Transition from Critical Path to Critical Chain: A Case Research Analysis

Srijit Sarkar

Abstract— The purpose of this paper is two-fold: first of all, it provides a comprehensive overview of the problems associated with the traditional Critical Path Method of project management, and how Critical Chain Project Management has contributed towards mitigating those problems. This is accomplished by reviewing the research carried out by eminent scholars in prior publications. Secondly, the case research methodology is applied to a private construction project initiative. The case research analysis presented in this paper deals with the scheduling processes of both CPM and CCPM, and aims to shed light on the incongruence between the two procedures. The case research analysis has been prepared with the help of MS Project – a project management software that uses Gantt Charts to apprise the data and related complications. First of all, research is conducted on the construction project using the traditional Critical Path Method of project management. Next, using the same data, research is carried out with the Critical Chain Project Management Technique. The results are compared and positive conclusions can be drawn regarding CCPM technique's efficacy. The research findings, albeit provisional, substantiate the claim that CCPM has indeed provided a more efficient and reliable method of project management. However, this study, does not delve deep into the significant role of buffers in CCPM.

Keywords– buffers, critical chain project management, critical path method, Gantt chart, ms project, project management.

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1 INTRODUCTION

A project can be theoretically apprised as an effort which is undertaken to engender a particular product or service [1]. It has particular start and end dates, and is resource dependent. Projects often have to be completed within definite time limits and therefore, project managers are required to schedule necessary activities in an efficient manner so as to facilitate project completion within the specified date and at the minimum cost. Moreover, projects are almost always conflict-ridden. Therefore, efforts should be made towards minimizing such conflicts.

Concepts regarding conventional project management have been around for over three or four decades. However, in the early years of its development, it had been discovered that for commercial projects, cost and duration estimates often exceeded their initial estimates by at least 40 to 50 percent respectively. Critical Path-based project management was later introduced as a much needed remedy for such perturbing problems.

Critical Path Method (CPM) is a project scheduling method intended to rectify the major problems associated with conventional project management techniques. The sole purpose of the CPM, since its ascension into the world of project management, has been to deliver projects within the original cost and time estimates. Despite its penchant for satisfactory scheduling of projects, this process of project management revealed many fallacies which needed to be rectified in order to obtain satisfactory results.

The Critical Chain Project Management (CCPM), since its inception in 1997, has been deemed as a major breakthrough in the field of project management. It has amended most of the problems that were inherent to CPM and other traditional PM methods, in addition to providing a quicker way of completing projects. Moreover, CCPM employs buffers to act as safeguards against various problems that may arise during the execution of the projects.

The purpose of this paper is to present a case study on the interim research findings of a private construction company's ongoing project. The paper also dichotomizes between the novel CCPM method of scheduling and the traditional Critical Path-mode of scheduling, through utilization of the MS Project software; in order to determine is more reliable and efficient.

2 LITERATURE REVIEW

The paper differentiates between two major project scheduling techniques – the traditional Critical Path Method of project

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scheduling and the novel Critical Chain Scheduling – using data gathered from a real-life project scenario. Both these project management techniques have been developed to ensure that projects are completed on time and within the proposed budget.

In their research paper, Peter Stelth and Professor Guy Le Roy have drawn several analogies relating to the conventional CPM and the new CCPM-based project management technique [2]. They have touched upon various issues such as the influence of CPM and CCPM on project scheduling, the need for project tracking and monitoring, etc. It is imperative that every individual involved in the planning and execution of the project understands the need for developing a fixed schedule and adhering to that particular schedule. According to Doloi and Jaafari, planning is essential for all projects [3]. However, projects nowadays are becoming increasingly convoluted. There are numerous risks involved in the execution of the project. So, unless there is a means of tracking the implementation of the project, there is no way of stymieing the risks and uncertainties involved. A number of simulation models have come into play nowadays because of the aforesaid reasons. One such simulation software which can aid in the planning, scheduling, control and tracking of the project, effectively and accurately, is Microsoft Project. This is the simulation software that I'll be using in my case research analysis.

2.1 Overview of Traditional Project Management

Critical Path Method was conceived in the late 1950's by Morgan R Walker and James E. Kelley [4]. Even in the wake of recent outstanding developments in field of project management, CPM is still recognized today as the forerunner of project management scheduling.

K.G. Lockyer (1969), in his book An Introduction to Critical Path Analysis, presented the concept of critical path analysis, which helps to identify the alternate paths or plans that can be undertaken to reduce the blockades that may arise during the execution of the project [5]. CP analysis thus allows project team members to determine the best estimates of the time that is needed to complete the project.

Project managers are responsible for the smooth execution of the project. They face an eclectic multitude of problems during the project planning, scheduling, and control phases. These problems undermine the project's efficacy, causing unexpected delays and dissension among the project resources. Some of the root causes of these problems, as mentioned by Dr. Goldratt (1997) are:

- Student Syndrome: People assume that there is sufficient time to complete the project and hence they wait until the deadline is in close propinquity.
- Parkinson's Law: Work expands to fill the available time.
- Murphy's Law: The perception that "anything that can go wrong will go wrong."
- Multi-tasking: The problem of assigning multiple tasks to the same resource.

Numerous attempts had been made to develop an effective construction planning module, through various conventional project management techniques such as integer programming (IP), dynamic programming etc. But none of these processes have proven computationally biddable for any realistic problem, thus rendering them unfeasible.

In their research paper, Ming Lu and Heng Li have tried to address the limitations of CPM based resource scheduling [6]. Their findings on Resource-Activity Critical Path Method have proven quite useful in the field of Project Management. However, even though it has clarified some of the "resource critical" issues pointed out by Fondahl (1961), the emergence of a new and completely different project management technique was still inevitable.

2.2 Advent of Critical Chain Project Management

According to Dr. Eliyahu Goldratt, "Critical Chain is the longest chain of tasks that consider both task dependencies and resource dependencies." Critical Chain Project Management is a concept that was pioneered by Dr. Goldratt himself [7]. It boasted a number of improvements over the traditional Critical Path Method.

- Faster completion of projects
- Elimination of multi-tasking
- Amendment in the attitude of the workers
- Absence of milestones
- No chance of student syndrome
- Simple way of tracking and monitoring project progress

In his publication, Larry Leach (1999) has delineated the various improvements that CCPM has introduced over conventional PM techniques [8]. He explains that the use of Critical Chain Scheduling and the application of safety buffers have taken project measurement and control to an entirely different summit. According to Leach, CCPM has contributed to the Project Management Body of Knowledge (PMBOKTM) by molding project planning and management in a manner so as to eliminate the problems that lead to poor project performance.

Leach mentions that CCPM uses three definite theories – Theory of Constraints (TOC), Common Cause Variation, and Statistical Law of Aggregation – to improve project performance. These theories have been incorporated into the methodology of CCPM and play an integral role in delivering efficient project scheduling and control. The Theory of Constraints (TOC), first introduced by Dr. Goldratt in his book The Goal, draws attention to the fact that in order to achieve the company's goals; efforts should be made to manage the system constraints [9].

In his book, Critical Chain, Goldratt assess the significance of safety time with respect to project management. He avers that buffers are inserted into the critical chain to act as wadding against overrunning tasks, thereby safeguarding the overall critical chain.

In the research paper titled Critical Chain Project Scheduling: Do not Oversimplify, Willy Herroelen, Roel Leus and Erik Demeulemeester have drawn extensive analogies between Critical Chain Scheduling (CCS) and Buffer Management [10]. Their research has been invaluable in understanding the role of buffers in project management. According to their research, the process of inserting and supervising resource, feeding and project buffers provide a simple and functional tool for setting reliable project due dates and for monitoring the project during execution. They have also warned potential project managers to be careful while inserting buffers into their projects without understanding their implications. Pinto (1999), in his research, has expressed concern over the thought that most companies, without fully understanding the consequences of buffer insertion, might consider it as a means to solve any project contentions regardless of their unique circumstances [11].

Francis S. Patrick, through his research, has averred that Critical Chain Project Management is not only a tool for effective Critical Chain Scheduling and Buffer Management; it is also a means to developing risk-focused plans that counteract uncertainties [12]. According to him, recognition of uncertainty and its associated risks are key elements for Critical Chain Scheduling. His studies provide an insight into risk management and hold the key to protecting projects from uncertainty.

3 THE THEORY OF CPM AND CCPM

3.1 Project Management

As stated earlier, a project is an effort undertaken to manufacture a product or provide a particular service. This, in turn, insinuates that every project has a particular start and end date. However, pragmatic insight into this definition reveals that some projects do not have clear end dates and the uniqueness of the project is also relative. Despite the assumption that no two projects are exactly alike, it has been argued that some projects – the construction of building at different sites – do follow an explicit pattern.

In general, project management comprises three phases:

- Project Planning Phase
- Scheduling Phase
- Project Control Phase

In the project planning phase, the entire layout of the project is devised: first by sequencing the activities or tasks involved in the project and then developing a network diagram representing the same. This can be accomplished by adhering to the following steps:

- Identify various tasks to be performed in the project.
- Determine the requirement of resources such as manpower, materials, money, etc. for carrying out those particular tasks.
- Assign responsibility for each work package.
- Allocate resources to work packages.
- Estimate cost and time at various levels of project completion.
- Develop work performance criteria.
- Establish control channels for project personnel.

In the scheduling phase, the duration estimate of each task is determined and the probability of completion within the prescribed deadline is calculated. The different steps involved during this phase are:

i. Identify all the individuals who will be responsible for each task.
ii. Estimate the expected duration of each task, taking into account the resources needed for their execution in the most economic fashion.
iii. Specify the inter-dependencies among various tasks.
iv. On the basis of these time estimates, evaluate the total project duration, identify critical path; analyze floats; fulfill resource leveling exercise for critical resources, taking into consideration the resource constraints (if any).

In the project control phase, the actual progress of the project is measured against the set plan. If considerable differences are detected, then the scheduling and resource allocation decisions are altered in order to update and revise the unfinished part of the project.

3.2 Critical Path Method (CPM)

The Critical Path Method is a project scheduling technique developed in the late 1950s by Morgan R. Walker and James E. Kelley. It is the most widely used technique in project scheduling. Critical Path provides the order of project network activities which sum up to the longest overall duration. This, in turn, determines the shortest time to complete the project. In other words, if even one task belonging to the critical path is delayed, then the entire project will be delayed.

The CPM employs a Work Breakdown Structure (WBS) where the projects are divided into individual tasks. These tasks are inter-dependent, and the success and timeliness of the project depends upon how well these tasks are sequenced and how the resources are utilized.

Although CPM has become quite pervasive in the field of project management, the process has come under much opprobrium due to the many shortcomings associated with it. The slowly diminishing faith in Critical Path Analysis (CPA) may be imputed to the following disadvantages:

- As the project expands, i.e. as the number of activities increase, the critical path becomes increasingly convoluted. Thus there lies the ubiquitous risk of making a miscalculation due to over-reliance on the technique.
- People tend to add more safety to each task without considering incentives to finish early.
- The focus is more on task dependencies than on resource dependencies. Resource dependencies are either ignored or considered after the critical path is identified; thereby frequently causing non-critical tasks to become critical.
- The CPM runs on a definite concept, which assumes that the project managers as well as the working staff are well acquainted with the various tasks and inter-dependencies. Unfortunately, practical experience has shown that the principal assumption pertaining to CPM techniques, i.e., the project team's ability to reasonably predict the scope schedule and cost of each project is usually far beyond control.
- Critical paths are labile and may change during the project execution.
- Often one might discover multiple critical paths embedded in the same project, which, in turn, complicates situations even further. In many cases, the aforementioned critical paths might be parallel and might feed into a common node in the network diagram. In such cases, it becomes problematic to ascertain the best utilization of resources and technology for the critical paths.

Owing to the aforementioned problems, CPM has been subjected to a lot of deprecation, especially regarding its use in the construction companies. This is why, for many years, a plethora of exuberant and resolute project managers and analysts kept on searching for a more reliable method of project planning and scheduling. Their anguish was finally resolved in 1997, when Dr. Eliyahu Goldratt introduced the revolutionary new concept known as Critical Chain Project Management.

3.3 Theory of Constraints (TOC)

The Theory of Constraints is an overall management supposition from which the concept of Critical Chain Project Management has been derived. Introduced by Goldratt in his book titled The Goal, TOC aims at helping organizations to continually achieve their goals.

TOC concentrates on identifying and repairing bottlenecks in order to improve the throughput (the rate at which the system generates money through sales), inventory (the money that the system has invested in purchasing things which it intends to sell) and operational expense (the money the system spends in order to turn inventory into throughput) of the overall system.

Dr. Goldratt has proposed a five-step procedure to attain constant enhancement and to get the most out of a production system.

i. Identify the system constraints.
ii. Decide on how to exploit those particular constraints.
iii. Subordinate all other processes to the aforesaid decision.
iv. Elevate the constraints
v. If the constraint has moved, return to step (i). Do not allow inertia to become a constraint.

This process of ongoing improvement, as elucidated in the five points mentioned above, aspire to ensure that the ongoing improvement endeavors are centered on the organization's constraints.

3.4 Critical Chain Project Management (CCPM)

Critical chain deals with both the inter-relationship between tasks as well the resource conflicts associated with the tasks. This is unlike the Critical Path which only considers task dependencies. The Critical Chain-based project management technique aims at overcoming the problems inherent in traditional Critical Path Method.

According to PMBOK, "Critical chain method is a schedule network analysis technique that modifies the project schedule to account for limited resources." This signifies that the Critical Chain Project Management technique represents a project planning and scheduling technique that is capable of adjusting the project schedule, according to its own convenience, to facilitate limited resource allocation, without compromising the project deadline or the cost.

3.3.1. Protection from Uncertainties

There are various uncertainties linked to the traditional methods of project management. Critical Chain Project Scheduling manages these uncertainties by the following ways:

- Using average activity duration estimates
- Scheduling backwards from the project finish date
- Placing cumulative buffers in the project plan for safeguarding the entire projects as well as crucial tasks.
- Utilizing the concepts of buffer management to control the plan. The crucial tasks are the ones on which the ultimate duration of the project depends, otherwise known as the Critical Chain.

3.3.2. Identification of the Critical Chain

The following steps are used to aid in the identification of the critical chain of tasks:

i. Determine the 50% duration estimate of the tasks and identify the primary resource constraints.
ii. Identify the resource conflicts and initiate steps to resolve them. Start with the task closest to the project completion date or with the one that shows most conflict.
iii. After all the resource conflicts have been abolished, identify the critical chain as the longest chain of dependent events.
iv. Insert the Project Buffer at the end of the critical chain.
v. Add Feeding Buffers wherever non-critical chain tasks try to feed into the Critical Chain. Feeding Buffers protect the Critical Chain from accruement of negative variations.
vi. Time constraints, especially in the case of tasks having no predecessors, should be adjusted to "as late as possible" so that multi-tasking can be avoided.
vii. Make use of buffer management to control the plan. Buffers provide information to the project manager, for example, when to plan for recovery and when to take recovery action.

3.3.3 Buffer Management

3.3.3.1 Types of Buffers

Critical Chain uses three types of buffers – Project Buffer, Feeding Buffer and Resource Buffer – to act as safeguards, placing them at key points in the project. The function of these buffers is to protect the tasks against statistical discrepancies and act as a cushion against overrunning tasks, without affecting the project completion date. No resources are assigned to buffers. CCPM uses the following buffers:

- <u>Project Buffer</u>: This is inserted at the end of the critical chain, after the last task in the critical chain has been identified.
- <u>Feeding Buffer</u>: This buffer is inserted at places where the non-critical tasks feed into the Critical Chain. Feeding Buffers should be placed with sufficient care or an undesired increase in the baseline schedule may occur.
- <u>Resource Buffer</u>: These buffers are positioned in places wherever a particular resource has a job on the critical chain, and the previous critical chain activity is done by a different resource. Resource buffers ensure that resources are available whenever needed and critical chain tasks start on time or early, if needed.

3.3.3.2 Calculation of Buffer Size

One of the most essential steps in Buffer Management is determining which buffer sizing method to choose. Ideally, the project manager would prefer to select the buffer sizing method that would give him and his team the best chance of completing the project on time. The project manager's experience, eruditeness and buffer management skills play a critical role in making that particular decision. However, in order to have better control over the entire project, the project manager needs to consider generating buffers that take into consideration statistical variations as well as project dynamics.

In this section, we review the most common buffer sizing methods (C&PM and RSEM) and discuss the merits and demerits of implementing each.

3.3.3.2.1. Cut and Paste Method (C&PM)

The C&PM method was originated by Dr. Goldratt himself and is the simplest method of sizing the buffers. Considering that the safe estimate of each task is provided, the critical chain as well as the feeding chain is computed using 50% of the safe estimates as the activity duration. Then the project manager needs to add the 50% duration estimates of all the tasks pertaining to the feeding chain and divide the total by 2. The resultant numeral would be used as the feeding buffer.

The axiomatic advantage in the application of this method lies in the fact that it is simple and easy to implement. Conversely, there is one major drawback for implementing this particular technique which is that the size of the buffers increases linearly with the size of the feeding chain. Therefore, this method should be approached meticulously.

3.3.3.2.2 Root Square Error Method

Introduced by Larry Leach (1999), this method of buffer sizing is a little more complicated but provides much more efficient results.

In the first step, Leach used a simple formula to measure the "Uncertainty" of each task:

- Ui = Si – Ai

Where Ui is the Uncertainty of task 'i', Si is the safe estimate of task 'i', and Ai is the average duration estimate of task 'i'. In the next step, he calculated the buffer size as:

- Buffer size = sqrt[∑(Ui)2]

The major advantage of this method is that generates buffers that are neither very large nor very small in size, and unlike C&PM method, it is unaffected by the length of the feeding chain.

3.3.4 Project Monitoring in CCPM

Monitoring of the project's progress, in CCPM, is done by keeping a track on the consumption rate of buffers as opposed to the individual task performance schedule. This is known as the *green-yellow-red* buffer monitoring.

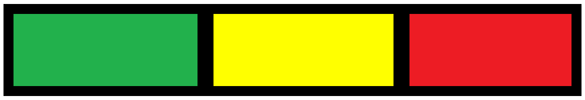


Fig. 1. Green-Yellow-Red Buffer Monitoring

These color-coded signals act as indicators which aid in making decisions regarding resource usage and task performance.

If the buffer penetration is in the green zone, no action is to be taken. If the penetration enters the yellow zone, then one needs to gauge the problem and consider possible courses of action. If the penetration enters the red zone, the project manager needs to focus on finishing the incomplete tasks in the critical chain and figure out ways to precipitate future works so as to ensure that buffers do not penetrate into the red zone.

3.5 Deviation from Traditional PM

CCPM deviates from traditional PM methodology, in the following ways:

i. Identifies the Critical Chain, which is the longest chain of activities that considers both task dependencies as well as resource dependencies. The irony in defining the Critical Chain is that, unlike the Critical Path, the Critical Chain does not change during the project execution.
ii. Utilizes 50% duration estimates and provides allowances so as to tackle uncertainties in the project environment.
iii. Buffers are used, which act as important measuring tools to control the project schedule.
iv. Aims to instill a more positive attitude among the project managers and workforce alike. Motivates workers to report early completion of tasks and eliminates multi-tasking by assigning 100% of a resource to individual tasks instead of assigning multiple tasks to the same resource at the same time.

4 BASELINE SCHEDULING USING CPM: A CASE STUDY

4.1 Need for Baseline

During the project planning phase, the duration of each task is estimated and then resources are assigned to them. While planning is crucial, it is equally important to track the actual progress of the project against the set plan. A Baseline is a fixed standard that allows the project manager to do just that – compare the estimates against the actual.

On or about the commencement of the construction related project, a baseline CPM schedule is developed, typically by the construction manager, to provide an understanding of how he intends to organize his resources and execute the project in a timely manner. Once this baseline schedule is published, the construction manager's progress can be periodically monitored and evaluated to determine what activities are critical to completing the project by updating the baseline schedule.

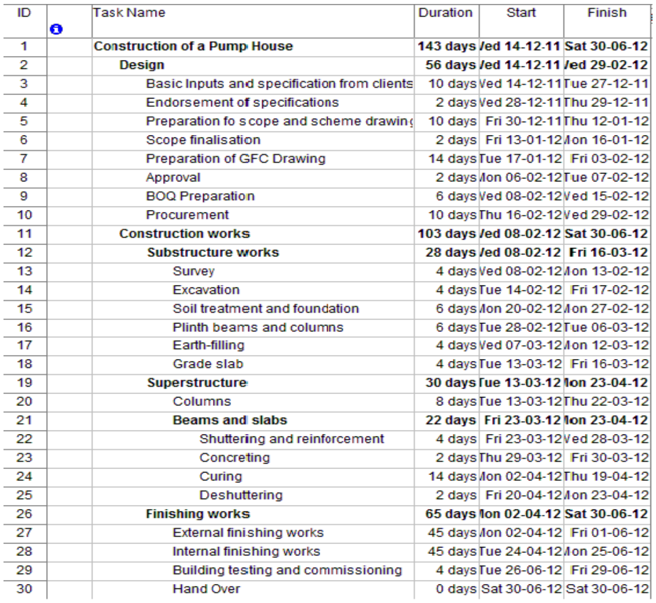
A baseline CPM schedule is essential to ensure that the schedule is reflective of the project's scope and is consistent with the project's prescribed scheduling specifications and the construction manager's intended plan for executing the project.

Moreover, it is important to realize the significance of properly updating the CPM schedule to include current scope of work remaining, actual start and finish dates for activities completed and work sequencing for the balance of the work remaining as of the observation date.

4.2 Case Study

The data for CP Analysis has been acquired from a construction site in Kolkata, and the project start and end dates have been slightly altered for our convenience. The data contains major structural activities performed during the "construction of a pump house". The duration estimates and task inter-dependencies are given as per the assumptions of the construction manager.

The simulation software used for the purpose of scheduling and identifying the Critical Path is MS Project. The original project schedule is shown in Fig. 2(a) & (b).



ID	ℹ	Task Name	Duration	Start	Finish
1		**Construction of a Pump House**	**143 days**	**/ed 14-12-11**	**Sat 30-06-12**
2		**Design**	**56 days**	**/ed 14-12-11**	**/ed 29-02-12**
3		Basic Inputs and specification from clients	10 days	Ved 14-12-11	Tue 27-12-11
4		Endorsement of specifications	2 days	Ved 28-12-11	Thu 29-12-11
5		Preparation fo s cope and scheme drawin	10 days	Fri 30-12-11	Thu 12-01-12
6		Scope finalisation	2 days	Fri 13-01-12	/on 16-01-12
7		Preparation of GFC Drawing	14 days	Tue 17-01-12	Fri 03-02-12
8		Approval	2 days	/on 06-02-12	Tue 07-02-12
9		BOQ Preparation	6 days	Ved 08-02-12	Ved 15-02-12
10		Procurement	10 days	Thu 16-02-12	Ved 29-02-12
11		**Construction works**	**103 days**	**/ed 08-02-12**	**Sat 30-06-12**
12		**Substructure works**	**28 days**	**/ed 08-02-12**	**Fri 16-03-12**
13		Survey	4 days	Ved 08-02-12	/on 13-02-12
14		Excavation	4 days	Tue 14-02-12	Fri 17-02-12
15		Soil treatment and foundation	6 days	/on 20-02-12	/on 27-02-12
16		Plinth beams and columns	6 days	Tue 28-02-12	Tue 06-03-12
17		Earth-filling	4 days	Ved 07-03-12	/on 12-03-12
18		Grade slab	4 days	Tue 13-03-12	Fri 16-03-12
19		**Superstructure**	**30 days**	**Tue 13-03-12**	**lon 23-04-12**
20		Columns	8 days	Tue 13-03-12	Thu 22-03-12
21		**Beams and slabs**	**22 days**	**Fri 23-03-12**	**lon 23-04-12**
22		Shuttering and reinforcement	4 days	Fri 23-03-12	Ved 28-03-12
23		Concreting	2 days	Thu 29-03-12	Fri 30-03-12
24		Curing	14 days	/on 02-04-12	Thu 19-04-12
25		Deshuttering	2 days	Fri 20-04-12	/on 23-04-12
26		**Finishing works**	**65 days**	**lon 02-04-12**	**Sat 30-06-12**
27		External finishing works	45 days	/on 02-04-12	Fri 01-06-12
28		Internal finishing works	45 days	Tue 24-04-12	/on 25-06-12
29		Building testing and commissioning	4 days	Tue 26-06-12	Fri 29-06-12
30		Hand Over	0 days	Sat 30-06-12	Sat 30-06-12

Fig. 2(a). Original Schedule

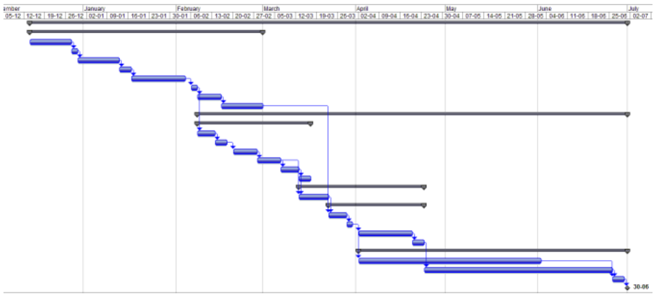


Fig. 2(b). Gantt Chart View

At this stage, before actual commencement of the project, it is crucial to understand the critical tasks that the project manager needs to work with. These tasks are critical in the sense that a delay in any of these tasks would ultimately delay the entire project completion. The Critical Path for the project is shown in Fig. 3(a) & (b).

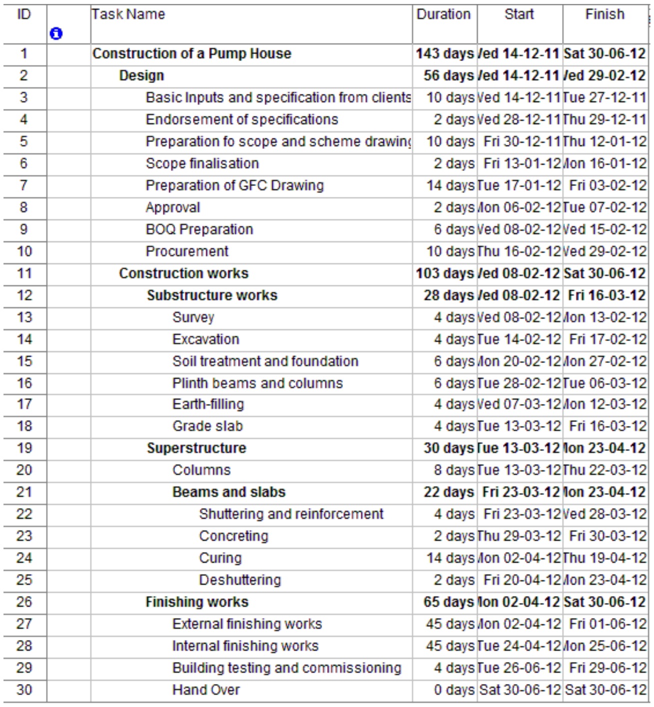


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Fig. 3(a). Representation of the tasks and their duration estimates.

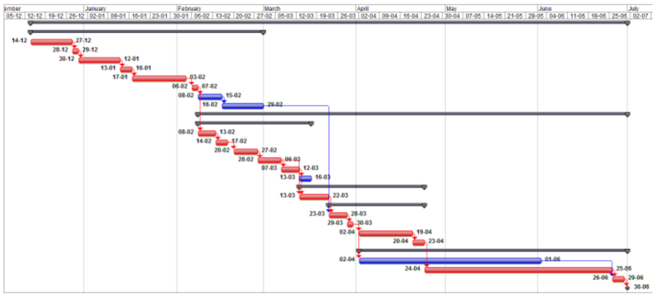
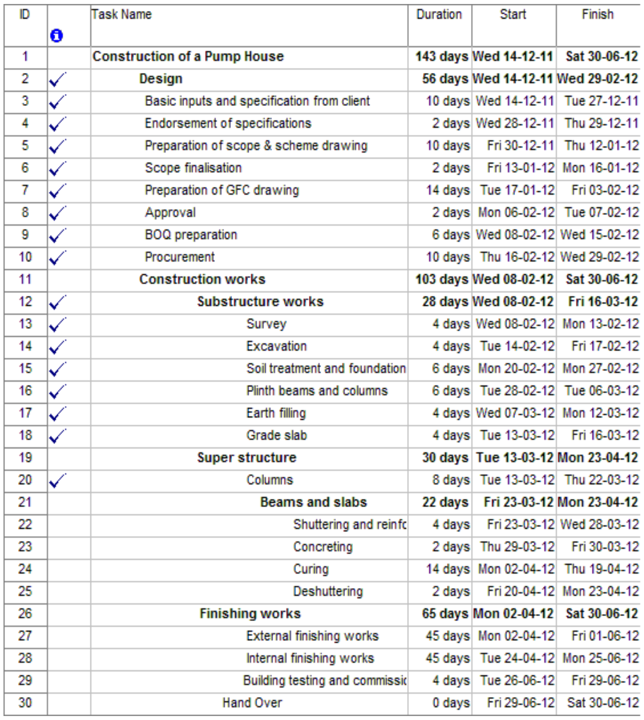


Fig. 3(b). Gantt Chart View of the Critical Path (in red)

The importance of setting a Baseline has already been discussed in detail. In Fig. 4(a) & (b), a baseline has been set for March 25th and the project was updated on the 27th of March.



ID		Task Name	Duration	Start	Finish
1		**Construction of a Pump House**	**143 days**	**Wed 14-12-11**	**Sat 30-06-12**
2	✓	**Design**	**56 days**	**Wed 14-12-11**	**Wed 29-02-12**
3	✓	Basic inputs and specification from client	10 days	Wed 14-12-11	Tue 27-12-11
4	✓	Endorsement of specifications	2 days	Wed 28-12-11	Thu 29-12-11
5	✓	Preparation of scope & scheme drawing	10 days	Fri 30-12-11	Thu 12-01-12
6	✓	Scope finalisation	2 days	Fri 13-01-12	Mon 16-01-12
7	✓	Preparation of GFC drawing	14 days	Tue 17-01-12	Fri 03-02-12
8	✓	Approval	2 days	Mon 06-02-12	Tue 07-02-12
9	✓	BOQ preparation	6 days	Wed 08-02-12	Wed 15-02-12
10	✓	Procurement	10 days	Thu 16-02-12	Wed 29-02-12
11		**Construction works**	**103 days**	**Wed 08-02-12**	**Sat 30-06-12**
12	✓	**Substructure works**	**28 days**	**Wed 08-02-12**	**Fri 16-03-12**
13	✓	Survey	4 days	Wed 08-02-12	Mon 13-02-12
14	✓	Excavation	4 days	Tue 14-02-12	Fri 17-02-12
15	✓	Soil treatment and foundation	6 days	Mon 20-02-12	Mon 27-02-12
16	✓	Plinth beams and columns	6 days	Tue 28-02-12	Tue 06-03-12
17	✓	Earth filling	4 days	Wed 07-03-12	Mon 12-03-12
18	✓	Grade slab	4 days	Tue 13-03-12	Fri 16-03-12
19		**Super structure**	**30 days**	**Tue 13-03-12**	**Mon 23-04-12**
20	✓	Columns	8 days	Tue 13-03-12	Thu 22-03-12
21		**Beams and slabs**	**22 days**	**Fri 23-03-12**	**Mon 23-04-12**
22		Shuttering and reinfc	4 days	Fri 23-03-12	Wed 28-03-12
23		Concreting	2 days	Thu 29-03-12	Fri 30-03-12
24		Curing	14 days	Mon 02-04-12	Thu 19-04-12
25		Deshuttering	2 days	Fri 20-04-12	Mon 23-04-12
26		**Finishing works**	**65 days**	**Mon 02-04-12**	**Sat 30-06-12**
27		External finishing works	45 days	Mon 02-04-12	Fri 01-06-12
28		Internal finishing works	45 days	Tue 24-04-12	Mon 25-06-12
29		Building testing and commissic	4 days	Tue 26-06-12	Fri 29-06-12
30		Hand Over	0 days	Fri 29-06-12	Sat 30-06-12

Fig. 4(a). Tasks Completed (✓)

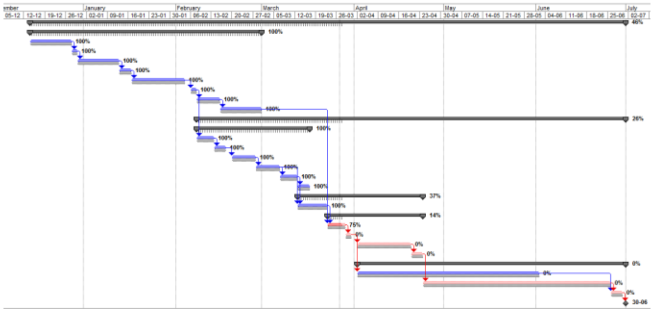


Fig. 4(b). Tracking Gantt view of the completed tasks as well as the tasks in progress

4.3 Results and Discussion

According to the studies conducted above, it can be said that the critical path established in Fig. 3(a) & (b), allows the project manager to focus on the critical tasks, so as not to cause any unwarranted delays in the project completion date. The duration of the project is 143 days.

The project has been completed and updated till the 27th of March, 2012, and that is exactly what has been shown in Fig. 4(a) & (b). The baseline was set for March 25th to compare the progress of the project against the scheduled plan. The summary of the project is given in Table.1 below.

TABLE.1 PROJECT SUMMARY

Duration (Scheduled)	143 days
Duration (Remaining)	77.69 days
Percent Complete	46%
Tasks not yet started	8
Tasks in Progress	5
Tasks Completed	17
Total Tasks	30

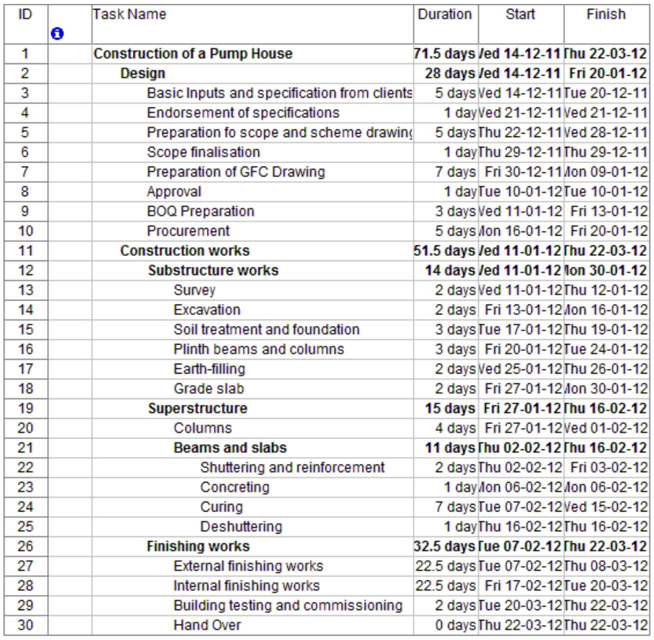
Despite the amenities that CPM-based project management entails, it doesn't provide any incentives for early finishing of tasks. That, coupled with an eclectic variety of problems, denigrates the technique's efficiency. These problems are, however, solved by applying the Critical Chain-based Project Management Technique.

5 CRITICAL CHAIN SCHEDULING: A CASE STUDY

5.1 Procedure

The same data that was used for Critical Path Analysis and Baseline Scheduling has been used for Critical Chain Scheduling as well. The data has been obtained from a construction site in Kolkata and the project start and end dates have been slightly altered for our convenience. The data contains major structural activities performed during the "construction of a pump house". The duration estimates and task inter-dependencies are given as per the assumptions of the construction manager, and have been displayed in Fig. 2(a) & (b).

The identification of the Critical Chain begins with determining the 50% duration estimate of the tasks, as shown in Fig. 5(a) & (b), given below.



ID	ℹ	Task Name	Duration	Start	Finish
1		**Construction of a Pump House**	**71.5 days**	**/ed 14-12-11**	**Thu 22-03-12**
2		**Design**	**28 days**	**/ed 14-12-11**	**Fri 20-01-12**
3		Basic Inputs and specification from clients	5 days	Ved 14-12-11	Tue 20-12-11
4		Endorsement of specifications	1 day	Ved 21-12-11	Ved 21-12-11
5		Preparation fo scope and scheme drawin(	5 days	Thu 22-12-11	Ved 28-12-11
6		Scope finalisation	1 day	Thu 29-12-11	Thu 29-12-11
7		Preparation of GFC Drawing	7 days	Fri 30-12-11	Ion 09-01-12
8		Approval	1 day	Tue 10-01-12	Tue 10-01-12
9		BOQ Preparation	3 days	Ved 11-01-12	Fri 13-01-12
10		Procurement	5 days	Ion 16-01-12	Fri 20-01-12
11		**Construction works**	**51.5 days**	**/ed 11-01-12**	**Thu 22-03-12**
12		**Substructure works**	**14 days**	**/ed 11-01-12**	**Ion 30-01-12**
13		Survey	2 days	Ved 11-01-12	Thu 12-01-12
14		Excavation	2 days	Fri 13-01-12	Ion 16-01-12
15		Soil treatment and foundation	3 days	Tue 17-01-12	Thu 19-01-12
16		Plinth beams and columns	3 days	Fri 20-01-12	Tue 24-01-12
17		Earth-filling	2 days	Ved 25-01-12	Thu 26-01-12
18		Grade slab	2 days	Fri 27-01-12	Ion 30-01-12
19		**Superstructure**	**15 days**	**Fri 27-01-12**	**Thu 16-02-12**
20		Columns	4 days	Fri 27-01-12	Ved 01-02-12
21		**Beams and slabs**	**11 days**	**Thu 02-02-12**	**Thu 16-02-12**
22		Shuttering and reinforcement	2 days	Thu 02-02-12	Fri 03-02-12
23		Concreting	1 day	Ion 06-02-12	Ion 06-02-12
24		Curing	7 days	Tue 07-02-12	Ved 15-02-12
25		Deshuttering	1 day	Thu 16-02-12	Thu 16-02-12
26		**Finishing works**	**32.5 days**	**Tue 07-02-12**	**Thu 22-03-12**
27		External finishing works	22.5 days	Tue 07-02-12	Thu 08-03-12
28		Internal finishing works	22.5 days	Fri 17-02-12	Tue 20-03-12
29		Building testing and commissioning	2 days	Tue 20-03-12	Thu 22-03-12
30		Hand Over	0 days	Thu 22-03-12	Thu 22-03-12

Fig. 5(a). Critical Chain Schedule with 50% activity duration.

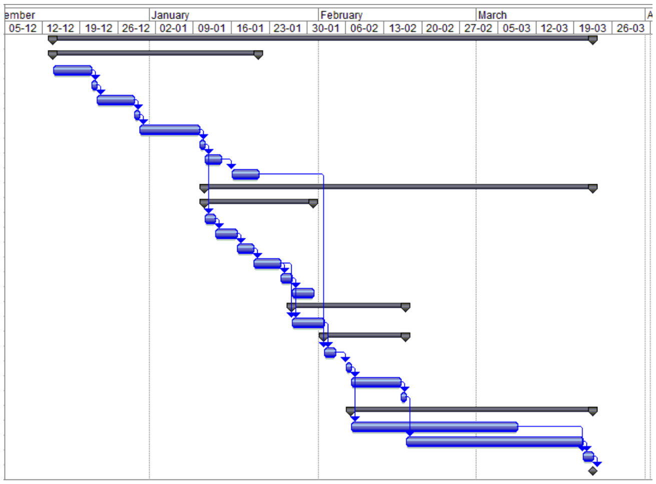
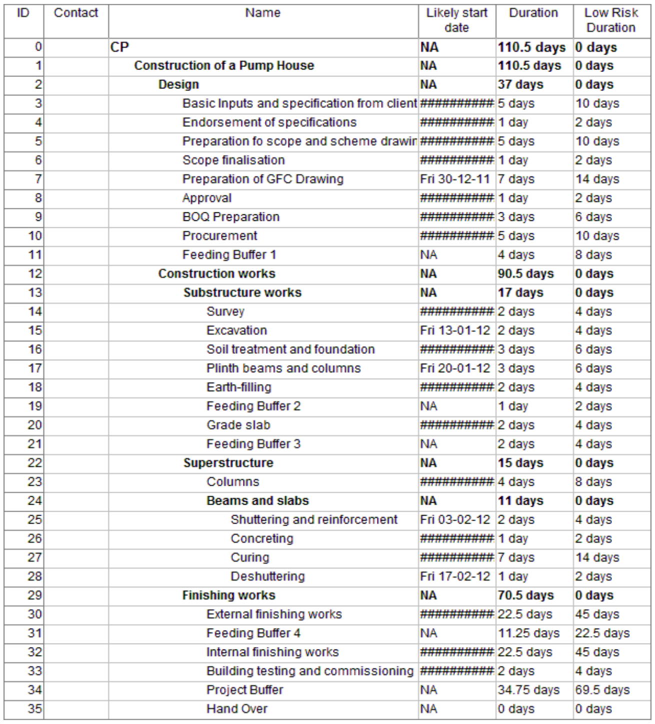


Fig. 5(b). Gantt Chart View

Next, any and all resource contentions are solved prior to identifying the Critical Chain. The Critical Chain is then identified, which is the longest chain of tasks considering both task dependencies as well as resource dependencies. The Critical Chain should be reviewed to ascertain whether or not re-sequencing the tasks would further shorten the overall duration of the project. If so, then it is to be done.

In the next step, buffers are inserted wherever need. At first, the Project Buffer is added at the end of the critical chain. Next, Feeding Buffers are inserted wherever the non-critical tasks feed into the Critical Chain. The process of buffer sizing has already been discussed in detail. The entire Critical Chain along with the necessary buffers is shown in Fig. 6(a) & (b).



ID	Contact	Name	Likely start date	Duration	Low Risk Duration
0		**CP**	**NA**	**110.5 days**	**0 days**
1		**Construction of a Pump House**	**NA**	**110.5 days**	**0 days**
2		**Design**	**NA**	**37 days**	**0 days**
3		Basic Inputs and specification from client	###########	5 days	10 days
4		Endorsement of specifications	###########	1 day	2 days
5		Preparation fo scope and scheme drawir	###########	5 days	10 days
6		Scope finalisation	###########	1 day	2 days
7		Preparation of GFC Drawing	Fri 30-12-11	7 days	14 days
8		Approval	###########	1 day	2 days
9		BOQ Preparation	###########	3 days	6 days
10		Procurement	###########	5 days	10 days
11		Feeding Buffer 1	NA	4 days	8 days
12		**Construction works**	**NA**	**90.5 days**	**0 days**
13		**Substructure works**	**NA**	**17 days**	**0 days**
14		Survey	###########	2 days	4 days
15		Excavation	Fri 13-01-12	2 days	4 days
16		Soil treatment and foundation	###########	3 days	6 days
17		Plinth beams and columns	Fri 20-01-12	3 days	6 days
18		Earth-filling	###########	2 days	4 days
19		Feeding Buffer 2	NA	1 day	2 days
20		Grade slab	###########	2 days	4 days
21		Feeding Buffer 3	NA	2 days	4 days
22		**Superstructure**	**NA**	**15 days**	**0 days**
23		Columns	###########	4 days	8 days
24		**Beams and slabs**	**NA**	**11 days**	**0 days**
25		Shuttering and reinforcement	Fri 03-02-12	2 days	4 days
26		Concreting	###########	1 day	2 days
27		Curing	###########	7 days	14 days
28		Deshuttering	Fri 17-02-12	1 day	2 days
29		**Finishing works**	**NA**	**70.5 days**	**0 days**
30		External finishing works	###########	22.5 days	45 days
31		Feeding Buffer 4	NA	11.25 days	22.5 days
32		Internal finishing works	###########	22.5 days	45 days
33		Building testing and commissioning	###########	2 days	4 days
34		Project Buffer	NA	34.75 days	69.5 days
35		Hand Over	NA	0 days	0 days

Fig. 6(a). Details of Tasks showing buffers

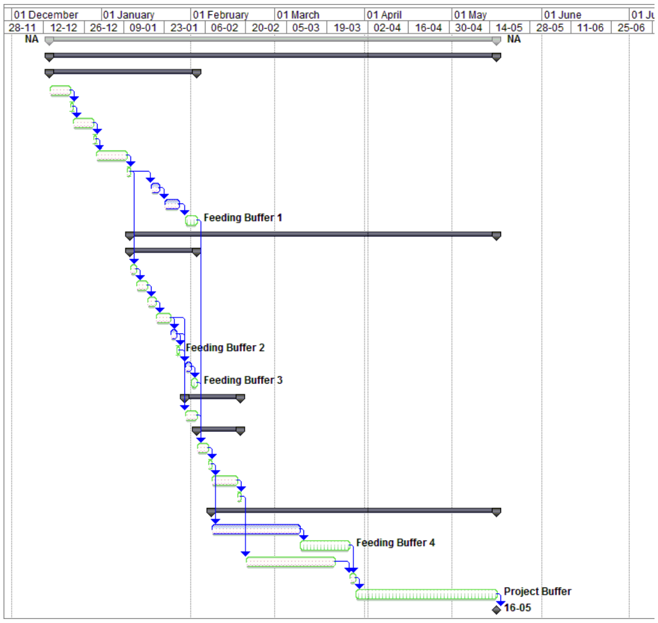


Fig. 6(b). Gantt Chart View displaying the Critical Chain and the Buffers inserted.

5.2. Results and Discussion

From the studies conducted above, we can emphatically conclude that the application of CCPM does indeed reduce the project duration without putting too much strain on the resources involved.
From, Fig. 2(a) & (b),
Original Duration = 143 days

From Fig. 5(a) & (b),
50% Activity Duration for "Construction of a Pump House" = 71.5 days

From Fig. 6(a) & (b),

Project Buffer Duration = 35.75 days

Feeding Buffer 1 = 4 days

Feeding Buffer 2 = 1 day

Feeding Buffer 3 = 2 days

Feeding Buffer 4 = 11.25 days

Total Project Duration = 110.25 days

Some of the important things to remember while conducting a study like this are:

- Before inserting the buffers, the Critical Chain should be thoroughly reviewed to ensure that no further re-sequencing is required.
- The buffers should be periodically monitored to ensure that they remain in the "green" zone of penetration.
- Multiple tasks should never be assigned to a particular resource, especially on the same date.

6. CONCLUSION

This paper addresses the numerous problems associated with the most commonly utilized project management technique, i.e. the Critical Path Method (CPM), while also shedding light on the evolving Critical Chain Project Management (CCPM) technique.

Nowadays, major industrial organizations strive to attain a high level of profit on their projects, which can be accomplished by reducing the average duration of the tasks involved. Although, CPM provides knowledge of the tasks that may cause a delay in the project completion, the process is marred by several problems. For one thing, it is a time-constrained endeavour. This, in turn, insinuates that CPM is less focused on the resources involved in executing the project, and is more concerned with completing the project on time. Multitasking, often leading to over-allocation of resources has also become a cause for concern in this particular method. Moreover, issues such as student syndrome, Parkinson's Law, Murphy's Law etc., further inhibit the project manager's ability to execute the project in a timely and systematic fashion.

Critical Chain Project Management provides innovative adjustments to conventional project management techniques. It offers organizations the unique opportunity to keep a track on their resources and allows them to reduce the average duration of their projects.

From the case research analysis presented in this paper, it can be inferred that CCPM entails the following advantages over CPM:

- Project duration can be reduced by 20-30%
- Resources can be utilized effectively
- Project is focused on both critical as well as non-critical tasks.

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