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Alleviating Time Overrun with the Implementation of Critical Chain Project Management in Construction Industry

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Abstract:- **Today in this technological era, Construction project needs to be completed with a great amount of speed and within budget. Industry needs to accept new treads in equipment, material and new techniques of planning the project. The objective of this research is show the difference between the completion time of project using traditional method and Critical Chain Project Management (CCPM). Basic concept behind this method is not to consider the safety margin as we do in traditional method. Instead buffers will be provided and will act as an early warning to the execution team. To calculate the buffer size Root Square Error Method (RSEM) is adopted. Keeping this in mind, a construction site was selected to implement this method. Construction of Hostel Building with 870 student occupancy was commenced. Furthermore, the data related to research like availability of resource and duration estimates were gathered. Not only the data were just collected but also compiled with the help of MS Project to form a schedule. After that, to avoid the multitasking resource contention will be removed and duration of project will be derived as well as compared with the traditional method.**

Keywords:- *Buffers, Critical Chain, Multitasking, Root Square Error Method.*

I. INTRODUCTION

In India, agriculture and construction sector contributes much to GDP. Indian construction industry expects to growth rate of 7-8% per annum over the coming year. As construction industry requires huge capital to build an infrastructure, technological advancement also needs to update. Spending some time to learn new planning techniques and implementing on site will also help in one or the other way.

Building an Infrastructure needs a proper planning. To plan a construction project, Project Manager must be well versed with the latest scheduling techniques, new construction methods and quality tools. . In India, majority of the construction project are being scheduled using Critical Path Method (CPM) and Program Evaluation and Review Techniques (PERT). Focusing on the latest scheduling techniques Critical Chain Project Management in gaining fame from the last two decades.

In 1997, Dr. Eliyahu Goldratt came up with an idea of using Theory of Constraint (TOC) into the project management in his bestselling book “Critical Chain”. This approach gained so much popularity in the field on management. Many researcher have tried to implement this method to their respective fields. Motive of introducing this techniques was to overcome the drawbacks of traditional scheduling techniques. According to the PMBOK, “Critical Chain method is a schedule network analysis techniques that modifies the project schedule to account the limited resources”. Therefore, CCPM not only focus on the time estimates but also on the resources of the project which was overlooked in traditional method.

Basic concept behind this method is not to consider the safety margin as we do in traditional method. In book, Goldratt mentioned that time estimates must be taken at 50% confidence and proceed with the last start schedule. Buffer Management will also play key role in the method. There are usually three types of buffer available. Buffers are named as project buffer, feeding buffers and resource buffer. Project buffer will be added at the end of critical chain to protect the project from getting delayed. Feeding buffer will be added to the non-critical activities which are further joining the critical chain to prevent noncritical activities from delaying critical one. Lastly the resource buffer gives an alert about the resources planned on the critical chain and which different resources have been used in the previous critical chain activities [3].

II. LITERATURE REVIEW

As mentioned in [1] the merit and pitfall of critical chain project management. They contradicts the statement of Goldratt which he made in his book Critical Chain that, “time for each task must be cut down to 50 %”. To validate their statement they conducted computational experiment using visual C ++. They conclude that Critical Chain (CC) acts an eye-opener to many practitioners and allow them to interact between activity duration, precedence relations, resource availability and resource requirement. Furthermore, they said updating the baseline schedule will give the strong outputs.

In the article**,** [2] author introduces two buffer sizing methods namely as adaptive procedure with delay (APD) and Adaptive procedure with resource tightness (APRT). This

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methods were compared with different sets of activities ranging from 7 to 51 with 8 projects. They have evaluated the new methods based on the performance indicator and obtained only the scientific results. Now to improve the accuracy between the activities and project determination a comprehensive resource tightness is proposed [3]. To analyze the data between activities and calculating the rework time from the information resource tightness, Design structure matrix (DSM) was adopted. Using DSM overcomes the pitfall of traditional method for not considering information resource tightness. Moreover, the experimental result reveals that DSM helps considering the comprehensive resource tightness on a project buffer.

After the buffer related studies, it was the time to see how CCPM works on the field. There are several uncertainty in the project which needs to be dealt with. Data from the studies manifests that only 44% of the project gets completed on time using traditional method [4]. They say that project is involved with uncertainty like Murphy's Law, Parkinson Law and Student Syndrome. To eliminate the above Parkinson's Law, the schedule will be prepared with no safety margins as well as give the actual completion time of the project. Resource buffers and Project buffers will prevent the Murphy's Law consequences.

Uncertainty will raise the several consequences such as project takes longer than the planned duration, budget overrun, and unavailability of resources. In order to save the project from the consequence, a large part should be freeze in the project pipeline. Freezing at least 25% of the project is enough to boost up the progress of work as well as project completion time [5]. They came to the conclusion that, pipeline, project planning method, critical chain buffers and management decision based on buffers completes more than 95% of the projects on time also reduces the project duration by 20 – 25 %. Results were obtained without adding additional resources or investment in their system.

III. PROPOSED METHODOLOGY

Research is based on the scheduling of a construction project with CCPM technique. To validate the study, an appropriate construction site was selected i.e. Hostel Building. Site is located in the vicinity of Diu, India. Purpose behind this construction is to accommodate the student who come from the surrounding.

Initially, general inspection of the site was done and data related the CCPM technique was gathered. Data such as pile layout, resource availability and duration estimation was collected. Secondly, list of activities and duration of each task will be calculated. Furthermore, MS Project will be used to schedule the project. Schedule will be done with traditional and CCPM techniques. Lastly, the duration of both method will be compared to derive a conclusion. Below Figure 1 depicts the methodology of the study.

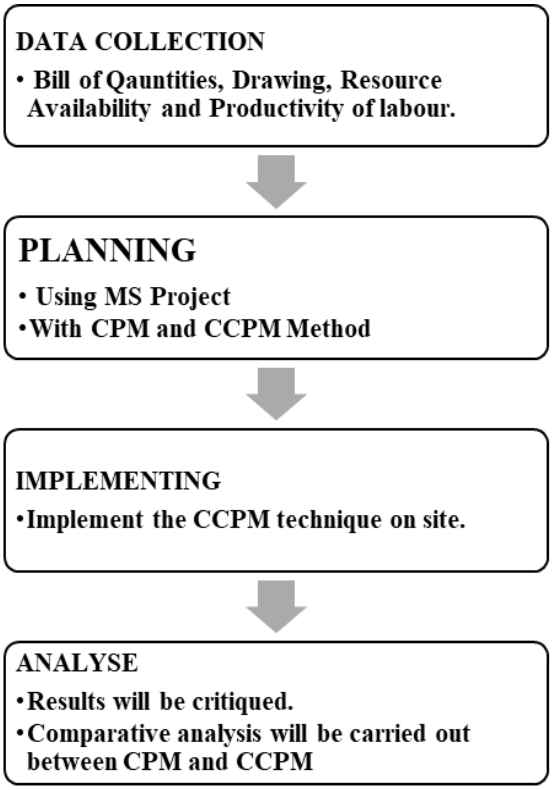

Fig 1:- Methodology of Study

IV. CASE STUDY

A. Data Collection

To implement CCPM, proper data must be available such as drawings, availability of resources and productivity of resources. Initially, the design data was collected from the PMC i.e. BOQ and drawings related to hostel building. Quantities will be worked out from BOQ and drawings will help to list out the activities. In order to get the project manager familiar with the technique, a small verbal example was explained to him and was asked to provide a sufficient required data. In order to schedule the project, data such as availability of resources (i.e. Man, Material, and Machinery), productivity of the respective resources and material available on site is needed. CCPM is the method where the data related to resources plays an important role. So, the resources available to them were noted down for the further steps. For scheduling the project, only labor resources are assumed for this study.

Data collected from the PMC was very beneficial in terms of learning the project insights. General specification of building was separated and pile layout was deeply studied to know the number of piles and pile caps. Major part of the project was to complete the piling within stipulated time. As the piling delays, the whole project will be delayed. Studying pile layout lead to know the exact number of pile and pile cap which helped in further estimating the duration of activities. To imagine the structure easily, 3D model of Hostel Building is shown in Figure 2.

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Fig 2:- 3D Model of Hostel Building

Total occupancies, area of the building also the room type is shown below:

- Total Student Capacity – 870 Nos.
- 640 Boys – 246 Rooms
- 230 Girls – 92 Rooms
- R2 Rooms for 2 Students
- R3 Rooms for 3 students
- Type 1 – on Ground Floor (R2) Area – 15.4 m^2
- Type 2 – on Ground Floor (R3) Area – 21.6 m^2
- Type 3 – on First Floor (R2) Area – 16.6 m^2
- Type 4 – on First Floor (R3) Area – 21.4 m^2
- Built-up Area of Ground Floor – 3967 m^2
- Built-up Area of First Floor – 3967 m^2
- Total Built-up Area – 7934 m^2

Scheduling a project requires lot of data like availability of resources and their productivity, throughput, quantity of work to done and how much it costs to the project. This data can be gathered from a contractor and not from the PMC. As contractor puts his money and have to complete the project, he can ensure the details of each and every point. Contractor will put his all effort to complete the project on time. So, to being with the work duration of activities was taken from an experienced person. Further to assign the work to an individual person, data related to the manpower was gathered. They have distributed the each block to different subcontractor. Below Table 1 shows the manpower and machines to complete the Hostel Building.

Hostel Building is divided into seven blocks namely A,B,C,D,E,F,G where A is subcontracted to Hardik, B and F to Popat, E to Dinesh, G to Swaminarayan and C and D is handle by Tirupati Sarajan Ltd. Table 2 shows the manpower of individual subcontractors.

Estimation of duration was done with analogous and parametric estimating. Project Managers, Junior Engineers, Site Supervisor and sub-contractor were asked how much work they can complete within a day or like how many days will it take them to complete their respective tasks.

B. Duration Estimation of Major Concerning Activities.

Hostel Building is been construction on a sandy soil. In order to rest the building, pile foundation with M25 grade of concrete was adopted as an alternative. Whole building will be resting on these pile foundation. As it was the most time-consuming activity, delay piling will cause the end date of the project. For instance, if piling delays for about 2 weeks the further construction also gets delayed. So, to complete with desired work with a stipulated time frames, piling must not be delayed at all.

Resources		
	Type of Resources	Available Resources
Man	Engineers	5
	Supervisors	5
	Electrician	2
	Storekeeper	1
	RMC Operator	2
	Skilled Labour	
	Steel Binding	180
	Centring & Shuttering	150
	For Masonry	20
	Unskilled Labour	500
Machines	Boring Machines	6
	Concrete Mixer	4
	Transit Mixer	2
	Excavator	2

Table 1. Available Resource on Site

Subcontractor				
Name of Contractor	Work of Contractor	Skilled		Unskilled
		Steel	Shuttering	
Hardik	S &S	40	30	50
Popat	S&S, RCC	40	30	80
Dinesh	S&S, RCC	40	30	80
Swaminarayan	S&S, RCC	40	30	80
S&S = Steel and Shuttering				

Table 2. List of Subcontractor

To avoid such consequences, proper scheduling of the project should be done. Scheduling the project will indirectly leads to find the quantities of work and resource required to finish the task. Prior calculation, resource available with contactor was gathered. Next to that the pile under each block was counted and summed up to total. Even the type and number of pile caps were figured out. In total there are eleven pile caps present in the hostel building. Lastly the steel required for each pile and pile were calculated. Figuring out the duration of piling activity, it was assumed that four boring machines will be deployed to each block.

A Block Pile = 369,
Productivity of each Boring Machine = 3 piles/day
Therefore, Total piles bored per day = 12 piles
Duration of Piling Activity for A Block = 369/12
= 30.75 ~ 31 days.

Similarly, duration of reinforcement pile cap in block A is calculated. Reinforcement of 10 Pile cap per day can be done. There are total of 119 pile caps present in block A.

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So, Duration of Reinforcement of Pile Cap Activity = 119/12
= 11.9
~ 12 days

Duration of pile work and reinforcement of pile cap for each block in show in Table 3.

Hostel Block	Total Piles	Pile Cap	Piles per day	Pile cap Per Day	Duration of Piles (days)	Duration of Pile Caps (days)
A	369	119	12	10	31	12
B	478	149	12	10	40	15
C	486	146	12	5	41	29
D	319	89	12	5	27	18
G	377	94	12	10	31	9
E	351	108	12	10	29	11
F	369	111	12	10	31	11
Note: 1 Machine = 3 piles/day. So, considering 4 working at a time.						

Table 3. Duration of Pile Work and Reinforcement of Pile Cap

C. Scheduling of Hostel Building

Hostel Building was scheduled using Critical Chain Method and Critical Path Method. Keeping in mind some set of questions like does CPM gives real time schedule? Do CPM considers the resources which are available to complete the project? How consideration of resource will help construction industry to deliver the project with a given timeframe?

Above question can be answered with help of CCPM. CPM do not provide a real time schedule because of the assumption it made. Schedule prepared using the CPM method, assumes that there are unlimited number of resources available to work, which is not practically true. This assumption jeopardize the project completion time. To overcome this drawback, CCPM comes into picture and will make great impact on the project deliveries. As per the definition, Critical Chain is the longest sequence of resource levelled task from the start to end.

Schedule of Hostel Building will be prepared with both the methods using MS Project Software. Initially, CPM schedule will be prepared. Further duration of each activity will be made aggressive and CCPM schedule will be prepared as well as the buffers will be calculated.

Results of CPM schedule came out to be 312 days. Now to moving towards CCPM schedule, resource must be assigned to each task. Moreover, the resource contention present in the schedule will be rectified. Over allocation of the resources is levelled using MS Project without hampering the critical path. Fig shows the over allocation of the manpower and machines. Further step is to calculate the buffer size of project buffer and feeding buffer.

Buffer management plays very important role in CCPM. Buffer such as project buffer and feeding buffers will be used to protect the project from delays. Project buffer will be placed at the end of critical chain and feeding buffer will be placed at the end of noncritical activities which merges with critical chain.

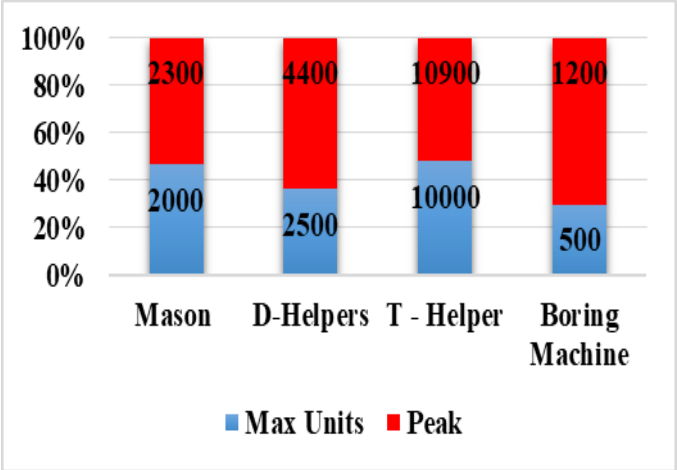

Fig 3:- Resource over Allocation

There are two method for deriving the size of buffer. Methods are named as Cut and Paste Method (C&PM) and other is RSEM. As mentioned in the previous studies, 50% rule of buffer sizing may lead to serious overestimation of the required buffer size [1]**.** Keeping the words of Herrolen and Leus in mind RSEM is adopted to validate the schedule of CCPM in construction of hostel building.

Determination of buffer size with the help of RSEM needs two estimates i.e. one is safe duration and other is aggressive duration. Inclusion of safety margin will be there in safe duration whereas in aggressive duration there is no safety margin. Actually, this method calculates the uncertainty of the project. Uncertainty is the difference between the safe duration and aggressive duration. Depending upon the critical chain and non-critical chain activities project buffers and feeding buffers are calculated respectively.

$U_i = S_i - A_i$,
Where U_i – Uncertainty, S_i – Safe Duration, A_i – Aggressive Duration.

Therefore, Buffer Size = $\sqrt{U_1^2 + U_2^2 + \cdots + U_n^2}$

Project Buffer Size before rescheduling the project = $\sqrt{5186}$
= 72.01 ~ 73 days.

Total Duration of the project using CCPM Technique is 281 days out which 73 days is project buffer.

D. Rescheduling of Hostel Building

Project was schedule from the commencement date and it was found that the project was delayed by six months. To validate the implementation of CCPM in real case, the hostel building was rescheduling with the current scenario. Initially, the project was scheduled using CPM method with the help of MS Project. Duration of remaining project came out to be 302 days. Secondly, the project was schedule using CCPM technique and resource contention was removed. Figure 3 shows the resource contention and balance resource assignment. Furthermore, the duration of the project using CCPM came to be (202+86) days. 202 days is the project

deadline while 86 days is the project buffer placed at the end of the critical chain and total 288 will be the customer deadline.

Calculation of project buffer before and after rescheduling the project is shown below.

Project Buffer size after Rescheduling = $\sqrt{7319}$

= 85.55 days

~ 86 days.

E. Monitoring Using Fever Chart

In CCPM, monitoring is done using the buffer consumption and Fever Chart. Fever Chart is divided into three part each of $\frac{1}{3}^{rd}$ in size. Each zone is named as Red, Yellow and Green, where green zone will reflect the safer side of the project while the yellow give early warning to the manager to prepare corrective action if project gets delayed. Lastly, the red zone indicates that project has been delayed and corrective action must be implemented. Table 4 shows the buffer consumption of the project.

PB Consumed	PB Available	% PB Consumed	Project Duration Completed	Baseline Planned Duration	Baseline Estimated Duration	% G Block Project Duration Completed
Days	Days	%	Days	Days	Days	%
0	86	0.00	16.16	202	202	8
24.4	86	28.37	57.699	202	213.7	27
32.7	86	38.02	64.38	202	222	29
43.95	86	51.10	72.9275	202	235.25	31
68	86	79.07	127.988	202	261.2	49
68	86	79.07	129.32	202	244	53

Table 4. Buffer Consumption of Project Progress

Now the project was reschedule using CCPM and further it was monitored with the help of fever chart. Fever chart was prepared on MS Excel and this data was used as input for the project progress. Table 4 shows the detailed progress of the project with an interval of 10 days. Figure 4 shows the fever chart of the project progress.

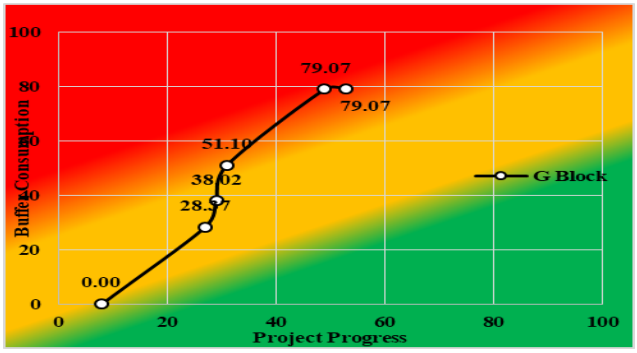

Fig 4:- Fever Chart for Project Progress

V. CONCLUSION

CCPM is step forward to traditional method of scheduling i.e. Critical Path Method. It was clear after the implementation of CCPM that this method gives the reduction in the project time line. Below are the point of conclusion mentioned.

- CCPM abolish the multitasking involved in the project. Multitasking amongst the resources is eliminated because of solving the resource conflicts present in the project and critical chain is identified.
- Project Duration obtained using the CPM was 312 days.
- After the implantation of CCPM Technique, duration came out to be 281 days including 73 days of Project Buffer size.
- It is quite obvious that there is reduction in project planned duration.
- Percentage Reduction in project planned duration is = $\frac{(312-281)}{312} X\ 100$
  = 9.93 % ~ 10 %
- After Rescheduling the project the duration using CCPM came out to be 288 days including 86 days of project buffer.
- Percentage Reduction in project duration after rescheduling the project = $\frac{(302-288)}{302} X\ 100$
  = 4.63 %
- Reduction in time without adding any additional resources will indirectly lead to cost saving of the project.
- Fever Chart depicts that the project was initially delayed and continuously keeps delaying. There was no corrective action were implemented and project lead to red zone. So, fever chart is easily understandable.
- For ease of understanding, Fig shows the graphical representation of project planned duration using CPM and CCPM techniques.

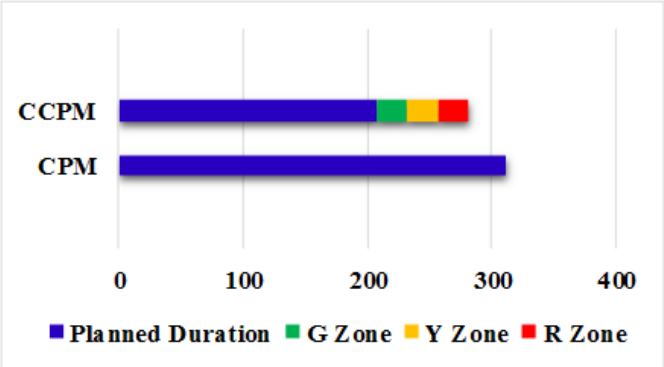

Fig 5:- Difference between Duration Using CPM and CCPM Techniques

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