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PUTTING THE CORE ELEMENTS OF CRITICAL CHAIN PROJECT MANAGEMENT INTO PERSPECTIVE: A GENERAL FRAMEWORK FOR BUFFER MANAGEMENT

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ABSTRACT

Since the publication of Goldratt's Critical Chain, most of the books and articles devoted to Critical Chain Project Management (CCPM) present it in contrast to an assumed well-known but undefined "traditional" CPPM (Critical Path Project Management), spending more attention to describe how CCPM differs from traditional CPPM than in describing the methodology, techniques and assumptions behind CPPM. There is already good evidence that CCPM delivers results when applied to real situations. The paper dissects the Critical Chain Project Management CCPM philosophy, discusses its distinctive elements, grouping them around five main issues. The paper combines a theoretical presentation of the issues with empirical evidence from the results of a survey and the application of CCPM techniques to a large shipbuilding company.

Keywords: project management, critical chain, buffer management.

INTRODUCTION

There is no doubt that with the publication of his Critical Chain book (Goldratt, 1997) has prompted many people to reexamine the way they plan and manage projects. As it is customary in Goldratt's work, although "anecdotal and intuitive in nature, showed excellent insights and solution directions to the problems faced by traditional project management methods" (Anavi-Isakow and Golany, 2003). The Critical Chain (CC) concept is presented as an application of the Theory of Constraints (Goldratt, 1999) to project management (Rand, 2000), by extending the concept of Critical Path to take into account resource constraints. (Leach, 1997) defines CC as "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".

Since the publication of his first book, The Goal (Goldratt, 1992) has used a story telling approach to present concepts or methods, which have an appealing beauty, are practical,

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and have an intuitive simplicity. This makes them very attractive to the practitioners and also allows Goldratt to avoid entering into the messy computational details, or having to present any proof of its efficiency or efficacy in solving particular problems.

In his Critical Chain, Goldratt does not make any single reference to anybody else's work, as it has been traditional in all his previous publications. He has been right on many occasions on presenting the drawbacks of some existing practices (e.g., cost accounting when it uses unit cost for production decisions), but he has failed to give credit to other authors and textbooks which have pointed to ways to solve these shortcomings (e.g., by using linear programming to determine the profit per unit of scarce resource).

The CC material is managing to get into most project management textbooks, with different fortune. While (Maylor, 2003) devotes a whole chapter to the Critical Chain approach, (Gray and Larson, 2002) discuss it in just a few pages of their 500+ pages textbook. Some books, such as (Newbold, 1998) and (Leach 2000) focusing on the Critical Chain approach, have filled some of the details of the methodology, but not all. The topic makes increasing appearances in specialized journals.

Most of the books and articles devoted to Critical Chain Project Management (CCPM) present it in contrast to an assumed well-known but undefined "traditional" CPPM (Critical Path Project Management), which corresponds to some characterization of the reality of the application of current project management tools. They spend more attention to describe how CCPM differs from the traditional CPPM than in describing the details of the proposed methodology, the techniques, and the assumptions behind CPPM. However, there is already good evidence that CCPM delivers results when applied to real situations, as documented in the publications of the Goldratt Institute (Leach, 1999), ITT Night Vision (Cook, 1998), and a recent case study (Ribera, Grasas, 2003a) which reviews the application of the CC to the shipbuilding industry. (Steyn, 2000) claims that "it is difficult to determine to what extend the TOC technique or the mere emphasis on network planning contributed to the success"

The paper dissects the Critical Chain Project Management CCPM philosophy, and discusses its distinctive elements, grouping them around five main issues: (1) the estimation of activities' durations, (2) the definition and computation of the critical chain, (3) the definition, positioning and sizing of buffers, (4) the assignment of resources, and (5) the project monitoring via buffer penetration. The paper combines a theoretical presentation of the issues, referring whenever possible to previously published (but mostly forgotten) literature, with empirical evidence from both a survey of practitioners in Spain (Ribera, Grasas, 2003b) and the recollection made by the authors of experiences from companies applying the CC methodology. The paper complements the work of (Herroelen and Leus, 2001) which follows a similar outline with a more theoretical approach.

The project management survey (Ribera and Grasas, 2003b) was conducted during the period January-March 2003, using a convenience sample, former participants in a Project Management intensive course run by one of the authors at IESE for the last few years. Out of 300 distributed surveys, we got a response of 105 (35%), which provided quantitative as well as descriptive aspects of their project management practices.

CRITICAL CHAIN PROJECT MANAGEMENT MAIN ELEMENTS

1. Activity duration estimation

CCPM claims that the traditional CPPM incorporates some time contingency in the estimate of the duration of each activity. This time buffer guarantees the activity owner some safety level, a reasonable probability that the task can be completed in the specified total time. In the mentioned survey we found this claim to be true for many companies. Project managers admitted incorporating buffers to most activities to cover for the uncertainty in their duration (Fig. 1). Furthermore, two thirds of the respondents mentioned the inclusion of some extra buffers the functional managers and the project manager. When these practices result in too long a project, the buffers are reduced in a negotiation process, but care is taken to keep enough contingencies in the "critical" activities, criticality defined in a loose way, including activities for which there is high uncertainty and activities which are dependent on the client or a third party, thus not directly controlled by the project manager's company. The definition of 'critical' used by practitioners bears a resemblance more to the 'critical core', the set of activities that are either pacing the project, or within striking range of being the pacing item (Mascitelli, 2002).

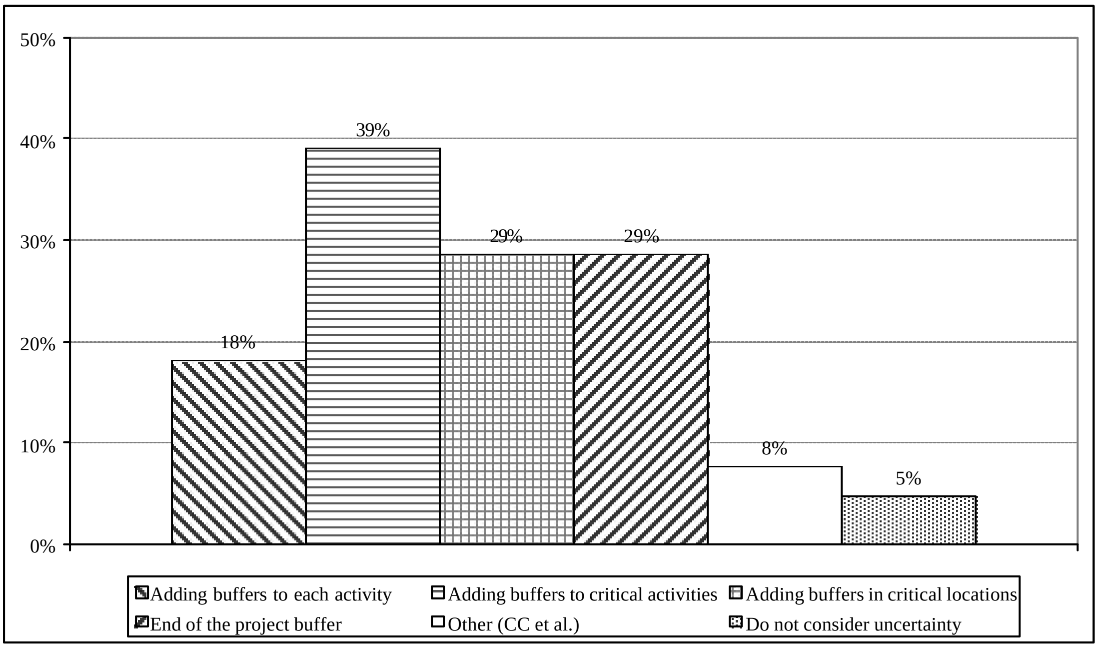

Figure 1 - How uncertainty is incorporated in planning

The main problem with these time buffers is that they are not transparent, as the activity owner when producing the estimate does not disclose which part of the total time corresponds to the expected activity duration and which part to the contingency buffer. Furthermore, the rationale behind the buffers is not made explicit, is not shared, is mainly based on intuition and not on facts, and therefore cannot be managed at the project level, nor can any learnt lessons about the buffers be developed at the completion of the project.

The existence of these (hidden) buffers, which activity owners consider to be under their responsibility, favours some perverse behaviour during the project execution phase. Together with the project overload, which will be discussed later, the first behaviour is known as the "students' syndrome", consisting of using up the buffer before the activity begins; that is, only starting those activities which are already late. The second behaviour is the focus on finishing the activity as planned, not earlier, even though the existence of a buffer should guarantee frequent early finishes. As the buffer is considered by the activity owner as his[2] only safeguard against the uncertainties of the tasks, he does not want to show that in some cases the buffer may not be needed because he fears that if he shows it, the buffer size will be reduced in future estimates. Since the owners of the activities following a given one do not expect it to finish earlier than planned, they are not ready to start even in the event that once in a while an activity finishes before its time.

To make the contingency explicit, Goldratt suggests that two estimates be made for each activity duration, an estimate of the expected duration and another of its "safe" duration. The difference of these estimates will define the size of the "hidden" contingency. This is one way of estimating the uncertainty in the duration, not much different from the PERT method, consisting of getting three values for the estimate, the optimistic, the pessimistic, and the most likely. Under some assumptions about the underlying Beta distribution (Sasieni, 1986) and (Gallagher, 1987) these values are used to compute the duration average and standard distribution. Goldratt's method lacks the theoretical justification of the PERT assumptions and therefore estimates for the uncertainty on the chain cannot be derived in a theoretical form, but we must admit that it is easier for practitioners to understand and apply. In our survey we found that only 5% of the users were making estimates based on the concept of "safe" duration.

2. Definition and computation of the critical chain

The concept of critical chain, as an extension of the critical path to include resource availability constraints, is not new. (Wiest, 1964) already extended the concept of slack to the resource constrained case and defined a critical sequence:

"When resources are limited, the usual concepts of 'critical path' and 'job slack' basic to these methods (CPM and PERT) lose their normal meaning. Jobs may be delayed by the unavailability of resources as well as by technological orderings (…) A new procedure for calculating slack values lead to the identification of '*critical sequence*' of jobs (…) a notion analogous to that of critical path in the unlimited resources case"

He also pointed out at the relation between his critical sequence and the concept of '*active chain*' of operations in a job scheduling problem (Giffler and Tompson, 1960). (Aquilano and Smith, 1980) present a combination of CPM and MRP as a possible vehicle to overcome the shortcomings of CPM in dealing with limited resources. (Woodworth and Shanahan, 1988) propose an algorithm for identifying the critical sequence in a resource constrained project.

Goldratt method to determine the critical chain of a project is not completely well-defined, as it depends very much on the heuristics used to level the resources, a step that lies at the core of the procedure to define the critical chain. Critical Chain authors (Goldratt, 1997), (Newbold, 1998) and (Leach, 2000) do not provide a clear answer on the 'best' way to define the critical chain, and often refer to using strategic considerations when determining it. This is similar to the approach taken by Goldratt himself in the development of the TOC

[2] In order to avoid the cumbersome "his/her" and "he/she" along the text, we have decided to use only the masculine form, even though we refer indistinctively to both female and male managers and workers.

when he declared that a process bottleneck (or constraint) must be a strategic decision and not be based on the accidental situation of a plant at a given time.

3. Definition, positioning and sizing of buffers

CCPM proposes the use of three types of buffers: (1) *project buffer*, located at the end of the critical chain to protect the project completion date from the uncertainty in the critical chain activities, (2) *feeding buffers*, placed whenever a non-critical chain joints the critical chain, intended to protect the critical chain from interferences due to uncertainties in the duration of the activities of non-critical chains, and (3) *resource buffers*, which take the form of an advanced warning, placed whenever a resource is needed for an activity on the critical chain and the previous chain activity did not require the same resource.

Resource buffers are quite different, both in concept and treatment, from the other two and we will discuss them later, in the resources management section. Project and feeding buffers could be seen as special situations in the buffer map (Figure 2), where we can picture CPM as a deterministic planning tool that incorporates no buffers, followed by PERT, already incorporating a project buffer (PB) which takes in to account the uncertainty along the critical path (which is the same as the critical chain when there are no active constraints on the resources). CCPM includes feeding buffers to protect the critical chain (FB), and we could continue by defining and adding feeding buffers to the previous feeding chains (FB^2), and then feeding buffers to the previous ones (FB^3), and so on (Figure 3 illustrates this concept with a specific project network). We can also envision CPM as the limit when every activity incorporates its own buffer, which is the practitioner's approach when using CPM and there is uncertainty in the activities' durations.

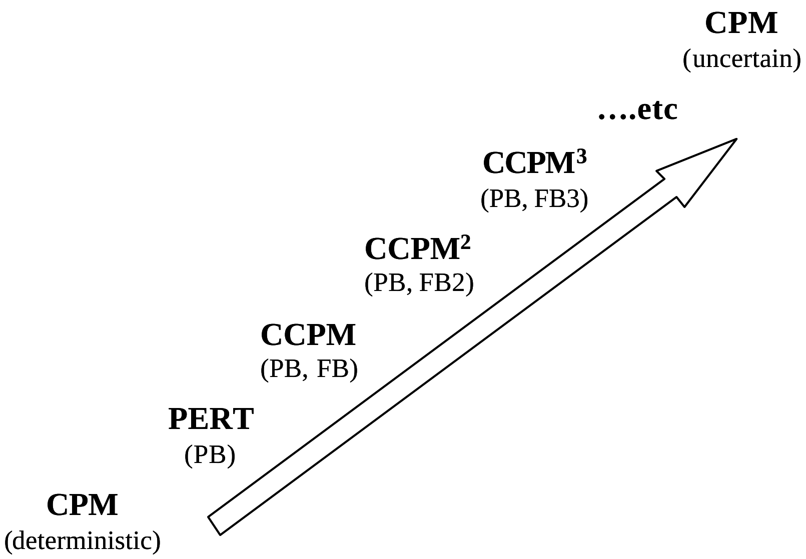

Figure 2 – Buffer map

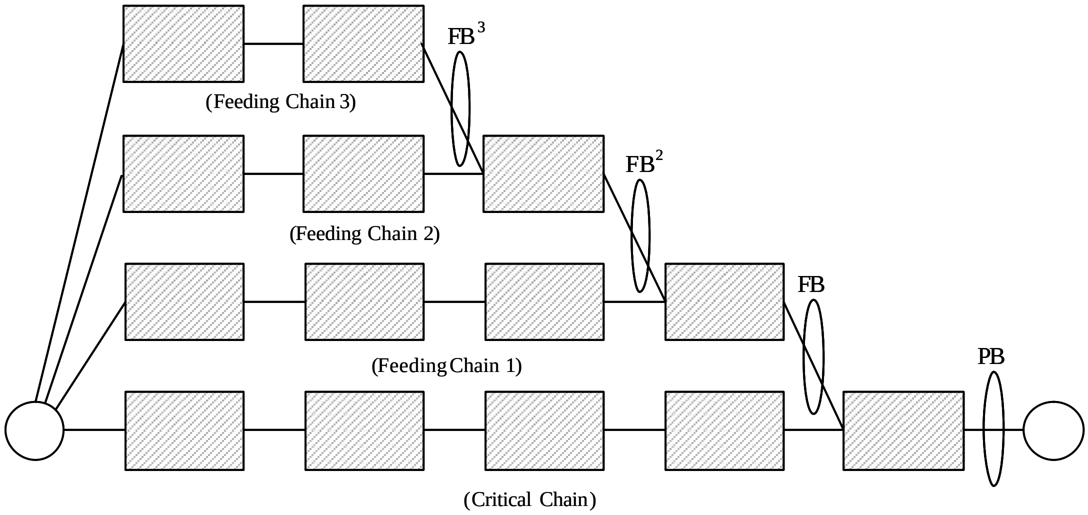

Figure 3 – Feeding buffers at different levels

After adding these buffers, it is very likely that the critical chain is no longer the longest chain in the project, especially if the uncertainty in some feeding chain activities is larger than the uncertainty in the critical chain ones. This effect can already appear in the case of a single feeding chain.

With respect to the size of the buffers, Goldratt proposes using a buffer equivalent to 50% of the contingency times removed from the corresponding chain. That is, planning is done using the activities expected duration, and half of the activity buffer (safe time – expected time) is moved and aggregated to the end of the chain. (Newbold, 1998) and (Herroelen and Leus, 2001) perform buffer computation under the assumption of independent lognormal distributions of activity durations. Goldratt's rule of thumb usually overestimates the size of the buffer. See Figure 4 for the resulting safety when aggregating a number of activities, when compared to a normal distribution of the chain duration, as done in PERT.

It must be noted that compared to the traditional CPM where a buffer is included in each activity, Goldratt's rule of thumb turns out to generate shorter plans with a much higher probability of success. We have found in practice that activities' owners are more willing to accept showing and removing the contingency of their tasks when this whole contingency is moved to the end of the chain. Even though this would not result on shorter plans, it has proven to be a very useful first step when changing the mentality of a company from traditional contingency to critical chain. Once the contingency has been made transparent and shared, the project manager can push to achieve more important aspects, such as the roadrunner mentality described in the next section.

4. Assignment of resources

CCPM stresses that activities should be planned to start as late as possible (ALAP) but resources should be ready to start the activities as soon as the technological and constraints and precedence relationships are met. This practice has two important consequences: first of all, it does not distinguish between cost generating activities (or chains) and margin generating activities. Our survey revealed that 60% of practitioners do make this consideration when scheduling activities. Second, by scheduling every activity ALAP, it eliminates the concept of slack, which is an important concept in project management, not to be confused with buffer size. It is worth remembering that the original critical sequence of (Wiest, 1964) was created “with the intend of preserving for the project scheduler the operational utility of the slack concept”.

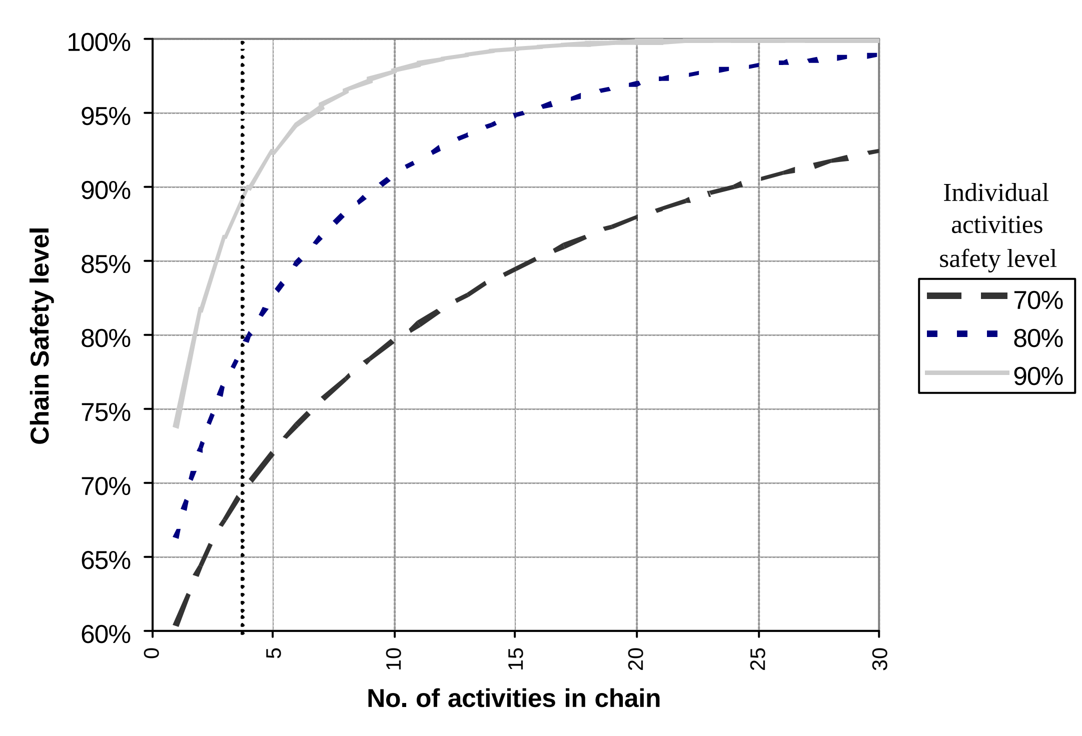

Figure 4 – Chain safety level using Goldratt’s rule of thumb

The literature of CCPM does not make a distinction between the technological uncertainty of an activity and the possible delay due to unavailability of the required resources at the time the activity is due to start. This delay is the waiting time in queue for the required resources. In the case of a single project with low (or no) uncertainty about the execution duration, the resource levelling phase would eliminate most of the queuing effect; however, when resources are multitasking among different projects and/or the uncertainty about the execution time of some activities is high, queuing accounts for a significant share of the activity perceived duration. We believe it is not appropriate to handle queuing time as extra uncertainty and deal with it via buffers. Traditional network queuing concepts and limiting the number of active projects (Anavi-Isakow and Golany, 2003) can prove more useful.

The assumption of no multitasking by resources in CCPM is critical to the roadrunner mentality of resources, that is, start an activity as soon as the predecessor activities are finished. However, we have found in practice that multitasking is quite common (Figure 5), some of the rationale behind it being the large periods of idleness that would occur otherwise due to the dependency of some activities on third party resources, or the need to change the focus outside of the current activity to foster creativity in some development projects.

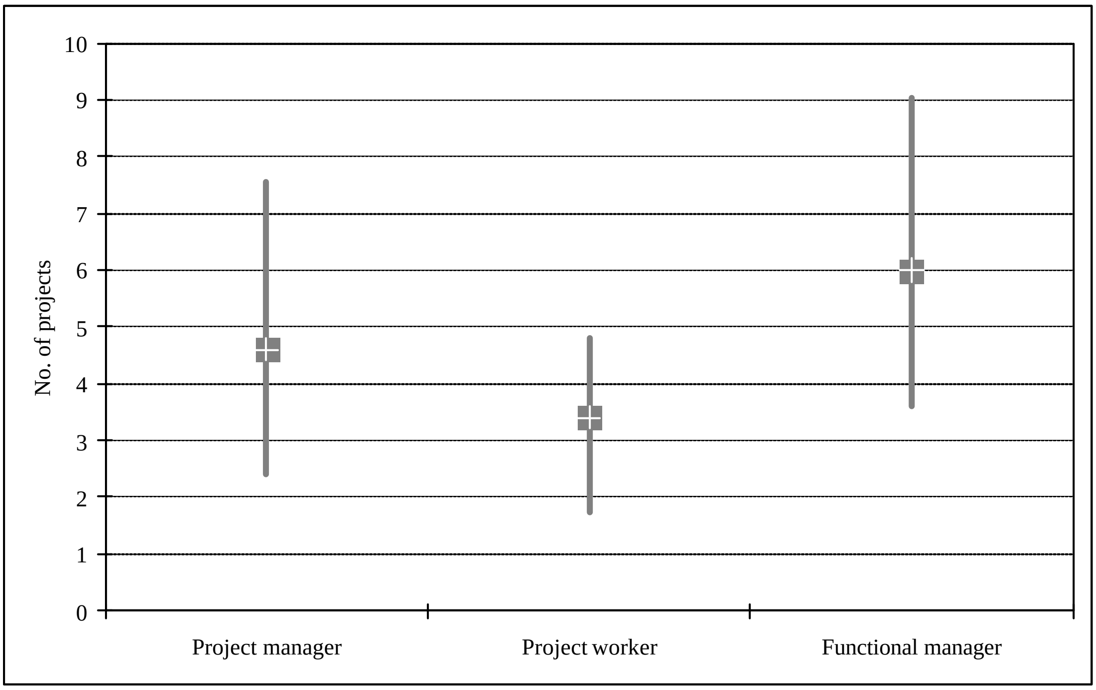

Figure 5 – Multitasking at different levels

The other critical factor on the roadrunner mentality is the sharing of information between activity owners, implemented in CCPM via the resource buffers, notifying resources needed in coming activities of the advance or delay of the execution of preceding activities. (Hameri and Heikkilä, 2002) provide a related advice when they stress that "project schedules need to be managed by putting special emphasis on the time-use within individual tasks and ensuring that work proceeds smoothly along the critical chain of tasks. To achieve this, high transparency is needed on how time is used in project organizations".

5. Project monitoring via buffer penetration

An important attribute of CCPM is the simplicity of monitoring via buffer penetration. CCPM practitioners insist that the Critical Chain must remain constant during the execution of the project and that buffer penetration (an activity variation that consumes a buffer by a certain amount) provide proactive warnings to the project manager, who can plan and execute some actions to recover the buffer. These actions may involve expediting, working overtime, subcontracting, reducing the project scope, etc.). We believe that this issue has not yet been thoroughly studied and that further research is needed.

(Herroelen and Leus, 2001) discuss a phenomenon that often occurs simultaneously with buffer penetration, namely, the creation of new resource conflicts, and therefore the need to recomputed the critical chain, in opposition to CCPM rules, but do not offer any alternative.

Practitioners are attracted to the simplicity of buffer penetration monitoring, using the fever chart, standard to CCPM software packages (e.g., Prochain, Concerto). It is our experience that they maintain the old monitoring tools (Gantt baselines, Earned Value, etc.) in order to obtain different complementary views of project evolution.

CONCLUSION

The core concepts of CCPM have been examined. Some of them have been around for more than four decades, but have been back to the stage thanks to Goldratt's work. When compared to traditional project management practices, CCPM proves very successful in practice, but more research is needed in evaluating the impact of its different elements and solving some of its problems.

In a limited set of simulation experiments we have found that some of the concepts are more critical than others. For instance, the transparency of the individual activities time contingencies is more important than the definition of the buffer to allocate at the end of the chain. Similarly, the roadrunner mentality has produced more impact than the definition of the critical and feeding chains and the inclusion of the corresponding buffers.

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