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A Systematic Review on Critical Chain Project Management

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Abstract:

Theory of Constraints (TOC) is the parent concept for the development of critical chain project management (CCPM). CCPM is the application of TOC. The project management literature has taken a keen interest in this. The key element of CCPM such as the Theory of Constraints, CCPM scheduling, Activity duration, types of buffers and their positioning, and buffer sizing techniques are reviewed by the author. This includes activity duration factors such as student syndrome and Parkinson's laws. Multitasking affects project cost and CCPM & TOC provide the solution. The authors conclude that, even though CCPM contains several useful principles, it does not entirely address all project management requirements. As a result, companies should exercise extreme caution when excluding conventional project management techniques.

Keywords: CCPM, Buffer sizing, Buffer type, Project Management

1. Introduction

Scheduling is a very significant and crucial task in project management. CC considers problems common to all projects such as overruns of budget, time, and schedule are highly probable to occur.[1]. Dr. Eliyahu M. Goldratt (1997) introduced Critical Chain Project Management [2]. For the development of CCPM Theory of constraint (TOC) and system thinking were adopted [3]. A shortfall of resources was considered in CCPM [4]. CCPM is a project scheduling technique that reduces project change and cost overruns by buffer management and developing sound and improved performance schedules [3], [5]. Overall project completion is protected using Project buffer (PB) and Feeding buffer (FB) use to prevent the critical chain from path merging. When unavailability of resources in CC is protected by placing resource buffer (RB) work as a signal for determination of resources is ready by a project manager and resource manager. Buffer management helps in decision-making for project control. CCPM eliminates the effect of “student syndrome, Parkinson’s Law, and multi-tasking” which enhances the schedule, cost, and scope performance of the project as well as the focus of the project manager and performers are improved [3]. **Buffer size** depends on the uncertainty of the project. If more uncertainty buffer time will be larger and vice versa. It is more important to decide the amount of a buffer in new product development, where there is a lot of uncertainty than it is to do so in a building when there is less ambiguity.[7]. **Several buffer** sizing methods have been identified by researchers. Cut and Paste method (taken out safety time 50% from activity duration and aggregation of remaining 50% of these safety time as the buffer size) and Root Square Error Method (RSEM) are easy and mostly used for buffer sizing [7]. Tukel et al., (2006) introduced “adaptive procedure with density (APD) and the adaptive procedure with resource tightness (APRT)” which integrated project properties in it [7]. Several other buffer sizing method and algorism developed using fuzzy approach, considering activity dependencies, and resource reliability is reviewed in this paper. **Table 1** shows all categories of literature review.

Table 1. Categories Of Literature Review in This Research

Sr no	Author	Year	Research subjects																
			CCPM	TOC	Buffer sizing	C&PM	RSEM	ADP	APRT	Fuzzy approach	Buffer management	RCPSP	Multitasking	Student syndrome	Rescheduling	Multi project environment	Control	CPM	Parkinson' s Law
1	[8]	1995										*							
2	[9]	1998		*															
3	[3]	1998	*	*		*	*							*					
4	[10]	2000	*	*															
5	[11]	2000	*	*	*	*													
6	[4]	2001	*	*											*				
7	[6]	2001	*	*	*	*	*				*	*	*						
8	[12]	2002	*	*		*					*				*				
9	[13]	2002	*	*									*						
10	[2]	2003	*													*			
11	[14]	2003	*											*					
12	[5]	2004	*													*	*		
13	[15]	2004	*	*		*	*				*	*			*	*			
14	[16]	2005	*	*							*				*			*	
15	[17]	2005	*			*					*	*						*	
16	[7]	2006	*		*	*	*	*	*										
17	[18]	2007	*		*	*	*												
18	[19]	2007	*		*	*	*			*									
19	[20]	2008	*		*	*	*												
20	[21]	2008	*		*	*	*			*	*								
21	[22]	2008	*				*					*							
22	[23]	2009	*	*		*								*					*
23	[24]	2009	*							*		*							
24	[25]	2009	*	*							*								
25	[26]	2010	*		*					*		*							
26	[27]	2010	*											*		*			*
27	[28]	2010	*		*	*													
28	[29]	2010	*	*											*				
30	[30]	2011	*		*					*									
31	[31]	2012	*		*	*	*	*	*										
32	[32]	2012										*							
33	[33]	2012	*									*	*						*
34	[34]	2012	*	*	*														
35	[35]	2014	*									*							
36	[36]	2014	*									*				*			
37	[37]	2014	*		*	*	*												

38	[38]	2015	*	*	*	*	*						*			*			
39	[39]	2016	*		*														
40	[40]	2016	*		*	*	*												
41	[41]	2017	*									*				*			
42	[42]	2017	*		*	*	*	*	*	*		*							
43	[43]	2019	*			*						*				*	*		
44	[44]	2020	*			*	*								*				
45	[45]	2020	*		*	*	*												
46	[46]	2021	*	*	*														
47	[47]	2022	*		*														
48	[48]	2022	*															*	

2. Theory of Constraint (TOC)

The TOC was described by Goldratt first in The Goal (1984). This system was applied to the production system**.** TOC can be encapsulated by: "Any system must have constraints" otherwise, its output would increase without boundary, or go to zero [3]**.** Instead of balancing capacity, TOC frequently focuses on optimizing the flow of work through a system.[9]**.** The theory of Constraints adopts an approach to transfer the safety time in a strategic position [10]. CC is the application of TOC.

Basic Steps for applying TOC:

1. Find out the constraints in the system
2. How does Exploit the system constraints
3. For above decision subordinate everything
4. Alleviate the constraint(s)
5. Repeat as needed

3. Difference between CPM and CC

At the philosophical level Lechler et al., (2005) gave the difference between CPM and CC in terms of theory, Goal, Focus of attention, Uncertainty, Resource management, and Behavioral issues. According to Theory, CPM and CC both depend on graphs and systems. But in CC TOC is applied which considers the goal of the entire system and multi-project environments. As related to the Goal, CPM tries to reduce the project duration under resource constraints while the project schedule is planned which stratifies only three constraints of time, cost, and performance for a single project. On the opposite, CC addresses single as well as multi-project cases. CC considers complexity and uncertainty in the schedule as well as includes three constraints also. As per the focus of attention, CPM focuses locally while CC focuses globally. One distinctive feature of CC is the recommendations it makes for enhancing performance when several projects are sharing limited resources. "Uncertainty" and risk significant issues in project management. In CPM, For protection from risk safety margin is added to activity duration. Uncertainty is managed by float and trade-off decisions. While CC removes safety time from the activity duration and uses it as a buffer to protect the schedule from risk and uncertainty. In resource management, CPM resource constraints are managed leveling based on precedence relation while in CC bottleneck resource is identified and managed it. According to the behavioral issues, The responsibility for the numerous acts is the last behavioral problem. The main goal of CP is to complete local tasks by the deadlines. Meeting deadlines and managing the schedule are made possible by this. CC, on the other hand, concentrates on the deadline for the entire project and controls the timeline by keeping an eye on the project buffers [16].

4. Concept Influencing the Calculation of Activity Duration

According to CCPM, each task owner overestimates the time needed to complete the assignment by a specific safety margin, and as a result, each work will take longer to accomplish as the allotted amount of time approaches. In other words, the length of the work itself is a self-fulfilling prophecy [2]. The following factors affect activity duration.

Student syndrome

"Procrastination, often known as Student Syndrome" is an example of an archetypical habit. To be more specific, we plan a contingency to handle the emergence of unanticipated circumstances. We all recall the sarcastic comments made at the students who dared to turn in their homework early while the rest of the class was requesting extensions., though, just like in the classic case of the student who puts off beginning their term paper until practically the end of the semester. Because of this situation, procrastination is rife in the workplace. It is perfectly OK to wait until you have more than enough time to finish anything before beginning an assignment or other activity. When one increases. Figure 1 is showing the student syndrome [27]. According to (Rand, 2000) [10] The staff believe they do not need to worry about beginning on time since they are aware that safety time is factored into the predictions. Thus, beginnings are postponed.

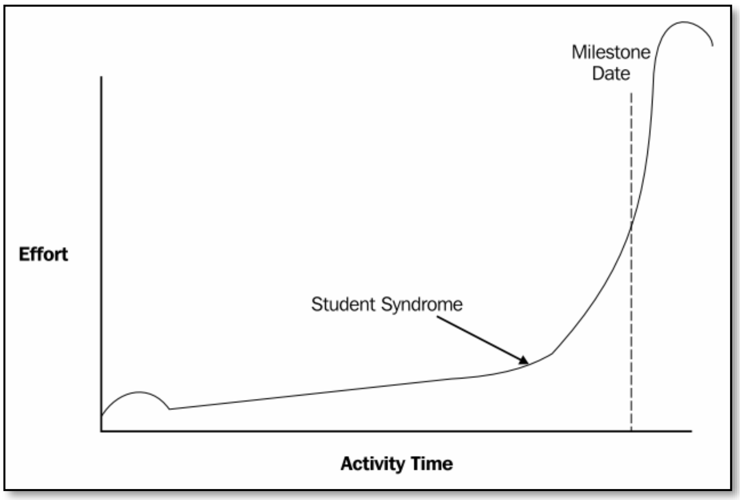

Figure 1. Typical Work Pattern (adapted from [3])

Parkinson's laws

According to [9], [3], PMBOK, "Parkinson's Law where work expands to fill the time available for its completion" Assume a task has a 90% chance of being finished on time if it is begun well in advance, say on the day specified in the initial project planning. An obstacle still stands in the way of timely completion. The adage that Parkinson's Law states that "work expands to occupy available time is widely accepted". For example, if a task completion period is 15 days but the worker knows that the task takes only 8 days to complete. If no issues arise, how probable is it that the employee will work as quickly as possible and complete on the 8th? No. That would entail that the employee would have nothing to do from the 9^{th} to the 15^{th}. He could lose his job if someone decides he is unnecessary. To complete the assignment by the 15th, the worker will either multitask, include additional tasks into his core task, or just dither. Now, the work won't be completed on time if something goes wrong toward the end of the timeline (for instance, a software issue that stubbornly refuses to be detected).[23].

Multitasking

When a resource moves between or among tasks often, it has an impact on how long it takes to finish each job, as seen in Figure 2. In the example, a single resource is managing four tasks that are identical but are part of multiple projects or subprojects in a multi-project / programme context. Each task is completed uninterruptedly from start to finish while using the non-multitasking strategy. This implies that the fourth project's job must wait to be begun until the previous three tasks have been finished. From the standpoint of the project manager or customer of the delayed project, this condition is undesirable in many businesses (s). As a result, pressure is usually applied, forcing the resource to demonstrate growth [27].

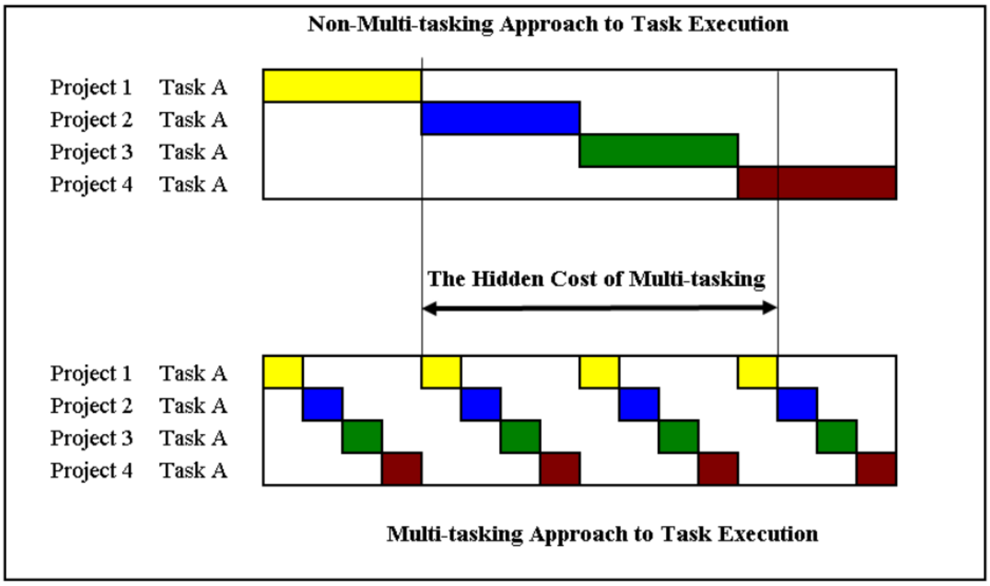

Figure 2. Muti-tasking with its negative effect [27]

5. Buffer

When estimating activity duration people or managers do make considerable provision for contingencies. Taking out contingencies from an individual task (lower level) are replaced by a "buffer" at the project level [10]. The following are the buffers used for the preparation of critical chain scheduling as shown below.

1. *Project buffer can be stated as* the safety time taken out from critical chain activity duration which aggregated safety time shifted at the end of the critical chain in terms of project buffer [12]. The project plan lists buffers as activities, but there is no work assigned to them.
2. *Feeding buffers can be stated as when a* non-critical path joins a critical chain where a feeding buffer is provided which serves the protection and control mechanism [12]. Figure 4 shows how the buffer absorbed the late path.
3. *Resourced buffer* is used as a warning bell. This provides the signal to the management to ensure the availability of sufficient resources for succeeding tasks and protect from scares of resources [12]. Sometimes resource buffer is called a "flag" because it does not account time in critical chain. [3].

The location of project buffer (PB) and feeding buffer (FB) are shown in figure 3.

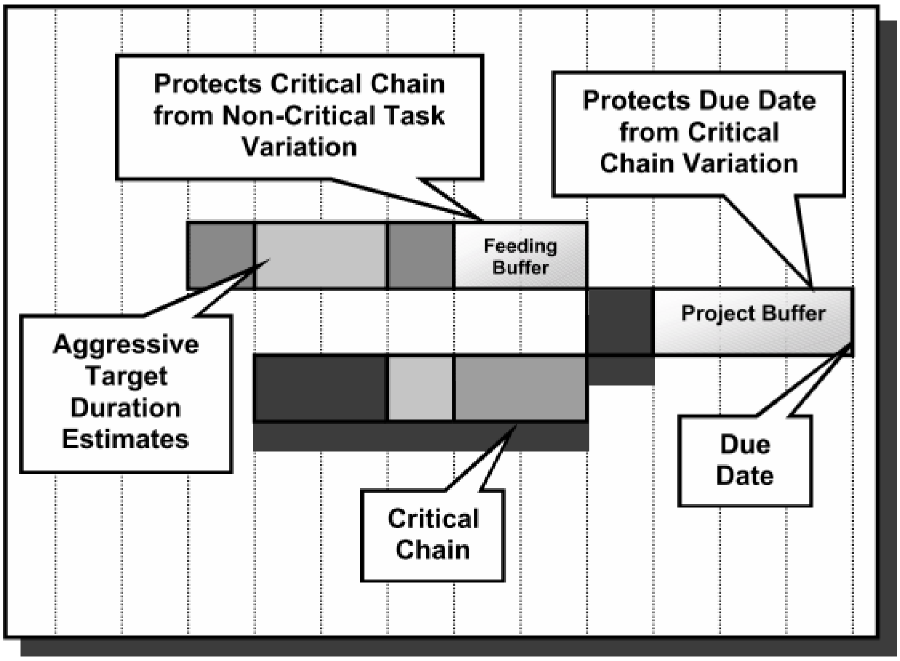

Figure 3. A typical schedule of critical chain (adapted from [9])

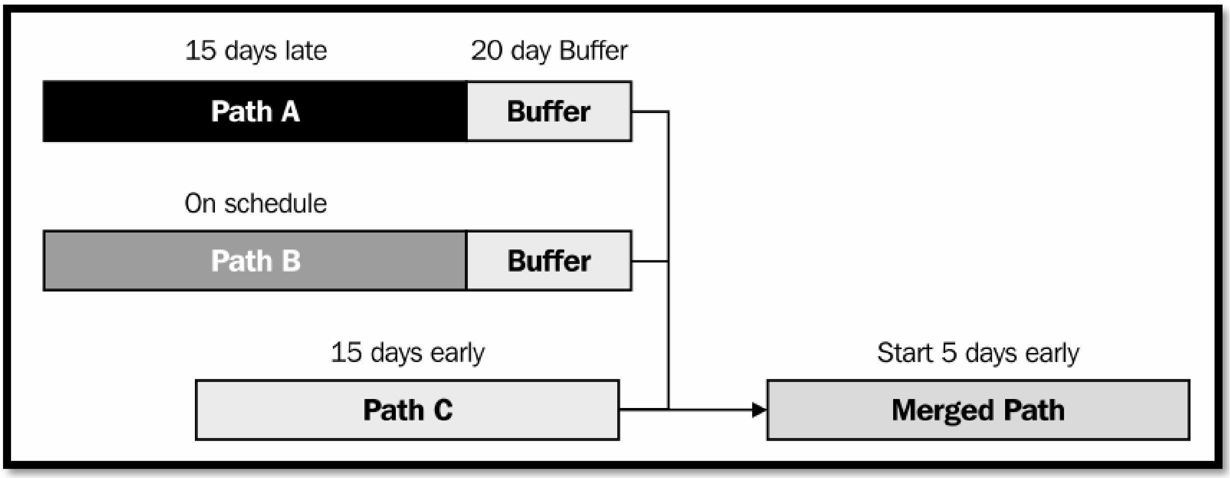

Figure 4. Feeding Buffers Absorbing Delays (adapted from [3])

Organizational goals and measurements are two important things in an organization. “Measurement” shows the impact of a taken decision on organizational goals. Goldratt had established an improved measurement system for production operation which follows in CCPM. To measure the activity chain performance buffers are used (time). For that [3] have suggested certain escalation levels for decision. The selection of buffer size is expressed in days. Figure 5 illustrated measurement for CCPM project control. This has divided the project buffer into three equal parts. Up to the one third (1/3) portion of the buffer, action is not necessary. In the two third (2/3) portion of the buffer While penetration occurs the situation must be evaluated and an action plan is made. In the last portion while penetration occurs action is taken. Apply measures to both project buffer (PB) and feeding buffer (FB) [3].

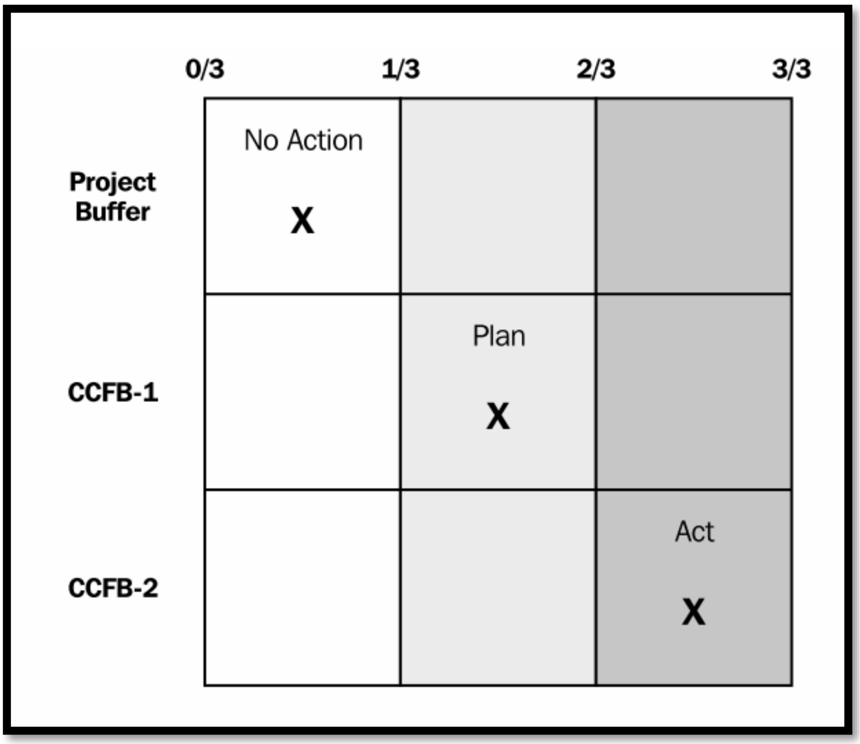

Figure 5. Measurement for CCPM project control (adapted from [3])

6. Critical Chain Scheduling Process

6.1 Main features of the critical chain

Figure 6 shows the main characteristics of the project critical chain solution that meet the functional needs of the project system. The aspects that are depicted point out how CCPM and critical path planning and management vary from one another. These crucial characteristics are:

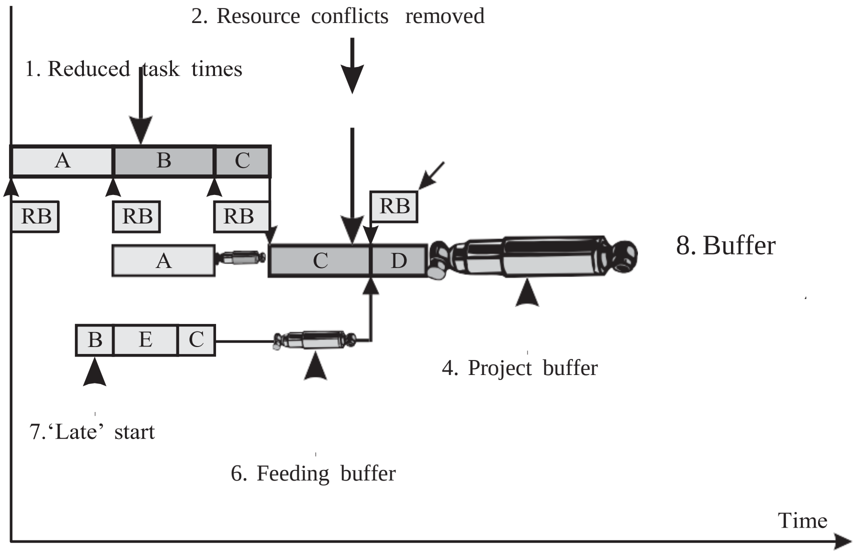

Figure 6. Critical chain project system requirement key features

a. Critical chain: "It is the longenst path through project should consider the precedence relation, task logic and the resource constrainits".
b. Before choosing the critical chain, removing resource contention from the project design;
c. Using Goldratt 50-50 rule develop a plan, at the end of the task chains accumulate uncertainty into the buffers;
d. Add feeding buffer to protect merging path (while continuing to resolve resource conflicts);
e. The resources should accessible in critical chain task when required, include resource buffers;
f. Feeding and the project buffer are used as controls to manage project performance.

6.2 Steps for critical chain scheduling are described in detail below[45]:

Removing contingencies associated with each individual activity: The schedule contingency is incorporated into the activity time estimates in traditional project scheduling techniques. This results in the allocation of a project's contingency that is overly substantial, together with people's tendency to only commit to time estimates they are quite convinced they can meet. In order to overcome this problem, CCPM sets the activity completion time to an aggressive estimate because there is evidence of inflated task estimations in actual practise. This action aims to reduce the propensity for activity execution delays in general.

Schedule activity as late as possible (ALAP): When scheduling a project, CCPM works backward from the deadline and moves all of the activities to the latest start date feasible while still maintaining resource feasibility and resolving conflicts.

Identifying the critical chain: "It is the longenst path through project should consider the precedence relation, task logic and the resource constrainits".

Location of buffer and buffer sizing: Figure 7 depict the position of buffers. For illustration, A-B-C is the critical activity which form critical chain. At the end of critical chain project buffer is placed. The feeding chain is D-E and the feeding buffer is placed after the last activity of the feeding chain. Resource buffer is placed between B & C activity which gives a warning for resources required for starting activity C.

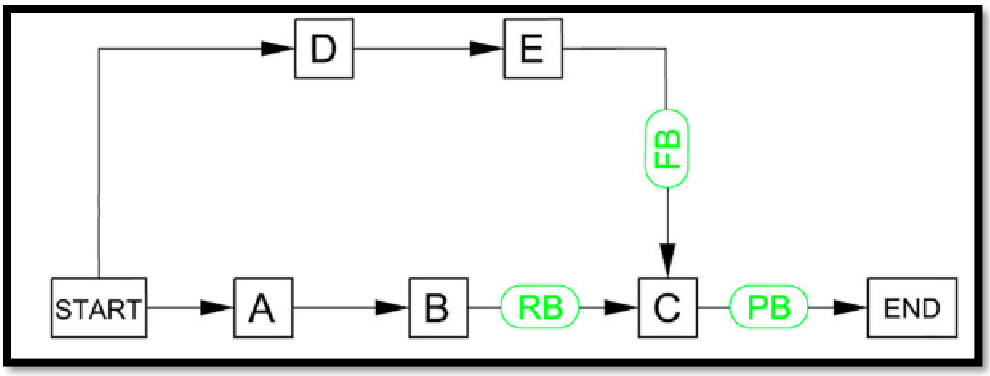

Figure 7. Position of PB, FB & PB (adapted from [45]

7. Buffer Sizing Methods

Goldratt (1997) suggested that half of the activity time out of the total activity duration consider and aggregation of that time is used as a buffer. Sometimes it is called a 50-50 rule [3]**.** Yongyi Shou & Yao, (2000) proposed a new method of buffer sizing considering uncertainty and different safety levels [11]. (Tukel et al., (2006) considered characteristics of project in the formulation of Adaptive Procedure With Density (APD) and Adaptive Procedure With Resource Tightness (APRT) [7]. Behzad Ashtiani et al., (2007) proposed a modified Root Square Error Methods buffer sizing [18]. Kun Li & Yun-xiang Chen, (2007) used a fuzzy activity duration approach and consisted manpower balance factor [19]. (Min & Rongqiu, (2008) gave a method of buffer sizing using the fuzzy sets theory. This method uses trapezoidal fuzzy numbers to model activity durations and incorporates the agreement index (AI) [21]. Shi & Gong, (2009) introduced an improved buffer sizing method under resource constraint and fuzzy uncertainty. They included uncertainty such as "resource tightness, network complexity, and Risk preference of the project manager" in the calculation of buffer size [24]. Fallah et al., (2010) developed an Adaptive Risk Based Procedure (ARBP) and considered the lognormal distribution parameter for activity duration and uncertainty [28]. Xiaoming Zhang et al., (2011) proposed a fuzzy comprehensive evaluation that considered the chain size, human behavioral factor, and uncertainty due to the environment. It employs the root variance approach to determine the link buffer size

[30]. Bie et al., (2012) proposed a method for buffer sizing that considered dependence assumptions between activities by using Dependence degree (DD) and dependence factor (DF) were two properties that show a dependence of a project [31]. J. Zhang, Song, Chen, et al., (2016) suggested a technique by using the rework probability matrix to determine the rework safety time, output and input of information time factors, and rework impact matrix [39]. J. Zhang, Song, & Díaz, (2016) introduced buffer sizing using comprehensive resource tightness which having of physical and information resource tightness [40]. J. Zhang et al., (2017) employed the fuzzy logic approach to improve buffer sizing accuracy by calculating the relationship between activity time and buffer size [42]. Zarghami et al., (2020) considered resource reliability and proposed a novel procedure for the calculation of buffer size based on resource reliability. The time buffer can be calculated more accurately using this new technique [45]. Nie et al., (2022) proposed an estimation of buffer size based on Duration Distribution, Multi-resource Constraints, and Relay Potential [47]. Table 3 shows the work done in the field of project buffer sizing.

Table 3. Work done on Project buffer sizing

Sr. No.	Author	Year	Research subject	Research method
			Buffer sizing	Model/Methods buffer sizing
1	[11]	2000	√	√
2	[7]	2006	√	√
3	[18]	2007	√	√
4	[19]	2007	√	√
5	[20]	2008	√	√
6	[21]	2008	√	√
7	[24]	2009	√	√
8	[26]	2010	√	√
9	[28]	2010	√	√
10	[30]	2011	√	√
11	[31]	2012	√	√
12	[39]	2016	√	√
13	[40]	2016	√	√
14	[42]	2017	√	√
15	[45]	2020	√	√
16	[47]	2022	√	√

8. Future Scope

From the above literature, some lack of work has been identified which needs to be resolved.

1. Add additional project features, such as activity costs and network complexity, by modeling resource reliability's life distribution characteristics using other distribution models, like the normal, exponential, or Weibull distribution [45].
2. Create a strategy that, when used in the execution phase of repeated building projects, detects and manages any possible discontinuities [49].
3. A method for resolving resource conflicts across running projects is by reactively allocating finite irregular resource slacks among them while taking various goal functions into account [50].
4. To accomplish informed and thorough project management, consider the possibility of multi-objective optimization, with consideration of project length as well as const control and logistic management [37].
5. CCPM's value in managing a range of construction projects from the perspective of a project portfolio will be shown [41].
6. Calculate the complexity and uncertainty of the DSM-based project duration estimation. Conduct clustering studies to determine the buffer's effectiveness or practicability using DSM [39].

9. Conclusion

CCPM developed from the parent concept of Theory of Constraints (TOC). TOC can be applied using five basic steps such as identify, exploit, subordinate, and elevate the system constraints. CCPM is the application of TOC. According to CCPM, project management may be carried out using the same logical procedure that is effective for production management. Contingences or safety time from the activity is removed and aggregated at the end of the path which reduces the effect of student syndrome and Parkinson’s law. CCPM reduces the multitasking effect by focusing on resources that should complete one activity at one time. To do this, CCPM modified the bottleneck and material buffer ideas created within the scope of Goldratt's Theory of Constraints, renaming them critical chain and time buffers in the context of projects. If the preconditions and assumptions are properly understood, several CCPM concepts may be used carefully to increase performance in specific situations.

The project can monitor and control using a buffer in CCPM. The use of a buffer gives the signal to the project manager. In a multi-project environment capacity buffer is provided. Buffer sizing is very significant for CCPM scheduling. All initiatives that have been zealously applied to the project were completed by CCPM in a significant amount less time than anticipated, within the intended scope, and for less money than anticipated.

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