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APPLICATION OF CRITICAL CHAIN PROJECT MANAGEMENT TO CONSTRUCTION PROJECTS: A REVIEW

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ABSTRACT
The three constraints of any project are Time, Cost & Scope that affect the quality of project & are interrelated to each other. In today's competitive environments it is very important to complete the project with the least possible time. So, it is very important for project managers to plan & schedule the project effectively such as to achieve their targets on time. One of the traditional methods used worldwide is Critical Path Method (CPM) which leads to ineffective scheduling. In CPM, the task estimates are based on guess work which leads to increase in the project completion duration. Also the availability of resources is not considered by the scheduler to develop optimal schedules. To overcome the shortcomings of CPM, a new project management methodology called "Critical Chain Project Management" (CCPM) was developed in 1990's by Dr. Eliyahu M. Goldratt after which various additions were given by different researcher to his research. CCPM is based on the philosophy of "Theory of Constraints" (TOC) which believes that every system has a constraint & without eliminating this constraint the system cannot progress. CCPM achieves its goal through buffer management. The developing countries like India mostly face the problems of project delays so CCPM can be applied to save the projects from time and cost overruns. This paper aims at presenting the current status and past studies in the area of CCPM.

KEYWORDS: CCPM, TOC, Buffer Management, fever chart

INTRODUCTION
India is a developing country which is on a pace of transformation towards growth. It is necessary for any developing country to develop its infrastructure for continual improvement in its GDP as infrastructure sector and real estate sector contribute majorly towards it. With the new Real estate Bill passed by the Parliament of India, it is very important for construction firms to complete their projects within the stipulated time failing which they will have to pay penalty for delays to their customers. Traditional methods of planning like CPM have various drawbacks which leads to inefficient planning. One of the major factors which contribute to the delays is the non-availability of resources at proper time, multi-tasking by the workers, uncertainty and inefficient planning of the project. It has been found that most of the project planners normally include excessive contingency time within each activity while planning for a project to keep project completion duration on a safer side. There are various laws given by researchers for such inefficient planning like Student's syndrome, Parkinson's law, murphy's law etc. In India mostly, CPM is most used for planning the construction projects. But the activity times is usually based on a guess work. The Project managers based on their past bad experiences add safety to their project so that it can complete on time which only adds to an increase in the complete duration of a project.

CCPM is another methodology which can be adopted by the project managers to complete the project within their due dates by reducing the duration consumed by the activities which in turn help in reduction of the overall project duration and helps to reduce the time and cost overruns. CCPM is based on the philosophy of Theory of Constraints. This philosophy has mainly focused on finding the constraint first which acts as an obstruction towards on time completion. In CCPM this is achieved through buffer management. There are various types of buffers like Project Buffers, feeding buffers, resource buffers which prevent the Critical chain and the feeding chains from adding to the delays in project completion dates. The use of CCPM and TOC is not only restricted

to the construction projects rather it finds its application to other fields also like production, software development. This study can help the planners and schedulers to adopt a new methodology to schedule and monitor the project within time and avoid the unnecessary safety to achieve the organizational goals.

LITERARURE REVIEW

Hosein Iranmanesh*, Fatemeh Mansourian and Samaneh Kouchaki, Critical Chain Scheduling: A New Approach for Feeding Buffer Sizing [2016], The paper contributes to effective buffer sizing. If the buffer is not sized to accommodate the uncertainty, it can lead to the loss of critical chain technique. The paper suggests Post density method (PDM) to take into account the uncertainty, post density factor and dependence factor to decide the effective buffer size. Four performance indicators have been used in the study to violate the times namely, Average buffer Size, Proportion of buffer consumed , Proportion of time estimation exceeds in each project planning and Proportion of the number of 100% PB consumed . Kolish-Hartman datasets have been used in the simulation study. The results of simulation indicate that PDM, estimates smaller size of buffer in environment with less uncertainty and bigger size of buffer in high uncertain environment than available methods. According to the results of the study it is found that PDM protects time of project and is adjusted with principal goal that is CC management, i.e., decreasing WIP & may be used as suitable method for specifying size of buffer.

Junguang Zhanga, Xiwei Song and Estrella Díaz, Critical Chain Project Buffer Sizing Based on Resource Constraints [2016], The paper proposes a comprehensive resource-constrained method and points the problems in resource leveling. It has considered the general average resource constraints (GARC) and the highest peak of resource constraints (HPRC) in order to propose a new buffer sizing method. The paper has developed a buffer sizing method based on a fuzzy resource-constrained project scheduling problem to obtain an appropriate proportionality between the activity duration and the buffer size. The method provides an appropriate buffer size as an effective protection for the project. It also measures the effect of resource constraints on the project. Actual duration and cost has been used for simulating rather than planned cost and duration which gives more convincing results. The method can be helpful to the managers as it gives a reasonable buffer size and thus, reduces the project risk.

Junguang Zhang, Saike Jia and Estrella Diaz, A New Buffer Sizing Approach Based on the Uncertainty of Project Activities [2015], The authors have pointed that that the uncertainty of a project is a fuzzy concept & it is therefore difficult to calculate the buffer sizing with any other method. The method proposed in this paper aims at improving the accuracy of buffer management. The assumption made in this research is that the project activities follow lognormal distribution. A buffer sizing method based on uncertainty has been introduced which integrates both resource tightness and project attributes. The Monte Carlo Simulation has been used to check the effectiveness of the proposed method. The paper identifies various factors which affect the project buffer like resource tightness and network complexity. The method proposed is 'Extended Optimization model' which considers the factors affecting the project buffer. MATLAB software has been adopted to simulate the model. The result show that the proposed model gives less duration of buffer as compared to C & PM and RSEM methods.

Shurrab M, Traditional Critical Path Method versus Critical Chain Project Management: A Comparative View [2015], The main aim of this paper is to compare the traditional CPM against CCPM. It uses the two methods of buffer management namely SSQ method and C&PM techniques to analyze the project performance in terms of cost and duration. The networks are tested by two ways for the study. Firstly, the networks are developed without using mixed resources and after that with mixed resources. To achieve the research objectives, 120 combinations of randomly generated project networks were studied and evaluated by the author by using the 2 methods i.e. traditional CPM and CCPM with SSQ and C&PM methods. The results show that there has been a considerable reduction in cost and duration using SSQ method while C & PM method overestimates the duration but it also saves the cost.

M.Ghaffari & M.W.Elmsley, Current Status and Future Potential of the Research on Critical Chain Project Management [2015], The paper aims at reviewing the research on CCPM critically. This study covers 140 journal & conference papers which have been reviewed to carry out the extensive research on CCPM. The papers have been categorized into 6 groups using "hierarchical coding method", based on the approach & contribution of these papers towards CCPM. The six categories as reviewed are introductory studies, critical studies, improving studies, empirical studies, case-reporting studies and exploiting studies. The introductory studies mainly addressed the introduction of CCPM, its principles and support the practice of CCPM against the other traditional methods. The Critical studies highlight the drawbacks of using CCPM and propose various

means of overcoming them. Researches done under improving studies category aimed at improving the drawbacks addressed in the critical studies. In this task duration improvements, buffer management improvement and project monitoring improvements have been addressed upon. In empirical studies, researches have been carried out to investigate the performance of CCPM with the help of experiments and simulations like Monte Carlo Simulation which mainly show that CCPM performs better than the other traditional methods. Under case-reporting studies category, the author has studied 20 case studies on CCPM and most of the papers reviewed have reported the benefits of CCPM viz. increase in productivity, efficient on time delivery rate, reduction in multi-tasking, increase in throughput & increased work progress. Through exploiting studies, the application of Exploiting studies through TOC to other fields have been focused which include accounting firms, procurement management, supply chain management, software development firms etc.

P.M. Chavan, Ganesh P. Gaikwad, Prashant S. Gosavi, CCPM:TOC bases Project Management Technique [2012], The paper gives a brief about the traditional project management techniques and gives an overview of the CCPM technique. The paper also suggests the advantages of using CCPM over the traditional methods. The various reasons for the project delays are the use of excessive activity duration estimates, little actual activity positive variation, project delay caused due to merging of activity paths, multi-tasking and loss of focus. The paper describes various theories on which CCPM is based viz. Theory of Constraints, Common Cause Variation and Statistical Laws Governing Common Cause Variation. With the help of this paper, the author has pointed out towards the undesired effect of the traditional methods of scheduling.

Rob Newbold, Schedulling for success with Critical Chain [2010], The paper suggests that multi-tasking should be avoided to complete the project within stipulates time. If a same type of resource is to be used for more than one activity at certain point of time, such activities should be scheduled at different points of time. The paper also gives an idea about the use of fever charts, buffer penetration, and consumption of buffer which represent the status of the activities on the fever charts. The fever chart is divided into three zones viz Red Zone, Yellow Zone and Green Zone. Also the paper gives definitions of some important terms related to CCPM such a project buffers, iteration risk, fever chart, critical chain, buffer consumption.

Oya I. Tukel , Walter O. Rom and Sandra Duni Eksioglu, An Investigation Of Buffer Sizing Techniques In Critical Chain Scheduling [2006], The authors have introduced two methods to determine feeding buffer sizes for preparing schedules using critical chain approach. The proposed methods integrate project characteristics into the formulation. One of the method incorporates resource tightness while the other uses network complexity. The authors have made an effort to incorporate the critical chain concept into the resource constrained project in their study which could be starting point for further research into scheduling. The paper has tested & compared the two common of buffer management i.e. the cut and paste method and the root square error method, by using no buffer as a benchmark. The comparison is done by means of a simulation study using the Patterson data set. The authors have introduced the adaptive buffer sizing methods (APD) which are expected to generate buffer sizes which would improve the chances of a project completing on time.

Lawrence P. Leach,Critical Chain Project Management, [2005], The author takes reference from Goldratt's 'The Haystack syndrome and quotes 'Measures drive actions that move you towards the goal'. It means that one must measure his performance which can help to judge the impact of the decisions to accomplish the ultimate goal. The paper suggests various action levels which are used to make decision regarding buffer. They are categorized as no action, assessment and plan and implement the plan. The author has adapted a methodology in which Firstly the buffers are arranged according to the properties of the chain. Secondly, assessing the project progress and buffer consumption needs to be done on a regular basis. Thirdly, plans should be developed to accelerate the project progress if the pre-defined threshold of buffer consumption increases. If the second pre- defined threshold is exceeded, the developed plans should be implemented. Based on these thresholds, the author has developed fever charts in which % feeding path complete is plotted against % buffer consumption. It is suggested that monitoring of fever charts should be done on a regular basis either daily or weekly.

Thomos G. Lechler, Boaz Ronen and Edard A. Stoh, Critical Chain: A New Project Management Paradigm Or Old Wine In New Bottles?[2005], Engineering Management [2005], In this paper, the authors analyze the CC approach to manage projects. Their discourse compares systematically CC & CPM on three conceptual levels to reveal the differences between the two approaches. Following the approach of Ronen & Starr (1990), who analyzed, among other issues, the fundamental differences between Just In Time (JIT) & Optimized Production Technology (OPT) management on a philosophical & tactical level, their analysis of CO & CC is conducted on two level i.e philosophical and operational level. Further, the paper identifies the conceptual

difference between CC and CP approach. It is concluded that CP is a well established approach while CC completes the project faster but includes considerable investment in terms of training & infrastructure investment costs is needed to change to a CC approach.

Tzvi Raz, Robert Barnes and Dov Dvir, A Critical look at the Critical Chain Project Management, [2003], The paper reviews the key elements of CCPM like duration estimates, buffer design calculations, progress measurement, task completion notification and priority setting. The authors have done a critical analysis of CCPM by using the evidences available in literature and in practice. The points addressed includes duration estimation practices, project network structure, stability of the critical chain, various resource productivity under multi-tasking and project's organizational and operational environment. The CCPM takes place in the broader project management context and the costs associated with it that although CCPM has a number of valuable concepts, it does not provide complete solution to project management.

Herman Steyn, Project Management Application of The Theory of Constraints beyond Critical Chain Schedulling [2002], The paper explains the reasons for reducing the project duration. The author has mentioned various reasons for reducing the project duration. First reason being, human behavior to provide considerable provisions for contingencies during project planning which further leads to over estimation. Secondly, multi-tasking by the worker leads to negative effect on the project which should be avoided. Thirdly, CCPM provides the contingency reserves to whole of the project rather than to individual activity due to which project duration is affected.

Francosis Retief, Overview Of Critical Chain Project Management, [2002], In this paper, the author provides a brief overview of the principles of critical chain project management. He persists that the project performance can be improved by scheduling project using CCPM. The improvement in project performance can be achieved by modifying team behavior to eliminate bad work habits and by using aggregated safety in the form of buffers, which protects the project completion date. This paper also points towards the different ways as mentioned below due to which having planned tasks containing safety, people proceed to waste the available safety. The essential changes in CCPM as compared to CPM practices have been mentioned which are as, reduction of activity times to 50% ,development of critical chain using activity and resource logic, provision of Various buffers to protect the critical chain from delays etc. All such essentials in CCPM lead to faster completion of project and provide an effective project management tool to the executives needs and organizations should be very careful in adapting CCPM techniques. The paper also points towards the various challenges which an organization might face in adopting a CC approach.

Graham K. Rand, Critical Chain: The Theory of Constraints Applied to Project Management [2000], The paper gives an introduction on the development of the 'theory of constraints'. It explores the relationship of CCPM and other traditional methods like CCPM through the study of novel "Critical Chain". The traditional methods like CPM/ PERT does not consider the human behavior while constructing the project network. Thus, CCPM can be highly beneficial for the senior management level. The paper addresses, the project managers may avoid the use of CCPM approach as against CPM/PERT because it reduces the activity duration.

Goldratt EM, Critical chain. Great Barrington, MA: The North River Press, [1997], The author, Dr. E.M.Goldratt, has described the application of 'Theory of Constraints' to Project Management through the novel. The novel revolves around two main characters, one of which is a lecturer who is trying to save his tenure in the university and the other that of the university president who is expecting a reduction in the MBA admissions. The lecturer has to teach the Project Management subject to working professionals in an executive MBA class. The students are mainly project managers which seem to be a challenge for the lecturer because they will have much practical knowledge than him. The lecturer addresses the constraints of a project and challenges faced by the project managers through an open discussion in the executive class.

The class is given a number of practical based assignments by the lecturer to find the various problems in the field of project management, bottlenecks which delay a project and to find out the solution to all the reported problems. One of the major problems reported by the students is the delay in the projects. With this the novel gets oriented towards the concept of 'Critical Chain', finding the weakest link and the finding the constraints which leads to such delay and how TOC can be applied to increase the throughput. Further through discussion between the lecturer and the student on the assignments, a new theory called 'Theory of Constraints has been developed. TOC has been portrayed as a solution to the problems faced by the project managers in managing the projects on time.

CCPM METHODOLOGY

To derive the Critical Chain solution Dr. Goldratt applied the five focusing steps, identified in his writings[15]

1. Identify the systems constraints
2. Decide how to exploit the constraint
3. Subordinate everything else to the above decision
4. Elevate the system's constraint
5. If, in a previous step, the system's constraint has been broken, go back to step 1

CONCLUSION

Following conclusions can be drawn from the literature review carried above:

- ➢ Most of the researchers have focused on the buffer sizing.
- ➢ Experimentally it is shown through the simulation results that CCPM performs better than other traditional approaches.
- ➢ The fever charts give a graphical interface to check the consumption of the buffer which makes easy for the executives to take actions to protect project completion dates from delay.
- ➢ CCPM has been used by various software and production firms who have completed their targets within or before time.
- ➢ It is recommended that CCPM approach should be used by construction industry also to achieve their targets within time.

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