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CRITICAL PATH METHOD (CPM) NETWORK AS A TOOL FOR EFFECTIVE PROJECT EXECUTION IN SOME SELECTED CONSTRUCTION FIRMS IN ENUGU STATE.

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***Key Words**: Critical path method (CPM) network, Project planning, Project control, Project crashing, Project scheduling*

***Abstract:** This paper examined how* the *Critical path Method (CPM) Network can be used as a Tool for effective Project Execution in some selected construction Firms in Enugu State. This is against the background of some of the challenges facing project managers in the course of project execution*. The specific objective of the study was to; (1) examine the nature of the relationship between the Critical path Method Network (CPM) and effective project control in some selected construction Firms in Enugu State. (2) examine the effect of the Critical path Method Network (CPM) on Project crashing in some selected construction Firms in Enugu State. (3) determine the nature of the relationship between Critical path Method Network (CPM) and project scheduling in some selected construction Firms in Enugu State. The data for this study were collected from two major sources; primary and secondary sources. The major instruments for data collection were questionnaire, interviews, and observations. The population of the study was forty (40). Content validity was used for the study. The reliability of the instrument was established through test re test method with coefficient value of 0.87. Data for the study was presented in a table tables and data analysis was done using simple percentages. Hypothesis one and three were tested using parson product moment correlation while hypothesis two was tested using regression analysis with the aid of SPSS version. *It was found that; there is a positive relationship between critical path method (CPM) network and effective project planning and control in manufacturing organizations and that Critical path method (CPM) network has a positive effect on Project scheduling analysis in manufacturing organizations. The work therefore concludes that CPM as a network model helps project managers to plan all tasks that must be completed as part of a project. It acts 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 and helps to indicate where remedial*

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action needs to be taken to get a project back on course. It was recommended among others that; Project managers in manufacturing organizations should use CPM in planning, scheduling and controlling of both complex and flexible projects. This is because CPM enables the managers to make a detailed analysis and structure of the various elements of the project in form of a network.

1.1 Introduction

Critical path method is a powerful tool that helps managers to schedule and manage complex projects.

It was developed in the 1950s to control large defense projects, and have been used routinely since then by organizations. The critical path method (CPM) is one of several related techniques for doing project planning. It is for projects that are made up of a number of individual activities. If some of the activities require other activities to finish before they can start, then the project becomes a complex web of activities. Therefore CPM helps project managers to plan all tasks that must be completed as part of a project. It acts 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. It helps to indicate where remedial action needs to be taken to get a project back on course.

Planning and control are two of the most important functions of management. Planning involves the formulation of objectives and goals that are subsequently translated into specific plans and projects. The function of control is to institute a mechanism that can trigger a warning signal if actual performance is deviating (in terms of time, cost, or some other measure of effectiveness) from the plan (Loomba, 1978). According to this author, if such a deviation is unacceptable to the manager, he will take corrective action to bring performance in conformity with the plans. The manager therefore is expected to develop more realistic plans so that a viable correspondence between plans and performance can be maintained.

Project planning involves the development of a strategy for the commitment of resources to support the project objectives and goals. It is a rational determination of how to initiate, sustain and terminate a project (Cleland: 1999). He stressed that the basic concepts of project planning is developing the plan in the required level of detail with accompanying milestones and the use of available tools for preparing and monitoring the plan. Therefore project planning and control are interrelated; it is the philosophical foundation of CPM model. The CPM model is extremely useful for the purpose of planning, analyzing, scheduling, and controlling the progress and completion of large and complex projects. Though the concept and the mechanics of CPM can be used in any type of work, the focus of this model is on one-time projects. It is particularly suited for the co-ordination and control of one-time projects.

Projects and projects management are taking increasingly roles in our today industry, commercial and public sector organizations. The application of project management has extended far beyond industries such as oil, chemical, defence and construction industries to many less traditional industries and to more intangible applications. This is because according to Harrison (1992) (1) Management is recognizing that many of its organization's activities are projects and that the management of projects is different to the management of its other operations (2) Market conditions are becoming more demanding and projects are becoming larger (3) The rate of change facing industry is increasing resulting to more undertakings to be carried out as projects under tight time, limited resources and high cost of production (4) the problem of integrating multiple disciplines in multi-company undertakings is making the adoption of project management critical to their success. Therefore this work is aimed at examining theoretically how critical path method (CPM) network can be used by the project manager and project team for planning and controlling the progress and completion of large and complex projects in an organization.

1.2 Statement of the Problem

Project management and efficient resource allocation are two critical aspects of the production and operations manager's responsibilities. Because of the non-repetitive nature of projects, the mode of management differs from the usual job shop or other related types of scheduling. In a project, the project manager is confronted with a task of considerable size which requires substantial investment in time, effort and money. A project consists of tasks with definite starting and ending points. Most of the projects carried out in some organizations experience poor flow that is to say that the job is not moving as expected. Poor project flow in an organization is as a result of managers attempting to implement planning and scheduling approaches that are far too complicated to work on. Also inability of these organizations to identify an effective project scheduling analysis which may result to inability of the project manager to determine the many activities required by the project, the precedence relationship of the activities, time requirements and the best sequence for executing the project hence resulting to untimely completion of the project and waste of resources. Therefore this work would theoretically review how critical path method (CPM) network can be used as a management tool for project planning and control in manufacturing organizations.

1.3 Objectives of the Study

The broad objective of the study is to examine how Critical Path Method Network can be used as a Tool for Effective Project Execution in some selected construction Firms in Enugu State.

The specific Objectives were:-

1.To examine the nature of relationship between Critical path Method Network (CPM) and effective project planning and control in some selected construction Firms in Enugu State.

2.To examine the effect of Critical path Method Network (CPM) on Project crashing in some selected construction Firms in Enugu State.

3.To determine the nature of relationship between Critical path Method Network (CPM) and project scheduling in some selected construction Firms in Enugu State.

1.4Research Questions

1.What is the nature of relationship between application of Critical path Method Network (CPM) and effective project planning and control in some selected construction Firms in Enugu State.

2.To what extent does Critical path Method Network (CPM) has effect on Project crashing in some selected construction Firms in Enugu State.

3.What is the nature of relationship between Critical path Method Network (CPM) and project scheduling in some selected construction Firms in Enugu State.

1.5 Research Hypotheses

1.There is significant relationship between application of Critical path Method Network

(CPM) and effective project planning and control in some selected construction Firms in Enugu State.

2. Critical path Method Network (CPM) has a significant effect on Project crashing in some selected construction Firms in Enugu State.

3.There is significant relationship between Critical path Method Network (CPM) and project scheduling in some selected construction Firms in Enugu State.

2. Review of Related Literature

Critical Path Method Network Model (CPM)

The critical path model is useful for the purpose of planning analyzing, scheduling and controlling the progress and completion of large and complete projects (Loomba 1978).

The working procedure of CPM consists of five steps:

a. Analyze and breakdown the project in terms of specific activities and/or event
b. Determine the interdependence and sequence of activities and produce a network
c. Assign estimates of time, cost or both to all the activities of the net work
d. Identify the longest or critical path through the network
e. Monitor, evaluate, and control the progress of the project by re-planning, rescheduling and reassignment of resources.

The central task in the control aspect of CPM model is to identify the **longest** path through the network. The longest path is the critical path because it equals the minimum time required to complete the project if, for any reason, the project must be completed in less time than the critical path time, additional resources must be devoted (e.g., overtime work) to expedite one or more activities comprising the critical path. Paths other than the critical part (i.e. non critical or slack paths) offer flexibility in scheduling and transferring resources, because they take less time to complete than the critical path. In support of the above assertion, Banjoko (2004) opines that CPM helps in identifying critical activities or tasks that must be continuously monitored. Usually, these critical activities are potentially bottleneck activities as they determine the entire project duration. The longest time to complete a project occurs along the critical path. The critical path, therefore, contains all critical activities which if delayed, can prolong the completion time of the entire project. It is the longest path on the network.

In estimating the activity time for CPM, the assumption is made that activity times are deterministic (i.e., under specified conditions, a single time estimate is made for each activity). Also in the cost estimates for completing various activities, the CPM model does give explicit estimates of activity costs. Furthermore, in CPM, two sets of estimates are provided. One set gives **normal time** and **normal cost** required to complete each activity under normal conditions. The second set gives **crash time** and **crash cost** required to complete each activity under conditions that gain reduction in project completion time by expending more money. The purpose of this dual estimate is to enable the management to obtain a clear picture of the costs associated with deliberate acceleration of the project completion.

Another unique feature of CPM is that all activities along the critical path have no slack time. It follows, therefore that along the critical path all activities have their earliest starting time equal to their latest starting time, i.e. ES= LS.

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Common terms used in project planning and scheduling

(1) **Activities:** These are the individual tasks to be performed. E.g in the construction of a school building, laying the foundation is an **activity** or **task** roofing is another one. Generally, project activities follow a special precedence and this procedure must be strictly adhered to.

(2) **Nodes/ Events:** A node marks the starting or the ending points of an activity or task. Consequently, the major difference between activities and events is that activities represent the passage of time while events are special points in time.

(3) **Network:** This is a graphic display of all activities and events and their relationships in specified precedence order

(4) **Slacks/or non-critical paths:** These are excess periods that exist between the latest starting (LS) and earliest starting time of an activity (ES). Slack= LS-ES.OR it can be seen as paths other than the critical part.

(5) **Dummy Activities:** Dummy activities are non-existing activities. In real life, these activities do not exist but their use helps in showing some logical precedence relationship. They have zero duration time.

(6) **Project Scheduling models:** Emphasis in this work will focus on CPM as a simple project planning technique others are Gantt chart and PERT.

Illustration 1

CPM as a network model for project planning and control.

Table 1: Network Analysis Information

Activities ($_i$)	Predecessors	Time requirements in wks (t_i)
A	-	4
B	A	3
C	A	2
D	B	4
E	C	1
F	DE	4
G	A	6
H	F.G	4
I	H	3

Adapted from: Banjoko S.A (2004), Production and operations management. Ibadan Oluseyi press ltd.

Procedures for using the network Analysis

(1) Identify and specify all required activities
(2) Determine the precedence requirements
(3) Indicate the precedence relationship using arcs
(4) Specify time estimate for each activity
(5) Determine the critical path

Example as lifted from Banjoko (2004), suppose SABAN engineering company has agreed to undertake the design, fabrication and testing of prototype transmission for a major automobile firm. The company has identified the following activities and their

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associated times and precedence relationships as shown below.

Here we are going to construct a network diagram that represents this project, find the critical part, earliest starting time (ES) and latest starting time (LS).

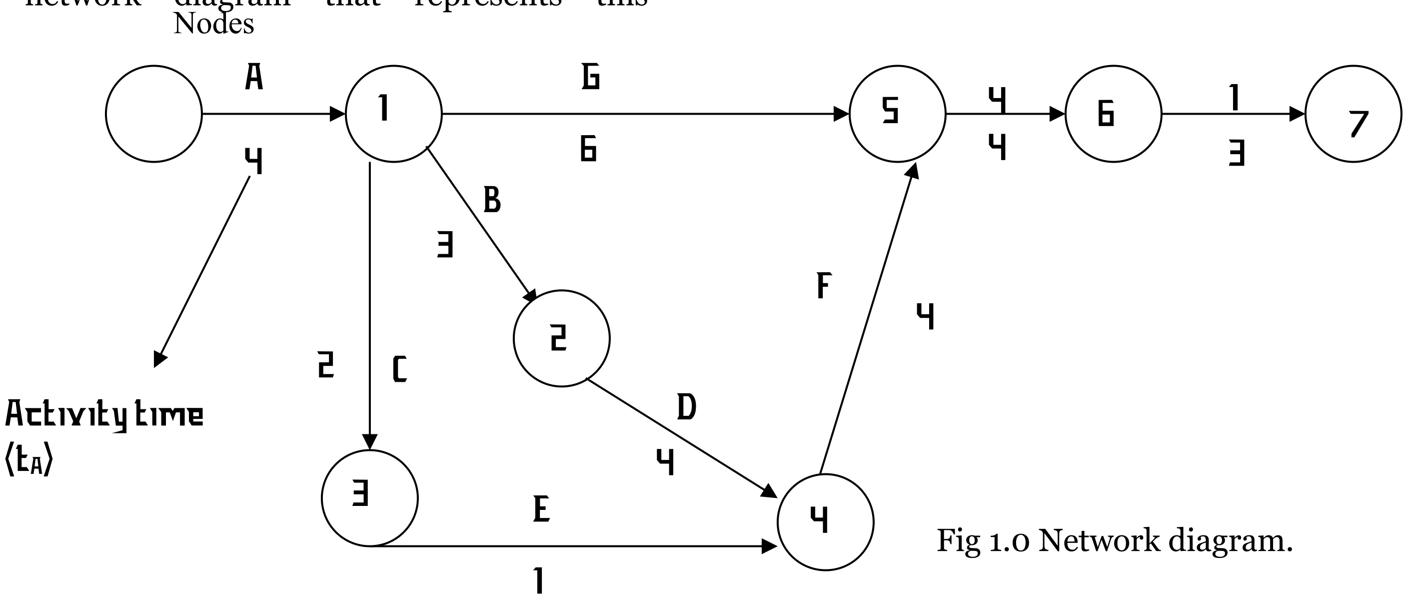

Fig 1.0 Network diagram.

To identify the critical part, earliest starting time (ES) and latest starting time (LS) we are going to use the Network below:

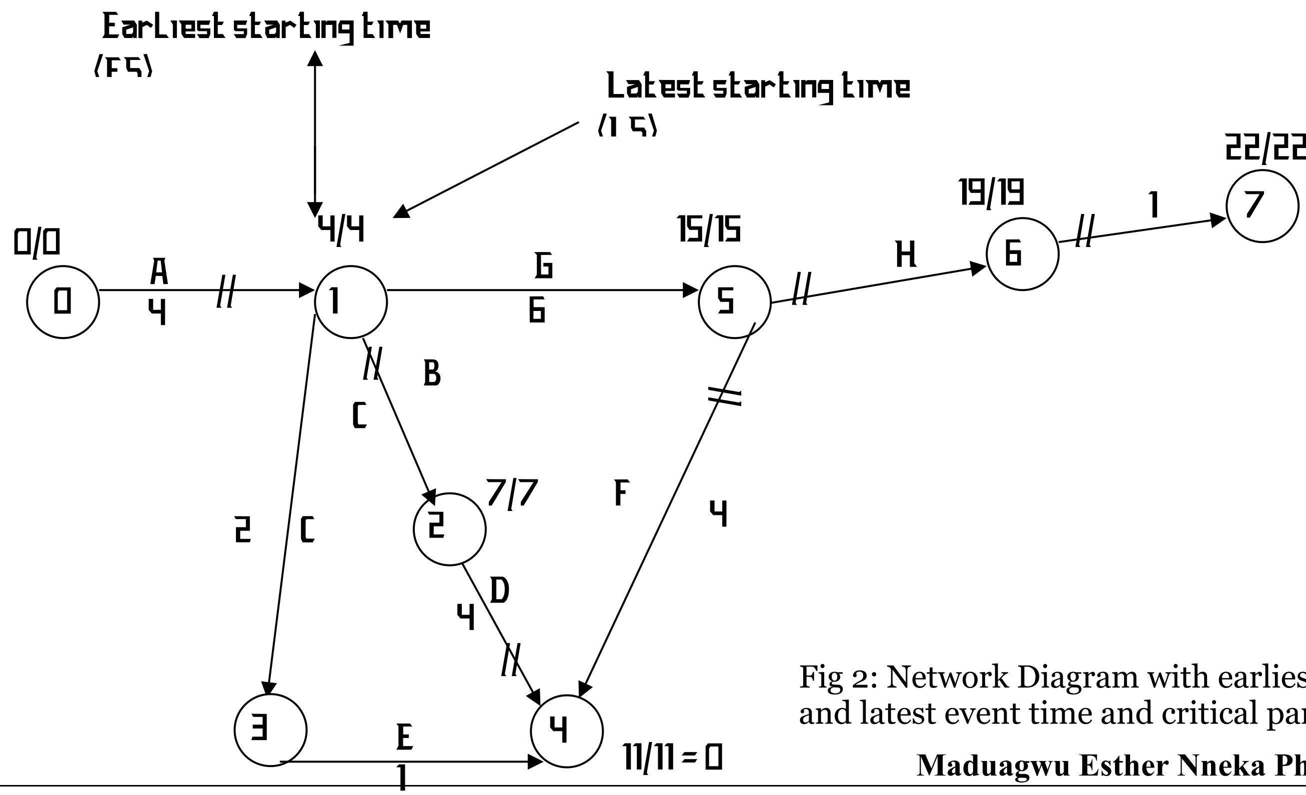

Fig 2: Network Diagram with earliest and latest event time and critical part.

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Earliest Starting Time (ES): It is the earliest time a task can be started. Thus, in the network above (fig 2), the earliest starting time for activity A (ESA) is 0. For activity B, which is preceded by activity A, its earliest starting time (ES_B) is 0+4 = 4. this shows that the earliest starting time of succeeding activity (B) is determined by the earliest starting time of the preceding activity (A) plus the duration of such preceding activities (t_{A-}) i.e. $ES_B = ES_{A-} + t_{A-}$. Where t_{A-} is time duration for activity A (i.e. 4 in the sample above). Similarly for activity C, $ES_C = ES_{A-} + t_{A-}$. Where two or more arcs lead to a node as the case with node 4, the highest of the ES_i is usually selected. For example, for activity D, the earliest starting time ES_D is 7 (i.e. 4 +3). For activity E, ES_E is 6 i.e. after the preceding activities A (4) and C (2) are completed. Thus, activity D will be completed in 7+4 weeks while activity E will be completed in 6+1 weeks since both activities precede activity f, the earliest starting time for activity F is the higher of the completion times of activities D and E i.e. 11 weeks. Hence, 11 is written on node 4 as shown in figure 2. Other earliest starting times are similarly calculated.

Latest staring time (LS): The latest starting time (LS) is the latest time an activity can be started from a node without causing any delay to the minimum completion time for the entire project. To determine the latest starting time (LS) for each activity, we only need to work backward by subtracting the time duration for each activity as we move back along the network path. For example, the earliest time activity I can be completed is 22 weeks and the earliest time any activity following it if any can be started is 22 weeks. For activity H, the latest time it can be completed is $LS_1 - t_1$ = 22-3= 19 weeks, that is the latest finishing time of the succeeding activity (1) minus the time duration of activity 1 (t_1). Similarly, the latest finishing time for activity F is $LS_H - t_H$ = 19-4 = 15 weeks. Note that two arcs meet at a node 5. In cases where two or more arcs meet at a node, the derivation of the latest starting times for other nodes follow the method described above.

Identifying the critical path: The critical path is that part that contains the critical activities and whose earliest starting time are equal to the latest starting times, that is, where the slack is zero (LS/ES = 0). The critical path also has the longest project duration. From fig 2 above the critical part is along nodes 0-1-2-4-5-6-7or along activities A,B,D,F,H, and I.

The concept of Activity Slack: The slack of an event represents the time by which one can **delay** the realization of that event without jeopardizing the timely realization of successor events. The slack of an event is denoted by S, and is calculated as follows: S = TL – TE, where

TL = Latest starting time

TE = Earliest starting time.

Slack is usually zero or positive. However, if for some business reason the project must be **expedited** (say the project were one forth complete and then management announces a bonus for completing the project earlier than the T_E of the terminal event) then a **negative slack** could exist along the critical path. A negative slack implies that the project is behind schedule.

The concept of slack is important because it indicates a measure of flexibility for the manager in terms of scheduling activities, allocating resources and achieving a balanced rate of production.

Another means of utilizing the concept of slack for planning and controlling the network is to

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calculate the slack associated with each activity. If we examine figure 2, we note that there are two noncritical paths through the network path 0-1-5-6-7 and path 0-1-3-4-5-6-7. On any non critical path, we can identify activities in terms of critical activities and non-critical activities. For example in path 0-1-5-6-7-, activity 0-1 is the only critical activity while activities 5-6-7 are non-critical activities and so on.

It is obvious that each non critical path contains some slack and that one or more non critical activities along each non critical path can be delayed in terms of starting or completing dates without delaying the overall project completion time. The availability of slack along non critical paths offers the manager a great deal of flexibility- because the slack of a noncritical path can be distributed over the noncritical activities of that part to suit the specific needs of the project.

Advantage of CPM

A big advantage of CPM lies in its extensive planning. Network development and critical path analysis reveal interdependencies and problems that are not obvious with other planning methods. CPM therefore determines where the greatest effort should be made to keep a project on schedule (Kerzner, 2000).

The second advantage of CPM is that one can determine the probability of meeting deadlines by development of alternative plans. If the decision maker is statistically sophisticated, he can examine the standard deviations and the probability of accomplishment date. If there is a minimum of uncertainty, one may use the single-time approach, while retaining the advantage of network analysis (Charles and Cooner, 2002).

A third advantage is the ability to evaluate the effect of changes in the program. For example, CPM can evaluate the effect of a contemplated shift of resources from the less critical (slacks) activities to the activities identified as probable bottlenecks. Fourthly, CPM can also evaluate the effect of a deviation in the actual time required for an activity from what had been predicted (Churchman and Ansoff, 2007). Finally, CPM allows, a large amount of sophisticated data to be presented in a well-organized diagram from which contractors and customers can make joint decisions.

Many companies have taken a hard work at the usefulness of CPM on small projects. The results have been the development of CPM procedures, which can do the following:

(1) Cut project costs and time
(2) Coordinate and expedite planning
(3) Eliminate idle time
(4) Provide better scheduling and control of subcontractor activities
(5) Develop better troubleshooting procedures
(6) Cut the time required for routine decisions, but allow more time for decision making

Criticism of CPM

1. Time and labour intensive
2. Decisions making ability reduced
3. Lacks functional ownership in estimates
4. Lacks historical data for time-cost estimate
5. Assumes unlimited resources
6. Requires too much detail (Kerzner, 2000)

Project Planning and Control

Project planning is an important part of the deciding aspect of the project team's job. It is the process of thinking through and making explicit the objectives, goals, and strategies necessary to bring the project through its life cycle to a successful termination when the project's product or service takes its rightful place in the execution of project owner strategies (Cleland 1999). According to

Harrison (1992), the work required to achieve these objectives must be defined, and the people to carry out the work will have to be recruited from within or outside the parent organization. Responsibility for elements of the project work will have to be assigned a project organization established. These organizational elements will have to be coordinated and relationships and links established that is there must be effective integration among the project team members.

Furthermore, the work required to complete the project will then have to be sequenced and scheduled in such a way that it can be carried out in a logical and efficient manner. The resources and cost of the project will have to be estimated and a time-phased budget and cash flow constructed. The mechanism to enable the project manager to take the above decisions, allocates these resources and carry out the above actions is the project planning process, the end result of it is project plan or plans. Planning can be used to provide the mechanism to integrate the many diverse elements and companies and to provide the necessary information and communication lines so that they can be managed as one global organization instead of several separate entities.

In addition to initial planning requirement, the project manager must be able to determine quickly and with minimum effort, how all parts of the project are progressing and how the people and the organizations involved are performing. The manager must be able to high light the problem areas and deviations from plan and budgets and be able to take action to maintain efficiency and achieve its objectives.

This is achieved through the collection and analysis of information and comparison of actual progress and performance with the baseline of schedule, cost and resources established in the project plan. This means that the project manager must be able to "**Control**" the project.

As soon as a project is lunched, control becomes the dominant function of the project manager. Planning and control merge through the "control cycle" into the integrated management function after the lunch phase. Control is but another name for the on-going management of the project (Harrison 1992). Thus the control function of project management is of equal importance to the planning function. They are not separate and discrete functions; they interact with each other and are interdependent. Project planning and control techniques includes: (1) work breakdown structure (2) Network (Arrow scheme, Node scheme, precedence diagram) (3) Bar chart (with precedence, without precedence) (4) critical path method (5) PERT (6) GERT simulation (7) Time/ cost analysis (8) Resource leveling (9) Computer assistance (10) linear responsibility chart.

The Difficulties of Project planning and Control:

Project planning and control is difficult, and many projects fail because of problems with both the scientific and human elements of these functions of project management. The principal problems in project planning and control arise in the following areas:

(1) The uniqueness of every individual project and its organization.
(2) Human factors related to people's abilities, training, philosophies and cultures
(3) The complexity and dimensionality of the typical project, involving a large number of activities, people, groups and companies
(4) The large amount of uncertainty and change associated with any large project.

(5) Knowledge of and skills in the specialist techniques and advanced methodologies of project planning and control, and the design of project management information systems.

CPM Networks and Project Crashing:

Crashing is the process of fine-tuning your project schedule to shorten delivery time. It is a possible solution when stakeholders ask for a faster delivery while not willing to reduce the scope of work. So, how does crashing work? Simple. Reduce the time to complete the tasks in the critical path. Note that crashing works only on tasks in the critical path because reducing time on non-critical tasks will not affect the project delivery time. Do not waste your time crashing non-critical path tasks; instead, crash on tasks in the critical path to get immediate results. You can think of several ways to crash a task. You can put two resources to work in parallel and have the task completed in half the time. Or you can assign a more productive resource who can finish the work earlier. In any case, make sure you assess the risks. There are tasks that cannot be performed by two persons, like installing a software or hammering a nail. Also, make sure you are not over-assigning critical tasks to your best resource, because it can only be 100% productive and anything above it will be counter-productive. It is mindless to assume that the best resource can work 16 hours a day for the next three weeks (Meyer, 2002) (Project SMART, 2008) http://www.executivebrief.com.

For many projects, there is a trade-off between project cost and project duration. When a project lags behind its schedule, extra people may be assigned to the job to speed it up. Even for an on-time project, there may be opportunities to 'crash' the project by hiring personnel or purchasing additional equipment. A manager must assess the costs and benefits of speeding up the project (Robert, 2003).

Method for Crashing a Project

Step 1: Assess the cost-effectiveness of crashing activities on the critical paths (it may be necessary to crash more than one activity to have an effect). If no set of crashes leads to a net gain, stop;

Step 2: Implement the most cost-effective crash until it is no longer cost-effective or the paths involved are no longer critical;

Step 3: A crash in step (2) may create new critical paths. Revise the network and identify the new critical paths. Return to step (1),(Robert, 2003).

Two sets of time and cost figures are obtained for each activity: (1) Normal time and normal cost, and (2) Crash time and crash cost. Therefore we have a time-cost trade-off function for each activity. It is also assumed that the relationship between time and cost is linear (Loomba, 1978).

This linear relationship is illustrated in figure 3 below;

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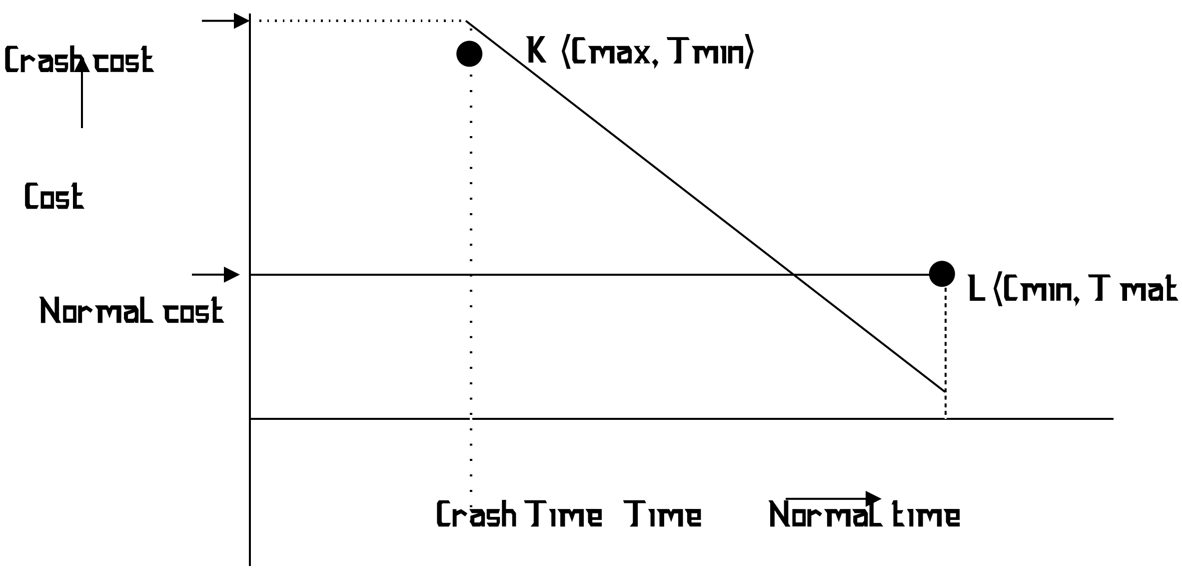

Figure 3; adapted from Loomba (1978). Management – A Quantitative Perspective. New York; Macmillan pub.

As shown in figure 3, point K represents the crash cost (maximum cost) and crash time (minimum time) for the activity, and point L represents the normal cost (minimum cost) and normal time (maximum time). We can calculate the slope of the cost-time line (for each activity) to measure the cost-time trade-off. That is, how much additional cost will be incurred by saving one unit of time (say I week) in completing an activity?

:. The slope of the cost-time line = change in cost crash cost normal cost

Change in Time = Crash time- normal time

Where D = measures change and are read "delta"

Using a network to illustrate the concept of project crashing

Table 2:

Activity	Time (weeks) Normal	Time (weeks) Crash	Cost (Naira) Normal	Cost (Naira) Crash	D Cost / D Time (change in cost per week) ₦
1-2	10	7	1,000	1,600	200
1-3	15	10	2,000	3,000	200
2-4	8	6	1,800	2,600	400
2-5	20	16	4,500	5,300	200
3-6	30	20	7,200	9,600	240
4-5	14	12	5,000	6,000	500
5-6	12	9	3,300	4,500	400
Total			24,800	32,600	

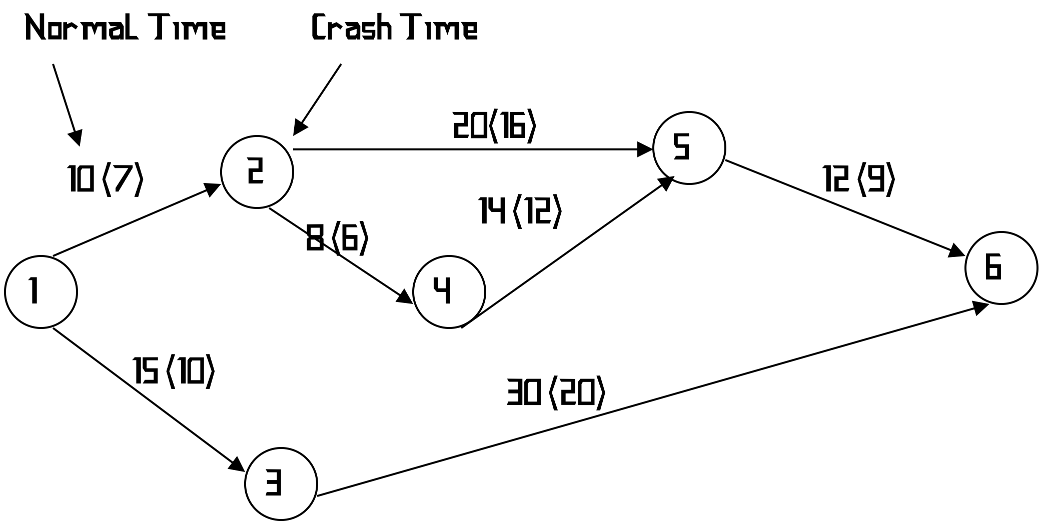

Figure 4. adapted from Loomba (1978). Management – A Quantitative Perspective. New York; Macmillan pub.

The normal, as well as crash time and cost data for the network of figure 4 are given in table 2. In the last column of table 2, we list, for each activity D cost/ D time per week. D cost/D time will always yield a negative slope as shown in figure 3

The idea of project crashing is that, under certain circumstances, it is necessary and desirable to expedite project completion even though it will result in higher cost. Since, in CPM both the minimum project completion time and the cost-time relationships of all activities, is known, then the objective is to design a program that will yield minimum project completion time with the least increase in costs over the normal cost.

Project Scheduling

The target of project scheduling is to construct a timetable where each individual activity receives a start time and a corresponding finish time within the predefined precedence relations and the various predefined activity constraints. The scheduling process is based on the traditional critical path based forward (to create an earliest start schedule) and/or backward (to create a latest start schedule) project scheduling calculations aiming to construct a project schedule with a minimal project lead time (Vanhoucke, 2009).

Its necessary to monitor the progress to ensure that everything is going according to schedule. This involves measuring actual progress and comparing it to the schedule. If at any time during the project it is determined that project is behind schedule, corrective action must be taken to get back on schedule. The key to effective project control is to measure actual progress and compare it to planning progress on a timely and regular basis and to take necessary corrective action immediately. Based on actual progress and on consideration of other changes that may occur, it's possible to calculate an updated project schedule regularly and forecast whether the project will finish ahead of or behind its required completion time (Gido, 2009). Project scheduling is often the most visible step in the sequence of steps of project management. The two most common techniques of basic project scheduling are the critical path method (CPM) and program evaluation and review technique (PERT). The network of activities contained in a project provides the basis for scheduling the project and can be represented graphically to show both the contents and objectives of the project (Badiru, 2008). A basic CPM project network analysis is typically implemented in three phases: (Badiru, 2008)

• Network-planning phase
• Network-scheduling phase
• Network-control phase.

Network Planning: In network-planning process begins by clearly defining the project objective (chudhury, 1988). This step is necessary to find out resources needed. Once the activities have been identified, their sequential relationship needs to be determined, what activities must be completed before other can begin. This step typically I done using flowchart-type diagrams (Stephen, 1999).

Network scheduling: is performed by using forward-pass and backward-pass computations. These computations give the earliest and latest starting and finishing times for each activity. The amount of "slack" or "float" associated with each activity is determined. The activity path that includes the least slack in the network is used to determine the critical activities. This path also determines the duration of the project. Resource allocation and time–cost trade-offs are other functions performed during network scheduling (Badiru, 2008). Then the project schedule is compared with the objective and necessary adjustments are made to control the project (Stephen 1999).

Network control involves tracking the progress of a project on the basis of the network schedule and taking corrective actions when needed. An evaluation of actual performance versus expected performance determines deficiencies in the project progress.

Theoretical Review

Optimization Theory

Formal optimization on "linear programming" was started by Leonid Kantorovich in 1939. The first well-known approach, the Simplex Method, was published in 1947 by George Dantzig, and in the same year, the Theory of Duality was published by John von

Neumann.Optimization Theory is the more modern term for operations research. Is a branch of mathematics which encompasses many diverse areas of minimization and optimization. Optimization theory includes the calculus of variations, control theory, convex optimization theory, decision theory, game theory, linear programming, Markov chains, network analysis, optimization theory, queuing systems, etc.

Optimization models in environmental systems consist of a set of objectives, constraints, and decision or control variables. The decision variables detail the possible operational, planning, or design alternatives. In many problems, decision variables include state variables of the environmental system. The optimization models are predicated on mathematical models describing the underlying flow, mass, or energy transport processes. The mathematical models are used in optimization modeling to relate how the decision variables affect the state variables of the environmental system. https://en.wikipedia.org/wiki/Mathematical_optimization

Project Management Theory

Until 1900, civil engineering projects were generally managed by creative architects, engineers, and master builders themselves, for example, Vitruvius (first century BC), Christopher Wren (1632–1723), Thomas Telford (1757–1834) and Isambard Kingdom Brunel (1806–1859). In the 1950s organizations started to systematically apply project-management tools and techniques to complex engineering projects.

As a discipline, project management developed from several fields of application including civil construction, engineering, and heavy defense activity. Two forefathers of project management are Henry Gantt, called the father of planning and control techniques, who is famous for his use of the Gantt chart as a project management tool (alternatively *Harmonogram* first proposed by Karol Adamiecki); and Henri Fayol 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. His work is the forerunner to modern project management tools including work breakdown structure (WBS) and resource allocation.

The 1950s marked the beginning of the modern project management era where core engineering fields come together to work as one. Project management became recognized as a distinct discipline arising from the management discipline with engineering model. In the United States, prior to the 1950s, projects were managed on an ad-hoc basis, using mostly Gantt charts and informal techniques and tools. At that time, two mathematical project-scheduling models were developed. The "critical path method" (CPM) was developed as a joint venture between DuPont Corporation and Remington Rand Corporation 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 as part of the Polaris missile submarine program.

PERT and CPM are very similar in their approach but still present 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

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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.

Empirical Review

Ahmad, A. M. (2013) wrote on 'Project Management using Critical Path Method (CPM): A Pragmatic Study'__Traditional techniques of decision-making have hindered the technical efficiency of most professionals and executors of the public project in many developing countries such as Nigeria. The use of Gantt chart in project planning has continued to increase as a source of last resort in spite of its severe limitations for ineffective project management and delivery. CPM has gained widespread commendation and acceptance in the developed countries. This technique is yet to gain any appreciable acceptance for the implementation of public projects in Nigeria. Professionals and executors of public projects in Nigeria have remained conscientiously on the Gantt chart. In order to address this problem of project planning, the CPM was applied to the "construction of a complex building at Federal University of Technology, Yola." This paper describes a specific case study with real data and an application. The results show the effectiveness of the CPM in, planning, scheduling, and organizing, coordinating, managing, and controlling of project time and cost.

Zulia and Yuliani (2015), wrote on "Project Effectiveness Improvement: A Case Study In PT.X" Project management is important and powerful tool in global business because increasingly technically complex products and processes, vastly shortened time to market demand, and the need for cross-functional expertise. PT X is aircraft industry with complex product with millions of individual components and many dependencies. The project success can achieve the customer and contractor objectives of a project, and getting the job done within the constraints of time, cost and quality. The company is delayed delivery Tail boom to Airbus Helicopter. It makes customers give complaints related to the performance of company. CPM used to analyze the project planning. After decide the method for evaluate the planning project, we must clustering 455 elementary part into activities in process production Tail Boom. PERT analysis is used when the duration of activities are not known with certainty, calculated expected time using scenario base of PERT. The expected time will use in new critical path diagram for calculate total time in actual or reality at the time happen the problems of delayed delivery Tail boom. Project Crashing used for compare the project planning and actual to know the appropriate project management.

Chao and Wang (2019), wrote on "A Hybrid Approach for Project Crashing Optimization Strategy with Risk Consideration: A Case Study for an EPC Project" The study aimed to develop and provide a comprehensive evaluation strategy for schedule-related variations and time-cost analysis for an engineering–procurement–construction (EPC) project. Time-cost analysis is an important aspect of project scheduling, particularly in long-term and costly EPC projects. In this study, a hybrid method is proposed for the time-cost optimization strategy evaluation of a project. Monte Carlo simulation is applied to determine contingency plans and realize the effective management of estimated schedule uncertainties. A mathematical integer linear programming optimization model coded using CPLEX is developed to assess appropriate strategies for project execution under time and cost constraints. A set of project evaluation optimization models considering risk and project crash plan and the relationship between crash cost and delay penalty is also developed for assessing project feasibility. The correlation between project risk and crashing strategy has seldom been evaluated simultaneously in previous research. This work fills this research gap by quantifying the feasibility of a project, with combined data on risk, schedule, and cost as evaluation indicators. It allows project managers to consider management issues and strategies before they implement projects. A practical example with numerical applications is presented to illustrate the contribution of the decision-making support mechanism, and several managerial insights are provided. Batool Atiyah (2011) wrote on "Scheduling Project Management Using Crashing CPM Networks to Get Project Completed on Time & Under Budget" Most of Iraqi companies suffer from difficulties & challenges due to complexity of project, and because of its dependency on the traditional tool to plan, schedule, and control the project development. The needs for continuous control of time, cost, and performance of projects, also can be completed on time with good quality and within the allocated budget. This research provident dynamic approach will let the user evaluate the project network to determine a crashing strategy at the beginning of the project and also during the life of the project. To reduce a projects completion time, a technique called "crashing is performed, which involves bringing in additional resources for activities along the critical path of the network. The research created model to determine the order in which activities should be crashed as well as using CPM technique helps good project management in achieving the objective with minimum of time and least cost and also in predictive the probable project duration and associated cost meeting the desired project.

Salifu and Amponsah (2013) wrote on "Project Planning and Scheduling, the Critical Path Method Approach. BUI Power Project as a Case Study" This paper is aimed at minimizing project time subject to the available resources using Critical Path Method (CPM) as a planning and scheduling tool and the visual display of activities to showing project execution flow and coordination between activities based on a defined algorithm using the Bui Power Project (BPP) as a case study. Data was gathered from both primary and secondary sources from a sample of 50 selected respondents consisting of consultants, engineers, and other workers of the Bui Power Project using nonprobability sampling techniques. Analysis of data was network-based and use was made of Lingo software and GenStat in solving linear programming problems and performing some statistical tests respectively. Sensitivity analysis and improvement to optimality using various methods were also looked at to meet an optimum value.

3. Methodology

The researcher adapted a descriptive survey design. The construction firms studied were BUXTEC Construction Company Limited, Anbeez construction Services Limited. The data for this study were collected from two major sources; primary and secondary sources. The major instruments for data collection were questionnaire, interviews, and observations. The population of the study was made up of 5 project managers, 10 supervisors and 25 Foremen of the two firms studied. Therefore the total number of the population of study was forty (40). The entire population of the study was used as the sample size. The content

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validity of the research instrument was used in this study. The reliability of the instrument was established through test re test method. The reliability coefficient was 0.87. Data for the study was presented using simple tables and analysis was done using simple percentages. Hypothesis one and three were tested using parson product moment correlation while hypothesis two was tested using regression analysis with the aid of SPSS.

4. DATA PRESENTATION

TABLE 4.1: DISTRIBUTION AND RETURN R ATE OF QUESTIONNAIRE

Categories	Number distributed	Number returned	% number returned
Managers	5	5	12.5
Supervisors	10	10	25
Foremen	25	25	62.5
Total	40	40	100

Field Survey, 2021

Table 4.1 shows that 5(12.5%) questionnaire was distributed to project managers and returned, 10(25%) questionnaire was distributed to supervisor returned and 25(62.5%) questionnaire was distributed to the Foremen and returned. This shows a 100% return rate of the questionnaire distributed.

TABLE 4.2: Research Question I whether there is a relationship between application of Critical path Method Network (CPM) and effective project planning and control in some selected construction Firms in Enugu State.

Options	Managers	Supervisors	Foremen	Frequency	Percentage
S. Agree	5	6	18	29	72.5
Agree	___	2	5	7	17.5
Undecided	___	___	2	2	5
Disagree	___	2	___	2	5
S. disagree	___	___	___	___	___
Total	5	10	25	40	100

Field Survey, 2021

Table 4.1 shows that 36(90%) of the respondents agreed to the statement while 4(10%) disagreed to the statement. This shows that there is a strong positive relationship between application of Critical path Method Network (CPM) and effective project planning and control.

Table 4.3: Research Question 2: whether Critical path Method Network (CPM) has effect on Project crashing in some selected construction Firms in Enugu State.

Options	Managers	Supervisors	Foremen	Frequency	Percentage
S. Agree	3	5	12	20	50
Agree	2	3	10	15	37.5
Undecided	___	___	3	3	7.5
Disagree	___	2	2	2	___
S. disagree	___	___	___	___	5
Total	5	10	25	40	100

Field Survey, 2021

Table 4.3 shows that 30 or (80.5%) of the respondents agreed that Critical path Method Network (CPM) has effect on Project crashing in construction Firms in Enugu State. while (5 or 12.5%) of the respondents disagreed to the statement. This shows that Critical path Method Network (CPM) has good effect on Project crashing.

Table 4.4: Research Question 3: Whether there is a relationship between Critical path Method (CPM) Network and project scheduling in some selected construction Firms in Enugu State.

Options	Managers	Supervisors	Foremen	Frequency	Percentage
S. Agree	5	8	13	26	65
Agree	___	2	18	10	25
Undecided	___	___	2	2	5
Disagree	___	___	___	2	5
S. disagree	___	___	___	___	___
Total	5	10	25	40	100

Field Survey, 2021

Table 4.4 shows that 36 or (90%) of the respondents agreed that there is a positive relationship between Critical path Method (CPM) Network and project scheduling in construction Firms in Enugu State while 10 or (10%) of the respondents disagreed to the statement. This shows that Critical path Method (CPM) Network will contribute positively to effective project scheduling.

Discussion of findings

It was found that;

There is a strong positive relationship between application of Critical Path Method (CPM) Network and effective project planning and control as 36 or (90%) of the respondents agreed to the statement._ Project planning and control techniques includes: (1) work breakdown structure (2) Network (Arrow scheme, Node scheme, precedence diagram) (3) Bar chart (with precedence, without precedence) (4) critical path method (5) PERT (6) GERT simulation (7) Time/ cost analysis (8) Resource leveling (9) Computer assistance (10) linear responsibility chart. He opines that the control function of project management is of equal importance to the planning function. They are not separate and discrete functions; they interact with each other and are interdependent (Harrison, 1992, Ahmad, 2013).

Critical path method (CPM) network has a positive effect on Project crashing in construction Firms in Enugu State as 30 or (80.5%) of the respondents agreed to the statement. The idea of project crashing is that, under certain circumstances, it is necessary and desirable to expedite project completion even though it will result in higher cost. Since, in CPM both the minimum project completion time and the cost-time relationships of all activities, is known, then the objective is to design a program that will yield minimum project completion time with the least increase in costs over the normal cost (Loomba, 1978).

Critical path Method (CPM) Network has a positive relationship with project scheduling in construction Firms in Enugu State as 36 or (90%) of the respondents agreed to the statement. This in line with the views of Banjoko (2004) that Network Scheduling Techniques has so many advantages among them is that they form the basis for all planning and predicting the project and help management decide how to use its resources to achieve time and cost goals.

Test of Hypothesis

Hypothesis One

Ho: There is no relationship between application of Critical path Method Network (CPM) and effective project planning and control in some selected construction Firms in Enugu State

Hi: There is a relationship between application of Critical path Method Network (CPM) and effective project planning and

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control in some selected construction Firms in Enugu State

Descriptive Statistics

	Mean	Std. Deviation	N
Critical path Method Network (CPM)	1.4250	.81296	40
Effective project planning and control	1.7750	1.20868	40

Correlations

		Critical path Method Network (CPM)	Effective project planning and control
Critical path Method Network (CPM)	Pearson Correlation	1	.909**
	Sig. (2-tailed)		.000
	N	40	40
Effective project planning and control	Pearson Correlation	.909**	1
	Sig. (2-tailed)	.000	
	N	40	40

**. Correlation is significant at the 0.01 level (2-tailed).

The descriptive statistics of Critical path Method Network (CPM), shown in Table -----. The table shows a mean response of 1.4250 and standard deviation of .81296 for critical path method Network (CPM) and a mean response of 1.7750 and standard deviation of 1.20868 for Effective project planning and control and number of respondents 40. A close examination of the standard deviation values reveals a significant difference in the scores of the two variables. This implies that the variability of data points between the dependent and independent variables is about the same.

Table displays the Pearson correlation coefficient for critical path method network and effective project planning and control. The correlation coefficient shows a value of 0.909. This value indicates that correlation is significant at 0.05 level (2tailed) and implies that there is a strong positive relationship between Critical path Method Network and Effective project planning and control (r = .909). The computed correlation coefficient is greater than the table value of r = 0.196 with

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38 degrees of freedom (df. = n-2) at alpha level for a two-tailed test (r = .909, p< .05). As a result, since the computed r = .909, is greater than the table value of 0.196. We reject the null hypothesis and concluded that there was a significant positive relationship between Critical path Method Network and Effective project planning and control (r =. 909, P<.05).

Hypothesis Two
Ho: Critical path Method Network (CPM) has no effect on Project crashing in some selected construction Firms in Enugu State.
Hi: Critical path Method Network (CPM) has a effect on Project crashing in some selected construction Firms in Enugu State.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.826[a]	.683	.674	.65846	.683

a. Predictors: (Constant), Critical path Method Network
b. Dependent Variable: Project crashing

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	35.425	1	35.425	81.706	.000[b]
	Residual	16.475	38	.434		
	Total	51.900	39			

a. Dependent Variable: Project crashing
b. Predictors: (Constant), Critical path Method Network

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.098	.249		-.394	.695
	Critical path Method Network	1.205	.133	.826	9.039	.000

a. Dependent Variable: Project crashing

R = 0.826
R^2 = 0.683
F = 81.706
T = 9.039
DW = 0. 683

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Interpretation:
The regression sum of squares (35.425) is greater than the residual sum of squares (16.475), which indicates that more of the variation in the dependent variable is not explained by the model. The significance value of the F statistics (0.000) is less than 0.05, which means that the variation explained by the model is not due to chance.
R, the correlation coefficient which has a value of 0.826, indicates that there is a positive relationship between Critical path Method Network and Project crashing. R square, the coefficient of determination, shows that 68.3% of the Project crashing is explained by the model.
With the linear regression model, the error of estimate is low, with a value of about .65846. The Durbin Watson statistics of 0.683, which is not more than 2, indicates there is no autocorrelation.
The Critical path Method Network coefficient of 0. 826 indicates a positive significance between Critical path Method Network and Project crashing, which is statistically significant (with t = 9. 039). Therefore, the null hypothesis should be rejected and the alternative hypothesis accordingly accepted. Thus Critical path Method Network has a significant effect on Project crashing

Hypothesis Three

Ho: There is no relationship between Critical path Method Network (CPM) and project scheduling in some selected construction Firms in Enugu State

Hi: There is a relationship between Critical path Method Network (CPM) and project scheduling in some selected construction Firms in Enugu State

Descriptive Statistics

	Mean	Std. Deviation	N
Critical path Method Network	1.4250	.74722	40
Project scheduling	1.7250	1.21924	40

Correlations

		Critical path Method Network	Project scheduling
Critical path Method Network	Pearson Correlation	1	.729*
	Sig. (2-tailed)		.000

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	N	40	40
Project scheduling	Pearson Correlation	.729*	1
	Sig. (2-tailed)	.000	
	N	40	40

*. Correlation is significant at the 0.05 level (2-tailed).

The descriptive statistics of Critical path Method Network (CPM), shown in Table. The table shows a mean response of 1.4250 and standard deviation of .74722 for critical path method Network (CPM) and a mean response of 1.7750 and standard deviation of 1.21924 for Project scheduling and control and number of respondents 40. A close examination of the standard deviation values reveals a significant difference in the scores of the two variables. This implies that the variability of data points between the dependent and independent variables is about the same.

Table displays the Pearson correlation coefficient for critical path method network and Project scheduling and control. The correlation coefficient shows a value of 0.729. This value indicates that correlation is significant at 0.05 level (2tailed) and implies that there is a strong positive relationship between Critical path Method Network and Project scheduling and control (r = .729). The computed correlation coefficient is greater than the table value of r = 0.196 with 38 degrees of freedom (df. = n-2) at alpha level for a two-tailed test (r = .729, p< .05). As a result, since the computed r = .729, is greater than the table value of 0.196. We reject the null hypothesis and concluded that there was a significant positive relationship between Critical path Method Network and Project scheduling (r =. 729, P<.05).

5. Summary of Findings

The findings at the end of this study include the following

i. There was a relationship between application of Critical path Method Network (CPM) and effective project planning and control in some selected construction Firms in Enugu State (r =. 909, P<.05).
ii. Critical path Method Network had a significant effect on Project crashing (r = 0.826; F= 81.706 t = 9.039; P< 0.05)
iii. There was a significant positive relationship between Critical path Method Network and Project scheduling (r =. 729, P<.05).

Conclusion

Critical path method (CPM) network has been identified as a powerful tool that helps project managers to schedule and manage complex and even small projects. It helps in identifying critical activities or tasks that must be continuously monitored. The critical activities are potentially bottleneck activities as they determine the entire project duration. Therefore, the critical path contains all critical activities which if delayed, can prolong the completion time of the entire project. Therefore CPM as a network model helps project managers to plan all tasks that must be completed as part of a project. It acts 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 and helps to indicate where remedial action needs to be taken to get a project back on course.

Recommendations

Project managers in construction firms should be backed by these policies:

i. Use CPM network in planning, scheduling and controlling of both complex and flexible projects. This is because CPM enables the manager to make a detailed analysis and structure of the various elements of the project in form of a network. From the network, it is easy to identify those activities that are critical to completing the job in a specified time period and cost.

ii. The project manager should be able to guide projects safely and as quickly as possible to their destination through application of project crashing when and where it is necessary, this will help to reduce cost and also save project completion time.

iii. The project manager should ensure that projects are scheduled using CPM network to enable them to track the progress of the project on the basis of the network schedule and taking corrective actions when needed.

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