Aggregate Risk Critical Path Planning:
A Discussion of Leveraging Critical Chain Concepts for Critical Path

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Introduction

One of the central tenants of Critical Chain Project Management (CCPM) is that the resources required to execute a project be explicitly defined and tracked. The critical chain is actually defined as the sequence of both precedence- and resource-dependent tasks that prevents a project from being completed in a shorter time, given finite resources. It would be easy to extrapolate from these facts that all of the CCPM concepts could not be leveraged to improve critical path analysis. However, many of the benefits of CCPM are independent of resources.

If resources (labor/non-labor) are always available in unlimited quantities, then a project's Critical Chain is identical to its critical path. Put more practically, if there are always enough (finite) resources so that there are never any resource conflicts then a project's Critical Chain is identical to its critical path.

For many critical path projects that do *not explicitly* model resource constraints, resources are considered to some degree *implicitly* in the durations and/or temporal constraints. For example, a construction project might utilize subcontractors for much of the work, and the subcontractors provide task duration information to the general contractor. The general contractor scheduler will not schedule the subcontractor through some form of schedule restriction mechanism to work in an area when there is not enough room due to other work occurring; this space constraint (a type of resource constraint) has now been defined implicitly via a temporal constraint versus explicitly via a resource constraint.

So how can critical path projects leverage some of the concepts of the critical path method? By looking at all the concepts used to define a critical chain implementation and leverage those concepts that do not require explicit resource constraints.

A major benefit of Critical Chain is the concept of aggregated risk. This aggregated risk concept helps fight the Student Syndrome and Parkinson's Law, and leads to the use of buffers, and buffer management during execution to help set priorities. These concepts could benefit critical path projects as much as critical chain projects. This paper discusses the potential benefits of applying Critical Chain concepts to critical path projects. This paper is not promoting a new methodology, but raising issues that may be worth investigating further.

Uncertainty & Risk

All Projects deal with uncertainty and risk. When a project plan is established the uncertainty is accounted for in some way, most typically by; padded time estimates, contingency plans (e.g., overtime), etc. and as the project is executed, the plan is updated to deal with actual delays in a continual effort to mitigate the changing uncertainty and risk landscape. This is a non-trivial problem as exemplified by the high rate of Project Management failure across all industries. In an article on its website, The British Computer Society states that, "Project failure is not discriminatory – it pretty much affects all sectors and all countries in equal measure."

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The search for solutions to the problem of high rate of project failure has yielded many valuable contributions. The *Critical Chain* method appears to be one note worthy contribution. After ten plus years of field testing and refinement, the Critical Chain method has shown much success. As discussed, the critical chain of a project, by definition, requires resources to be more explicitly defined than many in the field customarily do or can do, per real-world limitations, e.g., outsourcing to subcontractors. Fortunately, most of the methods used by Critical Chain to mitigate uncertainty and better handle risk; do not require the modeling of resources.

In the Critical Chain method as well as more conventional methods, in order to make firm commitments regarding the outcome of a given project, despite the existence of uncertainty, provision is made in the model to accommodate a reasonable amount of the unexpected. This provision is usually in the form of extra time and or budget above and beyond what it is thought would be required were it possible to know all there is to know about the project before its execution. The extra time or budget is frequently referred to as safety or contingency. It is generally understood that the safety or contingency component of a plan is as much a part of the commitment as the rest of the plan, and therefore can not be separated out or be unfunded.

Adding unnecessary contingency can significantly increase the expected time and money required for the project. Therefore, there is pressure to minimize the amount of contingency added to a project. As a result of this pressure, in order to ensure that there is enough protection in each project plan to make the related commitments achievable, project management practices have evolved to disguise the existence of apparently wasteful protection.

Non-Aggregated Risk

The traditional Critical Path implementation uses what will be referred to as a non-aggregated risk technique.

The basic building block of the project model is the task or activity (referred to as an 'activity'). An activity consumes time and resources and produces an output that can be used by another activity. There are explicit and implicit relationships between activities which together comprises the overall model of the project logistics. From this overall model, cycle time/due date and budget commitments can be derived. A fundamental assumption, common to the practice of project management today, is that; in order for us to have high confidence that a project will finish on time and on budget, we must necessarily ensure that all activities finish on time and on budget. The existence of this assumption is foundational to the discipline of variance analysis. In order to handle the uncertainty and risk required to make realistic commitments, the practice has been to embed enough contingency in each activity to ensure that its chance of completing on time and on budget, is reasonably high.

The amount of contingency required by each activity to make its performance highly reliable is not trivial. The discipline of Project Management is typically applied in environments that by their nature, is highly uncertain and where the consequences of that uncertainty costly in terms of time, money and missed opportunities. In general, it is safe to say that the more uncertain the environment and the more significant the consequence of missing the commitment, the greater the amount of safety incorporated into the planning of *each* activity must be, in order to maintain a high degree of reliability. This is the *non-aggregated risk* technique; each activity is lengthened to provide protection against all its associated risk.

The paradox, however, is that even with all this apparent safety; projects still have a tendency to be late. The problem is that human nature, as exemplified by Parkinson's Law (Parkinson, 1957) and the student

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syndrome (Goldratt, 1997) (both further described below) make it difficult for us to benefit from the generous helpings of safety and thereby deliver the majority of projects on or within schedule and budget.

The Critical Chain method has considered these factors in the application of its risk mitigation strategy, and this has resulted in the concept of aggregated risk. The entire concept of aggregated risk is independent of resources, therefore, it should apply equally well to Critical Path planning and execution.

Needs for Aggregated Risk

The need for risk aggregation is well established through the long history of accepted practices such as the insurance industry and other methods of pooling risk. Anywhere that a reservoir is utilized to dampen the effects of large local system deviations, the aggregation principle is in practice. In the domain of project management two major factors will be used to illustrate the need for aggregated risk (Parkinson's Law and the student syndrome), in addition to a third factor (multi-tasking).

Student Syndrome (Procrastination)

As in the classic case of the student who waits until the term is almost over to start working on the term paper, procrastination is rampant in the work place. Having more than enough time to do an assignment or task is reason enough to let time pass before investing any serious effort into its completion. Add to this the fact that in the work place there are often several other more urgent work responsibilities, it is then understandable that many tasks or activities are only executed when the level of urgency associated with them is sufficiently high to justify the effort required to accomplish them. Frequently, we discover aspects to the assignment that require more time than we had given ourselves. This is the true damage of procrastination. In the end, when something goes wrong, we have squandered the contingency that we had purposely built into the plan in to save us from the unpredictable. The phases of the student syndrome are:

1. Initial Activity
2. Inactivity
3. Deadline Trigger
4. Burst of Activity

A general depiction of the level of effort on put towards an activity when worked according to the student syndrome is shown in Figure 1.

Parkinson's Law and Failure to Report Early Completions

Parkinson's Law: "Work expands so as to fill the time available for its completion". Not every activity suffers from the student syndrome. There are many activities (maybe even the vast majority) that do complete (or almost complete) in less time and use fewer resources than are actually allotted per plan. This should be the case since the risk mitigation occurs within each task. In correctly functioning environments, this situation is seen for the good fortune it is and efforts are taken to ensure that the project overall reaps the benefits of this good fortune every time it occurs. Unfortunately, there are various factors that make the reporting of such situations non-beneficial; Parkinson's Law at work, e.g.,

- I can make it better.
- I don't want to be wrong on my estimate.
- The reward for finishing early is more work.

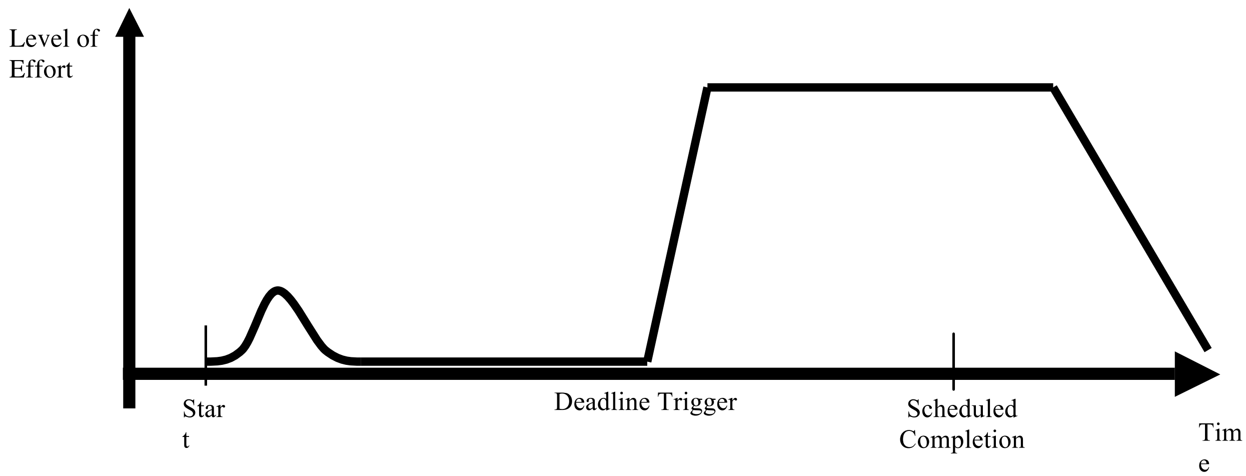

Figure 1. Student Syndrome

For example, unused contingency is often viewed as a tell-tale sign of prior "sandbagging", the practice of knowingly asking for substantially more time and or budget than the job requires. Sandbagging is a negative characteristic in the business world in general, and project management environments in particular. Another factor is that the reward for good work, is more work; that is, if someone can effect when an activity is reported complete, they can effect when the next activities' clock is started.
The resulting behavior in project environments afflicted by these conditions is that tasks that may actually be completed early will appear to take nearly as much time and budget as was allocated, regardless of the degree of uncertainty that exists in the environment naturally.

If the universal measure of task completion is the due date of a task, then there is a good chance that tasks will never be reported as complete before the due date has past.

Multi-tasking

Although the pursuit of high resource utilization as an end in itself may appear on the surface to be a good idea, the practice that it requires, multi-tasking, can be detrimental. In its simplest form multi-tasking occurs when there is so much demand on a resource's time that the resource is forced to interrupt each activity before completion, in order to work on another activity (Goldratt, 1997). Every interruption and activity switch hurts the productivity of the resource, especially in the case of labor. When the activities involved are from different projects, the widespread practice of multi-tasking can result in significant delays to each project involved. The negative effects of multi-tasking are difficult to detect in project management organizations. On the contrary, multi-tasking has the effect of ensuring that resources appear to be in constant demand and therefore satisfying the expectation that they be fully utilized.

For labor, multi-tasking provides another reason to not complete an activity; each additional activity provides cover for not yet completing other activities one is multi-tasking on.

Aggregated Risk: The Critical Chain Solution

The Critical Chain solution to handling the problems mentioned above, is to aggregate the risk of many activities. In the Critical Chain methodology, project networks are rebuilt (versus Critical Path networks) in a way that:

removes the entire hidden contingency from activity durations and replaces it with explicit contingency provisions strategically located at key points within the project network or project model.

This results in:

project models that reflect a shorter overall cycle time while at the same time providing a higher degree of schedule and cost risk protection.

The process starts with the creation of a project network that reflects the logical dependencies between activities in a project. **Resource** requirements are then added (represented in the exhibit by different colors) and the tasks estimated according to the new rule of scheduling activities with no contingency embedded. The entire network is then scheduled to level the work load of each **resource** to fit within their stipulated capacity. The list of tasks comprising the "**Resource** Constrained Critical Path" otherwise referred to as the Critical Chain, is then identified and all remaining tasks assigned to one or more feeding paths (Goldratt, 1997). See the yellow outlined sequence of tasks in Figure 2. At this point the network is a very aggressive representation of the schedule as it has no provisions for uncertainty. The model at this point is therefore considered to be too high risk to be used as the basis for committing to a schedule or budget.

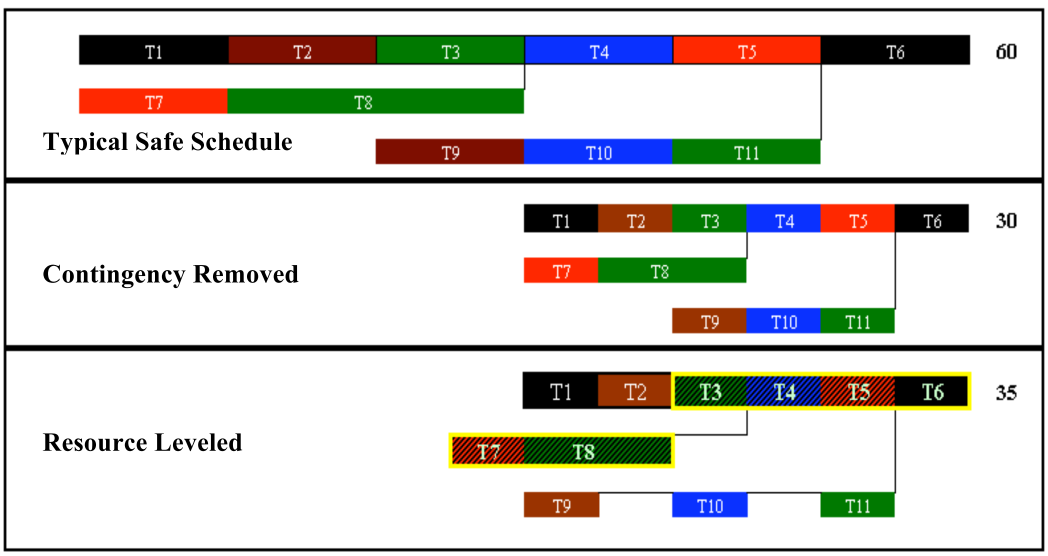

Figure 2. Going from a traditional schedule to an unprotected Critical Chain schedule

The final step of creating the single project Critical Chain schedule is to calculate and insert appropriately sized and located contingency buffers designed to render the schedule practically immune to the normal levels of uncertainty one is likely to encounter during execution of the typical project plan. An example of a fully protected Critical Chain schedule is illustrated in Figure 3, where FB stands for Feeder Buffer.

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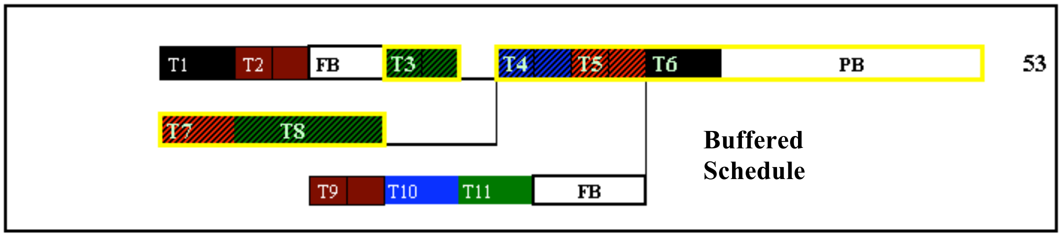

Figure 3. A fully protected Critical Chain schedule

A generously sized Project Buffer [PB] of approximately 50% more time is added to the end of the Critical Chain while similarly sized Feeding Buffers [FB] are inserted at the point where each feeding path joins the Critical Chain. The schedule is always re-leveled post buffering and cycle time commitments are made based on the entire schedule, including the buffers. Note that the Critical Chain, unlike the Critical Path, will cross over between logistical pathways as necessary to reflect resource constraints. All other factors being equal, when the 50% buffer sizing rule is used, the Critical Chain schedule is typically approximately 25% shorter than its resource leveled Critical Path equivalent but is substantially better protected from uncertain events due to the explicit use of buffers as a means of containing schedule risk. This apparent contradiction can be explained as resulting from the fact that in the Critical Chain environment, we can count on early activity completions to cancel out some of the effect of late completions, reducing the overall impact of activity delays on total project duration.

For purpose of schedule stability, even though feeding paths may overwhelm their buffers and impact the Critical Chain, only under extreme circumstances is the Critical Chain ever allowed to be recalculated during project execution (Goldratt, 1997).

Multi-tasking: Elimination of

In order to ensure that resources are able to dedicate a full level of effort on each task to which they are assigned, the Critical Chain approach to project management insists on the elimination of multi-tasking to the greatest possible extent. Resources are instructed to work each assignment to completion before starting a new assignment. All other pending assignments are to be queued up in such a manner that any available resource with the minimum pre-requisite skills can be assigned as soon as they become available. A system of work prioritization is strictly enforced. To ensure that resources are not overwhelmed with a large backlog of unassigned work, projects are delayed in their start date until resources are available to take on the new work. Excess capacity is maintained in the resource pool to absorb potential delays in work execution. With these changes, work moves swiftly yet smoothly, resulting in shorter cycle time per individual project and the completion of more projects in a given period of time compared to the case where multi-tasking is the normal mode of operations.

Buffer Management or Real Time Execution Management using CCPM

During execution, activity priorities are calculated based on the relationship [ratio] between the amount of buffer depleted and the remaining length of the Critical Chain. To compute these parameters it is essential that as each task is assigned and completed, feedback is provided regarding starts, completions and partial progress, in terms of time remaining to complete each incomplete task. The traditional Percent complete by task is not used. The project buffer (PB) is depleted as delays along the Critical Chain accumulate. The remaining length of the Critical Chain is computed as a percent of its original length and the same is done for the project buffer. These percentages are further compared as a ratio where the larger the value the better shape the project is in.

A value greater than 1.0 indicates that the rate of PB loss or delay accumulation is greater than the rate at which work is being completed along the Critical Chain. At any point during the execution of the project, this would be an indication that the risk of the project going late is substantial and that actions should be taken immediately to recover schedule and therefore replenish the buffer. A simple Fever Chart is used to depict the current status of a project. See Figure 4 for an illustration of how schedule risk for a single project can be tracked over time. A Red/Yellow/Green convention is used to depict the overall status of each project at regular intervals and a trend chart is used to project whether or not the project's status is changing for the better or for the worst.

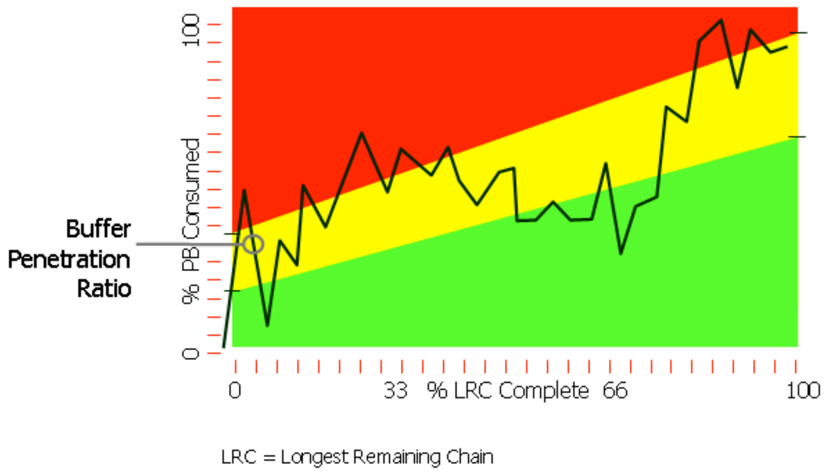

Figure 4. Fever Chart

Although the trend chart is only displayed at the project level, the data behind it is available for all buffers in a given CCPM project. Since all tasks feed at least one buffer, it is possible to compute for each task, its current impact to all buffers, and therefore the relative risk it posses to the project as a whole. This information can then be used to establish the priority of every task in the project based on relative current risk to the project.

Aggregate Risk Critical Path Planning

In the section above, "Aggregated Risk: The Critical Chain Solution" resources were rarely mentioned; actually the word *resource* is in bold text each time it is used. Only one (albeit important) part of the solution required the explicit modeling of resources, the determination of the critical chain and hence the feeder chains. Note that this determination of the critical chain and hence the feeder chains would proceed in the same way even if there were always enough resources so that a resource conflict never arose. That is, if the Critical Chain (i.e., the resource-constrained critical path) was the same as the Critical Path.

Therefore, the benefit of aggregated risk that has been beneficial to the application of Critical Chain is available to Critical *Path* project management. The approach is the same, sans the step of resource leveling.

The conversion from Critical Path Planning to Aggregate Risk Critical Path Planning proceeds as follows:

1. Update each activity duration to remove the entire hidden contingency, i.e., the activity duration is that duration where the probability of finishing on time is 50/50.
2. Insert Feeder Buffers (FB) where non-critical-path activities merge into the critical path.

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3. Insert a Project Buffer (PB) after the final critical path activity.
4. During execution prioritize activities using buffer penetration.

Conclusion

A major inhibitor to the application of the Critical Chain method is: the effort required to explicitly model resources. Since explicitly modeling resource constraints is part of the Critical Chain's definition, it would be logical to assume that all its other properties depend on this premise; but fortunately, many of the beneficial aspects of the overall Critical Chain methodology can be applied to critical path projects.

Therefore, both Critical Chain Project Management and Aggregate Risk Critical Path Planning minimize the negative outcomes of procrastination, and Parkinson's Law, as well as multi-tasking.

For all the projects that do not presently explicitly model resources, there is essentially only one trivial modeling step to exploiting or at least exploring Aggregate Risk Critical Path Planning (except possibly translating the model into a Critical Chain software package). Simply use the current model, then set all the activities to require one unit of a dummy resource and then define the available number of dummy resource units to the number of activities. At this point simply use the Critical Chain software as advertised and the result will be Aggregate Risk Critical Path Planning.

Of course there are many more inhibitors to the adoption of the Aggregate Risk Critical Path Planning, than simply eliminating the need for explicit resource modeling. However, by making some of the ideas promoted by the Critical Chain method accessible a la carte, they are more likely to be experimented with and incorporated into practice because the leap can become a series of smaller steps. In addition, many practitioners may find that a few steps serves them better than the entire leap.

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