Application of Theory of Constraint to Construction Project-A Case Study

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Abstract : For the completion of Building Construction project, time and cost overruns, availability of resources on time, unavailability of material etc can be a constraint and causes delay in project. On the other hand Project Manager should meet the client expectation of completing project within given time limit to maintain the good records and reputation in this competitive world. For this scheduling of Project should be proper to complete the construction activities within time and to avoid delay of project. As Critical Path Method (CPM) is traditional method which being used by so many years but it become inefficient. To overcome this Eli Goldratt's invented a new scheduling method by applying Theory of Constraint to Project Management which is called as Critical Chain Project Management (CCPM). In this analysis ongoing construction project is taken and two different tools 1. CPM and 2. CCPM were applied to it to find optimum scheduling method for construction project.

IndexTerms - Project Management, Theory of Constraints, Critical Chain Project Management, Optimum Scheduling.

I. INTRODUCTION

Theory of constraint is a systematic approach of project scheduling to complete the project objective successfully. As for the completion of any project, time is the constraint which needs to be handled carefully. TOC is a continuous improvement method which focuses on the bottleneck of the system to improve the performance.

1.1 History of TOC:

In the early 1980 Eli Goldratt published his first Novel "Goal" which is based on how the production should be planned and the methodology for optimized production technology (OPT) was given. This novel was read by so many planner, executive and workers. After that he broadened his idea about production and execution in his second novel "It's Not Luck" and this concept was developed into theory of constraints. Theory of constraints is divided into five eras.

Sr. No	Era	Details
1	The Optimized Production Technology Era	The secret algorithm
2	The Goal Era	Making drum-buffer-rope scheduling
3	The Haystack Syndrome Era	The TOC measures
4	The "It is Not Luck Era"	Thinking processes applied to various topics
5	The Critical Chain Era	TOC project management

Table No. 1 History of TOC

1.2 Types of Constraints:

According to researchers constraints are classified into five types they are follows-

1. **Legal constraint**- As legal constraint is there because there are many rules and regulations in construction industry. Legal constraint is mainly related to safety regulations, work law and supervision planning. Legal constraints deals with the issues related to legal regulations which causes delay of project.
2. **Economic constraint-** This constraint is mostly related to budget of project and allocated money for given activity. Delay in project can causes budget overrun which created difficulty for project manager to execute the work and that is why for the efficient working, performance and quality of work, economic constraint should be managed properly.
3. **Environmental constraint-** Before starting any project the permission from Environmental Department must be obtained in order to protect the tree prevention act, water act, air pollution act, noise control and traffic limit. This procedure may take time and project progress will be affected, and if the approval is not obtained project will stopped.
4. **Technical constraint-** Technical constraints are needed to overcome at early stage but it is not possible as some of them can arise while executing the work. Fire services, plumbing, ventilation and ducts, electrical wiring, all these works are considered in technical constraints. Defects in this work can lead to rework and delayed the project.
5. **Social constraint-** Social constraint is related with the people. Construction work is not supposed to be possible if there is no support from people. Constraint related to people classified into three types 1) Emotional Constraint 2) Human Resistance 3) Ownership problem. In emotional constraint people tend to be defensive rather than toleration. People have emotional mind set concerned about their job security and may lead to devastated effect. In human resistance constraint should be avoided at the implementation of project as human resistance can delay the project. Sometimes one refused to take accusation for Act of God and say they do not create a problem so not responsible for it.

1.3 Negative effect causing factors identified by Methodology of Theory of constraint of Project Management and Critical Chain:

1. **Bad multitasking**- work is stopped to finish another work which is more important than another work leads to bad multitasking. Each time the execution of work is stopped to complete the another one which causes loss of the efficiency of work also affect the mental tendency of worker to complete the previous task, which causes delay of whole project.
2. **Student syndrome**- working at the last moment is considered in student's syndrome as students started studying at the last night before the exam. Same thing is always happening in the construction project as workers wasted all the secure time of the activity and started the activity after consuming a lot of time this delays all the activities of the project and extends the target date of completion of project. To avoid this effective use of activity time should be done.
3. **Parkinson's Law**- workers always assumed that there is safety time in each activity so why start early but that extra time is given to improve or polish the work but no one actually taking it seriously and working as they have a lot of time, but if activity finishes on time then next activity can start early and whole activities of project will start and finish early before. This will help to complete projects on time.

1.4 Methodology:

In this work theory of constraint is applied to real life project. With CCPM approach to find out the best scheduling method over traditional CPM method is the main objective of this study. For this MS project software is used.
Following figure No 1 shows Methodology is adopted for this study

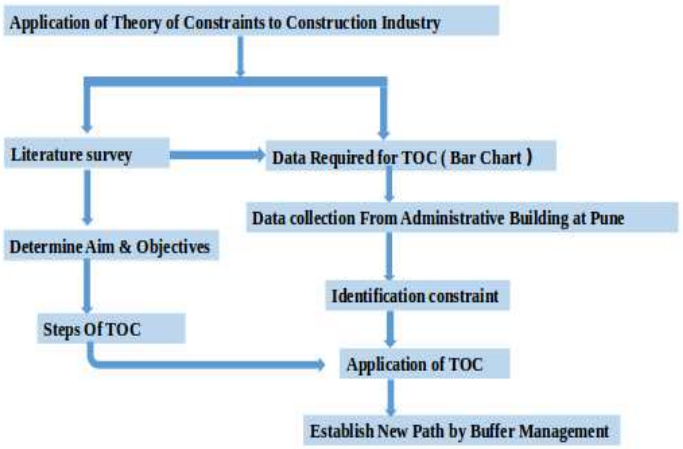


Fig. No. 1 Methodology adopted for the work

2. Review of Literature

From the previous literature traditional project management method CPM and CCPM method was studied and applied it to real life project.

The TOC can be applied to project management which leads to CCPM approach. There are two applications of TOC the first one is effective scheduling of project to avoid to delay and second one is to manage resources shared by project [7]
According to this paper critical chain project management (CCPM) is tool of planning and project management. We can use this method for single-project and multi-project where resources are available simultaneously. Why project delay? Why project overrun? What are the reasons for incompletion of documentary and many more questions answer is Parkinson's law, Student syndrome and bad multitasking. Also it is given that by using this approach the project duration is reduced by 25-50%. [4The steps to apply theory of constraints are given by Goldratt in 19984 is his novel 'Goal'. They are as follows- 1) Identify the constraint, 2) Exploit the constraint, 3) Subordinate the constraint, 4) Elevate the constraint, 5) To check go back to step 1.

2.1 Project Management

In Project management allocated project have definite duration of project which includes 1. Scope 2. Plan & 3.Resources. It is the application of tools, planning and skill to fulfill the project requirement. [6]

2.3 Types of Buffer

In CCPM safety time is termed as buffers. There are different types of buffers

1) Project Buffer (PB) -Add project buffer at the last of the activity of the critical chain, which prevents delay of project.

2) Feeding Buffer (FB) - Add Feeding buffer at the last task of non-critical chain to prevent merging of non-critical activities into critical activities.

3) Resource Buffer (RB) - Resource buffer is warning signal to that all the resources are providing on time. To ensure the provision of resources to critical chain to avoid delay of project. [6]
Important findings from literature review are summarized in the fig No 2 bellow,

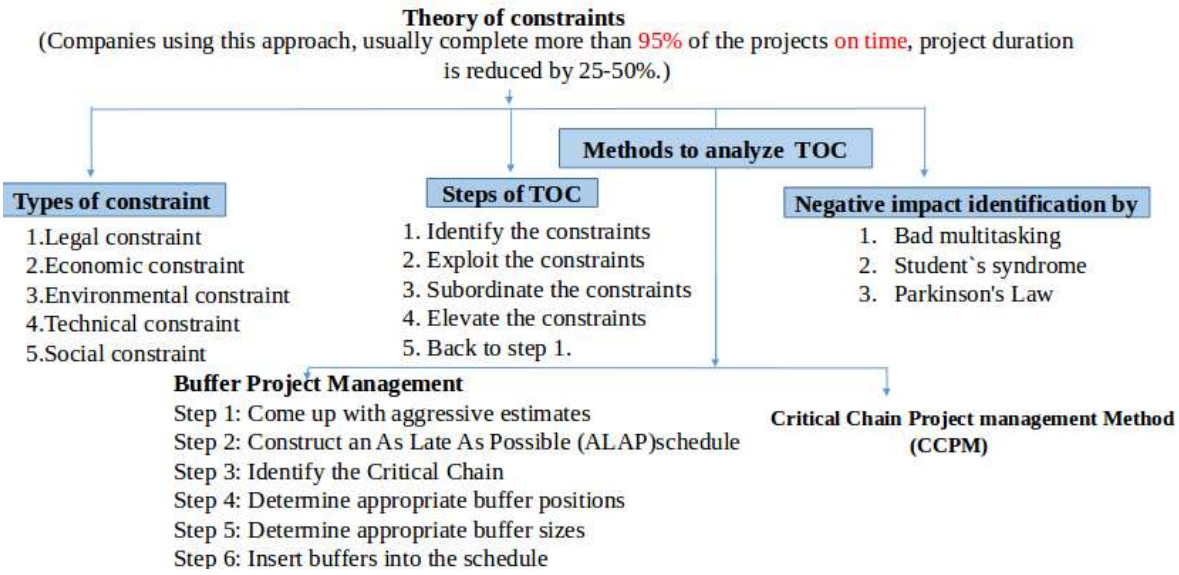
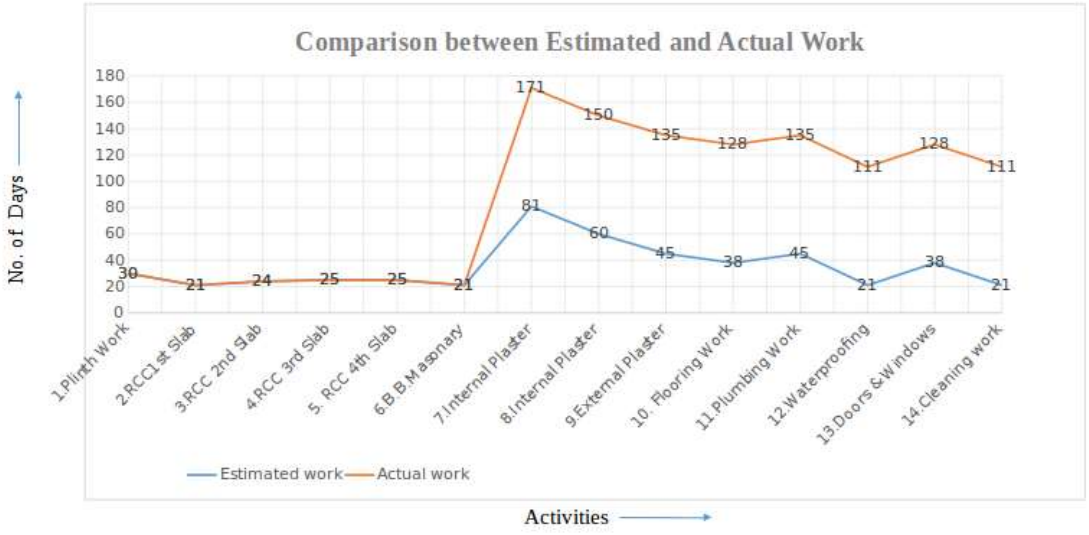


Fig. No.2 Shows findings from literature review.

3. Case Study:

In this case study, construction of administrative building is monitored throughout the construction period in Pune. Planning of proper time duration before starting of any activity should be done to avoid the extension of project duration. By this study we applied TOC to the case study of Administrative building of Pune to find out the better scheduling approach. The data required for this like estimated schedule of admin building was taken from contractor and actual progress was checked. Comparison of estimated duration and actual work duration is shown in Graph No 1 as follows,



Graph 1. Deviation between estimated and actual work.

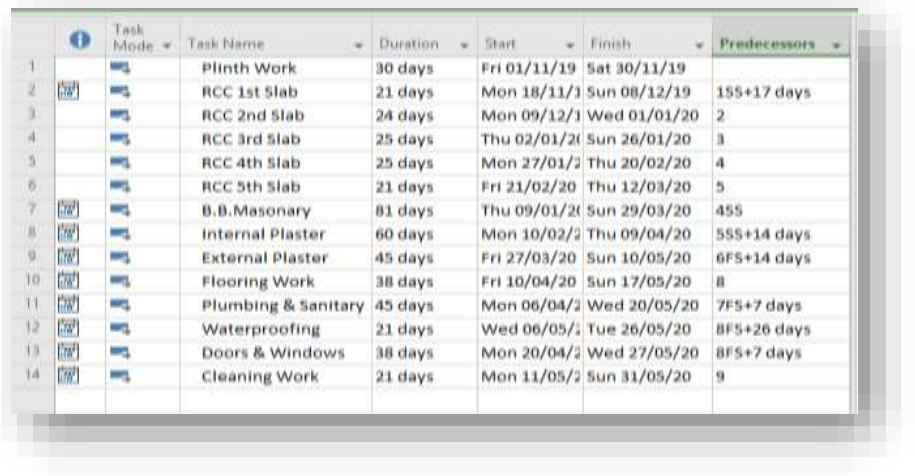
Form graph we can see the difference between estimated and actual work flow. Discussion with contractor is done to find causes of delay which affect the project delay.

Following are the causes of delay given by contractor-

1. **COVID-19-** Pandemic situation is the main reason that the project duration extended extremely. As due to pandemic situation whole country was under the lockdown for almost 3months which due to which whole construction was shut down.
2. **Resource Lacking**- This is the reason due to which many project fails to complete on time. So before starting any activity, availability of resources should be checked or providing resources timely avoid delay of project.

3.1 Working of Critical Path Method (CPM)

Scheduling using CPM for construction of Building is given in Fig.3 For this Microsoft Project Office (MSP) is used.



	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Plinth Work	30 days	Fri 01/11/19	Sat 30/11/19	
2		RCC 1st Slab	21 days	Mon 18/11/1	Sun 08/12/19	15S+17 days
3		RCC 2nd Slab	24 days	Mon 09/12/1	Wed 01/01/20	2
4		RCC 3rd Slab	25 days	Thu 02/01/2(	Sun 26/01/20	3
5		RCC 4th Slab	25 days	Mon 27/01/2	Thu 20/02/20	4
6		RCC 5th Slab	21 days	Fri 21/02/20	Thu 12/03/20	5
7		B.B.Masonary	81 days	Thu 09/01/2(	Sun 29/03/20	4SS
8		Internal Plaster	60 days	Mon 10/02/2	Thu 09/04/20	5SS+14 days
9		External Plaster	45 days	Fri 27/03/20	Sun 10/05/20	6FS+14 days
10		Flooring Work	38 days	Fri 10/04/20	Sun 17/05/20	8
11		Plumbing & Sanitary	45 days	Mon 06/04/2	Wed 20/05/20	7FS+7 days
12		Waterproofing	21 days	Wed 06/05/2	Tue 26/05/20	8FS+26 days
13		Doors & Windows	38 days	Mon 20/04/2	Wed 27/05/20	8FS+7 days
14		Cleaning Work	21 days	Mon 11/05/2	Sun 31/05/20	9

fig. No.3 Schedule prepared using CPM method

In CPM whole work is divided into number of sub activities using work breakdown structure (WBS).CPM works successfully if each task sequences and their interdependencies are connected properly with effective resource uses. As CPM is a traditional method used in project management but people loses their trust over this approach.
Due to following reasons CPM approach is being unpopular now-a-days-

1. In CPM approach individual safety time is added into each activity which further causes delay in project as people doesn't utilize the safety time properly.
2. In CPM method people only take task dependencies seriously and not resources dependencies.
3. In CPM, there can be multiple critical path at any stage which further leads into confusion.
4. While executing tasks there are chances that non-critical path can become critical path.

3.2 Working of CCPM

Following Fig. No 4 shows typical output using CCPM Method.

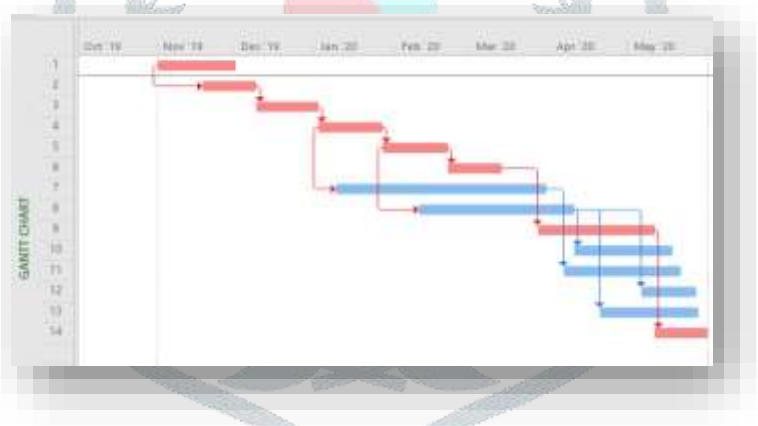


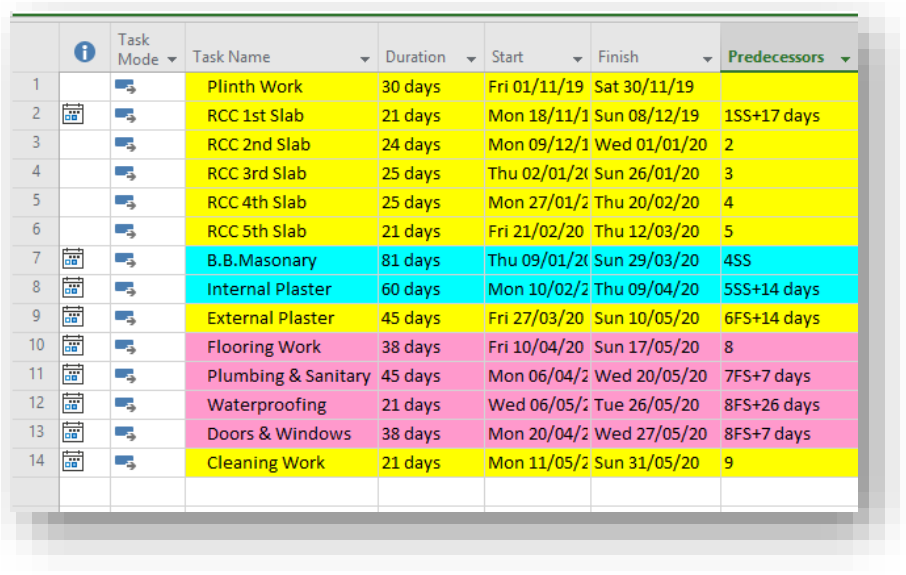
Fig. No. 4. Gantt chart prepared using CPM method

Following are the steps for CCPM

1. For each activity 50% aggressive time estimate is calculated.
2. Resource allocation and resource levelling for each activity should be done.
3. Relationship between tasks is established after resource levelling.
4. Longest path of the activity and resource is identified.
5. Rescheduling of the project is done without disturbing critical chain of project.
6. By calculating buffer sizes project buffer is inserted at the end of critical chain while feeding buffer is inserted where non-critical activities merging into critical chain, to prevent critical activities.
7. Proper buffer sizing and buffer management helps to complete project on time.

3.3 Critical and buffer chain in CCPM

In Figure No 5 Highlighted rows shows critical and buffer chain in CCPM for the Building Construction project.



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1		Plinth Work	30 days	Fri 01/11/19	Sat 30/11/19	
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14		Cleaning Work	21 days	Mon 11/05/2	Sun 31/05/20	9

Fig. No 5 Highlighted rows shows critical and buffer chain in CCPM

Where,

	Critical chain		Feeding buffer 1		Feeding buffer 2

Table No. 2 highlighted colors identification

From the above figure, 1-2-3-4-5-6-9-14 is a critical chain as resources are allocated ,is inserted with project buffer after task 14,feeding buffer 1 is inserted after task 8 and feeding buffer 2 is inserted after task 13. Let us show how the buffer sizes are calculated. Refer Table No 1

Sr. no.	Activity	Original time (Weeks)	Aggressive time (Weeks)
1	A	4	2
2	B	3	1.5
3	C	3	1.5
4	D	3	1.5
5	E	3	1.5
6	F	4	2
7	G	7	3.5
8	H	7	3.5
9	I	6	3
10	J	4	2
11	K	6	3
12	L	4	2
13	M	5	2.5
14	N	3	1.5

Table No. 3. Original & Aggressive Time in Weeks for the activities

3.4 Duration required in CCPM buffer calculations

Necessary data for calculations of Buffer as given in following table Table 3.1 Duration required in CCPM buffer calculations Where (A- Plinth work, B- RCC 1st slab, C- RCC 2nd slab, D- RCC 3rd slab, E- RCC 4th slab, F- RCC 5th slab, G- B.B. Masonry, H- Internal plaster, I- External Plaster, J- Flooring work, K- Plumbing & Sanitary L- Waterproofing M- Doors & windows N- Cleaning work)

3.5 Buffer sizing methods

For calculation of size of buffer following two methods are used:

1. Cut and Paste method,
2. Root squared error method

1. Cut and Paste method

In Cut and Paste method, 50% of the chain method is invented by Goldratt in 1997. He has suggested that,

1. Buffer size = (½) of the duration of the critical chain
2. Size of feeding buffer = (½) of the duration of feeding chain.

Project buffer = 14.5/2 = 7.25, Feeding buffer 1 = 7/2 = 3.5, Feeding buffer 2 = 9.5/2 = 4.75

2. Root Squared error method

This is the buffer sizing method, in which simple thumb rule like cut and paste method is not used. In this method the project buffer is square root of sum of the square of difference between original time and aggressive time estimate of each activity duration.

Project buffer = sum of the square of difference between original time and aggressive time estimate of each activity duration
Project buffer = 5.3, Feeding buffer 1 = 4.5, Feeding buffer 2 = 4.8

3.6 Monitoring and Management of Buffers

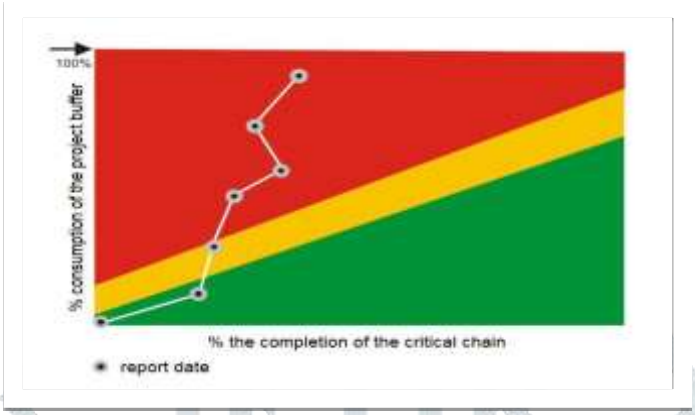

Fig. No. 6 Fever chart

1. Green Zone indicates Comfort Zone where NO actions needed.
2. Yellow Zone act as warning zone where main cause of delay shall be identified and planning shall be done accordingly.
2. Red Zone indicates Risky zone where corrective actions shall be taken and activities shall be started as early as possible.

In CCPM method project is not monitored on the basis of project duration, it is monitored on the basis that how much buffer is consumed by activity.

Following steps are to be considered by buffer management for monitoring.

- Appropriate buffer sizing should be done by proper buffer sizing method.
- Buffer consumption rate should be predicted for timely completion and smooth progress of work.

4. RESULTS AND DISCUSSION

4.1. Results for buffer size

Buffers	**CCPM**	
	Cut and Paste method	Root squared error method
Project buffer	7.25	5.3
Feeding buffer 1	3.5	4.5
Feeding buffer 2	4.75	4.8

Table 4.1. Results for buffer size

4.2. Results for project duration

	CPM Method (in weeks)	**CCPM**	
		Cut and Paste method (in weeks)	**Root squared error method** (in weeks)
Project duration	**28**	**22**	**20**

Table 4.2. Results for project duration

1. As per the calculations and observations it is concluded that CCPM method gives better results than CPM.
2. As total duration of CPM method is 28weeks and if we select cut and paste method for buffer sizing then the project duration is 22weeks
3. If we consider root squared error method for buffer sizing then the project duration is 20 weeks.
4. As root squared error method gives less time duration for this project, so we considered it a suitable method for buffer sizing.

CONCLUSION

1. It is experimentally proved application of TOC to project management i.e. CCPM method is better than traditional CPM method to prevent delay of project from it's completion time by avoiding uncertainties in the project.
2. For the construction sector, CCPM method uses software which makes work easier and fast.
3. Allocating safety buffer at the end of project instead of providing into each activity protect the critical chain against uncertainty.
4. CCPM focuses on critical chain which is the constraint of the project.
5. Avoidance of bad multitasking, student syndrome and Parkinson's law.
6. Using CCPM approach in this project, the duration of project is reduced by 28%.

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