An overview of Critical Chain applied to Project Management

FRANCISCO CORREIA, ANTÓNIO ABREU
ISEL, Polytechnic Institute of Lisbon,
Lisbon,
PORTUGAL
23546@alunos.isel.pt, ajfa@dem.isel.ipl.pt

Abstract: The characterization and assessment of the Critical Chain (CC) approach and the adaptation of the Theory of Constraints (TOC) to Project Management is an important element to help promoting the development of this field. Starting with a brief discussion about the CPM method and PERT method, this paper introduces some discussion about the advantages and disadvantages of the CC concerning to traditional approaches.

Key-Words: Project Management, Theory of Constraints, Critical Chain, PERT/CPM, Project Scheduling.

1 Introduction

The importance of projects is overwhelming in nowadays, and it will continue to grow in the future. It must be stated that not all companies have production, but all companies (or organizations) have projects. The last decades several studies were made to identify lacking of efficiency in project management. Usually they fall in one of two categories: focus on PERT/CPM techniques of project planning or focus on the human resources management. Both areas claim that project failure is due to problems regarding their subject study. The TOC approach (Theory of Constraints) to project management embodies these two areas of focus within a framework that uses the Critical Chain method and a resource management policy to achieve results. That is why, sometimes, Critical Chain Project Management (CCPM), is also used to name this approach.

2 Historical perspective

It started with Eli Goldratt first book “The Goal” [1], which is the story of a manager in problems due to his poorly run manufacturing plant. According to Goldratt, the ability of an organization (or system) for doing what should be done depends on its elements and their interdependencies. Consequently, when the number of interdependencies increases the variability also increases. However, the number of elements that control the performance of the system is extremely small, and they are called constraints. In order to improve the performance of a system under the effect of a restriction, it is necessary to apply the following rule “more is better”, meaning that: if it were possible to increase the production rate of the constraint element, then the total output will be higher. However, the same is not valid for a non-constraint element. In this case, the limit to improve dependents on the nature of interdependencies with the constraint element and to go beyond is waste recourses. In fact, in order to improve the performance of a system the reverse rule to non-constraints is applied: “more is worse”, working at full capacity the resource will produce excess inventory that will choke the constraint resource, increasing the lead times. Goldratt [1], states that a manufacturing plant can be controlled by three measures: throughput, operating expense, and inventory. And describes the Drum-Buffer-Rope (DBR) method, to produce only what is needed and avoid overproduction. This methodology was called OPT (Optimized Production Technology). Later, the OPT was extended to include concepts form Market and Logistics in the book “It’s not Luck”, by Goldratt and became the Theory of Constraints (TOC). The third book of Goldratt was called Critical Chain [2] and demonstrates the application of TOC to Project Management.

3 The Foundations of TOC

The foundations are not entirely clear; critics say that TOC concepts are a consequence of Lean; Goldratt [3] recognizes that Lean/JIT (production) was a fundamental step in Industrial organization and gives his version of the elementary concepts developed by Ford/Ohno:

- Improving Flow (or equivalent lead time) is a primary objective of operations;
- This primary objective should be converted into a practical mechanism that guides the operation when not to produce (prevents overproduction). Ford used space, Ohno used inventory;

- Local efficiencies must be abolished to achieve high overall efficiency;
- A focusing process to balance flow must be in place. Ford used direct observation. Ohno used the gradual reduction of the number of containers and the gradual reduction of parts per container.

Goldratt [3] also states that Lean Production System (TPS) needs stability on three aspects: product life, demand over time per product and constant load case of orders on the various resources. Lean companies to satisfy all the aspects absolutely need to focus in the Marketing and Sales areas of its products and not only in the production area. The stability required can´t be extended to all products and even less to project management environments (less stable and longer touch times). TOC solves the problem of stability by using the release time as the mechanism to prevent overproduction (Ford used space and Ohno inventory). Goldratt states that the material should not be released ahead of time in the system constraint, this way flow will diminished making it less sensitive to disruptions and consequently reducing lead times. The release time needs to be short enough (compared to the due date) to avoid long queues and variability effects, but not long enough to avoid backlog orders and the cycle effects describe in Figure 1:

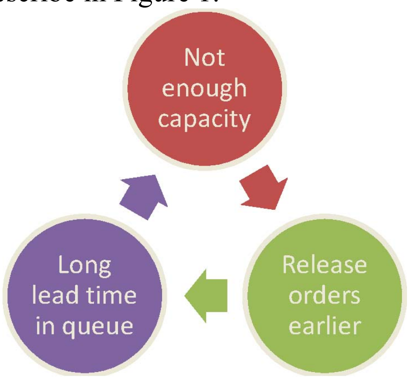

Fig.1- Cycle for long lead times.

The release time must be calculated using the touch time and a Buffer (Murphy exists). In practice there are four Buffer priorities divided by color: black (back orders), when a part is late; red, when 75% or more of the buffer time has been consumed; yellow, when between 50% and 75% of the buffer time has been consumed; Green, less than 50% of the buffer has been consumed. The system is easy to follow to the workers and straightforward to managers. But one question remains: what is the size of the time buffer? If the process of improvement is starting, Goldratt suggests half of the touch time and further adjustments on the buffer time. The issue will be discussed further ahead. The TOC framework has 5 steps: 1) Identify the system's constraint(s); 2) Decide how to explore the system's constraint(s); 3) Subordinate everything else to the above decision; 4) Elevate the system's constraint(s); 5) If, a constraint has been broken, return to step 1 and don't let inertia cause a system's constraint. System constraints are usually identified as the process that has a lot of unprocessed inventory. Exploring the constraint is assuring, in the short run, that it must be found a way to keep the constraint at work as must as possible (workers skipping coffee brakes, etc.).

4 Problems with PERT\CPM

It will be identify problems in a single and multiproject environment.

4.1 Single project problems

According to several authors [4] they are at least 8 major problems with the PERT\CPM approach, as illustrated in Figure 2. All simulations where made using Monte Carlo method with the software Crystal Ball and Microsoft Excel and in the next sub-subsection all references will be to Figure 2.

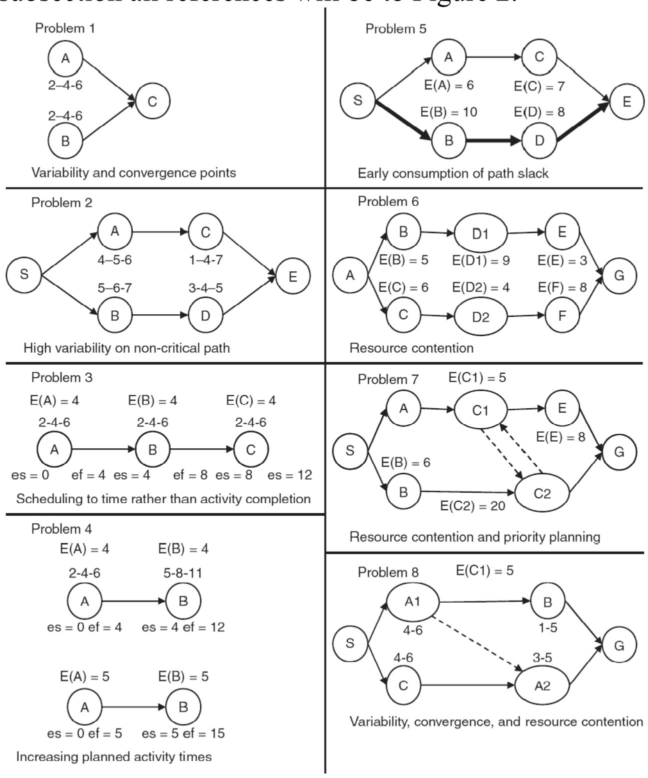

Fig.2- Eight problems with PERT\ CPM. According to Cox [2]

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4.1.1 Problem 1: Task Variability and convergence points

With two tasks that converge, like the tasks A and B to C notice, in Figure 3, that the average time for task C to start is not 4, but 4.47.

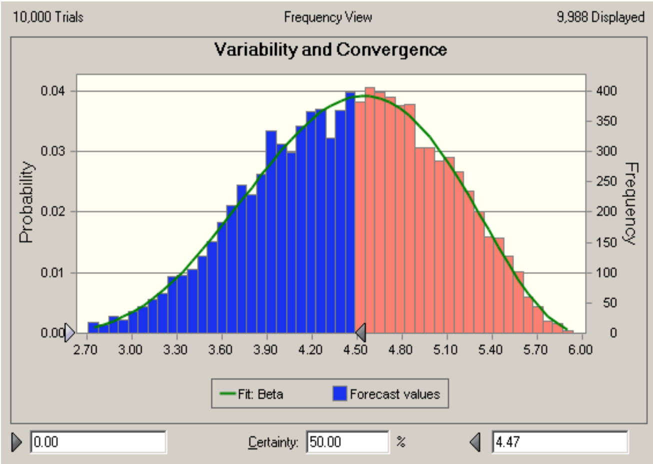

Fig.3-Convergence tasks problem simulation.

Task duration variability exists (Murphy exists) the start date of depended sequential tasks may be incorrect. The impact of this problem is felted continuously, because all projects have: paths that converge to an end node, dependent tasks and parallel paths that converge and PERT\CPM do not specifically handle task variability although risk integration can manage it.

4.1.2 Problem 2: High variability on a non-critical path

The critical path in problem 2 (Fig. 2) is S-B-D-E, with an estimated time of completion of 10. But path S-A-C-E has a completion time of 9, and task C has the most variability. In 25% of the time the will take longer than 10, due to path shift. Both paths must be carefully watched. If the two paths did not converge, the critical path would remain stable and the high variability of the non-critical path would not affect the completion date.

4.1.3 Problem 3: Scheduling to date rather than the completion of the prior activity

The planning of resources is made with reference to start date and task duration. If task A finish early, the next task will only begin at date 4. If task A was finish late then task B would also start late. The delay of a task is propagated to sequential tasks (the negative aspect of variability) and the benefits of early finish are not. PERT\CPM plans based on relationships and time estimates, it is not prepared to have the start of task B reference to the real action of finishing task A.

4.1.4 Problem 4: Increasing planned activity times

If scheduling to date is considered (see Fig.2 problem 3) the upper path will have a completion date of 12, and an estimated certainty of 41.83% (the average completion date would be 12, 03). On the other hand if the time estimated increased 25%, the start of task B will be schedule to start at date 5 and the completion path date would be 15, the same task would have a chance of success of 95, 86 % (see Figure 4) but the average certainty of path completion would be 13.

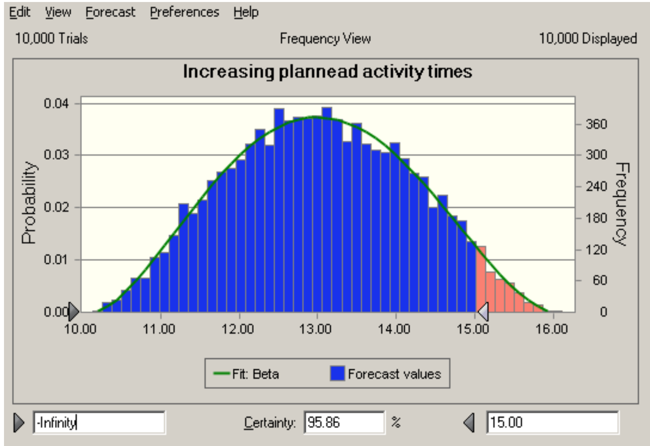

Fig.4- Increased planned activity time problem simulation.

Resource managers would like to compromise to the down path, it has a higher change of success and for project managers the delivery date of the down path is also more reliable although an extra day in average, will be lost to the project completion.

4.1.5 Problem 5: Early consumption of path slack

Considering the critical path (S-B-D-E), this leaves the non-critical path (S-A-C-E) with a total slack of 5. Considering the typical management practice of delaying activity expenditures in order to minimize cost, task A start date will be 5. All the task slack will be consumed in the planning phase and because it was all consumed it will not be available to protect sequential activities in the path/convergence point.

4.1.6 Problem 6: Resource contention

PERT\CPM assumes infinite resources a critical path exists without leveling the resources. Being Resource contention defined by Pittman (see Cox [4] p.31) as "the simultaneous demand for a common resource within a narrow time-span". In Fig. 2 (problem 6), has two task (D1, D2) using the same resource (D). There is a resource problem in

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spite of the critical path contained D2: if D1 starts first, D2 will be delayed and the project will be late; If D2 start first, D1 will be late, the non-critical path will became critical and the project will be late. Either option the project will not be deliver on time. Resource utilization is an important measurement to the success of the organization, and PERT\CPM does not explicitly recognize that it might be required for more than one task at the same time.

4.1.7 Problem 7: Resource contention and priority planning

This problem contains the previous and clarifies that PERT\CPM does not provide a heuristic or other approach to prioritize resources that may affect on-time project completion.

4.1.8 Problem 8: Variability, resource contention and priority planning

In problem 8 (Fig. 2) assuming that tasks have a uniform probability distribution. The critical path will be (S-C-A2-G). The upper path (A1-B), has a 24, 5% of exceeding the expected 9, due to the high variability of task B the slack of 1 will be consumed.

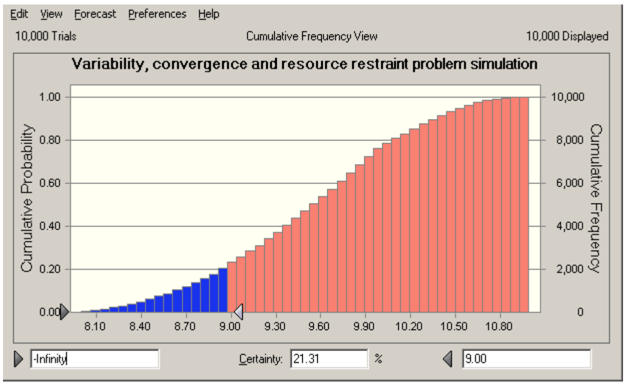

Fig.5- Variability, convergence and resource restraint problem simulation.

And there are two convergences in the network: the end node (B-A2-G) and in the A2 node due to the implicit use of the same resource in different paths. The start of the A2 task will also need to account for the task A1 variability. In conclusion, as it is showed in Fig.5, the total certainty of completing the project in 9 time units is 21, 31%.

4.2 Multiproject project problems

Some of the main problems with multiproject managed in a PERT\CPM environment are related to resources: contention, priority, variability caused by common and other resource usage. Some problems addressed in single project persist, namely: early consumption of slack, scheduling to time rather than activity completion and increased planned activity times. There are also no explicit monitoring metric for multitasking (in single project we have Earned Value) and all the preparation against adverse external events (p.ex: temporary breakdown in supply chain) are based on risk analysis which is external to PERT\CPM.

5 Typical Resource Behaviors

5.1 Safety times and multitasking

Project managers usually control the due date of a task, in spite of being the resource manager (or even the worker) who provides the task duration estimated time. Consider the traditional resource management techniques to assure the full deployment of resources: multitasking. In Fig.6, it is made a comparison between two paths in a project: in the upper path there is a prioritization of work, so task A is completed in 10 days, on the lower path multitasking is used with a delivery date of 20 days for task A. Both paths will be finish in 30 days.

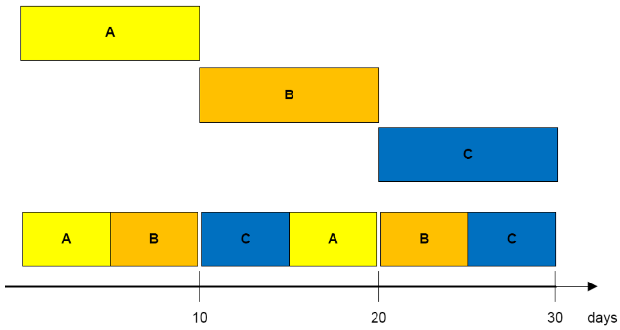

Fig.6- Multitasking versus prioritizing example.

There is another side-effect to multitasking: the lead time will take longer due to setup changeovers. So when resource manager are asked how long the task duration will take and because accountability for due date delays is mandatory to them. The time estimated will include the variability of the task time, the delays of multitasking and an extra time just to be on the safe side.

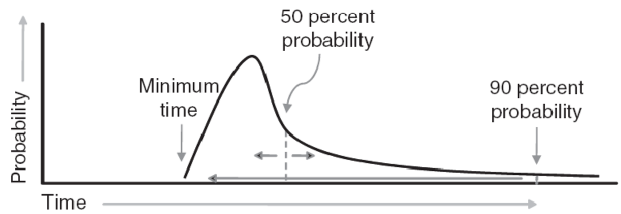

Fig.7- Task probability distribution according to CC, taken from Cox [2], p. 46.

As illustrated in Fig.7 the long tail of the distribution is a consequence of doubling the time to assure 90% accuracy in due dates.

5.2 Student Syndrome

Goldratt [3] identify the student syndrome from a common student behavior of lobbying for an extension to an exam. After a successful postponing of the exam, the students will procrastinate and late start the study because of the psychological effect of the “extra-time”.

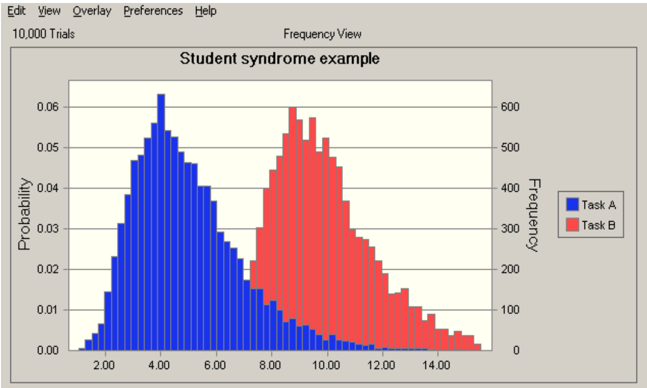

Fig.8-Student Syndrome example.

As illustrated in Fig. 8, there are two forecasts with exactly the same standard deviation, the mean of task B, is 5 units more than Task A. We can conclude that due to the student syndrome there will be a transposition from the initial distribution (or a delay) that could jeopardize the due date.

5.3 Sandbagging completed work

Sandbagging is holding a completed work until an appropriated delivery date. This is made in order to extend or artificially maintain the task’s duration. Early delivery is possible but only in special situations. Usually it is avoided recognition of an early finish, due to: believe that the next work center is not prepared to take advantage of the early finish (see Fig. 2, problem 3), the next same task will have a “shorter” estimated duration and resource manager accountability for prior “long” task durations will be enforced by upper management.

5.4 Parkinson’s Law

When the work is “formally” completed and the resource is still “improving” the work until the due date is reach. The resource will introduce “extras” that are not required that will lead to an expansion of task duration filling the time estimated.

6 Critical Chain approach

As already mentioned CC approach provides a framework that incorporates the behavior component of resource management and a set of planning techniques supported by TOC.

6.1 Objectives

They are: minimize duration of single project under resource constraints, maximize throughput in multiproject environments, satisfy the triple constraints of time, cost and scope and adopt a simple and stable approach to project scheduling.

6.2 Buffer Management

Newbold [5] talks about the need for uncertainty language in project management. There is probability concepts when dealing with networks, but it lacks words that combine statistical fluctuations and dependable events altogether in an accessible and simple project manager way. According to TOC-ICO Dictionary [6] Buffer Management is defined as:

‘‘A feedback mechanism used during the execution phase of operations, distribution, and project management that provides a means to prioritize work, to know when to expedite, to identify where protective capacity is insufficient, and to resize buffers when needed.”

Buffers are a way to explicitly quantify uncertainty, using it to obtain the concrete objective of prioritizing tasks within the same project and considering other project tasks.

6.2.1 Objectives

Buffers are inserted into strategic points to protect the Critical Chain tasks and the due date. Buffers are necessary to allow risk integration between convergence points as we can see in Fig 9.

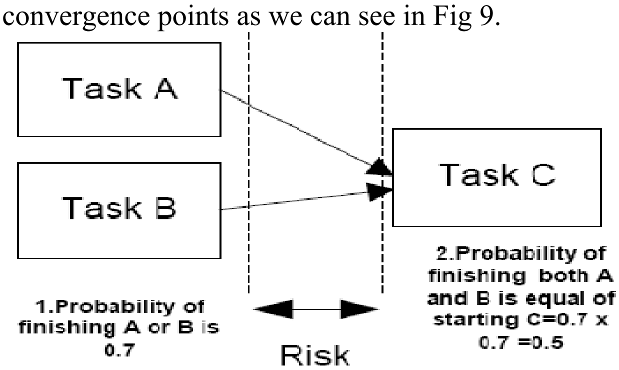

Fig.9-Integrating risk in a convergence point.

They allow: synchronization between Critical Chain tasks and non Critical Chain tasks through the use of

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warnings, fully use of Drum resource, aggregate safety margins taken from activities (this will reduce Student syndrome and Parkinson Law) as in Fig 10, avoid multitasking and preemptions, etc…

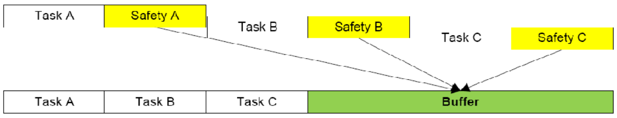

Fig.10-Aggregation of time into a buffer (see Rand [7]).

The buffer size is a key issue. As a rule of thumb, 50% of the time of the tasks are removed and aggregated after the last task within the path. But there are other methods like root-square-error-method or application of fuzzy logic theory to name a few. The focus is no longer on the tasks duration but on the buffers size which contain additional information and aggregated time that will protect the due date.

6.2.2 Types and control of Buffers

The type of buffer depends of the purpose:

- Project buffer aggregates safety time from the Critical Chain tasks and is placed just before the project due date. This buffer will be used when the Critical Chain tasks take longer than expected or when some feeding buffer is depleted bearing the consequence of a late Critical Chain task start.
- Feeding buffers are a time dumper that will decouple the non-critical path from the Critical Chain in order to prevent delays or late starts of the Critical Chain Tasks due to late deliveries of completed non-critical tasks. Because one hour lost in the Drum, means one hour lost of overall production.
- Resource buffer does not add time to the project lead time. It is used to take advantage of early finishes, and is placed in front of the task in the Critical Chain as a warning to the task resource(s) to be available, when needed.
- Scheduling buffer is only exist in a Multiproject environment and it is the time cushion placed in from of the first task of a project in order to delay its start to protect the new project of variation and minimize WIP. The latest is important because if work starts to pile up in front of the non-critical work centers it will increase the lead time and delay the project completion date.

Controlling Daily reports from Work Centers is made stating the amount of work (in time) to completion. This information is used for project and feeding buffers in order to determine buffer penetration. This penetration will determine management focus. The "fever chart" is a management tool (Fig. 11), that provides this information on a visual manner.

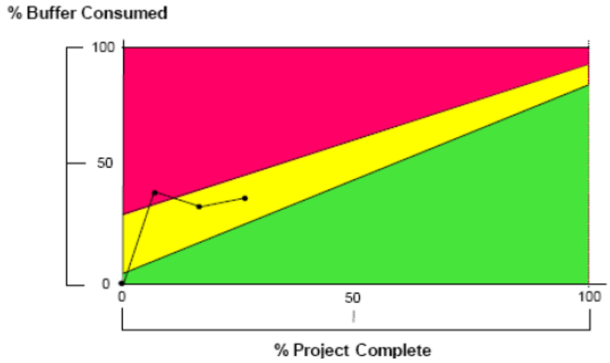

Fig.11- Project buffer "fever" chart example.

In Fig. 11 the green area is where we expect the buffer penetration to be in. This area represents the safety times redrawn from the tasks and placed in the buffer. The yellow area demands attention from the project manager, there could be some special cause variation occurring on some task. The red area needs the project manager to take action. There is definitely some problem that is in need of correction. If the problem is a serious one then we must reschedule the project. Notice that the schedule is stable until the red area, there is no need to constant rescheduling as in the PERT\CPM approach.

6.3 Method for single project

To schedule a project according to the Critical Chain method, we need:

- Determine a project baseline that takes into account precedence and resource constraints, working from the end of the project.
- Determine early start-based project schedule.
- Identify the Critical Chain ("The longest sequence of dependent events through a project network considering both task and resource dependencies in completing the project. The critical chain is the constraint of a project."[6]).
- Tasks that are not in the critical chain start as late as possible (ALAP), in accordance with the TOC theory for improving lead times and reduce WIP.
- If there are resource constraints then move the tasks to start earlier.
- Create and insert buffers.
- Keep the scheduling updated and the critical chain fixed during project execution.

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6.4 Method for Multiprojects

To schedule in a multiproject environment, we must follow six steps:

- Step 1- Prioritize the organizations projects.
- Step 2- Plan the individual projects, according to the method of a single project (above chapter).
- Step 3- Stagger the projects.
- Step 4- Insert Drum buffers and the scheduling buffer.
- Step 5- Measure and report the buffers.
- Step 6- Manage the buffers.

The purpose of step 1 is for avoiding multitasking. From step 2 to 4 are sequential, first it is necessary to determine the Drum resources. The projects are stagger according to those resources and then the buffers are inserted. Finally measuring and controlling the buffers (last two steps) is the same way as a single project.

6.5 Problems within this approach

There are some critics to Critical Chain. Herroelen et al [8] and [9] identify that the initial baseline resource constraint is a key element in selecting a Critical Chain. As a result longer baselines result in longer Critical Chains. When feeding buffers are inserted and if the Critical Chain is not chosen wisely it could lead to: longer project durations, tasks with a start date previous to the project start date, new resource constraints (sometimes leading to a new Critical Chain) and buffer penetration in one path implies buffer penetration in another path link by a non-constraint resource means that the buffer protection mechanism may fail to be proactive. Another major topic is rescheduling. The original CC approach stated that rescheduling is undesirable because it could lead to a change in the Critical Chain and into a project team losing focus. There are also the issues of organizational choices in delivery dates. Once a deadline is establish for suppliers or subcontracts, rescheduling cannot be taken lightly. But there is a major proven advantage in changing the schedule: it is an opportunity for speeding up the project due date and to have schedules incorporate the latest information on the project execution (per example: early finish non-critical paths). CC implementations have known to fail due to complicated buffer management and undefined metrics. On the other hand we have the PERT\CPM method that has: well defined reports on progress (with milestones), resources are clearly responsible and accounted for delays and an Earned Value method every project manager knows (it is possible with CC, but not straightforward). The project manager must understand the necessary preconditions and must rely on heuristic procedures for generate a precedence and resource baseline schedule.

7 Conclusions

The CC approach is a fresh approach. After PERT (60 years ago) there was nothing with the impact that CC has on project management. It provides a simple and workable tool. Not only in sorter project completion times but also focuses in what is important: sustainable result across a different range of projects (DELTA Airlines example [10]) and a growing Body of Knowledge [6]. Further investigation should be developing in: the buffer size method determination, identifying special preconditions for Critical Chain baseline that could cause problems in Buffer penetration, rescheduling and in Critical Chain project “task crashing”.

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