# CRITICAL CHAIN VERSUS CRITICAL PATH IN PROJECT MANAGEMENT

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*Project management is a fast growing area of management. A new approach, critical chain, is gaining popularity and poses challenges to the traditional approach that uses the critical path. This paper evaluates and compares the two approaches. Strengths and weaknesses of each are identified, followed by some conclusions regarding situations in which each would be more or less appropriate for use. Three key weaknesses are identified for the critical path. We see how critical chain addresses these. An example problem is provided to demonstrate some of the conclusions reached.*

## INTRODUCTION

Project management is a fast-growing area of management. As the percentage of work that can be described as "projects" continues to grow, this area of management will take on increasing importance.

For over fifty years, the governing principle for scheduling and managing projects has been the "critical path". This method, fifty years ago, represented a major breakthrough in management thinking. Today, it is well known to all who practice project management, and provides a basis of most thinking in this field. All project management software is based on this concept as well.

In recent years, a new concept has been introduced to alleviate some of the problems that are rampant in project management practice. This approach, known as critical chain, claims to overcome these problems.

The first goal of this paper is to provide a comparison of these two methods. Our next section will look briefly at the critical path method. The following section lists problems associated with that method and then we go on to describe how critical chain responds to these problems in the fourth section.

The second goal of this paper is to identify the strengths and weaknesses of each method. The next section of the paper summarizes these. We evaluate the claims and try to reduce them to core strengths. We then use this information to reach some conclusions regarding when to use each method. This is the third goal of the paper, to make recommendations for the use of each method.

Finally, we provide some test problems to explore the methods in practice and substantiate our recommendations.

## THE CRITICAL PATH METHOD

The critical path method is based on a very simple idea. If every task is scheduled to begin as soon as possible, as soon as all of its predecessors are complete, then the length of the project, the completion date, will be determined by the longest sequence of predecessors. This sequence is known as the critical path because the precedence relationships are commonly illustrated in a network diagram. In this diagram, any way of getting from the start of the project to the finish is a path, and the longest path is the bottleneck or critical path.

The critical path is used to calculate the completion date. The completion date found in this way is the best possible, the earliest possible completion date. Any task on the critical path is called a critical task because it cannot be delayed. Any delay on a critical task delays the project completion date by the amount of the task delay.

All tasks that are not on the critical path can be delayed if necessary without delaying the project completion date. The amount by which each can be delayed without delaying the project is known as the slack (or float) for that task. This is an important concept in the critical path method because it allows for flexibility in scheduling and helps act as a resource for adjusting the schedule during project execution.

## PROBLEMS ASSOCIATED WITH CRITICAL PATH IN PRACTICE

There are three problems associated with the critical path method. One is a serious limitation of the method, the second results from common misuse of the method, and the third results from using a deterministic model based on expectation instead of a more sophisticated statistical model.

The first problem, a serious limitation, is that the critical path method, the main scheduler for projects, attempts to develop "optimal" schedules without considering resource availability. Resources have been promised for the estimated duration of each task, but prior to developing a schedule, no one knows exactly when those resources will be needed. Once the schedule is developed, some of the required resources may not be available at the required times. This necessitates a revision of the schedule to accommodate the schedules of the resources. Thus, the critical path schedule was not a possible one in the first place. It was overly optimistic.

A second problem is referred to as the "student syndrome." If a task is estimated to take 12 days, and it has 4 days slack, somehow it always seems to take 16 days. People who know they have slack tend to squander it. Once slack is used up, every task becomes critical, greatly increasing the likelihood of schedule overruns. So slack, which is a strength of this method, can become a major weakness in practice. Once again, the critical path method seems to be very optimistic.

The third problem results from the use of best guess estimates for the task durations. While this is probably the best approach, the real issue is how those estimates are used to find the completion date. The task durations along a path are simply added to find the length of the path. What this actually gives is the expected length. Assuming a normal distribution of the path length, this project completion date has a 50% chance of overrun on this path. If other (shorter) paths could have an overrun as well, then the chance of completing the project on time is less than 50%. For a third reason, the critical path is much too optimistic.

It should not be surprising, then, to observe in practice that the critical path method leads to many late deliveries of projects. Everything has to fall in place perfectly to meet the scheduled delivery date. This rarely happens, if ever.

## THE CRITICAL CHAIN METHOD

The critical chain method, as it is used in practice, addresses the first two problems more than the third, but it gets its name from its response to the third problem. If the critical path can take longer than its estimated length, then we should plan for a longer length, probably using a confidence interval. We can then predict that the project has a certain probability of finishing by a certain date. Setting up the promised delivery date on this basis would give a high probability of success, instead of the almost certain failure that critical path seems to provide.

But the critical path method, through some of the probabilistic analyses more commonly associated with the PERT version, does recommend this approach. It should work well, but is not used much in practice. Similarly the proponents of project risk analysis make the same case, but that is rarely used in practice as well. The major software packages are most commonly used in a manner that ignores options for these additional analyses.

To this point, we seem to be assuming that the critical path is one path, it is known in advance. But in practice, a delay off the critical path could cause that other path to become critical. As tasks on different paths become critical at various stages of the work, we realize that there really is no one critical path, but multiple intertwined paths, parts of which are critical at different times. These intertwined paths are known as the critical chain.

The process of modeling this critical chain requires computer simulation, similar to that done in the risk analysis models. This is rarely done in practice.

As practiced today, critical chain address the first two problems. Recognizing that a high percentage of the delays in a project result from resources being unavailable when needed, critical chain schedules the tasks according to resource availability in the first place. Instead of the shortest possible schedule, a realistic schedule is achieved. The resources will be in place as scheduled and the project will finish as scheduled. This is a longer schedule, but achievable.

The other issue addressed by critical chain is the slack. This method eliminates it. If there is no slack it will not be misused. Instead the slack is accumulated at the end of the path, or where the path intersects a longer path. At these points time buffers are installed. The result is that the slack is not associated with a task, so no one owns it to use, or abuse. Instead, it is associated with a sequence of tasks. Any delays in this sequence can be accounted for by going into the buffer. Some make the size of the buffer equal to the slack at that point, but most make it larger, to account for the confidence level required for meeting the deadlines.

## COMPARISON OF METHODS – RECOMMENDTIONS

### The Resource Issue

The critical path technique achieves its goal, which is to identify the ideal schedule. It also identifies the resources required to meet this schedule. It is then the job of the project manager to put the team of resources into place as necessary. This is a difficult job, but a primary role of a project manager.

The critical chain takes the opposite approach, developing the schedule based on the resource availability. This provides a much longer schedule, but as pointed out earlier, a more achievable one. It also alleviates the pressure on the project manager to constantly be negotiating for resources.

With regard to the resource issue, if there is one project under consideration, the critical path seems superior. Critical chain "solves" the issue of overruns by promising a much later delivery date. That is too easy, and totally unacceptable to the customer. Time pressures drive projects and the project schedule should reflect this. The goal of the project manager should be to complete the project as early as possible and critical path clearly defines what this is.

The recommendation should be to use critical path to identify the shortest completion time. Then, the next step is to put a resource plan into place that achieves this. If this is not possible, develop the resource plan coming as close as possible to the ideal completion date. Firm commitments must also be obtained concerning the availability of these resources for this project at the correct times. Then develop a new schedule around this resource plan, and use this schedule as the project schedule. It will be achievable on a resource basis.

This resource issue becomes more complicated when multiple projects are being conducted simultaneously and they share resources. As the complexity of this joint use of resources grows, critical chain starts to seem to have a stronger case. When adjusting the critical path schedule to consider resource availability, it may have to be modified so much that it really becomes a resource driven schedule anyway. So it would seem to make sense that the critical chain method just be used in the first place. In this way, all of the projects get the resources they need when they need them.

One final recommendation must be made to bring the two techniques together. Both approaches have the same goal. One comes from a time perspective (CP), while the other comes from a resource perspective (CC). The critical path completion date should be viewed as a lower bound, an earliest date, something to be aimed at. The critical chain completion date should be viewed as more of a worst case date, or an upper bound on the completion date. The goal of the project manager should be to negotiate the resource availabilities toward achieving the critical path schedule. Once the resources are locked in, then that resulting schedule goes into the project plan. At that point it is neither a critical path nor a critical chain schedule. But it should be the shortest achievable one. And that was the goal in the first place.

**The Probabilistic Issue**

Critical chain, with its simulations, handles this most accurately. The proponents of risk analysis in critical path also suggest using simulations, so it is the simulation that is the solution, not critical path or critical chain. The dispute here is really whether the simulations are needed or the simpler probabilistic analyses from PERT. Everyone would agree that something needs to be done to consider this point.

The real problem resulting from this issue today in practice is that it is ignored. Dealing with it in either way would be a big help. The result from doing so by any method would be the same, a delay in the promised completion date. The method chosen would only determine the exact amount of that delay.

Again, the solution should be to do what the situation requires. For a simple single project scenario, the PERT calculations should suffice. This is especially strong if the critical path is the only one with a reasonable chance of going beyond the completion date. But as more projects are going on simultaneously, these calculations fail to take into account the joint probability distributions that the simulations can reproduce.

One more question, actually similar to the slack/buffer question, is where the extra time should be added. There is no dispute on the answer. Never spread it among the tasks. It should be a buffer at the end of the project. So the project schedule is set up in the same way, and the tasks and resources planned around it. As delays occur, the schedule is adjusted accordingly, always trying to use as little of the buffer as possible.

**The Slack/Buffer Issue**

The issue of how to handle slack can be decided separately from the resource issue. There is no reason that choosing the critical path method for the schedule development prevents the use of the buffer approach suggested by critical chain, or vice versa.

The dispute here concerns how management carries out the schedule, how they manage it and motivate the team. In theory, there are so many benefits to using slack that the buffer method cannot compare.

First, the use of slack most accurately portrays the true situation. Every task not on the critical path really can be delayed. Allowing for this gives flexibility to the project manager when scheduling and in negotiating for resources. This is the second benefit. Failing to allow for slack is very limiting in both of these cases, and worse yet, limits the resolution to the use of the longest schedule.

The third benefit, and perhaps the biggest, is the ability to use slack as a resource, just as if it was money or manpower. When the critical path (there still is one in critical chain) is delayed, the resources or budgets from non-critical tasks can be transferred to the critical path. This lengthens the tasks that can be delayed and reduces the critical path, getting the project back on schedule. This is one of the few resources that project managers have once the project is underway for adjusting the schedule and correcting it, guiding it to a successful conclusion. Eliminating slack and replacing it with buffers eliminates this resource too.

The fourth benefit, vital to a project manager, is trust. When a manager tells someone that a task must be finished by a certain date and they miss the date, only to find out that there was extra time, they see no reason to meet future dates. They know the project manager is not leveling with them. This practice, recommended by the critical chain proponents, will have negative consequences in other areas of the project.

Despite all of this, common observation says that the slack is misused. The buffer would work better. Perhaps the above arguments are those from the ivory tower, ones that are correct only if we can ignore human behavior. If slack will be wasted, then the benefits mostly disappear and the buffer approach should be used.

The recommendation with regard to this issue is education (staying in the ivory tower, but getting everyone in there). If everyone understands what slack means and how to use it, it will not be wasted. If it is a resource, it is to be passed on to those doing the next task in sequence. If that 12-day task has a slack of four days, then it still has to be done in 12 days. The only flexibility is a four day span on the start date. If this can be accomplished, that is ideal. If not, if human nature says that this time will be wasted, then the buffers are the correct approach.

## EXAMPLE PROBLEMS – COMPARISON OF RESULTS

Two sets of example problems are used to illustrate and compare the outcomes of using Critical Path Method versus Critical Chain. Problems 1 and 2 are simple project examples from a leading textbook (Kerzner, 2003).

Problems 3 and 4 involve the application of the two project management processes using an actual modified FDA Drug Submission project from a Pharmaceutical Company whose name and drug name will be changed for proprietary and confidentiality reasons. As you can imagine the Pharmaceutical Industry is highly regulated by the government with strict guidelines and timelines. This is an optimal environment for the application of project management. This will give us the opportunity to compare the different outcomes of the two philosophies with the subsequent impact on the project planning, scheduling and controls.

Example Problem 1. Critical Path Management – Kerzner, data taken from pages 838 to 846.

In the following example, a company has received a contract to build a tower that houses communications equipment. Each tower has to meet specific requirements of county and state governments regarding height, durability, tower capacity, ground preparation, fencing, wiring, and on-site staging and testing.

This problem shows a critical path project plan, "which is established by the longest time span through the total system of events." In this example the critical path is defined as the design custom parts, purchase available parts, test purchased parts and test the finished product or as design custom parts, original drawings, manufacture and test the finished product.

In this problem there are 10 tasks and 6 resources used to complete the project. Also, six of the tasks use 3 resources. We notice that Critical Path ignores any resource or task dependency as evidenced by the start of task 6 Purchase Available Parts on 6/2/04, which takes 30 days to complete and ends on 7/13/04. This task creates a schedule conflict with Task 3 Purchase Raw Materials, which starts on 5/26/04, takes fifteen days to complete and ends on 6/15/04. This creates a resource conflict because both tasks use the Procurement resource. In addition, we notice that there isn't any free slack available between task 2 and 6 to help manage the start or delay of either task to help manage the resource conflict. This gives support to the Critical Path Methodology, which is concerned with the project end date and has a disregard for resources or task management that can create conflicts during a project.

Due to the use of some sequential start dates, finish dates, task predecessors and task successors the total duration of Problem 1 is compressed 75 days even though the total number of project days is 150 and in light of resources being scheduled to complete two tasks at the same time. The accompanying Gantt chart that clearly shows the resource overlap supports this.

Please view Problem1 in the Gantt chart view to review the task names, task durations, task start dates, task finish dates, predecessors, successors, resources, free slack and total slack for the Microsoft Project Plan output of the project. In problem 2 we will see a stark difference in the outcome with the use of Critical Chain and how it manages the resource conflict

Example: Problem 2. Critical Chain Management – Kerzner, data taken from pages 838 to 846.

In this problem we will use the same project information from problem 1, except there are now 14 tasks and 6 resources to complete the project due to the addition of Feeding Buffers and a Project Buffer. Although, there are additional tasks to account for these buffers, remember that they do not contribute to the overall project duration. We can compare the Critical Path outcome of problem 1 with Critical Chain outcome of this problem. Critical Chain is defined as the "longest chain of dependent events where the dependency is either task or resource related. This definition assumes that the longest chain is the one that is most likely to negatively impact the overall duration of the project." The use of resource and task scheduling, and its impact on the duration of a project to avoid resource dependency and logical resource dependency conflicts are one the primary differences between the two philosophies.

The second primary difference between the two management philosophies is the use of feeding/path buffers and project buffers instead of slack time. Kerzner suggests that the path buffers should be calculated at 40% of the length of the paths and the project buffer should be calculated at 30% of the critical chain.

With the use of Pro-Chain Software we are able to convert Problem 1 into a Critical Chain example. When resource and task scheduling are taken into consideration along with the sequential start dates, finish dates, task predecessors and task successors included in problem 1 the results are an extension of the problem to a projected 85 days based on the Critical Chain of Modify Standard Parts 10 days, Purchase Raw Materials 15 days, Purchase Available Parts 30 days, Test Purchased Parts 10 days and Test Finished Products 20 days, which are in bolded text.

The primary adjustment that impacts the project duration is the resolution of the resource conflict between Purchase Available Parts, which is now task 8 and Purchase Raw Materials, which is still task 3. Unlike Critical Path, Critical Chain avoids resource and task conflicts and will lengthen a project as a result of accounting for scheduling overlaps. Since Purchase Available Parts and Purchase Raw Materials use the same resource Critical chain will automatically make adjustments to account for the resource or task dependencies. As a result Purchase Available Parts starts on 6/17/04, takes 30 days to complete and ends on 7/28/04, but unlike the tasks in problem 1 this start date comes at the finish of Purchase Raw Materials tasks, which finishes on 6/16/04.

The focus duration of the project is 123 days, but this is due to the difference between the projected finish date of 9/8/04 and the Focus Duration finish date when the 30% project buffer of 38 days is taken into account. The project buffer starts when the Test Finished Product task finishes on 9/27/04. In this problem the project can finish on 9/8/04, but the expectation for potential project completion is set based upon buffers that could extend the project to 11/1/04.

Please view Problem 2 in the Pro-Chain Gantt Chart view to review the task names, focus duration, task start dates, task finish dates, projected task start dates, projected task finish dates, predecessors, successors, resources, check chain and chain left for the Critical Chain output of the project.

Example: Problem 3. Pharmaceutical Company-A FDA Submission of Wonder Drug
Critical Path Management

Pharmaceutical Company-A is a large company that is in the final compiling and assembly stages of filing a New Drug Application to the FDA. This project is more complex than Problem 1 Critical Path, but has been modified to simplify the project. In this problem there are 27 tasks and 4 resources used to complete the project. Again, we notice that Critical Path ignores any resource or task dependency as evidenced by Cycle 1 tasks and the Final Cycle tasks using the some of the same start dates and the same resources to complete the task. Task 3 and Task 17 have the same start date of 3/1/04 and duration of 20 days, and use the same GDM, RAM resource. We see this conflict repeated for Task 4 and 18, which have the same start date of 3/29/04 and duration of 5 days, and use the GDM, Liquent TL, and Publisher resources. The same type of conflict appears with the Publisher resource for tasks 4 and 20.

Reading through the project we find that this conflict repeats itself numerous times. As we stated in problem 1 the Critical Path ignores the resource and task dependency overlaps and it becomes glaringly obvious in this project where there are two cycles that are started in parallel using the same resources.

There are instances where slack time is created for the GDM and RAM resource, but several of the task dependency conflicts occur with the Publisher resource and there isn't any slack time allowance calculated to compensate for the overlaps and this is due to the nature of Critical Path primarily being concerned with the end project date and not the efficient management of resources and tasks to complete the project smoothly. Using the Critical Path Method we find that the Critical Path is defined by tasks 17 through 27 in the final cycle and the overall duration of the project is 41 days, which is the exact duration it takes to complete Cycle 2.

As in problem 1 due to the use of some sequential start dates, finish dates, task predecessors, task successors and more importantly parallel cycles the total duration of Problem 3 is compressed 41 days even though the total number of project days is 81.25. The accompanying Gantt Chart that clearly shows the resource overlap supports this.

Please view Problem 3 in the Gantt Chart view to review the task names, task durations, task start dates, task finish dates, predecessors, successors, resources, free slack and total slack for the Microsoft Project Plan output of the project. As in problem 2, we will see a stark difference in the outcome with the use of Critical Chain and how it manages the resource conflict with problem 4.

Example: Problem 4. Pharmaceutical Company-A FDA Submission of Wonder Drug
Critical Chain Management

In this problem we will use the same project information from problem 3, except there are now 30 tasks and 4 resources to complete the project due to the addition of Feeding Buffers and a Project Buffer. As in problem 2 the buffers do not contribute to the overall project duration.

Using Pro-Chain Software we are able to convert Problem 3 into a Critical Chain example. When resource and task scheduling are taken into consideration along with the sequential start dates, finish dates, task predecessors and task successors included in problem 3 the results are an extension of the problem to a projected 82.25 days based on the dual Critical Chain of all the tasks in Cycle 1 and the Final Cycle. This is the first difference that we notice from the Critical Path Method used in Problem 3. Since the two cycles are operating in parallel both paths become critical, this is denoted by the bolded tasks in each cycle.

The second major adjustment that impacts the project duration is the resolution of the resource conflicts between the resources that were used in parallel for problem 3. The first example of this is the Task 3 and Task 17 conflict from problem 3 that have the same start date of 3/1/04 and duration of 20 days, and use the same GDM, RAM resource. In this problem Critical Chain has shifted Task 17 to Task 19 due to the inclusion of buffers and accounted for all of the tasks from Cycle 1 that use the GDM and RAM resource. As a result Task 19 doesn't start until 4/27/04 after Task 16 finishes due to the fact that this is the last task in Cycle 1 that uses these resources. Reviewing the two Cycles and each task we can see how the project was lengthened to 82.25 days due to the resolution of resource and task conflicts in the scheduling.

The focus duration of the project is 107.25 days, but this is due to the difference between the projected finish date of 6/23/04 and the Focus duration finish date of 7/28/04 when the project buffer of 25 days is taken into account, which was calculated at 30% of the Critical Chain and starts when the Ship Paper and Electronic task finishes. In this problem the project can finish on 6/23/04, but the expectation for project completion is set based upon buffers that the project could extend to 7/28/04.

Please view Problem 4 in the Pro-Chain Gantt Chart view to review the task names, focus duration, task start dates, task finish dates, projected task start dates, projected task finish dates, predecessors, successors, resources, check chain and chain left for the Critical Chain output of the project.

## CONCLUSIONS

The example problems support the comparisons made earlier. Most obvious is the difference in completion dates. In the first example, the critical path was 75 days, but the critical chain extended it to 123 days. In the second example, the critical path was 41 days and the critical chain was over 82 days, doubling the length of the project. This would be unacceptable at most businesses.

In each case the critical path was not achievable due to resource conflicts. So neither solution is acceptable. This supports our earlier recommendation. Let the project manager take these as bounds and work as hard as possible to get the resources to complete the project in the shortest possible time.

**ENDNOTES**

Kerzner, H. (2003). Project Management: A Systems Approach to Planning, Scheduling and Controlling, New York, John Wiley & Sons.