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Critical Chain Project Management Approach to 220 MW Turbo-Generator Overhauling – An Analysis

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Abstract: The overhauling of Power Plant Turbine Generators is a critical, time bound activity. Each day of delay in completion of the overhauling work causes huge losses in terms of lost power generation. Any improvement in the overhauling time has thus the potential to generate more power and earn money to the organization. Basic principles of Critical Chain Project Management are applied to analyse four overhauling of 220 MW Turbine Generator sets in two nuclear power plants in India whose overhauling schedule had always overshot the stipulated 30 day time schedule. The analysis revealed that with the resources deployed, it was impossible to complete the overhauling in the stipulated time schedule. It was also found that the resource allocation is not optimum and needs to be altered to give better results. It is further shown that a potential minimum of 10% saving on the overhauling schedule can be achieved by the application of the Critical Chain Project Management philosophy.
Keywords: Critical Chain Project Management, Turbine-Generator Overhauling, Resource Levelling.

INTRODUCTION

Time and cost overruns have been endemic to projects all over the world. This is true not only for big projects, but smaller ones too. Availability of un-interrupted power from any power plant to the national grid is an optimum requirement. However, to meet the equipment safety and maintenance needs, the turbine generator (TG) of the power plant has to be periodically overhauled. For economic reasons, it is not possible to have standby arrangement to ensure uninterrupted power during the maintenance period. Hence the only option open is to minimize the shutdown period to increase availability of the TG sets.

We have been involved with the overhauling of four 220 MW turbine generator sets in two power plants in India. The overhauling is done on a tight schedule of 30 days involving an exhaustive list of tasks covering the entire scope of work from stopping of the TG, its opening to its final box-up and synchronization with the grid.

In view of the criticality of putting back the TG sets into operation in the shortest possible time, the overhauling is carefully planned and sufficient advance preparations are made to ensure that the shutdown period of the plants for the overhauling work are not exceeded beyond the scheduled time frame of 30 days.

However, inspite of all the advance preparations and planning, it was observed that the overhauling work invariably got delayed by a few days. Hence any method that could shorten the total overhauling duration, or at least prevent overshooting the set time frame, would not only be most welcome but also result in considerable savings to the client organization. To this end, the applicability of Critical Chain Project Management (CCPM) framework, originally proposed by Dr. Eliyahu Goldratt was considered.

There has been considerable interest in the concept of CCPM for project scheduling and management since the publication of Dr. Goldratt’s book “Critical Chain” [1]. There have been several reviews of Goldratt’s book and Jeffery and Justin provide one of the good reviews [2]. Even Standard Project Management texts have started integrating the concept of CCPM into their structure [3].

The CCPM framework has been extensively applied in a diverse spectrum of industries [4,5,6] with impressive results being reported. Similarly, CCPM has been a topic of considerable research among academic students too, as can be attested to by a number of MS and PhD thesis that have been published based on applications of the CCPM methodology [7-10].

While there have been a number of papers on various aspects of the philosophy and applications of CCPM [11- 16], there have also been dissenting voices primarily relating to the originality of the concept or the rigour of its underlying assumptions [17- 19].

Our literature review has found that although a lot of areas have been studied by researchers with respect to the application of CCPM methodology, it has not yet been applied to the study of overhauling of power plant turbine generators, particularly in the Indian context. Hence this work is new and original in that respect.

Briefly, the Critical Chain Project Management methodology starts with the usual Critical Path Method (CPM) which is so ubiquitous in project management and scheduling. However, CCPM contends that most activities duration estimates are inflated to ensure that the activity gets completed within the estimated time with a near 90% confidence level. Looking at it in another way, it can be said that normal activity estimates are "padded up" to ensure that there is a 90% probability that the activity will get completed within the estimated time. Hence considerable contingency is normally built into each activity duration estimate. This contingency that is factored into each activity time does not get highlighted explicitly, but is a result of innate human nature to ensure that the activity time is kept as risk free as possible. So, CCPM removes the contingency built into each task estimate by reducing the estimate for completion of a task from a 90% confidence level to 50% confidence level, which is the median activity time (i.e. ensuring 50% probability of completing any task on time).

Then the task level contingency is aggregated into an overall "Project Buffer" and appended to the end of the project. This ensures that the buffer is available for delays to the project as a whole and not to individual tasks. Similarly, the contingency factor taken out of the individual tasks from the branches that feed the Critical Path are also aggregated at the end of the branch to form what are called "Feeding Buffers". Such Feeding Buffers insulate the Critical Path from variances in the feeding paths. Hence delays will not be passed on to the next activity unless the buffers are fully exhausted.

Due to the very important statistical fact that the overall variance of a sequence of activities will be much less than the sum of variance of the individual activities, the length of the buffer at the end of any chain of activities is kept to half of the length of the chain of activities it serves to protect.

Since multitasking is avoided in CCPM, activities are started as late as possible and worked upon till the activity is complete. All resources are levelled or de-conflicted to ensure that there is no multitasking. Once this resource levelling is done, the normal CPM schedule is converted into a CCPM schedule. Now instead of a Critical Path we get a Critical Chain which is the set of tasks having the longest duration which determines the overall duration of the project taking into account precedence and resource dependencies.

RESEARCH OBJECTIVE AND METHODOLOGY

The question we ask is - Can the current turbine generator overhauling schedule be improved upon to reduce the overhauling duration or is the current schedule the most optimum available given the prevalent resource deployment pattern? We address this issue by considering the implications of adoption of Critical Chain Project Management methodology to find out if it could help in reducing the overhauling time frame and consequently improve the turbine generator availability.

The turbine generator overhauling follows a laid down procedure. There are broadly 3 groups of stakeholders in the entire overhauling process. The client (i.e. owner of the power plant), the contractor doing the overhauling work and experts from the Original Equipment Manufacturer (OEM) under whose expert advice and supervision the overhauling work is carried out. The work once started is continued on 24X7 bases in shifts till completion of the overhauling and synchronization of the turbine generator to the grid.

The scope of the overhauling work enjoins upon the client the responsibility for making available all consumables like gaskets, replacement spares, welding accessories, etc as well as all repairs that may be necessitated based on inspection of the opened up turbine generator set. The client has to be very prompt in providing the necessary consumables/spares as well as in carrying out the necessary repairs to ensure that the schedules do not slip. This on some occasions creates delays since coordination is required between several departments within the client's organization. The client is also required to conduct Quality Assurance (QA) tests at various intervals of the overhauling work and give clearance to the contractor to proceed to the next step. This creates procedural delays on some occasions in moving to the next activity.

The client makes available all necessary special tools and tackles required for the overhauling work as well as all utility supplies (like compressed air, water, power, etc). Since most of the equipment are heavy in nature and have to be moved from one part of the turbine generator operating floor to another, use of crane is a constant necessity. In the four cases under study, the client could offer only one EOT crane for the entire turbine generator operating floor. The layout of the turbine generator operating floor is such that use of manual hoists or additional lifting facilities is very limited. Hence the availability of a single EOT crane was a serious resource constraint in the overhauling work. However, this is a system inherent constraint and it cannot be remedied by either the client or the contractor at this point of time.

The contractor provides the entire skilled and unskilled manpower along with supervisory engineers to conduct the entire overhauling work under the guidance of the OEM experts and with the support and stage approvals of the client. The contractor brings in about 65-70 skilled and semi skilled workers for the overhauling work, which includes Fitters, Riggers, Crane Operators, Helpers, etc. A typical manpower resource list is given at Table-1. Availability of skilled manpower resources like Fitters and Riggers at times become constraints when several tasks being performed in parallel require their services. The usual practice is multitasking, which as we have seen in Critical Chain philosophy actually leads to a cumulative increase in the task completion times.

Table-1: Manpower Resource Available for TG Overhauling

Description	**Number**
Engineers (3 per 12 hour shift)	6
Fitters	19
Riggers	18
Helpers	16
Crane Operators (1 per 12 hour shift)	2
Foremen (2 per 12 hour shift)	4

There are 8 OEM experts consisting of 2 Turbine experts, 1 Governing System expert, 1 Vibration expert, 2 Generator experts and 2 Instrumentation experts (1 hardware and 1 software). Their role is to provide expert guidance to the contractor and client. Being of purely advisory nature, they form a manpower resource that is not constrained to hamper the project (although their non-availability at the required time does create problems, but during the time frame of our study, such eventuality did not arise).

Before we proceed further with our analysis, a summary of the four TG overhauling projects completed so far in terms of the time schedule and its escalation is given in Table-2 below:

Table-2: Time overruns for the TG overhauling projects

TG Overhauling Project Reference	**Scheduled Completion Time**	**Actual Completion Time**	**Time overrun (%)**
Location 1, Plant 1	30 days	42 days	40
Location 2, Plant 1	30 days	35 days	16.7
Location 1, Plant 2	30 days	44 days	46.7
Location 2, Plant 2	30 days	36 days	20

The foregoing table clearly shows that there was much scope for improvement as none of the overhauling projects have been completed on time and in the worst case, there has been a time over-run of almost 47%!

Our analysis followed the Critical Chain methodology as detailed in the following steps.

- The major activities comprising of the total turbine generator overhauling and their individual duration estimates along with the precedence requirements were listed out. A total of 61 major activities were identified where each activity is composed of several smaller tasks. The total work is subdivided into four major heads as given below:

Part-A: Opening, Overhauling and Box-up of HP Turbine (consisting of 16 activities)

Part-B: Opening, Overhauling and Box-up of LP Turbine (consisting of 15 activities)

Part-C: Opening, Overhauling and Box-up of Generator (consisting of 13 activities)

Part-D: Miscellaneous Works (consisting of 17 activities)

So the activities are named as A1, A2, ... A16; B1, B2, ... B15; C1, C2,..... C13; D1, D2,..... D17. “S” being the dummy activity of Synchronization of the turbine generator to the grid.

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For arriving at the activity duration estimates, interviews were conducted with the client engineers, the project coordinators and project engineers of the contractor who were involved in all the projects. It was found that all the activity durations had been worked out considering a probability of about 90% successful completion within the estimated activity time. This information was found to corroborate the "Inflated Activity Duration Estimates" debility pointed out by CCPM philosophy

- Based on the activity duration estimates arrived at in the above step and considering the precedence requirements, the project schedule was prepared with MS Project software. The Critical Path was identified and the project completion time arrived at was 30 days, as per the expected completion schedule. Table-3 gives the activity durations and precedence requirements.

Table-3: Original Activity Durations and Precedence Requirements

ACTIVITY	TIME REQD (IN DAYS)	PRECEDING ACTIVITIES	ACTIVITY	TIME REQD (IN DAYS)	PRECEDING ACTIVITIES
AI	1	NIL	C1	3	D1
A2	2	A1	C2	3	D1
A3	2	A1	C3	2	C1,C5
A4	2	A1,A2	C4	2	C2,C6
A5	2	NIL	C5	2	C1
A6	2	NIL	C6	2	C2
A7	1	A1	C7	1	C5
A8	1	A4,A5,A6,A7	C8	1	C6
A9	3	A8	C9	2	C10
A10	3	A9	C10	2	C1 - C8
A11	5	A10	C11	3	C10
A12	3	A11	C12	4	NIL
A13	2	A5.A6	C13	8	C10
A14	3	A1,A7	D1	4	NIL
A15	8	A1,A3	D2	2	C10
A16	11	A1,A2	D3	2	C11
B1	2	B2	D4	2	A1
B2	2	NIL	D5	2	A1
B3	1	NIL	D6	2	A1
B4	2	B3	D7	3	A15.A16
B5	1	B2	D8	8	A15.A16
B6	1	NIL	D9	8	A15.A16
B7	1	B2,B5	D10	2	A15.A16
B8	15	B2	D11	2	A15.A16
B9	6	B5	D12	2	A5,A6,B3
B10	4	B9	D13	3	D11
B11	3	B10	D14	15	A4
B12	3	B11	D15	14	A5,A6,B3
B13	7	A7,A14,B6	D16	14	D15
B14	2	D12	D17	3	A15.A16
B15	2	B4	S	0	A12,B12,C13,D9,D16

- Then the resource dependencies for the various tasks were considered. Table-1 gives the total manpower resources available for the overhauling work.

The three critical categories of manpower resources required are Fitters, Riggers and Helpers. Apart from these three major categories, at least 3 supervising engineers, 1 Crane operator and 2 foremen are available in each shift. They are not a resource constraint. The resource constraint is primarily with the availability of Fitters, Riggers and Helpers. Further, since the client also constantly keep their engineers and technical staff on standby, minor availability gaps in these 3 critical resources can be overcome with these staff or with the help of contractor's engineers. Hence the "resource levelling" was done using this fact in mind and resource shortfall upto 3-4 personnel of any category were not considered a constraint.

Table-4: Activity wise Critical Manpower Resource Requirement

DAILY RESOURCE REQD / ACTIVITY				DAILY RESOURCE REQD / ACTIVITY			
ACTIVITY	FITTER	RIGGER	HELPER	ACTIVITY	FITTER	RIGGER	HELPER
AI	2	2	4	C1	3	3	3
A2	2	4	2	C2	3	3	3
A3	2	4	2	C3	3	3	3
A4	2	4	2	C4	3	3	3
A5	2	3	2	C5	3	3	3
A6	2	3	2	C6	3	3	3
A7	6	6	4	C7	3	3	3
A8	2	4	2	C8	3	3	3
A9	3	3	2	C9	3	3	3
A10	2	2	1	C10	3	0	2
A11	2	2	4	C11	3	5	2
A12	3	3	3	C12	4	4	2
A13	3	3	2	C13	4	4	2
A14	2	2	3	D1	3	1	2
A15	2	2	2	D2	3	1	2
A16	2	4	3	D3	3	1	2
B1	1	0	1	D4	3	1	2
B2	4	4	4	D5	3	1	2
B3	6	6	4	D6	3	1	2
B4	2	2	2	D7	3	1	2
B5	3	4	4	D8	3	2	2
B6	3	3	2	D9	3	2	2
B7	3	3	3	D10	3	2	2
B8	3	1	4	D11	3	2	2
B9	2	4	2	D12	3	1	4
B10	3	3	2	D13	4	1	2
B11	3	4	2	D14	3	0	0
B12	3	4	2	D15	4	1	0
B13	3	3	2	D16	7	2	0
B14	2	0	2	D17	3	4	2
B15	2	2	2				

We now resolve the resource conflicts by rearranging the activities in such a way that no resource is required to "multitask" since multi-tasking is an activity that is to be fully avoided in the CCPM framework.

Table-5: Resource Levelled/De-Conflicted Daily Activity Scheduling

		TOTAL DAILY RESOURCE REQUIRED			RESOURCE AVAILABLE			RESOURCE SURPLUS/DEFICIT		
DAY	ACTIVITIES SCHEDULED	F	R	H	F	R	H	F	R	H
1	A1,A5,A6,B3,B2,B6	19	21	18	19	18	16	0	-3	-2
2	A5,A6,A2,A3,B2,C12,D1	19	23	16	19	18	16	0	-5	0
3	D15,A2,A3,B8,C12,D1,B1	19	15	13	19	18	16	0	3	3
4	D15,A4,A15,A16,B8,C12,D1,B1	21	16	15	19	18	16	-2	2	1
5	D15,A4,A15,A16,B8,C12,D1	20	16	14	19	18	16	-1	2	2
6	D15,D14,A15,A16,B8,A7	20	13	12	19	18	16	-1	5	4
7	D15,D14,A15,A16,B8,B4,D4,A8	21	14	14	19	18	16	-2	4	2
8	D15,D14,A15,A16,B8,B4,D4	19	10	12	19	18	16	0	8	4
9	D15,D14,A15,A16,B8,D5,D6	20	9	12	19	18	16	-1	9	4
10	D15,D14,A15,A16,B8,D5,D6	20	9	12	19	18	16	-1	9	4
11	D15,D14,A15,A16,B8,A13,A14,B15	21	14	15	19	18	16	-2	4	1
12	D15,D14,A16,B8,A13,A14,B5,B15	22	17	17	19	18	16	-3	1	-1
13	D15,D14,A16,B8,A14,D12,B7,B9	22	16	18	19	18	16	-3	2	-2
14	D15,D14,A16,B8,D12,B9	17	11	12	19	18	16	2	7	4
15	D15,D14,B8,B9,B14,C1,C2	20	12	14	19	18	16	-1	6	2
16	D15,D14,B8,B9,B14,C1,C2	20	12	14	19	18	16	-1	6	2
17	D16,D14,B8,B9,C1,C2	20	13	12	19	18	16	-1	5	4
18	D16,D14,B9,B13,A9,C5	21	15	9	19	18	16	-2	3	7
19	D16,D14,B13,A9,C5,C6	22	14	10	19	18	16	-3	4	6
20	D16,D14,B13,A9,C6,B10	22	14	9	19	18	16	-3	4	7
21	D16,B13,A10,B10,C3,C4	21	16	11	19	18	16	-2	2	5
22	D16,B13,A10,B10,C3,C4	21	16	11	19	18	16	-2	2	5
23	D16,B13,A10,B10,C7,C8	21	16	11	19	18	16	-2	2	5
24	D16,B13,A11,B11,C10,D11	21	13	12	19	18	16	-2	5	4
25	D16,A11,B11,C10,D11	18	10	10	19	18	16	1	8	6
26	D16.A11,B11,C13,C9,C11	22	20	13	19	18	16	-3	-2	3
27	D16,A11,B12,C13,C9,C11	22	20	13	19	18	16	-3	-2	3
28	D16,A11,B12,C13,C11,D2	22	18	12	19	18	16	-3	0	4
29	D16,A12,B12,C13,D2	20	14	9	19	18	16	-1	4	7
30	D16,A12,C13,D3,D13	21	11	9	19	18	16	-2	7	7
31	A12,C13,D3,D13,D8,D9	20	13	13	19	18	16	-1	5	3
32	C13,D13,D8,D9,D7,D10	20	12	12	19	18	16	-1	6	4
33	C13,D8,D9,D7,D10,D17	19	15	12	19	18	16	0	3	4
34	D8,D9,D7,D17	12	9	8	19	18	16	7	9	8
35	D8,D9,D17	9	8	6	19	18	16	10	10	10
36	D8,D9	6	4	4	19	18	16	13	14	12
37	D8,D9	6	4	4	19	18	16	13	14	12
38	D8,D9	6	4	4	19	18	16	13	14	12

F = Fitter; R = Rigger; H = Helper

Based on our resource re-arrangement, we get revised activity estimates and a new project schedule is created which is "resource levelled". Now the project completion duration after de-conflicting the resources comes to 38 days. (Table-5)

The re-worked project schedule after considering the "resource constraints" was, as expected, found to be longer than the initially calculated Critical Path schedule. This yielded the set of activities with the longest path for completion of the project after "resource levelling" which in CCPM parlance is the Critical Chain

- In the final step, we reduced the activity durations by 50% of their original estimates. As mentioned earlier, this gives each activity a 50% likelihood of completion rather than the original 90%. This step is important in the CCPM philosophy to avoid Student Syndrome (waiting till the last moment when the

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activity becomes really critical) and minimise the impact of Parkinson's Law (Work expands to fill the available time). The resource allocation was also re-worked based on the revised daily activity schedule keeping the precedence requirements in view. The revised project duration now comes to just 18 days and the project schedule now looks as shown in Table-6.

Table-6: 50% probable activity durations and resource levelled project schedule

DAY	ACTIVITIES SCHEDULED	TOTAL DAILY RESOURCE REQUIRED			RESOURCE AVAILABLE			RESOURCE SURPLUS/DEFICIT		
		F	R	H	F	R	H	F	R	H
1	A1,A5,A6,B3,B2,B6,C12,D1	21	21	17	19	18	16	-2	-3	-1
2	D15,A2,A3,C12,D1,B1,B8	19	15	13	19	18	16	0	3	3
3	D15,B8, A4,A15,A16,A7,B4,D4	20	15	15	19	18	16	-1	3	1
4	D15,A15,A16,B8,D14,A8,D5,D6	20	11	13	19	18	16	-1	7	3
5	D15,A15,A16,B8,D14,C1,C2,A9,A14	22	15	16	19	18	16	-3	3	0
6	D15,D14,A15,A16,B8,C1,C2,A9,A14	21	16	16	19	18	16	-2	2	0
7	D15,D14,A16,B8,B5,C5,C6	19	14	14	19	18	16	0	4	2
8	D15,D14,A16,B8,A10,B7,B9,C3	19	15	14	19	18	16	0	3	2
9	D14,B8,A10,B9,D16,C4	19	12	10	19	18	16	0	6	6
10	D14,B9,D16,A11,C7,C8,D17	19	14	9	19	18	16	0	4	7
11	D14,B10,D16,A11,C10.D17,D11	22	11	11	19	18	16	-3	7	5
12	B10,D16,A11,C9,C11,D12	19	13	14	19	18	16	0	5	2
13	A12,D16,C11,A13,B13,C13,B11	21	19	10	19	18	16	-2	-1	7
14	D16.B13,C13,D8,B11,A12	23	18	11	19	18	16	-4	0	5
15	D16,B13,C13,D8,D9,B12	21	15	9	19	18	16	-2	3	7
16	B13,C13,D8,D9,B14,B15,D7,B12	22	18	15	19	18	16	-3	1	1
17	D8,D9,D7,D2,D3,D10,D13	20	10	13	19	18	16	-1	9	3
18	D9,D13	7	3	4	19	18	16	12	15	12

F = Fitter; R = Rigger; H = Helper

To factor Murphy's Law (Anything that can go wrong, will go wrong), and also since we had taken activity times that give them only a 50% chance of getting completed in the allotted time, the individual activity buffers built into the activity times is now clubbed as the project buffer and appended to the end of the project. The length of the buffer could be kept at the same length as the chain of activities they stand to protect. In our case, since the Critical Chain is 18 days in length, we could have a Project Buffer length of 18 days. However, utilizing the powerful concept of statistical aggregation, we cut the size of the Project Buffer (which is applicable to all Feeding Buffers also) to 50% of the chain length they stand to protect. So in our case the Project Buffer is kept as 9 days. Adding this to the revised project schedule, we find that the entire project schedule is now 27 days, which is the final project schedule with the CCPM philosophy.

We had a limitation in that in the absence of access to specialised software like Prochain used for CCPM scheduling, iterative process was used to find the best possible solution. Further, in view of the fact that a number of activities can be carried out independently, there is more than one way to schedule the activities by levelling the resources.

ANALYSIS

The following important facts emerged from our study:

- Even by retaining the original activity duration estimates, the minimum total duration for completion of the project after de-conflicting/levelling the three critical manpower resources comes to 38 days. This is a very important conclusion because it implies that the turbine generator overhauling work could never be completed within the stipulated 30 days with the deployed resources and/or the existing project scheduling and management methodology.

This conclusion is supported by the fact that in actuality, at no point of time has the overhauling work been completed in less than 35 days (Table-2). An examination of the records revealed that even in such cases, several short-cuts were employed and certain procedures were not fully carried out to prevent further delays.

- The manpower resource deployment shows that it is quite lopsided. The number of fitters required is almost always in short supply (even after considering extra 3 numbers availability from the client work pool) while riggers and helpers are almost always in excess supply. This resource imbalance was never observed previously during any of the overhauling work because the resources were never specifically allocated to individual tasks. Resource conflicts always happened and the available resources were made to multitask which hid the problem but nevertheless delayed the whole schedule.

- Applying the CCPM methodology of cutting down the task times to 50% of their original estimates and using the requisite buffers, we find that the revised project completion schedule is 27 days. This schedule has a very reasonable 9 day Project Buffer built in at the end of the project. This implies a saving of 10% over the scheduled project duration. In money terms, this is really important from any organization's point of view.

CONCLUSION

The analysis has shown that Critical Chain Project Management is an attractive tool for scheduling and managing critical time constrained projects with the potential to make significant savings in project time and cost.

The present work brings forth the serious mismatch in resource allocation for the turbine generator overhauling work which was previously un-noticed.

The application of CCPM methodology brings on table a potential saving of about 10% on the project time. This implies the availability of the turbine generator 3 days ahead of the scheduled time. Given that a day's power generation adds millions of rupees in revenues of the client, this would translate into considerable savings to the client. This is extremely significant not only in terms of monetary terms but also when we consider that all through the previous turbine generator overhauling projects have had a minimum of 15-20% time overrun.

This research requires validation as the theoretical analysis conducted needs to be validated on actual project which we hope to do at the earliest available next opportunity.

Though promising, the CCPM methodology needs to be investigated further, particularly in a multi-project scenario with resource sharing. Further, the underlying assumptions in the CCPM framework like using 50% activity times, the lengths of project buffer and feeder buffers used with respect to the chains they protect, etc need further validation and theoretical support. These are fertile areas for research by academic as well as industry scholars.

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