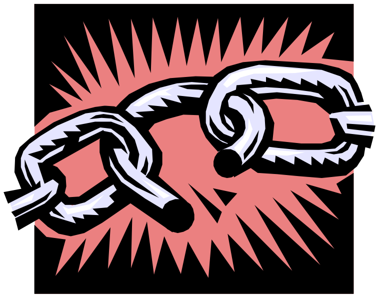
Critical Chain Project Management Improves Project Performance



By

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Abstract

Critical Chain Project Management (CCPM) provides a substantial step in ongoing improvement to the Project Management Body of Knowledge (PMBOK). The critical chain differs from the critical path by:

a) Including resource dependencies, and

b) Never changing.

CCPM improves the project plan by ensuring that it is feasible and immune from reasonable common cause variation (uncertainty, or statistical fluctuations). It does this by aggregating uncertainty into buffers at the end of activity paths. The Project Buffer protects the overall project completion on the critical chain path, and Feeding Buffers protect the critical chain from path merging. Buffer Management enhances measurement and decision making for project control. CCPM implements required changes in resource behaviors, including elimination of date-driven activity performance and multitasking. Most of all, CCPM improves the ***focus*** of the Project Manager and performers. Projects that use CCPM have a greatly improved record of schedule, cost, and scope performance. CCPM projects are normally complete in less than one half of the time of projects using previous planning and control methods.

Introduction

Critical Chain Project Management (CCPM) adds to the present Project Management Body of Knowledge (PMBOK), as described in PMBOK Guide[1] and supporting literature, in the areas of project planning, activity performance and control. CCPM emphasizes the time of project completion. It also reduces project changes and the major source of project cost over-runs by improving schedule performance. It accomplishes these results by changing the project plan, the project measurement and control system, and certain behaviors by the project team and supporting personnel.

Project Performance Problems

The continuing high rate of project failure drives the need for continuous improvement in project performance. One (now somewhat dated) study from Australia[2] found that construction projects completed only one eighth of building contracts within the scheduled completion date, and that the average overrun exceeded 40%. Chun and Kummaraswamy reported this in a recent study[3] of the causes of time overruns in Hong Kong construction projects. The same study noted, "Delays in construction projects are still very common in most parts of the world, even with the introduction of advanced construction technologies and more effective management techniques." Quantitative data on overall project performance statistics seem to be in short supply, but reported instances of project failures to achieve promised cost, or schedule abound. Substantial evidence exists in news reports for large projects, especially large government projects (of many nations.) Personal experience supporting large companies that manage many projects supports a view that a substantial percentage of projects fail to meet objectives.

The literature ascribes many potential causes to project failure.[4] While there appears to be some overlap in the causes reported by different sources, there is little overall consistency. No studies of project failure attempt to differentiate between common cause and special cause variation (see below.) The international scope and wide range of project types that experience project performance difficulty implicates the project management system as a leading suspect.

Theory of Constraints

CCPM derives from applying the Theory of Constraints to project management. Dr. Eliyahu Goldratt first described the essence of the Theory of Constraints in his international best seller The Goal[5]. The Goal presents an improved system of factory management that has had, and continues to have, dramatic improvements impact in many companies.

Dr. Goldratt named the method underlying development of his system improvements the Theory of Constraints, or TOC. Dr. Goldratt based TOC on the scientific method. TOC states, "*Any system must have a constraint. Otherwise, its output would increase without bound, or go to zero.*" Most people readily accept this statement as self-evident fact. The astonishing thing is the results that derive from it. TOC's impact has been compared to Newton's discovery of the laws of motion.

The primary message of The Goal is ***Focus***. ***Focus*** on the goal of the company. ***Focus*** on the constraint that blocks achieving the Goal of the company. The Goal ends with the **Five Focusing Steps,** which are applicable to any physical system. These steps are:

1. ***IDENTIFY*** the system constraint.
2. ***EXPLOIT*** the system constraint.
3. ***SUBORDINATE*** everything else to the system constraint.
4. ***ELEVATE*** the system constraint, and
5. If, in the previous step, a new constraint has been uncovered, repeat the process. Do not let ***INERTIA*** become the system constraint.

In part, because Dr. Goldratt wrote The Goal in the context of a factory production line, the project management community fails to understand the significance to projects. Publication of Critical Chain[6] corrects this. It describes the application of the underlying theory that led to the systems used in improving production management to project management. I describe the project management system developed in Critical Chain as Critical Chain Project Management (CCPM).

Goldratt and his associates developed and refined the application of CCPM since the early 1990s. Dee Jacob, a partner in the Avraham Y. Goldratt Institute and primary contributor, tested the methods with a prior Fortune 500 company, and successfully led many implementations. They now have a substantial experience base and success record to come forth with the method as a general improvement to the PMBOK, which many practitioners are now applying to an increasing variety of projects.

The following discussion follows the focusing steps.

Identify the Project Constraint

TOC identifies the constraint of a project as the *Critical Chain*, or "*The sequence of dependent events that prevents the project from completing in a shorter interval. Resource dependencies determine the critical chain as much as do task dependencies.*"

Defining the constraint of a project in terms of the schedule derives from the impact that schedule has on project cost and project scope. The three conditions are dependent. As schedule increases with fixed deliverable scope, cost usually increases. As scope increases with fixed cost (or resources), schedule tends to increase. As scope increases with fixed schedule, cost tends to increase.

Critical Path project planning has an often hidden assumption that an acceptable way to account for potential resource constraints on the project is to first identify the critical path, and then perform resource leveling. Network specialists know that there is no optimum method for resource leveling. Network configurations; some resource leveling algorithms give very poor results. For most networks, application of the resource leveling algorithms lengthens the overall schedule. For this reason, few projects use the resource leveling tools.

Figure 1 illustrates a typical deterministic project schedule. The colors represent unique resources. The plan identifies the last activity as a critical path activity. Resource leveling has eliminated the rest of the critical path. This is a frequent result of resource leveling methods.

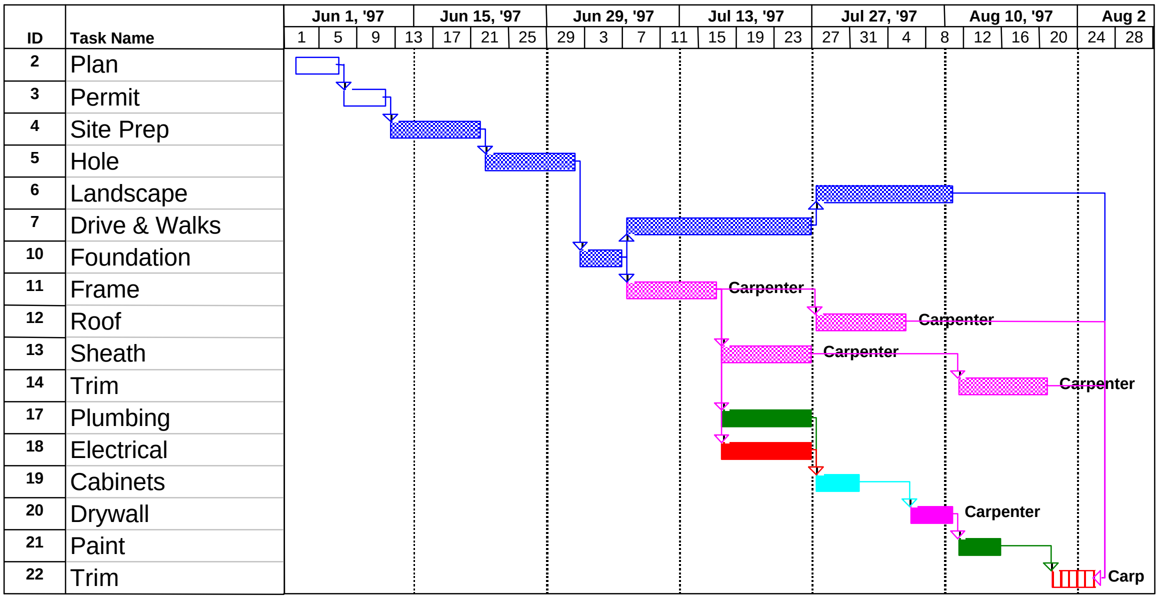

Figure 1: Example resource leveled critical path schedule.

Since the resource constraint is often a significant project constraint, the Theory of Constraints method of project planning always considers it. Thus, the critical chain includes the resource dependencies that define the overall longest path (constraint) of the project. The method resolves all resource constraints while determining the project critical chain. The project critical chain may have gaps between activities.

The improvements that result from CCPM do not depend on having significant resource constraints or conflicts in the project. They apply to any project, for the reasons outlined below. For a project without resource constraints, the critical chain will be the same initial activity path as the critical path. The project plan differs significantly, as described below.

The PMBOK Guide definition of critical path states that the critical path may change during the performance of the project. This occurs when other paths experience delay, and redefine the longest 'zero float' path to complete the project. The critical chain does not change during project performance. This is partly a matter of definition, but mostly a result of the overall critical chain plan construction procedure.

The next step follows the five focusing steps to develop and use CCPM. They exploit the constraint by **focusing** to get the most out of a given length of schedule.

Exploit

Exploit Common Cause Variation

Dr. W. Edwards Deming included 'an understanding of variation' as one of his four points of Profound Knowledge[7]. He identified two types of variation:

1. Common Cause Variation: A cause that is inherent in the system. The responsibility of management.
2. Special Cause Variation: A cause that is specific to some group of workers, or to a particular production worker, or to a specific machine, or to a specific local condition.

Dr. Deming notes that managers often make many systems worse by not understanding the fundamental difference between these two types of variation. He also notes, "I should estimate that in my experience most troubles and most possibilities for improvement add up to propositions something like this:

> 94% belong to the system (responsibility of management)
>
> 6 % special."

Projects have common cause variation in the performance time of activities. Although the time to perform individual project activities may be independent of each other, project activity networks define activity dependence. By the definition of the project logic, the successor activity can not start until the predecessor activity is complete (for the most frequent finish-to-start activity connection.)

Dr. Goldratt's improvements for production take advantage of (exploit) the reality of statistical fluctuations and dependent events. Figure 2 illustrates a typical activity performance time distribution. The solid curve (left ordinate) shows the probability of a given time on the abscissa. The dotted line shows the cumulative probability of completing the

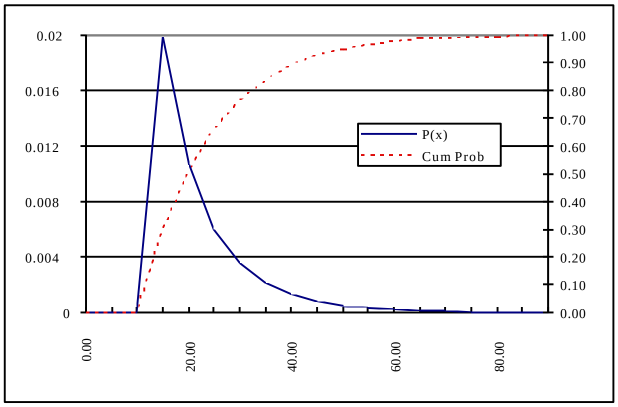

Figure 2: Typical project activity performance time probability distributions show a minimum time, left skew, and a long tail to the right.

activity in a time less than or equal to the time on the abscissa. Note the left skew of the distribution and the long tail to the right; this is typical of the common cause variation for many project activities.

Fluctuations in the actual performance of unique project activities are likely to be much larger than fluctuations in the time it takes a production machine or person to repeatedly process a part. The project activity network clearly shows the many dependencies that exist in a project. Comparison of nearly any project to a production line shows that there are more dependencies in even a modest sized project. For these reasons, the logic that improved production should also improve project management.

This common cause variation in activity performance is not an exceptional event, such as discrete project risk events. PERT attempted to estimate the impact of this common cause variation using three activity duration estimates, but for a variety of reasons did not succeed. The PMBOK Guide and literature still make mention of PERT in this fashion, although it is little used today. 'PERT diagrams,' as referred to in much of the project literature and in many project software packages are simply a way to show the project network logic independent of the time scale; not an application of the three time estimates. Some projects use methods such as simulation and Monte Carlo analysis to assess the impact of activity duration and cost uncertainty. While these methods propose a way to estimate uncertainty, they do not pose an effective systematic method to manage it.

CCPM accounts for common cause variation as an essential element of the project management system. The process removes identifiable special causes of variation, including resource unavailability and common resource behavior patterns, including the student-syndrome and multi-tasking. CCPM Project Managers use resource flags to identify and ensure availability of resources on the critical chain.

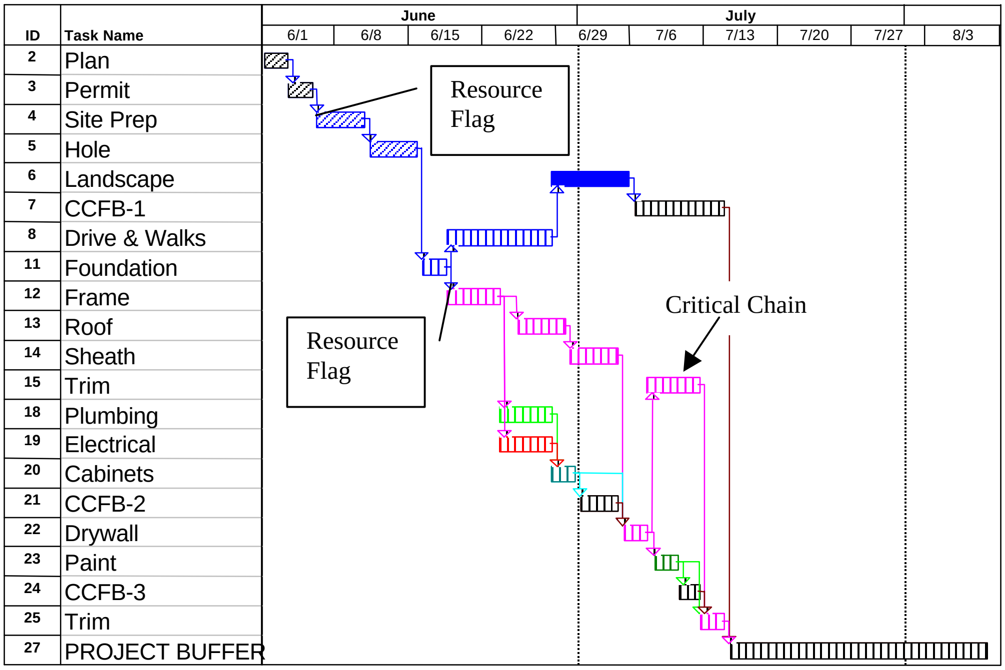

Figure 3: Example Critical Chain schedule identifies key features of the plan.

Exploit Project Activity Estimates

Most project managers attempt to account for individual activity common cause variation by adding contingency[1] time into each estimate. They usually do not specify the existence or amount of this contingency time. People estimating activity times for a project usually do so believing that the project manager wants 'low risk' activity times; perhaps a probability of 80% to 95% completion on or less than the activity duration estimate. Figure 2 illustrates that this estimate is two or more times the 50% probable estimate. In most project environments, people feel good if they complete an activity by the due date, and feel bad if they over-run the due date. This reinforces their attempts to estimate high probability completion times.

Walter A. Shewhart, mentor to W. Edwards Deming, noted[8]:

> *"It should be noted that the statistician does not attempt to make any verifiable prediction about one single estimate; instead, he states his prediction in terms of what is going to happen in a whole sequence of estimates made under conditions specified in the operational meaning of the estimate that he chose."*

This view clarifies why attempts to deal with uncertainty for individual activity estimates are fruitless.

Some experienced Project Managers state that, 'people tend to give optimistic estimates.' They base this contention on remembering the instances in which projects had difficulty meeting the delivery date. Generalizing this observation does not hold up under examination for several reasons.

First, extensive psychological research demonstrates that people tend to seek pleasure and avoid pain. In most project environments, people get pleasure and avoid pain by completing activities on the due date. Hardly anyone wants to be known as the person who can be counted on to deliver late. It is not reasonable to expect people to solicit pain by systematically giving 'optimistic' estimates.

Second, people remember selectively. They easily remember worst case outcomes (pain), but not necessarily all of the times things went to their advantage. Don't most people feel that they always pick the slowest line in a bank or supermarket? Do you really believe that this is true? People also will tend to forget predecessors leading to the outcome (See the Student syndrome, below). This mental feat has two interesting effects:

1. The Project Managers selectively remember the instances where activity duration estimates were exceeded, and therefore wants to add contingency of his own, and
2. Activity performers tend to add time to their next estimate.

Third, if underestimating activity durations were the predominant fact, nearly all projects would be late. Assuming that most of the potential positive variation in activity times is returned to the project (evidence suggests otherwise), the merging of activity paths ensures a very low probability of success if individual estimates are less than 50% probable. (Real project behavior is, of course, confounded by control actions taken during project performance. These control actions may help or hinder overall completion time performance.)

While many projects do fail to meet schedule, our observations indicate that a substantial portion do achieve the scheduled project end date. Almost all projects to create bid proposals complete on time. Nearly all major meetings come off as planned with few problems. The Olympics has not yet been delayed due late project completion. (The stadium in Atlanta caused anxious moments, but was ready none-the-less.)

Milestone performance in a very large project demonstrates that the activity performance data conform very closely with Dr. Goldratt's prediction that about 80% of the activity milestones are achieved exactly

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[1] **Contingency:** *the difference between the 95% probable estimate and the 50% probable estimate.* (An operational definition for this paper.)

on the scheduled date, with only one or two sooner and the rest later, including a few significantly later. This project consists of about thirty large subprojects, some of which contain yet smaller subprojects.

My experience shows project plans from a variety of organizations (numbering in the hundreds) either fail to specify what probability and confidence of estimate is expected for activity duration estimates, and/or fail to provide a quantitative basis for the estimate. The PMBOK Guide admonishes project managers to provide these estimates, but provides little guidance on what to do with them. Construction projects are somewhat of an exception, having access to extensive quantitative data. For example, the National Construction Estimator[9] uses an extensive database. The Construction Estimator lists many potential contributors to common cause uncertainty in the estimates. The guide states that many of these uncertainty items have ranges of several tens of percents of the cost estimate. Therefore, in many cases, they have the same potential impact on schedule.

CCPM seeks to use best estimate, or 50% probable, individual activity time estimates. The CCPM Project Manager recognizes that actual individual activity performance times include common cause variation, and does not criticize activity performers for individual activity duration performance.

Exploit Statistical Laws Governing Common Cause Variation

The PMBOK Guide (Table 11-2) describes the well known statistical law of aggregation, "The project variance is the sum of the individual activity variances." Note that in the statistical terminology, variance is the square of the standard deviation, usually represented by 's^2' or the Greek sigma squared. For a given statistical distribution, it requires a given number of standard deviations to provide a cumulative probability to that point. For example, with a normal distribution one standard deviation represents 67% of the data, or a cumulative probability that 67% of the time a result will fall within one standard deviation of the mean.

The statistical method to combine variances means that you can protect a chain of activities to the same level of probability with much less total contingency time than you can protect each individual activity. Aggregation of the contingency times dramatically reduces the overall estimated time for a chain of activities. Consider a chain of four activities, each of which has a 50% probability estimated duration of one time unit, and a 90% probable estimated activity duration of two time units. If you include the contingency in each activity, the chain of activities is eight units long. If you use the law of aggregation, you can protect the whole chain to 90% probability by scheduling the individual activities at their 50% estimates (a total of four units), and adding a two unit buffer at the end of the chain, for a total of six units.

A second factor that comes into play in aggregating activities is the central limit theorem. The central limit theorem states[10], "as sample size increases, the distribution of the sample mean becomes closer to the normal distribution." Many project activities have a skewed probability distribution. That is, they have an absolute minimum time, and a long tail to the right meaning that they can take much longer than the average time. These left skewed distributions also generally have a mean that exceeds the most frequent, or median time. A project chain of activities is therefore more likely to have a symmetrical distribution, and a variance that is much smaller than the algebraic sum of the individual activity distributions. This is true whether you know the real distributions or not.

CCPM exploits the statistical law of aggregation by protecting the project from common cause uncertainty of the individual activities in an activity path with buffers at the end of the path. Buffers appear as activities in the project plan, but have no work assigned to them.

Subordinate Merging Paths

Most projects have multiple activity paths. All activity paths must merge into the critical path by the end of the project; if for no other reason into a milestone that identifies project completion. Usually, the path merges tend to concentrate near the end of the project. One reason for this is that 'assembly' or 'test' operations tend to occur near the end of the project, requiring many elements to come together. The following demonstrates how this becomes a primary cause of the well-known project ‘truth’ that, ‘Many projects complete 90% in the first year, and complete the last 10% in the second year.’

Activity path merging creates a filter that eliminates positive fluctuations, and passes on the longest delay. The reason is that merging activity paths means that all of the feeding paths are required to start the successor activity. Therefore, the successor activity can not start until the latest of the merging activities completes. Consider an activity on the project critical path that requires three separate inputs in order to start. This a very frequent in assembly operations, and in many project results, such as a major show or meeting event where everything has to be ready on opening day. Usually, there are many more than three. However, even with three, if each has a 50% chance of being done in the estimated time, the probability that at least one is late is over 88%! Even if each individual activity had a 90% probability of completion, the probability of at least one is late is still 30%, or nearly one out of three times.

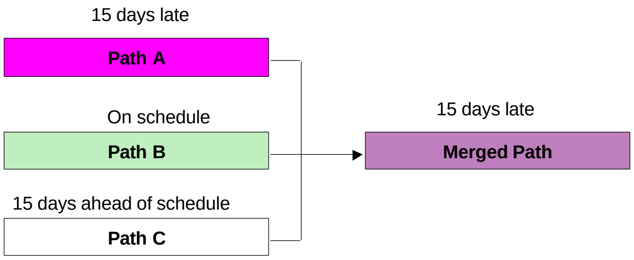


Figure 4: The impact of activity path merging.

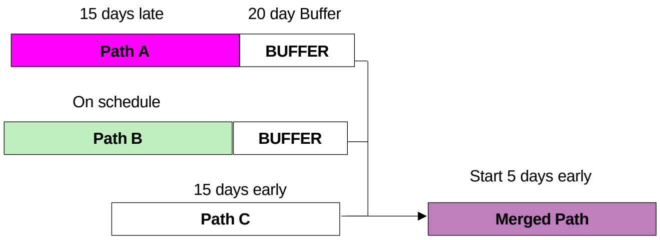


Figure 5: Critical Chain Feeding Buffers (CCFBs) absorb delays from critical chain feeding paths.

CCPM protects the critical chain from potential delays by subordinating critical chain feeding paths; placing an aggregated Feeding Buffer on each path that feeds the critical chain. This includes paths that merge with the critical chain at the end of the project. The feeding buffer provides a measurement and control mechanism to protect the critical chain, as described below. Figure 5 illustrates how the buffers absorb the late paths.

This innovation immunizes the critical chain from potential delays in the feeding paths. It also provides a means to measure the feeding paths, while keeping focus on the critical chain.

Activity Performance

Elevate Date Driven Performance

The primary local optimum of significance in project management is the estimate of each individual activity time. If management judges the performer of each activity based on completing their activity on the estimated milestone date (local optima), what does this do to the overall project completion time (System optima)?

Analysis of almost any project’s results reveals that people report very few activities as completed early. If you had 50% estimates, you should expect that people complete and report 50% of the activities early. If you have 99% estimates, you should have 99% of the activities reported completed early. Usually, people report most of the activities as done on the milestone date, and they report significant portions of the activities as late. Why don’t projects see much positive variation?

The reason is that most of the times; performing resources fail to pass on most of the positive variations. Critical Chain describes several effects that lead to performance systematically over-running these times, although they initially had extensive contingency time. Merideth and Mantel[11] state, "...operation of *Parkinson's Law* …clear and present danger. The work done on project elements is almost certain to 'expand to fill the additional time.'" In Dr. Goldratt's words, the safety time is wasted.

In most cultures, there is little or no reward for completing individual activities early, and plenty of punishment for being late or having quality problems. In many project environments, there is a significant disincentive to reporting an activity complete early. Work performed on 'time and material' contracts results in less revenue if the work is completed and turned in early. Many companies budget work performed by internal functional organizations as if it were time and material contract work. If the functional organization completes the work in less time than estimated, they can not continue to charge to the project. They must find alternative work for the resources. If individuals complete activities early, they get more to do. These cultures drive local optima, which means delivery on the milestone date, but not before. There are many ways to justify keeping the potentially early result. Managers can put its review or completion at 'low priority,' because it is not due yet, or the resource can 'polish the apple.' The result is the same: people waste contingency time originally included in individual activity time estimates.

Did you always study for you exams weeks ahead, so you could go to bed early the night before? Did you always write your papers to get them done at least a week before the deadline, to avoid the gap in the library where all the books on the topic used to be, and to get to the College computers before everyone else was on them all night? (They did not have many computers when I was in college, so this was not a problem for me.)

Many people have a tendency to wait until tasks get REALLY URGENT before they work on them. This is especially true for busy people in high demand. That is, all of the most important people the Project Manager is counting on to get the Critical Path work done on time. If people believe they have some extra time in their estimates, they are often willing to accept other 'higher priority' work at the beginning of the scheduled activity duration. This tends to waste their 'contingency time,' forcing them to perform most of the work in the later portion of the scheduled activity time.

Figure 6 shows the typical work pattern of many people. Dr. Goldratt calls this the student syndrome. They do less than a third of the work on an activity during the first two thirds of the activity duration, and the final two-thirds during the last third of the activity duration. They more likely to find they have a problem to complete the activity in the remaining time during the last third of the scheduled activity time. If they are working above 100% capacity already to complete two thirds of the work in one third of the time, it is unlikely they can keep to the activity duration. They have little chance to recover from an unanticipated problem, such as computer failures. This makes if *feel* like the activity was underestimated to begin with.

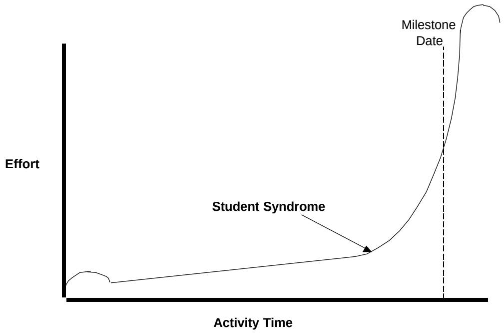


Figure 6: The student syndrome leads to late activity performance, even if there was contingency to begin with.

Student syndrome behavior is a second cause of losing the positive side of activity duration variation. The factors described above make it unlikely the project can take advantage of it, even if it did happen in the activity. The reality is that relative activity duration normally shows a skewed distribution, with a mean well above the Most Likely activity time. You often see over-runs on activity time, but rarely see under-runs.

Critical Chain Project plans only provide dates for the start of activity chains and the end of the project buffer. For the rest of the project, the plan provides approximate start times and estimated activity duration. Critical Chain Project Managers do not criticize performers that over-run estimated activity durations, as long as the resource a) started the activity as soon as they had the input, b) worked 100% on the activity (no multi-tasking), and c) pass on the activity output as soon as it is completed. They expect 50% of the activities to over-run.

Elevate Activity Performance by Eliminating Multitasking

Multi-tasking is the performance of multiple project activities 'at the same time.' Some people refer to it as the 'fractional head count.' Humans are not too good at rubbing their tummy and patting their head at the same time. People actually multi-task by dividing out time between the multiple activities. People might do this during the course of the day by working on one project in the morning, and one in the afternoon.

Most people think of multi-tasking as a good way to improve efficiency. It ensures everyone is busy all of the time. Often, I have to wait for inputs or for someone to call back before I can get on with an activity. Multi-tasking makes good use of this time.

Dr. Goldratt demonstrated in The Goal how focus on local efficiency could damage the overall performance of a system. He used the example of robots, which they operated all of the time in order to show high efficiency. In the case of production, this leads to producing excess inventory, and may 'plug' the constraint with work not necessary for current orders, increasing operating expense and delivery times with no positive benefit to the company as a whole.

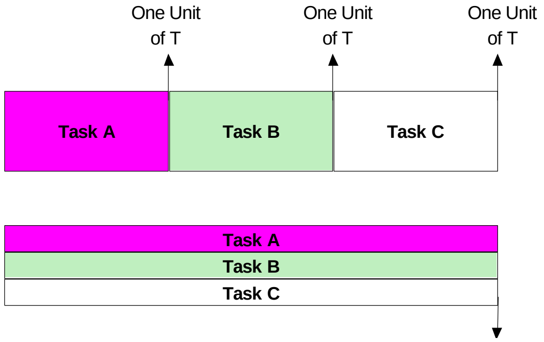


Figure 7: Multi-tasking extends activity duration.

Multi-tasking on project activities has a much worse impact. Consider a person who has to do three one-week tasks for three different projects. If they were permitted to work exclusively on each one, the first project would have its result in one week, the second project at the end of the second week, and the third project at the end of the third week. If the activity performer multi-tasks, spending for example one third time each day on each project, none of the projects get their output until the end of the third week. All three tasks have a three week duration; potentially extending the overall duration of each project.

If multi-tasking is a normal way of business in a company, three weeks becomes the normal activity duration for this activity. Performance data supports this inflated activity duration. If this is a critical chain activity, the practice directly extends the duration of the project. Most companies admit to encouraging extensive multi-tasking.

CCPM seeks to eliminate this type of multi-tasking by eliciting 100% focus on the project activity at hand by all resources supporting the project. Thus, eliminating 'fractional head counts' is a primary consideration in planning a critical chain project.

Early Start vs. Late Finish (Exploit)

Extensive studies have evaluated the desirability of using early start schedules or late finish schedules. Project managers believe early start schedules reduce project risk by getting things done early, and late finish schedules:

- Reduce the impact of changes on work already performed,
- Delay the project cash outlay, and
- Give the project a chance to focus by starting with fewer simultaneous activity chains, allowing the project team and processes to come up to speed.

Much project management guidance recommends that Project Managers use an early start schedule. Many schedule computer programs use the early start schedule as the ‘default.’ Early start means permitting all of the non-critical path activities to start earlier than is necessary to meet the schedule date. People working on those activities know that there is slack in their activity. How do you think this influences the urgency they feel in working on the activity? Does it encourage or discourage the student syndrome?

CCPM uses late start for all project activities. Note that the feeding buffers provide an explicitly sized buffer to protect the overall project from late completions in the feeding paths. This maximizes the advantages to the project, while ensuring project schedule protection.

Critical Chain Plan Summary

CCPM uses 50% probability activity duration estimates and an aggregated project buffer to deliver the project on time. This significantly reduces the scheduled project lead-time, and significantly increases the probability of completing the project

CCPM develops a Critical Chain, rather than a Critical Path, as the primary focus of the project. The Critical Chain includes BOTH logical and resource dependence. CCPM establishes the Critical Chain after removing resource contentions, rather than before considering the resource limitations. The Critical Chain remains unchanged for the entire duration of the project, and is the primary **focus** of the project manager.

Figure 3 illustrates the Critical Chain for the project Critical Path network shown in figure 1. The figure illustrates the reduction of activity duration, and additions of buffers. The Critical Chain scheduled project duration is about 10 weeks, including the project buffer. You should expect completion at the middle of the project buffer, or about 8 weeks. The critical path schedule was about 12 weeks. Experience suggests it would not make it in that time.

CCPM solves the merging activity problem and the early-start, late-finish dilemma by the use of Critical Chain Feeding Buffers (CCFB). Inserting CCFBs where each activity chain feeds the Critical Chain (including the entry to the Project Buffer) immunizes the Critical Chain from delay in these feeding paths. The Critical Chain Feeding Buffers (combined with the activity dependent schedule created with establishing the Critical Chain) lead to starting activities as late as possible, while protecting the overall project. These starts will be later than early-start times, giving the project the maximum **focus** and cash flow advantages from starting later.

Exploit the Plan Using Buffer Management

Measures drive actions that move you towards the goal. In The Haystack Syndrome, Dr. Goldratt notes “The first thing that must be clearly defined is the overall purpose of the organization--or, as I prefer to call it, the organization’s goal. The second thing is measurements. Not just any measurements, but **measurements that will enable us to judge the impact of a local decision on the global goal**.”

Figure 8 illustrates the ‘cybernetic view’ of measures used by Dr. Joseph Juran[12]. The Sensor makes the measure in block 2. An umpire (block 4) compares the output of the process as reported by the sensor to the goal for the process. The umpire makes a decision to cause an action, modifying the process to change output and minimize the gap. This is how all control systems work. This is the intent of project measurement systems, where the goal includes the

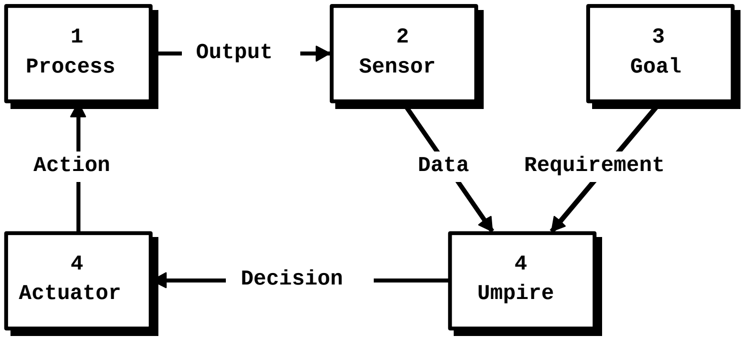


Figure 8: Dr. Joseph Juran’s depiction of measurement as a control system.

technical requirements, cost, and schedule for the project.

In The Haystack Syndrome[13], Dr. Goldratt defines data as, “every string of characters that describes something, anything, about our reality.” He defines INFORMATION as “The answer to the question asked.” Dr. Goldratt suggests that the information system should incorporate the decision.

The improved measurement system for Critical Chain Project Management follows the practice established by Dr. Goldratt for production operations. It uses buffers (that is, time) to measure activity chain performance. You size the buffers based on the length of the activity chain they protect. Buffer sizing uses the uncertainty in the duration of the Critical Chain activities to size the Project Buffer. Likewise, uncertainty in the duration of the feeding chain activities determines the size of each Critical Chain Feeding Buffer. CCPM sets explicit action levels for decisions. The decision levels are in terms of the buffer size, measured in days:

1. Within the first third of the buffer: no action.
2. Penetrate the middle third of the buffer: assess the problem and plan for action.
3. Penetrate the third third: initiate action.

These measure apply to both the Project Buffer and the Critical Chain Feeding buffers. Figure 9 shows an example of using the buffers.

Project teams monitor the Project Buffer (PB) and each Critical Chain Feeding Buffer (CCFB) at the appropriate time intervals for the project, usually weekly but at least monthly. For this tool to be fully useful, the buffer monitoring time must be at least as frequent as one third of the total buffer time. If the buffers are negative (i.e., latest activity on the chain is early relative to schedule date) or less than one third of the total buffer late (e.g., less than 10 days if the total buffer is 30 days), you do not need to take action. If extended durations penetrate the buffer between 1/3 and 2/3, the project team should plan actions for that chain to accelerate the current or future tasks and recover the buffer. If the activity performance penetrates the buffer by more than 2/3 of the buffer size, the project team should take the planned action. Through this mechanism, buffer management provides a unique anticipatory project management tool with clear decision criteria.

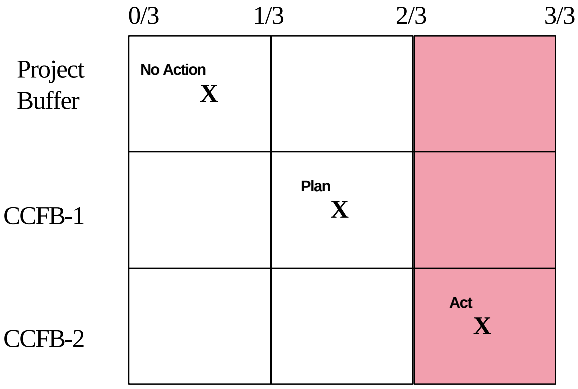


Figure 9 Buffer penetration provides the essential measurement for CCPM project control.

Project Managers update the buffers as often as they need by simply asking each of the performing activities how many days they estimate to the completion of their activity. They do this without pressure or comment on the estimate. They expect these estimates to vary from day to day, and some of the activities to exceed the original duration estimates. As long as the resources are working on the activities with the CCPM activity performance paradigm, managers evaluate them positively, regardless of the actual duration.

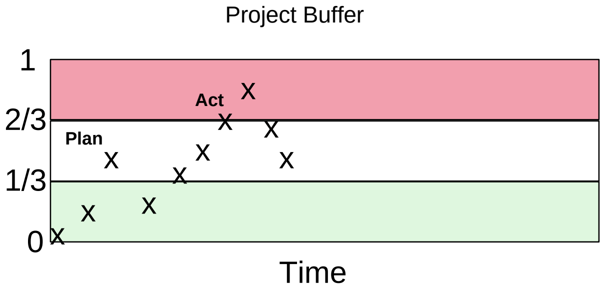
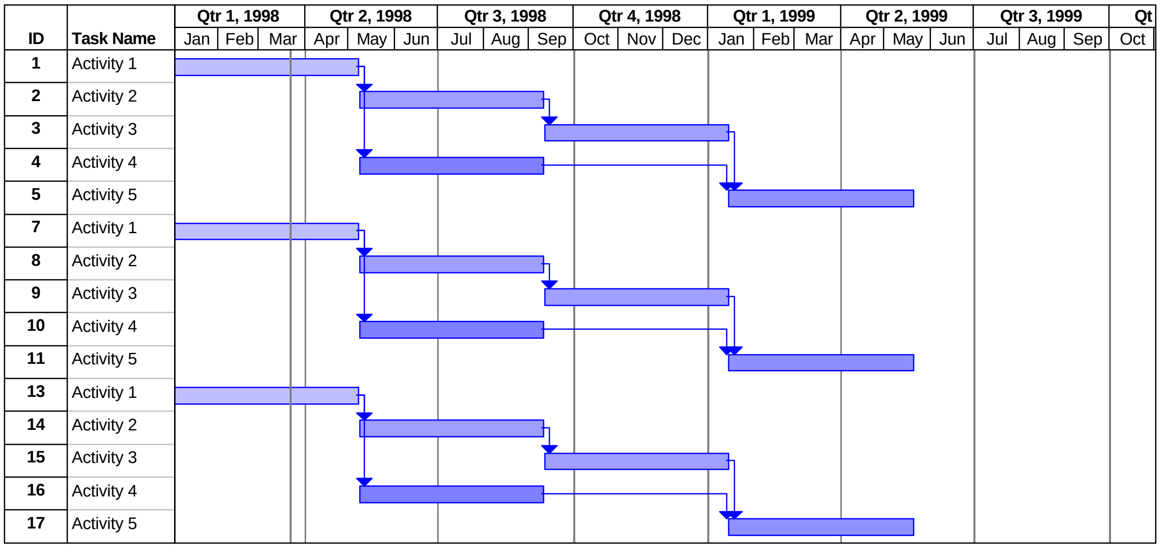


Figure 10: For long projects, it may prove useful to plot buffer penetration vs. time.

An enhancement in the use of the buffer for long critical chains is to plot trends for buffer utilization. The buffer measure then becomes, in essence, a control chart and can use similar rules. That is, any penetration of the red zone requires action. Four points trending successively in one direction require action.

Multiple Project Environments

The impact of multi-tasking on a single project is significant. In a multiple project environment, it is a disaster. The impact gets worse and worse as managers push more and more projects into the project performance system. CCPM project managers work to eliminate multi-tasking and create a pull system for the multi-project environment. Figure 11 illustrates an example critical path multi-project scenario. The patterns on the bars represent resources. Using conventional low risk activity estimates, and considering three project multi-tasking, each activity duration is 90 days.



ID	Task Name
1	Activity 1
2	Activity 2
3	Activity 3
4	Activity 4
5	Activity 5
7	Activity 1
8	Activity 2
9	Activity 3
10	Activity 4
11	Activity 5
13	Activity 1
14	Activity 2
15	Activity 3
16	Activity 4
17	Activity 5

Figure 11: Example critical path multi-project schedule.

The TOC process applies directly to manage projects in the multi-project environment. The management team has to first identify the company capacity constraint resource. This is most often a certain type of person, but may be a physical or even a policy constraint. The company constraint resource becomes the ‘drum’ for scheduling multiple projects. This terminology comes from Dr. Goldratt’s production methodology, where the drum sets the beat for the entire factory. Here, the drum set the beat for all of the company projects. Think of the drummer on a galleon. What happens if even one rower gets out of beat?

The project system becomes a ‘pull’ system because the drum schedule determines the sequencing of projects. Management pulls projects forward in time if the drum completes project work early. Delays could impact subsequent projects when the drum is late. For this reason, projects in a multi-project environment also require buffers to protect the drum…to ensure that they never starve the capacity constraint for work. CCPM schedules the projects to ensure that they are ready to use the drum resource, should it become available early.

Figure 12 illustrates the CCPM method. It uses reduced each activity time (15 days) by eliminating the three times multi-tasking, and using 50% probable duration estimates. The resource supplying activities 2 and 3 is the ‘capacity constraint resource.’ The plan exploits the resource by synchronizing the projects using this resource as the drum. The schedule subordinates to this resource by adding capacity buffers between the projects. The capacity buffers ensure that the capacity constraint resource is available for the subsequent project. (The figure does not show the drum buffers for simplicity. Early implementations of CCPM need not deploy the drum buffer.)

Note that CCPM does not attempt to schedule all resources across all projects. Companies demonstrate repeatedly that this is a losing proposition. It has never proven possible to get enough current information together and processed quick enough to exceed the ongoing variations in all activities. CCPM allows for this variation with the resource flags and buffers within each project.

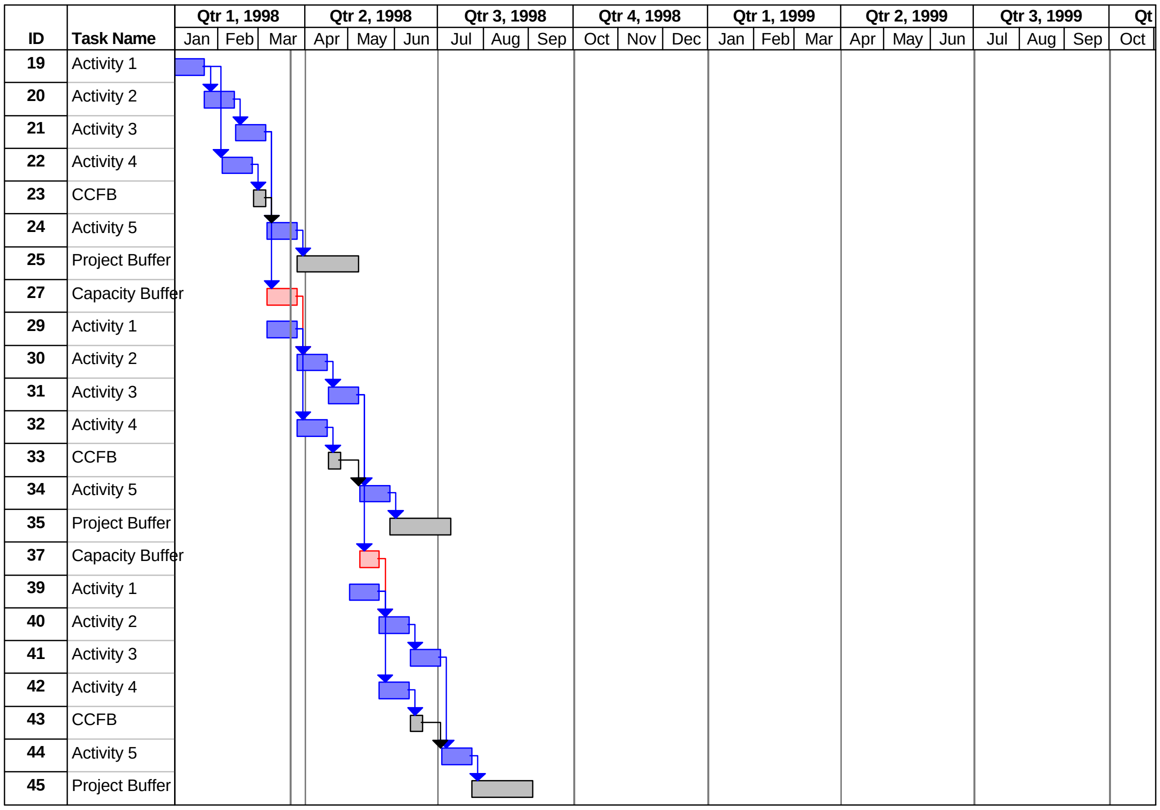


Figure 12: The CCPM multi-project plan synchronizes the projects, achieving much earlier completion of all of the projects.

Figure 12 shows the CCPM plan completing the three projects (including the project buffer) near the end of August, 1998. It shows the first two projects completing even earlier. Contrast this to the critical chain multi-project plans of Figure 11, all of which are scheduled to complete in May of 1999. Based on what single project results, CCPM projects should complete be early. Based on experience with critical path projects, they shouuld be late for even these extended schedules.

Also note that synchronizing the projects this way eliminates resource contention for all resources; not just the drum resource. This happens in the example because the projects are identical. While most multi-project environments do not have identical projects, synchronizing projects to the drum usually eliminates some resource contention, if not all. Resource manager prioritization of resources according to the penetration of project buffers resolves remaining resource contentions.

Simplicity

CCPM planning and project management is simple compared to many alternative techniques, such as simulation, quantitative risk assessment, PERT three time estimates, or Monte Carlo methods. The primary concepts are simple; comprising 50/50 estimates, the critical chain, buffers, and buffer management. CCPM requires neither statistical sophistication nor possession of actual distributions of activity performance data. Such data usually does not exist for projects, and even where it does exist, such as in the construction industry, it has not solved the problem of time overruns.

Busy project managers do not have the time or inclination to assimilate obtuse data. They need real information, gathered in real time. Everyone understands buffer management, measured in days of buffer penetration. Projects can collect and process buffer data and daily, if desired. Buffer penetration provides the decision on when to plan and when to act. Very few people really understand the meaning of earned value measurements, and how to use them for project management. For example, Ray Powers notes[14], "…the participants from leading Fortune 500 companies attending the last benchmarking forum were queried regarding their use of earned value calculations. None indicated that they were using the format described in the PMBOK Guide."

The five focusing steps are clear and concise. CCPM provides a recipe for straightforward application to real projects. CCPM does not require new computer software, although such software is already available to simplify the tasks of resource leveling, finding the critical chain, sizing and placing buffers, and performing buffer management.[15]

Success Examples[2]

CCPM demonstrates consistent success in achieving the expected benefits. Evidence of other users often gives people confidence to try new ideas. The present CPM project paradigm has been in force for over forty years, making change very hard for many people to accept. More and more companies, small and large, are demonstrating success with CCPM. Several examples illustrate this success.

Honeywell DAS[16]

"The RNLAF team was asked by the customer to deliver something we originally scheduled to take 13 months to deliver—and the team did it in six months…The team is experimenting with a new way of scheduling the program using critical chain concepts. Boeing has read the book, and is supporting the concept."

Lucent Technologies

Lucent Technologies has adopted CCPM as their primary tool for project management. (The author provides Lucent training and implementation assistance.)

[17]"In 1996, Lucent Technologies Advanced Technology Systems, now part of General Dynamics, was told by a sister organization that the yearlong project being considered was an impossibility. ..The project was used as a pilot effort, to evaluate TOC project management. The project was completed in June, 1997, with buffer to spare."

Harris

Harris recently decided to use CCPM to build a new eight-inch semiconductor wafer plant. The largest pervious wafer was six inches in diameter. Total investment for a plant of this size is in the range of $250 million. Revenue for such a plant is in the range of $ 2 million per day! (Raw material cost is very small). The industry standard to build a six-inch plant was 30 months up to the time the equipment was qualified; i.e., no production quantities. The industry standard to get the plant up and running to 90% of capacity is about 46 months. The plant was recently completed, and is up to 90% production in 13 months. Harris presented their results at a recent conference hosted by the Avraham Y. Goldratt Institute. See their Internet page: http//www.tp.semi.harris.com/raptor.html

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[2] We understand that anecdotal evidence does not prove a theory. The proof of CCPM lies in the development logic presented earlier in the paper. Our experience demonstrates that anecdotal evidence often affects people's willingness to try something new more than scientific evidence. Psychological theory calls this 'social proof.'

Israeli Aircraft Industry

The Israeli Aircraft Industry employs about 15,000 people. A major function is to maintain Jumbo Jets used in Passenger service. A particular type of maintenance, called ‘type D,’ normally takes 46 days in the industry. The penalty for non-performance to schedule is very steep...$60,000 per day, because the airlines need the planes back into scheduled service. The company had been paying up to $ 25 million per year in penalties. A letter from the manager to Dr. Goldratt (included on http://www.Goldratt.com) notes,

“...we succeeded to drop our average Turn Around Time per Aircraft Visit from three months to two weeks and to increase our backlog from two months to one year.”

(BOS) Better Online Solutions

“a project..was originally planned to be released to the market in August 1997 (there is no reason to believe that that it [would have been] on time-but who knows?). The TOC scheduling cut four months from this timetable-so it was planned to be ready on May 1, 1997. It was finished in [the] beginning of April, 1997, almost a month before the corrected time. Almost five months before the original time.”

Izzy Gal, President

Conclusion

Critical Chain Project Management provides a substantial step in continuous improvement to the Project Management Body of Knowledge. It is a conceptually simple and practical improvement. The simplicity is especially noteworthy for projects that might have considered use of project simulation or Monte Carlo analysis, or implementing complex Cost Schedule Control Systems. As with all TOC innovations, CCPM does not require substantial investment. It does not require new software. Project teams can create CCPM plans in a very short time (within a week for projects with the activity network and resource estimates available.) Results follow immediately.

Focus is a primary cause of the success of CCPM. The Critical Chain provides the focus for the whole project. The Buffers provide focus and clear decision criteria for the Project Manager.

The essential changes introduced by Critical Chain Project Management (relative to the current Critical Path practices) are:

1. Development of the Critical Chain, using both activity logic and resource constraints.
2. Reduction of activity estimated times to 50% probability estimates to account for aggregation of the activity contingency times.
3. Addition of a Project Buffer to protect completion of the Critical Chain.
4. Addition of Critical Chain Feeding Buffers to immunize the Critical Chain from delays in the feeding chains and merging effects.
5. Using buffer management as the primary tool for project management and control.
6. Using behaviors conducive to the global project optima, such as roadrunner activity performance and resource allocation to satisfy the company project needs.

All projects that have diligently applied CCPM have completed the project substantially under the original time estimate, fulfilled the original scope, and came in near or under the estimated budget. Project durations normally reduce by at least 50% in the first pass, and several companies have taken the early successes to cause further substantial reductions in project duration.

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