An analysis of Critical Chain concepts in the context of their possible application to traditional project management

Peter Schneider-Kamp
(Supervisor: Peter Bollen)

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Abstract

Critical Chain Project Management is a relatively new, popular project management paradigm. Due to its radically different approach of addressing common project management problems, there is a strong interest in researching its utility. Much of the debate is focused on determining or refuting the superiority of the specific paradigm presented by Goldratt in his 1997 novel ‘Critical Chain’.

In contrast, it is the objective of this paper to highlight the potential benefits of analysing and incorporating the underlying insights and ideas of Critical Chain Project Management into more traditional project management contexts.

Five principle constituent concepts are identified that appear to be of general use in project management: (1) the consideration of resource constraints in determining activity criticality, (2) the aggregation of contingency time at an activity chain’s end, (3) the explicit accounting for uncertain activity durations, (4) the monitoring of contingency time buffers for project control and (5) the timely alerting of project resources.
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1 Introduction

In 1997 self-proclaimed guru Goldratt published a novel “Critical Chain”[1] which describes a new, supposedly superior approach to project management based on identifying and managing a critical chain of activities. The “Critical Chain” does away with milestones, multitasking and per-activity contingency time and advocates project contingency buffers and a roadrunner mentality instead.

Due to this radical disregarding of established project management concepts the audience has ever since been split. Many conservative researchers and practitioners claim that Critical Chain Project Management is nothing new and therefore a waste of time, while a growing movement of Goldratt-disciples touts it as the new silver bullet of project management.

So, what is the straight dope on Critical Chain Project Management? There has been some detailed and critical research[2][3][4], but as usual a definite answer cannot be given. In a nutshell, the Critical Chain approach is found to be intuitively appealing, but many a doubt is cast on its general applicability and utility.

Instead of analysing the over-all concept of Critical Chain Project Management this paper focuses on the novelty and potential merits of the constituent concepts in order to research the following question:

In how far can Critical Chain concepts supplement current best practice in project management?

For a better understanding of these concepts, the following section takes a look at the major theoretical influences on Critical Chain Project Management, namely Goldratt’s Theory of Constraints[5] and the statistical concept of common cause variations. A short introduction to these theories and their application is given from a project management perspective.

Armed with this theoretical background, section 3 reviews the basic concepts of the Critical Chain approach to project scheduling and project control. An analysis is performed by contrasting it to traditional project management techniques.

Based on this analysis, the merits and pitfalls of the the concepts are discussed in detail in section 4. Basic assumptions of the Critical Chain approach are challenged and over-simplistic guidelines exposed.

Bringing it all together, section 5 first concludes on the utility of Critical Chain Project Management itself. Then the concepts found to be useful are generalised and suggestions for further research are given.


2 Theoretical Background

In order to understand where the basic ideas behind Goldratt’s Critical Chain approach originate, it is important to consider the two theoretical concepts that the approach is based on.

When managing a project, two of the most important questions are how to prioritise activities and resources and how to deal with uncertainty. The former can be answered by Goldratt’s self-made theory about system constraints, the so-called ‘Theory of Constraints’. The latter is approached by examining the statistical control concept of common cause variations.

Although some texts differentiate a third ‘theory’, that is to say the statistical laws governing chained probability distributions, this can be incorporated as part of the common cause variation argument.

2.1 Theory Of Constraints

Generally Goldratt advocates a global, i.e. systemic, view for management. An organisational process is thereby regarded as a system consisting of input, throughput and output.

The bottom line of his Theory of Constraints is that in every system there must exist a constraint on the output. This reasoning can be justified by pointing out that otherwise the system must have an infinite or a zero output. The constraint is either due to a constrained availability of input or to capacity limits of the throughput. By identifying, exploiting and elevating the constraint the system’s output can be increased.

Now, applied to project management the input of the system is resources, the throughput is the actual work done on the project and the output is in how far the project is completed on time, within budget and specifications.

In order to increase the output of the project, e.g. to make the project use less time and money to achieve the specified outcomes, an iterative step-by-step process based on the Theory of Constraints can be applied:

1. Identification of the system’s constraint:
   In a project management context the identification step must locate those critical resources and interdependent activities that will have the largest negative impact on the project’s duration, cost or scope.

2. Exploitation of the constraint:
   The exploitation step demands that these critical activities and resources are scheduled in an optimal way. The scheduling of all other activities and resources must be subordinated.
3. Elevation of the constraint:
In the case that the project’s likely output is deemed to be unsatisfactory the constraint must be elevated, i.e. critical resources must be added or activity dependencies resolved.

4. If the constraint is broken, go back to Step 1:
If by elevation of the identified constraint the critical activities and resources loose their criticality, one goes back to the identification step in order to identify the new constraint.

In section 3 it is shown how this Theory of Constraints approach is used by Goldratt’s Critical Chain Project Management.

2.2 Common Cause Variations
The great foe of planning is uncertainty. Dealing with uncertainty is an intrinsically dirty business, as information about the future is at best incomplete. Therefore, variations will undoubtedly occur during the course of any project of sufficient size.

Two types of variations can be distinguished — special cause variations and common cause variations. The former cannot be handled methodically, as they are specific to the people working on the project, to some physical resource or to the local environment. Resource-specific variations must be handled by developing or replacing problematic resources; risk management should provide contingency plans for discrete risk events[6]. The latter kind of variation, though, which is due to causes that are inherent in the system, can and should be handled by project scheduling and control.

Leach[3] argues that time is the output dimension which is most likely to be affected by common cause variations. Through activity dependencies the variations in activity durations accumulate for the whole project. This effect is added by the observation that typical project activity duration distributions are left-skewed, i.e. a more than moderately early finish of an activity is extremely unlikely, whereas there is a small but significant probability of large overruns.

Now, how can the project be protected against common cause variations of activity durations? An advantage can be gained by closely chaining activities according to activity dependencies and resource constraints. Statistics tells us that the variance of the chain will be the sum of the variances of all the individual activities. This implies that the standard deviation, i.e. the square root of the variance, is growing sub-linearly.

Additionally according to the central limit theorem the more individual activities on our path, the more similarity the overall distribution will bear to the normal distribution. Thereby and due to the sub-linear growth of the standard deviation the size of the buffer protecting the path can be significantly smaller than the sum of all the buffers necessary to protect each individual activity.
3 Analysing the Critical Chain approach

Goldratt bases the Critical Chain approach on a number of undesired side effects in traditionally managed projects. The conjecture is, that these effects, through direct or indirect means, impair the project output. Therefore, this analysis starts off by explaining their rationales.

In order to counter these effects the Critical Chain approach tries to identify, exploit and elevate the project’s constraints, i.e. the chain of critical events. Consequently, a short analytical description of the critical chain approach and its concepts is given in subsection 3.2. Now, this approach can only succeed when human factors receive appropriate consideration. Therefore, the basic human resource management challenge associated with Critical Chain Project Management is outlined in the following subsection.

Goldratt also proposes a way of controlling the project during the course of its execution by managing its buffers. A short introduction of this idea and Goldratt’s implementation is given in the last subsection of this section.

3.1 Undesired Effects in Project Management

Traditional project management, as e.g. described by Meredith and Mantel, tries to manage the project by breaking the whole down into small work pieces and then dealing with them individually. Interactions due to common resource dependencies and activity precedence dependencies are only considered for planning the overall duration. Optimisation only takes place at the local level.

This locally-oriented management and the ignoring of human psychology often results in a number of dire side effects:

1. Overly safe duration estimates:
   In estimating activity durations, it is rarely communicated what the probability of the estimate is and how much contingency time has been included in the estimate. Even in three-time PERT, where a worst-case, a most-probable and a best-case estimate are made, there is no clear definition of the probabilities. Because of this and the fact that not meeting a schedule is punished in most systems, project members tend to make an overly safe duration estimate for their activities.

2. Scarcity of positive variation:
   Goldratt agrees with Meredith and Mantel on the prevalence of Parkinson’s Law, i.e. that “Work expands to fill (and often exceed) the time allowed”. The cause for this probably is that people do not start to really work on their activity until it really gets urgent. This phenomenon is also called the ‘student’s syndrome’.

   The effect of this syndrome is a relative scarcity of positive variations playing havoc with the all-important schedules.
3. **Loss of positive variation:**
An organisation’s climate often discourages reporting of early finishes. People completing their activity before schedule are not rewarded but punished by being assigned more work. This leads to the loss of positive variation.

4. **Delays caused by path merging:**
Even if positive variation is timely reported and thereby realized, the delays caused by path merging offset the gained advantage. When multiple paths merge, a successor activity can only begin after the path with the longest delay has completed. In a nutshell, positive variations rarely contribute to overall project duration — delays always do.

5. **Multitasking:**
A side effect of traditional project planning much debated-on is the delays allegedly caused by multitasking. Goldratt argues that it increases average throughput time while at best the level of throughput is constant. This kind of local optimisation can damage over-all project performance.

6. **Loss of focus:**
Goldratt complains about the loss of focus in the management of projects. E.g. earned value project control does not consider schedule importance of activities, and if the thresholds are too tight, too many control actions are invoked.

This list of undesired side effects leads to the conclusion that a new project management paradigm should give clear focus on critical activities while providing a replacement mechanism for deadlines and individual activity contingency times.

### 3.2 Critical Chain Project Scheduling

The Critical Chain approach is Goldratt’s attempt to apply the Theory of Constraints to project management as described in section 2.1. The main focus is on identifying and exploiting the project’s constraint rather than elevating it. The project’s constraint is described by Goldratt as “the sequence of dependent events that prevents the project from completing in a shorter interval”. This so-called ‘critical chain’ is determined by activity and resource dependencies.

The difference to the Critical Path Method is that resource dependencies are considered by definition. Using the Critical Path Method resources are only levelled after finding the critical scheduling path.

For a project without serious resource constraints, the critical chain equals the critical path. More remarkable, though, is that the Critical Chain approach also uses different activity duration estimates, namely 50% estimates. These do not estimate the time required to safely complete the activity, but an estimate at what duration there is a fifty-fifty chance of the activity to complete. Substantially reduced in duration, the schedule is constructed. Where needed a Latest Finish Time heuristic is used for resource dependency resolution.
Practically, this results in the subtraction of individual activity contingency time. By aggregating this subtracted time into a *project buffer* at the end of the project schedule, compensation for the reduced safety of individual activities can be gained. Because of the statistical relations explained in section 2.2 it is of more use there, anyway. According to Goldratt 50% of the sum of all critical chain activities should be used as the preferred buffer size. Altogether, this way the length of the critical chain can be reduced, and thereby this exploitation of the project’s constraint leads to a reduction in overall project duration.

For non-critical chains a corresponding buffer, called a ‘feeding buffer’, is placed between the chain’s end and the merging into the critical chain. This protects the critical chain from non-critical chains feeding their delays into it.

Not only the schedule, but also the resources of the critical chain are protected in the Critical Chain approach. This is accomplished by so-called ‘resource buffers’ — basically a mechanism of alerting resources an appropriate amount of time before they are needed in order that they can be prepared and ready to start work when the activity they are required for really starts.

### 3.3 Human Factors

An application of the Critical Chain approach requires an extensive human resource program. As described in subsection 3.1 project members tend to overestimate activity times, to start late, if contingency time is available, and to not report early finishes before the appointed deadline.

Un-learning must always precede learning. Not until all these old habits have been unlearned, project members can be educated about the Critical Chain approach. Project members have to learn exactly what is expected of them.

One of the most important points is to make clear, that under- or overrunning the estimate is normal. Project member performance appraisal may not be affected by meeting or not meeting deadlines, but by observing if people really work on their current activity effectively and if they report accurately on their performance. This could be implemented as a pay for performance or even a pay for contribution reward system.

### 3.4 Critical Chain Project Control

The objectives of project control according to Meredith and Mantel are:

1. Regulation of results through alteration of activities
2. Conservation of organisational assets

In order to fulfil these objectives, the project’s performance must be monitored. In Critical Chain Project Management monitoring the buffers gives a good measure of the project’s performance.
Goldratt advocates a tripartite buffer monitoring and control approach which looks at the amount of buffer penetration:

- **Negative penetration or in the first third:**
  The project is doing fine within the bounds of the aggressive critical chain schedule. Consequently, *no action* needs to be taken.

- **Penetration of the second third:**
  Upon penetration of the second third, the risk of overrunning must be considered. Special cause variations or overly optimistic duration estimates are probably taking their toll. In this stage it is important to carefully *observe* further progress and *plan* control actions, but not to take any action yet. Disturbing common cause variations may prove costly.

- **Penetration of the third third:**
  When this final third of the buffer is penetrated, overrunning the buffer seems likely. If the project is not on the verge of finishing, *action* must be taken.

It is important that buffer penetration is updated and monitored at least as frequent as one third of the total buffer time as otherwise important penetration events can be missed. Penetration itself is measured by simply asking the project members how much longer they estimate to work until activity completion.

According to Leach[3], this approach “provides a unique anticipatory project management tool with clear decision criteria”.


4 Challenging the concepts

In this section first a critical look at some of the most prevailing concepts of the Critical Chain scheduling approach is taken. This implies that, after a short discussion of the Latest Finish Time scheduling heuristic, the reasons for avoiding multitasking and the assumption of single-unit renewable resources, the concept of the critical chain itself is evaluated.

In subsection 4.5 the proposed concept of a project buffer is examined in detail. In this context the utility of resource buffers is challenged.

In the final subsection it is discussed in how far assumptions about the human performance are correct, and if a Critical Chain set of mind can solve the problems at hand.

4.1 Latest Finish Time Scheduling

Latest Start Time and Latest Finish Time scheduling are known to be among the best priority rules for resource levelling. But computational experiments have repeatedly revealed that project durations generated by these heuristics easily exceed the optimum by 5% or more.

Raz and Barnes observe that the quality of the critical chain schedule depends on the quality of the optimisation used. Herroelen and Leus show that better optimisation techniques like branch-and-bound effectively shorten the project’s duration.

4.2 Avoiding Multitasking

In general the influence of multitasking on project duration is difficult to assess. In some cases multitasking can save time, e.g. when the amount of work a project member M working on activity A is constrained by the progress of activity B. Due to this interdependence it may be more time-efficient to have M work on B whenever he is waiting for output from B in order to be able to continue on A.

General research on scheduling in waiting queue theory shows that the benefit of multitasking depends on the system’s objective. If average throughput time is paramount, e.g. when other activities are depending on the enqueued activities, serial processing may be appropriate. On the other hand, if activities involve waiting operations, e.g. with interdependent activities, avoiding multitasking may prove a major mistake.
4.3 Single-unit Renewable Resources

The Critical Chain approach focuses on single-unit renewable resources. This is probably due to its background in manufacturing where often a single machine is the constraining resource. Non-singular renewable resources or non-renewable resources are not dealt with explicitly.

Although this is seen as a problem by Herroelen and Leus[2] results should not be any worse than with the traditional Critical Path Method and resource levelling.

Another detail that will be discussed in more detail in subsection 4.5 is that due to common cause variations a reliable resource graph cannot be deduced from a Critical Chain schedule. Raz and Barnes[12] call this phenomenon “incorrect resource graph”.

4.4 Critical Chain

As the critical chain not only considers activity precedence dependencies, but also resource constraints, it appears to be an improvement over the critical path.

But there are some caveats. As discussed in subsection 2.1, a consequent application of the Theory of Constraints would require to identify constraints on time, cost and scope. Leach[3] as well as Herroelen and Leus[2] analyse this matter and find that in the majority of cases ensuring the project is on time will ensure that cost and scope come in as planned either. Depending on the time-dependent costs of the project, cutting its duration can significantly decrease over-all cost.

Another obvious problem is that Critical Chain scheduling defines the critical chain as a constant entity. Depending on the way activities and resources are scheduled the critical chain is not unique[2]. Also generally there may be almost-critical chains. As the critical chain is given priority it is likely that they will eat their relatively short feeding buffers and thereby become critical. Similarly, changes in resources or actual activity durations may result in non-critical chains becoming critical[12].

Again a consequence of applying the Theory of Constraints would be that non-critical chains should be allowed to become critical. As defined in step 5, if a new constraint replaces an old one, the process has to start over. Goldratt argues that rescheduling and a changing critical chain will disrupt operations and that the buffer will have to absorb such variations.

4.5 Project Buffer

A lot of the discussion on the project buffer is concerned with the buffer’s size. Goldratt’s original rule of 50% of the critical chain length is seen by some as overly pessimistic. As argued in subsection 2.2 a method based on the root of the squares can be used. But, as Raz and Barnes[12] point out, this assumes the independence of activity durations — which is usually not a valid assumption in a project setting.
The more serious problem with the concept of a project buffer, though, is that secondary effects can prove any reasonable buffer size insufficient. First, it may not be possible to have appropriately sized feeding buffers because the non-critical chain is almost as long as the critical one. Increasing feeding buffers in these cases will result in prolonging the critical chain. Secondly, there is a high probability of resource conflicts whenever an activity under- or overruns its estimate. Resource buffers can try to ensure that resources are ready when needed, but non-critical paths will suffer substantial delays in the case of resource conflicts thereby endangering the whole project. Also, a realistic planning of resource usage does not seem feasible in this context of unsure resource requirements and unplannable resource usage changes.

4.6 Human Performance

Goldratt bases his approach on the assumptions that cutting activity times increases commitment and thereby defies the student’s syndrome. There is no empirical evidence to support this. If the estimates are perceived as realistic, and people feel that their quality of work life is not too adversely affected by the ‘roadrunner mentality’, the assumption might hold. Otherwise, this system can and will be tricked, skewed and exploited — just as any other system that is perceived to be unfair.

Raz and Barnes question whether the implementation of the necessary human resource and organisational changes will be easy to implement. Changing the way people work in such a fundamental way might prove to be hard or even impossible.
5 Conclusion

In the preceding sections it was shown that Critical Chain Project Management represents an interesting view on the project management challenge. Based not only on the clever use of statistical properties but also on some basic understanding of human behaviour, it seems that it can at least partly address the problems caused by Parkinson’s as well as Murphy’s Law.

As expected, the approach was also found to lack in some respects, e.g. the overly simplistic rules for buffer sizing and buffer monitoring. A more dire problem, though, seems to be the high probability of resource clashes due to the missing contingency time between consecutive activities.

5.1 Generalising the concepts

Getting back to the grindstone, the focus can be shifted back to the constituent concepts of the Critical Chain approach. From the discussion in section 4 it can be seen that Critical Chain Project Management really has some truly novel and useful concepts to offer. The ideas in the following list can be considered general enough to be of value outside the context of Goldratt’s Critical Chain approach and are probably well-suited to supplement existing best practices:

- Consideration of resource constraints in determining activity criticality:
  The concept of criticality is well-established in the realms of project management. Considering resources in addition to activity dependencies is an almost obvious extension of the critical path paradigm.

- Aggregation of contingency time at an activity chain’s end:
  As argued above, aggregating contingency time in a path or chain requires either less contingency time or results in a better protection provided that there are not excessive resource conflicts.

- Explicit accounting for uncertain activity durations:
  It is certainly a good idea to account explicitly for duration uncertainty — if only to make sure that the project manager and the project members are talking about the same levels of risk. The approach taken by Goldratt seems simpler and thereby more acceptable than e.g. GERT, which some describe as hard to understand and difficult to control[6].

- Monitoring of contingency time buffers for project control:
  In any schedule with contingency buffers, monitoring these should provide valuable additional information for project control decisions. As data collection is quite trivial, costs should be negligible.

- Timely alerting of project resources:
  The idea of preparing resources by alerting them an appropriate amount of time before they are needed is a measure of low costs and high potential benefits.
All of these concepts can be of use on their own, but it seems likely that a well-chosen combination will yield even better results. The exact way of integrating them with one of the Project Management Bodies of Knowledge should be considered a worthy research opportunity.

5.2 Further Research Opportunities

Additionally, further research could help to develop the still quite rough idea of Critical Chain Project Management into a new, truly superior project management paradigm. Here, the most important research issue should be how to keep the advantage of buffer aggregation while minimising resource clashing. Reviewing the inherent assumptions about human psychology would also be expected to be of great use in gaining a deeper understanding of the project management challenge.

Another issue, which research has already been started on, would be to apply the Theory of Constraints more consequently to project management. Possible areas where this could lead to improvements could be allowing moderate amounts of rescheduling\[4\] or broadening the constraint perspective from schedule-only to all the three dimensions of project performance\[13\].
References


