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APPLICATION OF CRITICAL PATH METHOD (CPM) TO OPTIMAL PROJECT SCHEDULING: A CASE OF MOSUL BUILDING COMPANY, YOLA NORTH LOCAL GOVERNMENT ADAMAWA STATE, NIGERIA

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ABSTRACT

Project cannot be done without planning, scheduling and an estimation of its duration for completion. Every project that has to be undertaken must have a deadline for it completion but not every project goes as schedule. Hence, applications of scientific method such as CPM, PERT are often very useful in project management and scheduling. This study was on the application of CPM in scheduling a building construction taking a case study of Mosul Estate building construction. Analytical research design was adopted for the study as the design suit the study at hand. Secondary data of the activities, their descriptions and predecessor as while as their duration were obtained from the construction site. The network activities diagram, the forward and the backward pass obtained by the temporary ordered routing algorithm (TORA) were drawn and the critical path represented in bold arrow heads. The results show that if CPM is applied into the project, the project can be completed in 27 weeks compared to the initial duration of 32 proposed weeks by the company. This results if implemented by the management of the firm will save cost of labour and time. We recommend that CPM should be used in a building construction company before embarking on the building. The construction firm should devote more resources, labour and equipment to the critical path in order to avoid unnecessary delay and high cost of labour.

Keywords: Critical Path Method (CPM), Project Management, Construction, Scheduling

INTRODUCTION

For every project that one has to be undertaken must have a deadline for its completion, but not every project goes as scheduled. There are uncertainties and other factors that make the project not to run according to scheduled. Project management is vital for an organization or group to achieved set goals and meets the standards for success on its own time. For instance, every project manager always faces diverse systems which often include the application of scientific methods. However, because projects are usually more difficult, it is often necessary to advance complex models that can cater for the complex needs of the project. Many at times, a successful project management needs to ensure sufficient project schedule and cost plans (Adiyan, *et al* , 2020; Bashiru & Douglas, 2022). In Construction, there are needs that involve unique environments, challenges, and project management needs not found in other industries (Halpin & Woodhead, 2011). Some category of firms often experiences the highest level of business failures (Davis, 2012). Factors contributing to failure includes: under bidding, insufficient cash flow, external difficulties, and lack of experience in estimating and monitoring costs among other factors. These if not properly handle, it will results to poor project and significant loss of resources and waste of time.

The Critical path method (CPM) has been a powerful tool that enables managers to schedule and manage difficult projects. ~~(CPM)~~ was developed in the 50s in order to control large defense projects, since then, its use have been a routine process by organizations. CPM is one of various techniques for undertaking project planning alongside Project Evaluation and Review Technique (PERT). However, we only considered CPM in this study. CPM is use for the projects that are made up of a number of individual activities (Bashiru & Douglas, 2022). Hence, CPM enables project managers to plan all tasks that must be completed as part of a project. It serves as the basis both for preparation of a schedule, and of resource planning. During management of a project, it allows the project manager to monitor achievement of project goals. In fact, it is the mirror of any project, as it helps to indicate where necessary adjustments needs to be taken to get a project in a right way (Maduagu, 2022). In CPM, a project management consists of interrelated activities which are to be executed in a certain order before the entire task is completed. The activities are all related in a logical sequence known as precedence relationship which indicates that one activity is always preceded by another activity. It is important to note that the sequence of activities are all in precedence relationship and cannot overlap one another.

In today's world, planning has become part and parcel of individual; hence, one has to plan before execution of a project as failure to plan means plan to fail. The most important aspect of a project management as while as the effective resource allocation is always carried out by the manager, as this is his statutory responsibilities. Because of these, managers are often confronted with decision on how to carry out the task ahead of them. These tasks ranges from how much resources are needed in the project, what types of skills and un-skills labour they will have to employ, when to start and when to end. Most importantly, extraneous unforeseen circumstances may also be part of the planning process; this accommodates unnecessary delay that may occur if on the cause of project execution, an unexpected happening crop in. How can this be done effectively without hitches? Uduaga (2022) reported that most of the organizations we have now seemingly experienced failure and poor flow in their project that is the project either has slow pace of movement and or experienced abandonment. Since the introduction of CPM and PERT, many organizations especially in the developed world have been applying these two models in project management. The applications of CPM to project management has saved time, cost and duration. It concepts has widely been in use and is now common tool alongside PERT for effective managements of a project. For instance, (Bashiru & Douglas, 2021) applied CPM and PERT to project management in the scheduled of Ph D studies in the selected Northern University of Ghana. A critical survey designed was adopted by them and questionnaire was designed and distributed to a sampled of 188 respondents. The outcomes of their results shows that, all Ph D students in the study area can applied CPM and PERT for effective study and guidance without stress and there will not be conflicting time for other activities. For instance Lu & Lam (2008), study critical path method and introduced a different way of joining the impact of multiple resource calendars on CPM scheduling. They also suggested a different technique to assess accurately, the effect of an activity on prolonging the total duration of the project, and the results are generated. Du Plessis, (2014) reported that for more than five decades of the use of the Critical Path Method technique and its wide recognition and commendation worldwide; the acceptance of CPM was rapid in the developed countries but the technique is yet to acquire any appreciable acceptance for the implementation of public and private projects in most of the developing countries which Nigeria and the study area is not an exception. He concludes that this could be as results of failures to adopt and implement the scientific systems analysis developed over the years by researchers and used in most advanced countries. Atin & Lubies (2019), studied the implementation of CPM in project planning and scheduling ; they found out that CPM can save project time and produce a critical path which can serve as a guide in implementating project that can be completed on time, their results were correlated to the study done by Putra and Hamzah whose results suggested that CPM can efficiently be applied to project for effective minimization of time, cost and labour.

Bashiru & Douglas (2021, in Chrzanowski & Johnston, 1986) asserts that the results of duo on the application of linear schedule and engineering have expressed tedious events as constant or changing slope lines on two axes over time need the application of CPM for effective time management and minimum labour cost. They also found out that discrete activities or events can conveniently be displayed at the suitable time and place in the linear schedule itself. Larry & Richard (1997) reported that, there is a great performance and improvement by using critical chain project management; they also explained that critical chain project management provides an important step for continuous improvement of project organization and project management (Burger, 2015).. For instance Zareei (2018), studied Critical chain project management (CCPM) and asserts that planning often becomes optimal by making sure that it is possible and protected from sensible prevalent cause limits. Chaou & Wang –Li (2019), compared the traditional CPM against CCPM. They employed two methods of buffer management viz: SSQ method and CPM logic to analyse the project capability related to cost and duration. They first developed networks without using mixture of resources and drew another network that resources were mixed together. They used 120 conjunctions of unplanned generated project networks and these were calculated and assessed by Critical Path Method and Critical Chain Project Management. Significant results were achieved in which there was a considerable reduction in cost and duration indicating that the CPM aided the reductions (Chaou & Wang –Li 2019).

Zhong & Zhang (2003) reported that project has to be planned and monitored, that is the aim of any project scheduling is to construct a timeline indicating where individual activity receives a start time and a corresponding finish time with a predefined precedence relations and others predefined activity constraints at hand. These processes are based on the traditional critical path based forward by creating the earliest start schedule as while as the backward by creating the latest start schedule time. These processes aim at timing up the duration of the completion of any project and the most widely use tool is the CPM (Burger, 2013). Although CPM has been effective in project management but its use has not gain emphatic knowledge in the study area. This study therefore, seek to apply CPM in Mosul building construction in order to optimize profit and minimize cost, time and the duration of the project execution and completion.

MATERIALS AND METHODS

Network modelling is often done by putting all the activities at par to give pictorial view of the task required in the execution of project using Critical path method (CPM) which provide analytic means for scheduling the activities. Hence, the study adopted an analytical research because the study is specific for the type of modelled used (CPM). The second reason for which analytical research was adopted was that it involves critical thinking in carrying out a study of this nature. We employed three methods sequentially taking each step one at a time: first, we defined the activities of the project, their precedence relationship, and their time requirement. The second step was to translate the project into network that indicates the precedence relationships among the activities. Finally, we carried out specific network computations that facilitate development of the time scheduled for the project.

Research Design

The structural analytical research design was employed in the study. This was first done by listening the list of all the activities, their predecessors as well as the estimation of the duration for each activity. The relationship among the activities was then represented on the network diagram. Each activity of the project was represented by a directional arc (arrow) pointing in the direction of the project movement. Nodes network (events) establish the different activities of the projects with the rules for constructing the network as follows:

Rule l: Each activity is represented by an arrow in the network.

Rule 2: Each activity, which is normally depicted by a dashed arrow consume no time or resources, they are used to keep the logic of the diagram consistent with that of the project herein refers to as dummy activity.

Rule3: the third rule asked questions in order to maintain the correct precedence relationships while activity is added to the network:

i. Which activity must precede the current activity after its predecessor completion?
ii. Which activity follows the current activity?
iii. Which activity occurs together with the current activity?

The last step we employed in the design was controlling the project by using row plot graph and time chart for steady monitoring and time reporting. We also applied forward and backward pass computation as well as conditions for critical path.

1. Forward pass calculation

$$Es_j = Max_i(Es_i + D_{i,j}) \quad (1)$$

Where:

Esj = earliest start time of activity j;

$D_{i,j}$ = duration of activity i to activity j;

Max_i = pick maximum from the calculation where the activity has more than one precedence activity coming to it.

2. Backward pass calculation

$$LC_i = Min_j(LC_j - D_{i,j}) \quad (2)$$

LC_i= latest completion time of activity i;

$D_{i,j}$= duration of activity i to activity j;

3. critical path conditions to be made

$Es_i = LC_i$ (3)

$Es_j = LC_j$ (4)

$Es_j - Es_{ii}$= $LC_j - LC_i = D_{i,j}$ (5)

4. Calculation of total Float

$LC_j - Es_i - D_{i,j}$ (6)

5. Free Float: this is the time that the activity culmination time can be retarded without poignant to the earliest start time of the immediate successor activity in the network.

$TF_{i,j} = Es_j - Es_i - D_{i,j}$ (7)

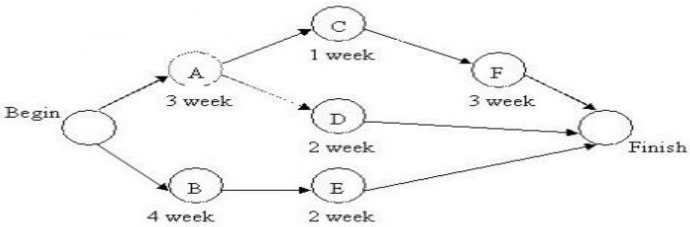

Figure 1: A typical network diagram

The data for this study were obtained from the study area and were presented in network flow first showing activities on node and the dummy activities from the start to sink. The solid arrows head indicates activities while the broken arrows shows the dummy activities which has zero duration. The forward pass computations were done using the earliest start time formula $Es_j = Max_i(Es_i + D_{i,j})$. The values obtained were put in a square bracket and the minimum duration time was obtained. The second method was to calculate the backward pass using $LC_i = Min_j(LC_j - D_{i,j})$, see figure 4. The result of the backward pass were also put in the same square bracket as the forward pass but after the forward pass result separated by comers. The critical path was shown in figure 5 with a bold arrows head which indicate the project to be done.

Table1: Depicting Description and Predecessor of each Activity

	Activity	Description	IMMEDIATE PREDECESSOR	DURATION (WEEKS)
1	A	Site cleaning/ Setting out	-	1.0
2	B	Excavation	A	2.0
3	C	Column Base/ Reinf. In Foundation	B	2.0
4	D	Concrete work	B	2.0
5	E	Block Work	C, D	4.0
6	F	Fame	E	1.0
7	G	Roof Structure / Covering	F	3.0
8	H	Electrical and Mechanical work	G	2.0
9	I	Wall, floor and Ceiling finishes	G	4.0
10	J	Doors, window	G	1.0
11	K	Fittings and fixtures	H, I, J	3.0
12	L	Painting and Decorations	K	3.0
13	M	External works	L	2.0
14	N	Clearing/ carrying away Debris	M	1.0
15	O	Handing over site	N	1.0

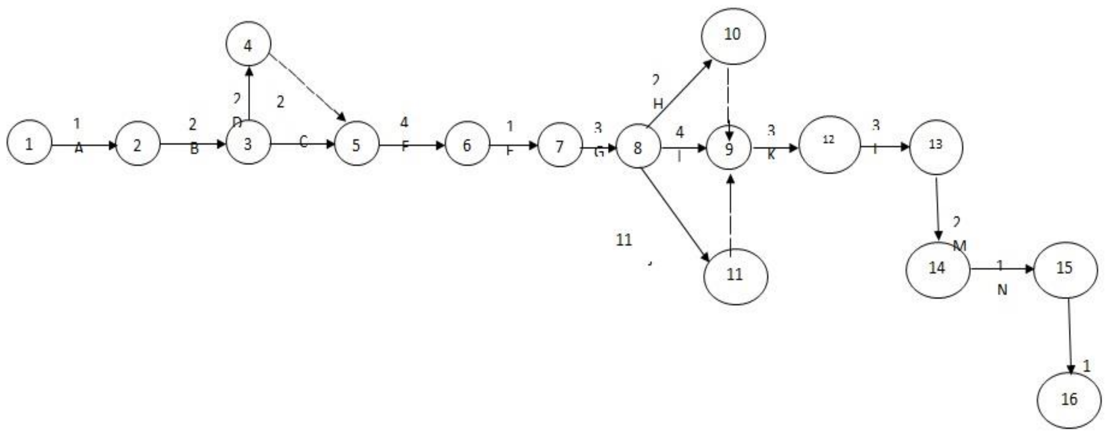

Figure 2: Network flow of the precedence activities and their duration

The figure above shows the network of Table 1 for their durations. Node with the 1 inside a circle is a starting node of the project and the sink (end node or activity) is node 16 inscribed in a circle. The letters on the arc underneath them shows the activities while the figures on the nodes are the durations in which the activity will be executed before its completion. The arc (arrow) with a dash are the dummy activities and this have no duration, they are used to keep the logic of the arc flow from source to sink. These were subjected to analyses using Temporary Ordered Routing Algorithm (TORA) software. The output of the results was extracted and put in the table (see Table 2).

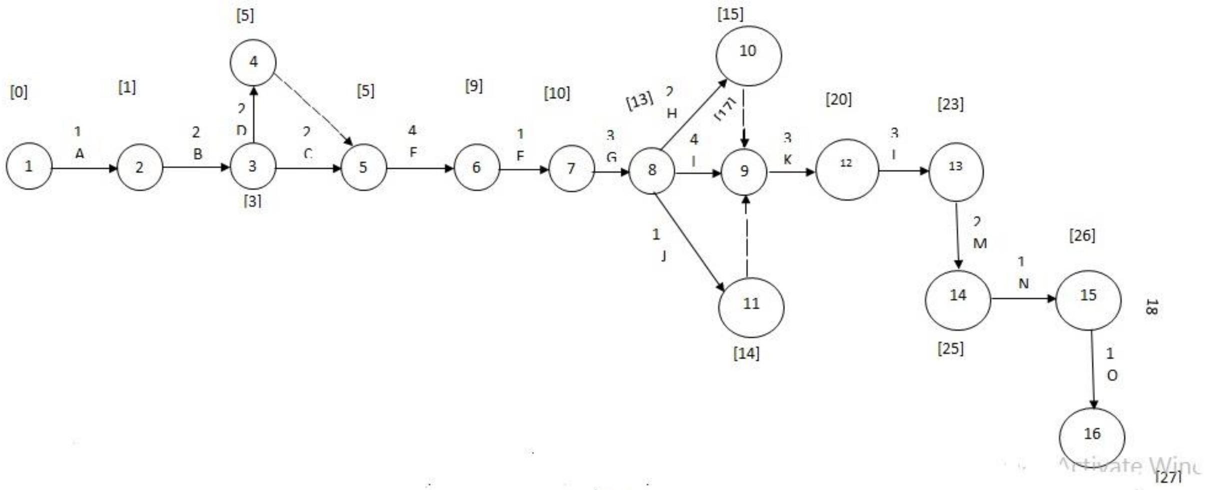

Figure 3: The network diagram showing the Forward Pass Computation (ES $_i$ and DF $_j$) times of activities.

Figure 3 above shows the forward pass computation of the CPM using the earliest start formula ESi +DFj**.** The figure on arc refers to the duration expected for each activity to complete. The ones in rectangular brackets are the earliest start of each activity after the forward passed computations. Where two arcs or activities entered the node, the maximum duration is picked as the completion time for that activity and placed in the rectangular bracket (see figure 3).

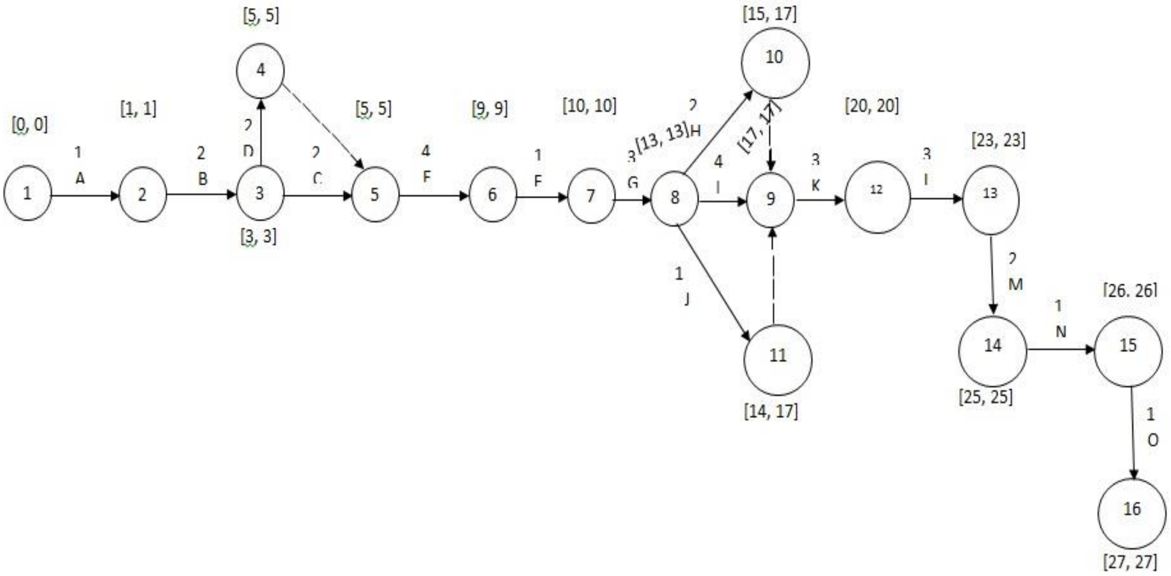

Figure 4: The Optimal Results of the Analysis

The backward pass was computed using the $LC_i = Min_j(LC_j - D_{i,j}$ The minimum duration is considered optimal in a case where two activities end on a particular node. The optimal results were placed in the same square bracket with the forward pass results separated by a comma and placed in the right hand side of the bracket (see figure 4).

Table 2: The Optimal Tableau from the TORA Output

Activity	**Duration**	**Earliest Start**	**Latest Completion**	**Total Float**	**Free Float**
A	1	0	1	0	0
B	2	1	3	0	0
C	2	3	5	0	0
D	2	3	5	0	0
DUMMY	0	5	5	0	0
E	4	5	9	0	0
F	1	9	10	0	0
G	3	10	13	0	0
I	4	13	17	0	0
H	2	13	17	2	0
J	1	13	17	3	0
DUMMY	0	15	17	2	2
DUMMY	0	14	17	3	3
K	3	17	20	0	0
L	3	20	23	0	0
M	2	23	25	0	0
N	1	25	26	0	0
O	1	26	27	0	0

The Table above shows the results obtained by TORA showing total float and free float. In CPM, the total float is the amount of time duration that a task can be delayed or extended without affecting the completion date of the project or violating the constraints scheduled, whereas free Float on the other hand indicates the amount of time that a task can be retarded (delayed) without affecting the start date of its subsequent tasks as well as a constraints scheduled. Total and free float are used when we are analysing the project network diagram and determining the critical path in a network. The zeros (0) are the critical path which always is the longest path of the project scheduled activities which must always be made before the project at hand is executed. They are the rout path that guide the manager and in which project is monitored, communicated to the stakeholders and the project is being prioritized (see Table 2). These zeros were then followed and drawn with a bold arcs indicating critical path of the project and the duration were then calculated (see figure 5).

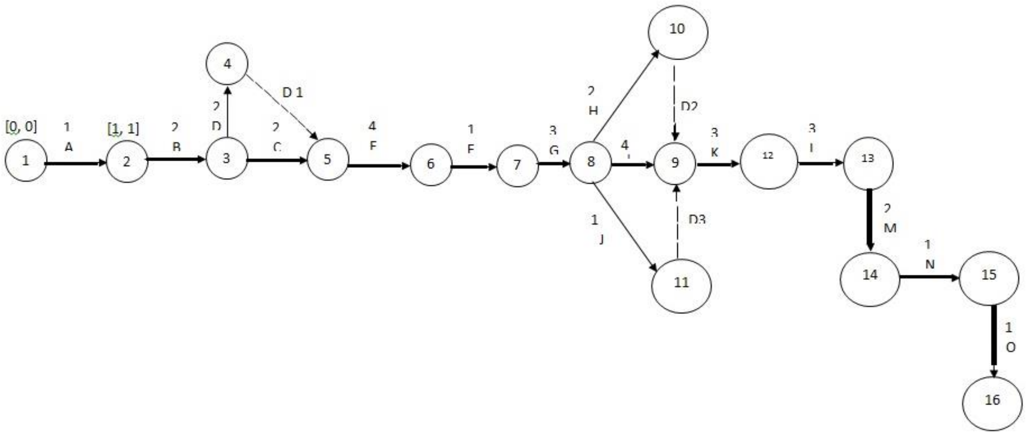

Figure 5: The final network with the critical path in bold arcs.

Figure five above shows the critical path network diagram. These were obtained from Table 2 where zeros occurred as the critical path. The (CPM) solution summary presented in table 2 reveals the following:

A) 12 out of the 15 activities of the network were found to be critical of the project.
B) These activities are;
A, B, C, E, F, G, I, K, L, M, N, O
C) The paths Are

A ⟶ B ⟶ C ⟶ E ⟶ F ⟶ G ⟶ H ⟶ I ⟶ K ⟶ L ⟶ M ⟶ N ⟶ O

1) The sum of the durations through the path was found as 27 weeks as illustrated in the path above.
1+2+2+4+1+3+4+3+3+2+1+1= 27 weeks.
2) The duration of the entire project was 32 weeks, hence there is an estimated reduction of 5 weeks when CPM was applied
3) Figure 3, 4 and 5 shows clearly activity time, late activity time and the critical activity of the network respectively.

DISCUSSION

The project management has been the major brain to a successful project in any organization. However, the time of completion and execution are not always made as earlier proposed. This often results to failure in the project and loss of huge financial resources, time and energy. This study applied Critical Path Method (CPM) to **MOSUL** building construction.

Data were collected on the onsite of the activities, network drawn and computation of the activities were done (see Table 2). The critical paths were seen to be zeros, that is the longest duration that a project can take before its completion and must be made else it will affect the project duration completion. The results showed that using CPM, the project can take 27 weeks as against the initial duration of 32 weeks. This study is in line with the study of Bashiru & Douglas, (2022); Maduagu (2022), where they applied CPM and found that it is effective in managing project and can be used to Ph.D studies for an effective planning and scheduling of time for their studies and other activities.

From Table 2, the path through data collection, project monitoring, project evaluation and activities on nodes and arcs are the critical path and the sum of their durations is 32 weeks (Table 1). The slack value of every activity shown in Table 2 indicates that, the project time or task can be delayed without affecting the project duration. However, identification of problem and final defense or execution was the non-critical activities of the results from the CPM activity diagram which indicate the optimal solution. Their slack values of 2 and 3 on activities J and H indicate that their task can be delayed for 2 to 3 weeks without affecting time of the project duration. The application of CPM in any project save time, cost, labour force and resources as in the case of MOUSUL building construction.

CONCLUSION

We used Critical Path Method (CPM) under Project Management and successfully applied it to MOSUL building construction in Jimeta Metropolis of the Yola North Local Government area of Adamawa State, Nigeria. The project has 16 events and 15 activities; these activities were determined using the critical and non-critical activities that constitute the programme using CPM. The results showed a reduction of 5 weeks duration from the initial project duration of 32 weeks. The application of CPM to this project has save time, cost, resources and energy as the five weeks duration can be used on other projects. The study has significantly reduced the duration for the completion of the project from 32 weeks to 27 weeks which is the optimal schedule completion time for Mosul building construction. We recommends that management should not lose sight of the critical and non-critical activities involved in the Mosul constructions building estate, as this will help a lot in monitoring the project. The management should take insight from this study as it will guide her on the subsequent project. We further recommend the application of CPM to be made as pre-requisite in contract requirement in both the public and private sector in order to checkmate delays encounter in project execution, Prompt weekly revision of estimated activity completion time has to be made in order to make contingency plan for any anticipated upcoming uncertainties.

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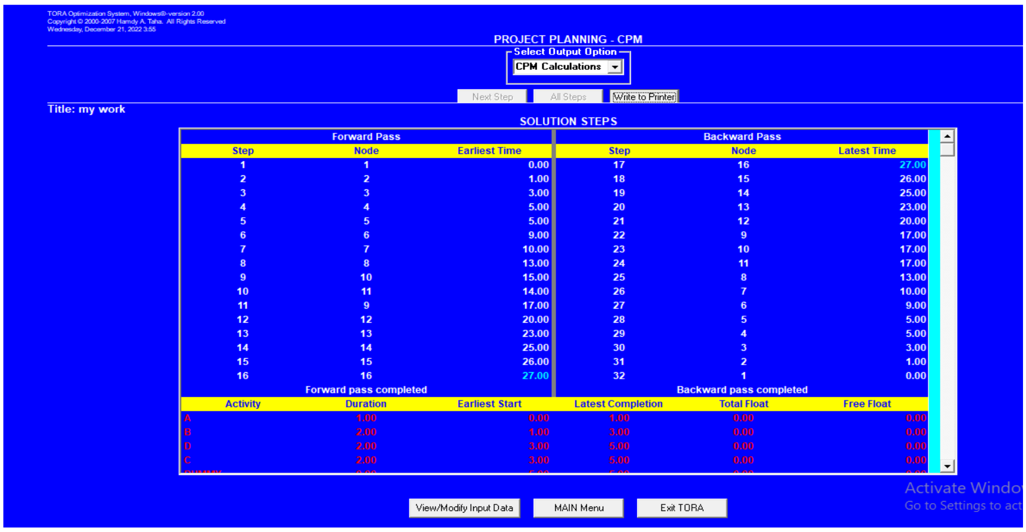
APPENDIX


TORA Optimization System, Windows®-version 2.00
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Wednesday, December 21, 2022 3:55

PROJECT PLANNING - CPM

Select Output Option: CPM Calculations

Next Step | All Steps | Write to Printer

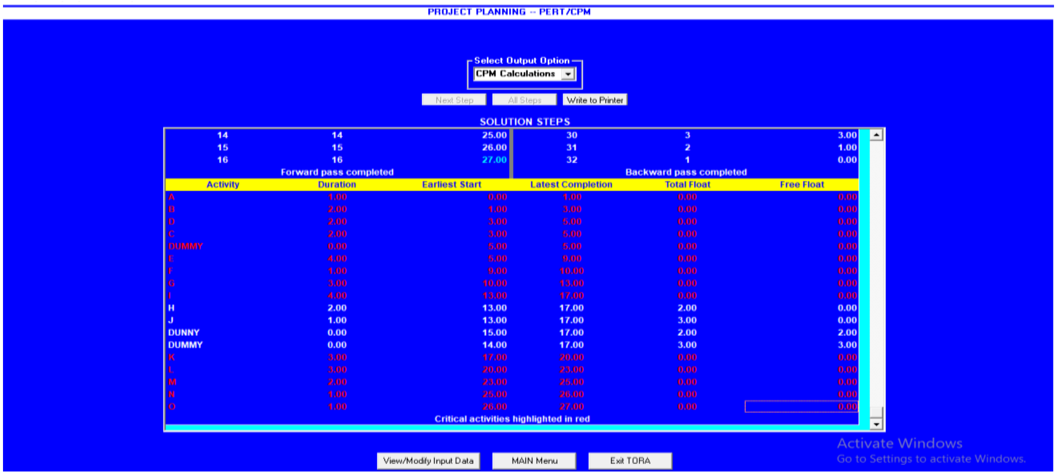
Title: my work

SOLUTION STEPS

Forward Pass			Backward Pass		
Step	Node	Earliest Time	Step	Node	Latest Time
1	1	0.00	17	16	27.00
2	2	1.00	18	15	26.00
3	3	3.00	19	14	25.00
4	4	5.00	20	13	23.00
5	5	5.00	21	12	20.00
6	6	9.00	22	9	17.00
7	7	10.00	23	10	17.00
8	8	13.00	24	11	17.00
9	10	15.00	25	8	13.00
10	11	14.00	26	7	10.00
11	9	17.00	27	6	9.00
12	12	20.00	28	5	5.00
13	13	23.00	29	4	5.00
14	14	25.00	30	3	3.00
15	15	26.00	31	2	1.00
16	16	27.00	32	1	0.00
Forward pass completed			Backward pass completed		

Activity	Duration	Earliest Start	Latest Completion	Total Float	Free Float
A	1.00	0.00	1.00	0.00	0.00
B	2.00	1.00	3.00	0.00	0.00
D	2.00	3.00	5.00	0.00	0.00
C	2.00	3.00	5.00	0.00	0.00

View/Modify Input Data | MAIN Menu | Exit TORA


PROJECT PLANNING -- PERT/CPM

Select Output Option: CPM Calculations

Next Step | All Steps | Write to Printer

SOLUTION STEPS

14	14	25.00	30	3	3.00
15	15	26.00	31	2	1.00
16	16	27.00	32	1	0.00
Forward pass completed			Backward pass completed		

Activity	Duration	Earliest Start	Latest Completion	Total Float	Free Float
A	1.00	0.00	1.00	0.00	0.00
B	2.00	1.00	3.00	0.00	0.00
D	2.00	3.00	5.00	0.00	0.00
C	2.00	3.00	5.00	0.00	0.00
DUMMY	0.00	5.00	5.00	0.00	0.00
E	4.00	5.00	9.00	0.00	0.00
F	1.00	9.00	10.00	0.00	0.00
G	3.00	10.00	13.00	0.00	0.00
I	4.00	13.00	17.00	0.00	0.00
H	2.00	13.00	17.00	2.00	0.00
J	1.00	13.00	17.00	3.00	0.00
DUNNY	0.00	15.00	17.00	2.00	2.00
DUMMY	0.00	14.00	17.00	3.00	3.00
K	3.00	17.00	20.00	0.00	0.00
L	3.00	20.00	23.00	0.00	0.00
M	2.00	23.00	25.00	0.00	0.00
N	1.00	25.00	26.00	0.00	0.00
O	1.00	26.00	27.00	0.00	0.00

Critical activities highlighted in red

View/Modify Input Data | MAIN Menu | Exit TORA

The above Appendix shows the output from TORA software