakar has analyzed a model based on Work Breakdown Structure (W.B.S.) of external electrification work, using CPM/PERT technique [2]. Mete Mazlum, Ali Fuat Güneri used the concept of fuzzy logic to implement the concept of CPM and PERT [3]. M.R. Kolhe and Dr. M.R. Khot worked on application of opencast coal mine using PERT and PETRI approaches. The main focus was on the planning of activities related to environmental concerns and decision-making strategies related to mining activities [4]. Biswasa S.K. et al., explored a construction project and performed the time-cost trade-off analysis. They have used the concept of regression analysis to predict the parameter of crash cost and the crash time based on normal cost and normal time respectively [5]. Dr. Pratibha Panth has developed networking model for civil engineering project by using CPM/ PERT and also optimize the model by using crashing technique [6] Amit Adate, Arpan Goel and Sundaramali G, countered the advantages and disadvantages of the networking techniques [7]. Fahim Ahmed in his dissertation has optimized the model for Department of Transportation, South California in USA, by using the networking scheduling [8].

The details project report submitted by Nagpur improvement Trust in 2013 provides all the dimensions for planning, scheduling, implementing phases of this mega project [9]. Procurement Plan of Maha-Metro (Nagpur Projects) and Project Updates helps us to build up parameters, their dependency and estimate duration for network scheduling statement [10]. Nagarjuna Pilaka and Ramakrishna Nallathiga had studied on various technical aspects and operational arrangements of Hyderabad Metro rail project [11]. Lin He et al. performed their study on a metro project in China on the various parameters associated in a transit network model. The characteristic and the challenges involved in the network operations are the major highlights of their findings [12]. Aniket Raut et al., has reflected the details of execution phases of Nagpur Metro Project and the various delays associated with its Infrastructure. This leads to the base for calculating the PRET part of our problem [13]. Bhagyalakshmi R and Dr. James K C had studied the influence of power factor in building the metro project. This paper gave a support for crashing technique for our problem [14]. Pratik D. Pakhale and Aritra Pal had worked on the details of the construction work processed in the Nagpur Metro project [15].

3 Data Processing:

The Nagpur Metro rail project has two Corridors viz.-Line 1 (North-South Corridor) and Line 2 (East West Corridor). The scopes for both these corridors are assumed to have the same completion time. The detail project report of Nagpur Metro and the available literature facts helped to identify the major parameters in terms of activities, their dependencies and estimate the duration in terms of months.

A. Critical Path Method (CPM)

In this deterministic approach only the tentative duration time is available to calculate the project completion time. Predecessors indicate the dependency on the previous activities. Following Table 1 provides the details to solve the problem by using the Critical Path Method.

Table 1. CPM project activities and duration

No	Activity	Code	Time (Months)	Predecessor(s)
1	Survey	A	9	-
2	Consent/Authorization	B	3	A
3	Work Plan and Time Schedule	C	4	B
4	Designing and Architecture	D	3	C
5	Area Approval	E	9	A
6	Tender Auction	F	3	A
7	Contract Signing	G	4	F
8	Finance and Evaluation	H	6	E,F
9	Resource and Man Power	I	12	F, G
10	Construction Work	J	24	D,H,I
11	Electrification Work	K	6	J
12	Technical Team/ Wagons Assembly	L	4	K
13	Metro Trials	M	2	K
14	Approval of NMC and NIT	N	2	L
15	Launch and Inauguration	O	1	N, M

Interpretation: There are total 15 major activities involve in this project, where each of the activity is represented by a respective code. The activity Survey (A) is the starting activity having no predecessors. Consent/Authorization (B) Area Approval (E) and Tender Auction (F) all these start after the successful completion of project Survey (A). Work Plan and Time Schedule (C), Designing and Architecture (D) and Contract Signing (F) directly dependent on their single predecessor respectively. Construction work (J) is the most dependent activity having the longest duration of 24 months followed by Resource and Man Power (I). The resource includes product and material, Construction plant, tools and major equipments, space and transportation facilities, human resource etc. Launch and Inauguration (O) is the last activity that deals with the project completion task. Activities Technical Team/ Wagons Assembly (L) and Metro Trials (M) both dependent on completion of Electrification Work (K), which ultimately depends on activity of Construction work (J).

The next step is to construct the CPM network diagram. The activity arrow diagram is given in the following Figure 1. The use of online software was used to produce the CPM network diagram.

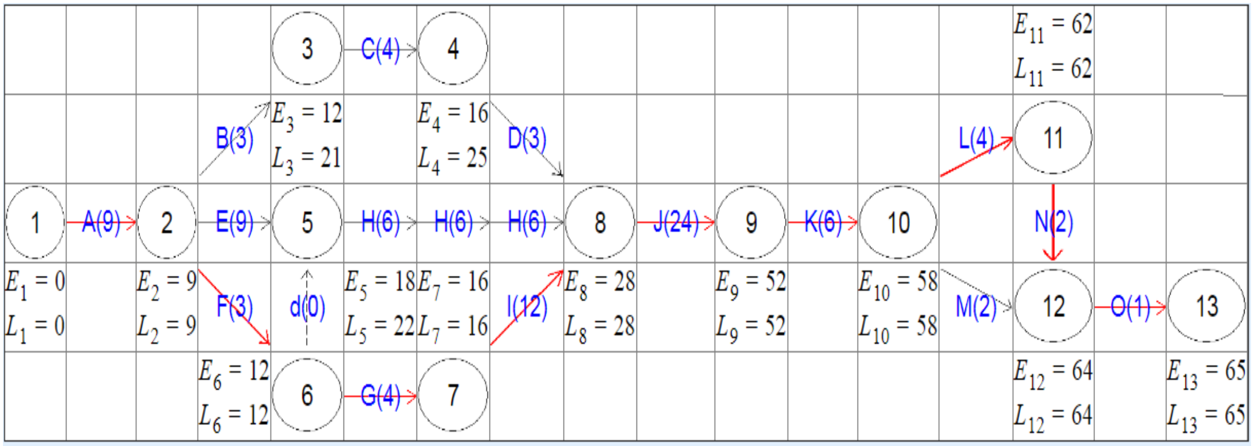

Figure 1. CPM Network Diagram

Interpretation: The circle denotes the node and the arrow denotes the activity code along with the given duration inside the bracket. The node numbers are adjusted by the software itself depending on the completion of the respective activity. The red arrow path indicates the critical path. Activity d(0) between node 6-5 is a dummy activity indicated by dotted arrow and consume zero month duration. Ei denotes the earliest time and Li denotes the latest time of the ith activity.

The critical path of the project is: 1-2-6-7-8-9-10-11-12-13 and the critical path activities are A-F-G-I-J-K-L-N-O. So the non critical activities are B, C, D, E, H, M and d the dummy activity. The total project completion time using CPM is 65 months i.e. approximate five and half year.

The slack time in terms of the various floats of the non critical activities is given in the following table.

Table 2. Float calculations for non critical activities

Activity	Nodes	Duration	EST	EFT	LST	LFT	Total Float	Free Float	Independent Float
B	2-3	3	9	12	18	21	9	0	0
E	2-5	9	9	18	13	22	4	0	0
C	3-4	4	12	16	21	25	9	0	-9
D	4-8	3	16	19	25	28	9	9	0
H	5-8	6	18	24	22	28	4	4	0
d*	6-5	0	12	12	22	22	10	6	6
M	10-12	2	58	60	62	64	4	4	4

Interpretation: Total float provides the buffer time whereas the Free Float provides the Lag time. The highest floats are associated with the dummy activity d(0) node[6-5] which can be neglected. Other non critical activities have quality time to spend which would not delay the project completion time. For example activities B, C, D, E, H and M can renovate themselves for any modification required, without delaying the activities on the critical path. The negative Independent float, which the part of total float associated with its preceding activity in case of activity C, can be assumed as 0. The floats of the critical path activities are always zero.

If we provide a lower bound and the upper bound time constraint to each activity, we can use the PERT, which is discussed in the next part.

B. Program Evaluation Review Technique (PERT)

In this probabilistic approach the tentative duration time is divided into three different times i.e. the optimistic time (to), the most likely time (tm) and the worst case of pessimistic time (tp). As compared to CPM the expected time (te) and corresponding variance □2 of each activity, are calculated. Following Table 3 provides the details to solve the problem by using the PERT.

Table 3. PERT project activities and time durations

No	Activity	Predecessor(s)	Time (months)			Expected Time	Variance
			to	tm	tp	te	σ^2
1	A	-	7	9	12	9.17	0.69
2	B	A	2	3	6	3.33	0.44
3	C	B	2	4	6	4.00	0.44
4	D	C	1	3	5	3.00	0.44
5	E	A	6	9	11	8.83	0.69
6	F	A	2	3	6	3.33	0.44
7	G	F	3	4	6	4.17	0.25
8	H	E,F	4	6	8	6.00	0.44
9	I	F, G	10	12	15	12.17	0.69
10	J	D,H,I	18	24	36	25.00	9.00
11	K	J	4	6	12	6.67	1.78
12	L	K	3	4	6	4.17	0.25
13	M	K	1	2	4	2.17	0.25
14	N	L	2	2	3	2.17	0.03
15	O	N, M	1	1	2	1.17	0.03

Interpretation: It is observed that for each activity to □ tm □ tp. The expected time is given by te = (to+4tm+tp)/6 and the variance □2 = ((tp-to)/6)2 .

The next step is to construct the PERT network diagram. The activity arrow diagram is given in the following Figure 2. The use of online software was used to produce the PERT network diagram.

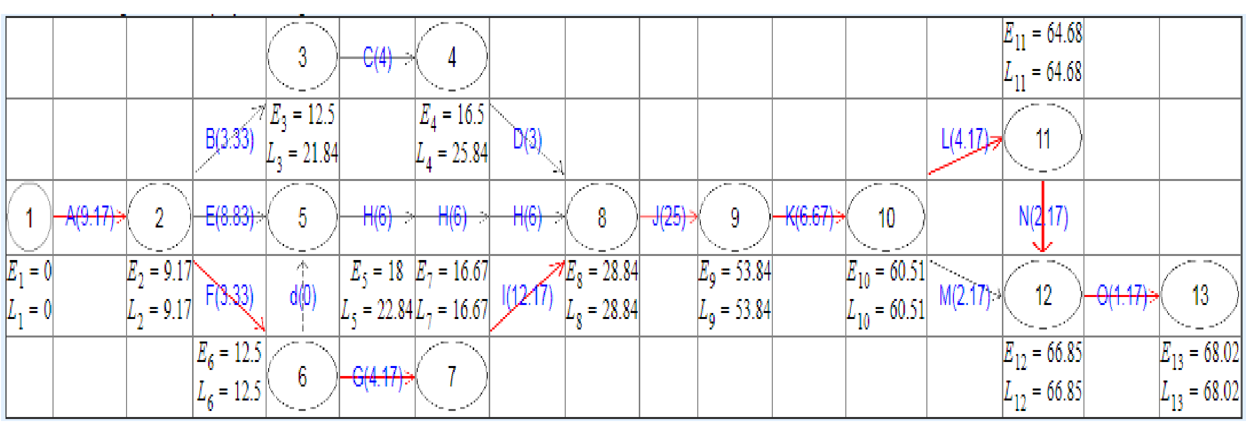

Figure 2. PERT Network Diagram

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Interpretation: The critical path and critical activities remains the same as of CPM. The expected project duration in this case is 68.02 months which is approximately 3.02 months more than as compared to CPM value.

Since PERT is the Probabilistic approach we have found the different probabilities of expected project durations. The expected project duration □ = 68.02 and □ is calculated by using the Table 3, as the square root of the sum of the □2 of the critical path activities. So, □ = 3.66. The value of z = (x-□)/□. Following Table 4 provides the necessary information for the given project durations.

Table 4. Probability distribution for project completion by using PERT

Years	4	4½	5	5½	6
Months	48	54	60	66	72
Z value	-5.47	-3.83	-2.19	-0.55	1.09
Probability (%)	0%	0%	1.40%	29.16%	86.21%

Interpretation: The probability the project will completed in 4 yrs seems to be zero% and goes on increasing as the number of months gets increasing. The probability of completing this project in 6 year is 86.21% .This may be due the worst case delay taken for the activity of construction work and the electrification work.

To check is there any other options to complete the project well within time; we can use the Crashing method which is discussed in the next part.

C. Crashing Method

If the normal time the crash time are same as the most like time (tm) and optimistic time (to) respectively to as what we have considered in PERT, then the estimated cost for normal and crash can be assumed on the basis of the priorities and expectation associated with each of parameter. The crash cost is estimate of the proportion of the normal cost with respect to the number of day(s) crash for the particular activity. Considering the measures for Time in months and Cost in Rs.(in Crores), following Table 5 provides the details to solve the problem by using the Crashing Method.

Table 5. Normal and Crash for Time and Cost table

No	**Activity**	**Predecessor(s)**	**Normal**		**Crash**		**Difference**		**Slope**	**Priority**
			Time	**Cost**	**Time**	**Cost**	**△Time**	**△Cost**	**△Cost/△Time**	
1	**A**	**-**	**9**	**250**	**7**	**350**	**2**	**100**	**50**	**4**
2	B	A	3	20	2	30	1	10	10	
3	C	B	4	10	2	15	2	5	2.5	
4	D	C	3	30	1	45	2	15	7.5	
5	E	A	9	25	6	35	3	10	3.33	
6	**F**	**A**	**3**	**10**	**2**	**12**	**1**	**2**	**2**	**1**
7	**G**	**F**	**4**	**30**	**3**	**35**	**1**	**5**	**5**	**2**
8	H	E, F	6	100	4	150	2	50	25	
9	**I**	**F, G**	**12**	**1350**	**10**	**1600**	**2**	**250**	**125**	**NA**
10	**J**	**D, H, I**	**24**	**1600**	**18**	**2000**	**6**	**400**	**66.67**	**NA**
11	**K**	**J**	**6**	**1300**	**4**	**1500**	**2**	**200**	**100**	**NA**
12	**L**	**K**	**4**	**160**	**3**	**200**	**1**	**40**	**40**	**3**

13	**M**	**K**	**2**	**50**	**1**	**50**	**1**	**0**	**0**	**--**
14	N	L	2	20	2	20	0	0	0	
15	**O**	**N, M**	**1**	**5**	**1**	**5**	**0**	**0**	**0**	**--**
		Direct cost:		**4960**						

Note: As per the DPR of November 2013, the initial estimated total cost associated with both the corridors is, Rs. 8260 Crores. If we assume 40% as associated indirect cost, then it is Rs. 3304 Corers which can be approximated to Rs. 3300 Crores. If the estimated time period for completion is fixed to 60 months, and assuming a fixed rate for the indirect cost per month, then we get the value as Rs. 55 Crores per month. On the basis of this indirect cost per month, we get the value for the direct cost as Rs. 4960 Crores. The direct cost shares 60% of the total project cost.

Interpretation: The shaded bold rows reflect the critical path activities. The last column provides the priority of the activities to be crashed. NA indicates not applicable because, even the activity is on the critical path, but since the slope value exceeds the indirect cost per month of Rs. 55 Crores, crashing is not possible. There is no scope for crashing on the last two activities of the critical path since cost slope is zero. There is a total scope of five days to be crashed which can reduce the project duration time form 65 months to 60 months.

Based on the mentioned priorities of Table 5, the detail analysis using the crashing process is given in the following Table 6.

Table 6. Normal and Crash for Time and Cost table

Activity	**Days crashed : (x)**	**Cost slope : (y)**	**Increase in cost : z = x.y**	**New prj. Duration : n**	**Saving : S = (indirect cost@mth).x**	**Net Saving : NS = S-z**	**New Cost : NewTC-NS**
F	1	2	2	65-1=64	55	53	8207
G	1	5	5	64-1=63	55	50	8157
L	1	40	40	63-1=62	55	15	8142
A	2	50	100	62-2=60	110	10	8132

Interpretation: Using the initial total cost Rs. 8260 Crores and the indirect cost per month as Rs. 55 Crores, we can reduce the project duration by 5 days. So the new project duration is now 60 months i.e. 5 years. The analysis table also determines the estimate of the new total cost of Rs. 8132 Crores by saving Rs. 128 Crores.

Following Figure 3 provides the new CPM Network after crashing the mention four activities.

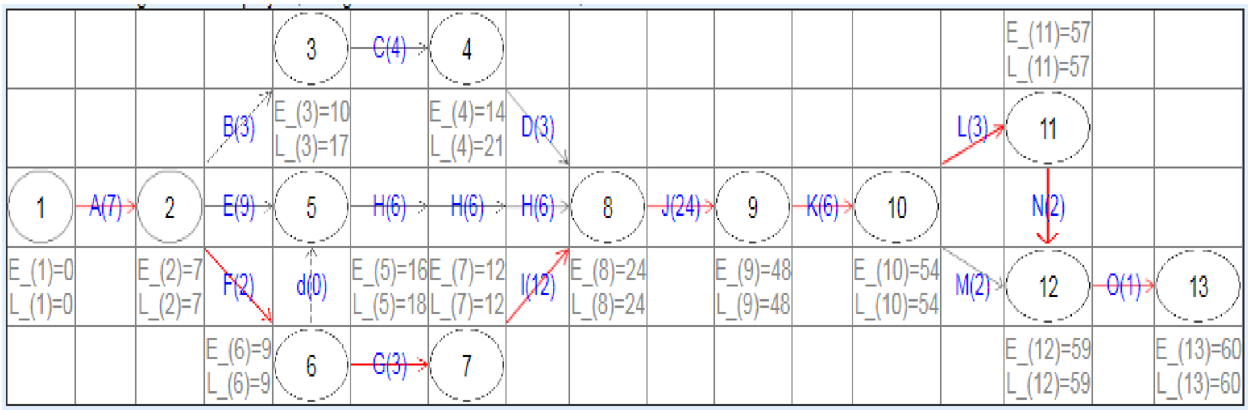

Figure 3. New CPM Network Diagram after crashing

Interpretation: In the new CPM network diagram, the project duration has been reduced by 5 months. The new project completion time is now 60 months. The corresponding earliest time Ei and Latest Time Li for the ith activity is adjusted respectively. The critical path remains unchanged after the overall crashing.

The adjustment s in floats of non critical activities is calculated in the following Table 7.

Table 7. Float calculations for Non critical activities after crashing

Activity	Nodes	Duration	EST	EFT	LST	LFT	Total Float	Free Float	Independent Float
B	2-3	3	7	10	14	17	7	0	0
E	2-5	9	7	16	9	18	2	0	0
C	3-4	4	10	14	17	21	7	0	-7
D	4-8	3	14	17	21	24	7	7	0
H	5-8	6	16	22	18	24	2	2	0
d*	6-5	0	9	9	18	18	9	7	7
M	10-12	2	54	56	57	59	3	3	3

Interpretation: After crashing, the highest floats are associated with the dummy activity d(0) node[6-5] which can be neglected. The float associated with the activities B, C, D, E, H and M has been proportionately updated after the overall crashing. The floats of the critical path activities are zero.

4 Conclusion:

The DPR of Nagpur Metro was published on Nov., 2013. If we assume that actual work came into its implementation dated from 1st Jan. 2014 and considering the inaugural date of 8th March 2019, then the estimated time comes to be 63 months. So there is a difference of 2 months in the time estimates of this study. Using the three approaches discussed in the data processing section, following are the findings of the study –

- The time estimate using CPM is 65 months. The floats provide more amount of flexibility in the schedule time of the non critical activities.

- Using the PERT, the time estimate is 68.02 months which is 3.02 month more as compared to the

CPM result.

- The probability of completion time for 5½ yrs and for 6 yrs seems to be only 29% and 86% respectively. This may be due to the delay in major parameters of construction work and electrification work.

- The four activities viz.- Tender Auction, contract Signing, Technical Team/ Wagons Assembly and Survey process, provide the scope of reducing the project completion deadline from 65 months to 60 months duration.

- The study implicates the new project completion time of 60 months, which is well in-line with the predicted deadline of 63 months and also a total saving of Rs. 128 Crores.

Thus the analysis on the sequential activity scheduling in this study provides the supportive results which can be helpful for the planning and scheduling of a mega project. The figures even are assumed data set values, but well support the observed facts of the Nagpur Metro rail project. The future scope of this study can include the varying indirect cost per month as nature of the sequential activities involves different costing.

References

1. A. M. Aliyu, "Project Management Using Critical Path Method (Cpm): A Pragmatic Study", Global Journal of Pure and Applied Sciences, Volume 18, Issue. 3-4, 2012.
2. Paritosh Tamrakar , "Analysis and Improvement by the Application of Network Analysis (Pert/Cpm)", The International Journal of Engineering And Science (IJES), Volume 2, Issue 1, 154-159, Jan., 2013.
3. Mete Mazlum, Ali Fuat Güneri, "CPM, PERT and Project Management with Fuzzy Logic Technique and Implementation on a Business", Elsevier Science Digest, 348-357, 2015.
4. M. R. Kolhe and Dr. M.R. Khot,"Pert and Petri Network Modeling For Opencast Coal Mine", International Journal of Advance Research in Computer Science and Management Studies Volume 3, Issue 3, 146-156, Mar., 2015.
5. S. K. Biswasa, C. L. Karmakera and T. K. Biswasa, "Time-Cost Trade-Off Analysis in a Construction Project Problem: Case Study", International Journal of Computational Engineering Research, Volume 6, Issue, 10, 32-38, Oct., 2016.
6. Dr. Pratibha Panth, "PERT and CPM Techniques: A Brief Review", International Journal for Scientific Research and Development, Volume 5, Issue 5, 166-168, Aug., 2017.
7. Amit Adate, Arpan Goel and Sundaramali G., "Analysis of Project Planning using CPM and PERT", International Journal of Computer Science and Mobile Computing, Volume 6, Issue. 10, 24 – 25, Oct., 2017.
8. Fahim Ahmed, "Impact of Critical Path Method (CPM) of Scheduling on On-Time Completion of Transportation Projects", 2018. https://scholarcommons.sc.edu/cgi/viewcontent.cgi?article=5579 &context=etd.
9. Nagpur Improvement Trust, Detailed Project Report for Nagpur Metro Rail Project Nov. 2013, http://www.metrorailnagpur.com/pdf/DPR.pdf
10. Nagpur Metro official website, http://www.metrorailnagpur.com/milestone.aspx
11. Nagarjuna Pilaka and Ramakrishna Nallathiga, "Technical Analysis of the Hyderabad Metro Rail Project, International J of Technology, Volume 5, Issue 2, Dec, 2015.
12. Lin He, Qiangsheng Liang and Siyuan Fang, "Challenges and Innovative Solutions in Urban Rail Transit Network Operations and Management: China's Guangzhou Metro Experience", Springer's Journal of Urban Rail Transit 2(1):33–45, 2016.
13. Aniket Raut , Ashutosh Tonpe, Ajinkya Kulkarni and Sakshee Bhaiswar, "Execution of Metro Rail Projects – A Case Study of Nagpur Metro Rail", International Journal of Science Technology &

Engineering ,Volume 4 , Issue 3, Sept., 2017.

14. Bhagyalakshmi R. and Dr. James K. C., " Study of Energy Utilization in a Metro Rail Limited Company", International Journal of Engineering Development and Research, Volume 5, Issue 4, 2017.
15. Pratik D. Pakhale and Aritra Pal, "Digital project management in infrastructure project: a case study of Nagpur Metro Rail Project", Springer's-Asian Journal of Civil Engineering, Jan., 2020.